ESTIMATING SIKA DEER ABUNDANCE USING CAMERA SURVEYS

by

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of the requirements for the degree of Master of Science in Wildlife Ecology

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ABSTRACT

Camera surveys are an accepted tool for estimating wildlife abundance and occupancy and have been used throughout the world. Camera surveys tend to be less invasive, less costly, and more accurate than other means in certain situations. I sought to expand and test the effectiveness of camera surveys during July and August of 2008 and 2009 for sika deer at Tudor Farm, LLC in Dorchester County, Maryland. In 2008, I setup surveys with a 7-day pre-bait period followed by a 7-day active camera survey with 15 cameras. In 2009, I changed the camera survey setup to account for any bias that may have occurred due to using the same camera sites for consecutive surveys. I also set camera surveys to run for the entire 14-day survey period to determine optimum survey length. Camera density for both years was 1 camera per 65-ha. The estimates generated by the Jacobson method and Bowden's estimator were similar between years. In 2009, increasing photo intervals from 1-minute to 5 and 10-minute intervals reduced the number of pictures by 66% and 81% while providing similar population estimates. I calculated the daily detection probabilities for all identifiable deer and I 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 as a result of greater amounts of bait being available in 2008. Camera surveys have proven to be an accurate and effective means

of estimating sika deer abundance and could be expanded to the entire population of Maryland.

Chapter 1

INTRODUCTION

Camera surveys have been used for multiple applications throughout the world, including estimating wildlife abundance, occupancy, and presence (Foresman and Pearson 1998, Swann et al. 2004). Estimating white-tailed deer (*Odocoileus virginianus*) abundance has been the main focus of most camera surveys (Jacobson et al. 1997, Koerth et al. 1997, Watts et al. 2008). Using camera survey to estimate abundance for sika deer (*Cervus nippon*) in Maryland could provide managers with a more refined tool to estimate the entire population. Sika deer in Maryland share a similar history with sika deer introduced throughout Europe and New Zealand, all beginning with a few individuals and then expanding to levels that compete with 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, MD DNR 2009 unpublished report). Research has documented sika deer competing 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 Zirovnicky 1982, Feldhamer & 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. Sika deer have more diverse feeding habits and digestive systems that can sequester more nutrients from sub-optimal forage giving them a competitive advantage when resources are limited (Feldhamer et al. 1978, Demarais et al. 2003).

The Maryland Department of Natural Resources (hereafter, MD DNR) wants to prevent further sika deer range expansion and maintain a population that can continue to provide unique hunting opportunities in Dorchester County, Maryland (T.B. Eyler, personal communication). In order for the MD DNR to achieve these management objectives, a better understanding of sika deer population dynamics is essential. Using population reconstruction in 2008, the MD DNR estimated the sika deer population to be 6,723 individuals (MD DNR 2009, unpublished report). This estimate only reflects deer within the core range due to limited hunter harvest outside Dorchester County. In order to estimate sika deer populations outside Dorchester County, a population estimator needs to exist that does not solely rely on harvest.

Methods used to estimate sika deer abundance include pellet counts, helicopter transects, and mark-resight spotlight counts (Eyler 2001, Marques et al. 2001, Sakato et al 2009). In the United Kingdom and Japan, sika deer densities were estimated using 2 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 Maryland (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 Tudor Farm LLC (hereafter, Tudor Farm) in Dorchester County, Maryland. He noted that spotlight counts were precise because sika deer tend to use open areas less than white-tailed deer (Eyler 2001). All previously listed methods can be costly and inaccurate and may not be applicable for the marshes and forests that sika deer inhabit in Maryland (Koerth et al. 1997, Eyler 2001, Watts et al. 2008).

The successful use of camera surveys to estimate deer populations make camera surveys a viable alternative to previously used methods in Maryland (Jacobson et al. 1997, Watts et al. 2008, Pei 2009). Depending on survey objectives, camera surveys use either baited sites or chance encounters to determine target species abundance or presence (Bowman et al. 1996, Jacobson et al. 1997, Sweitzer et al. 2000, Larruecea et al. 2007a, Larruecea et al. 2007b, Pei 2009). 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, Sweitzer et al. 2000, Kelly et al. 2008). Camera surveys have been used to estimate sika deer abundance in Kenting National Park, southern Taiwan; however, the study relied on chance encounters and yielded low photo-captures (Martorello et al. 2001, Pei 2009).

Jacobson et al. (1997; hereafter the Jacobson method) and two estimators within program NOREMARK (Bowden; hereafter, Bowden's estimator 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, Watts et al. 2008, Pei 2009). Program NOREMARK was used to analyze data collected from camera surveys for 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 and Pei 2009). The Jacobson method can be used 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 effect of lengthening picture intervals on the population estimates has not been explored by any other research. Reducing the number of pictures could reduce the costs associated with the survey and reduces the amount of time required to analyze photos. Refining camera survey techniques would allow researchers a more efficient, cost-effective survey, and more precise abundance estimates. Additionally, the optimum survey length and detection probabilities should be determined for Maryland sika deer to verify camera survey effectiveness. In order to refine the camera survey methodology used to estimate sika deer abundance, my objectives were to: determine if population abundance of sika deer can be estimated using data collected from camera surveys, determine if population abundance varies when increasing picture 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.

Chapter 2

STUDY AREA

I chose Tudor Farm LLC. (hereafter, Tudor Farm), an area in Dorchester County south of U.S. Route 50, as my study area because it provides a large, continuous property and is the central point of the sika deer population in Maryland. The area south of U.S. Route 50 has an approximate land area of 1,000 km^2 (MD DNR 2000) with elevations ranging from 0-2 m above sea level. During my camera surveys temperatures averaged 25ºC. Precipitation during both years was similar to the 20-year average of 109cm/year.

The landscape was classified into 3 dominant habitat types. Agricultural lands planted with corn (*Zea mays*), wheat (*Triticum spp.*) and soybeans (*Glycine max*) comprise ≈502 km^2 of Dorchester County (MD DNR 2000). Forests (505 km^2; MD DNR-Forest Service 2000) were separated into 2 different habitat types: lowland and upland. Lowland forests are characterized by 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 cerfera*), American holly (*Ilex opaca*), phragmites (*Phragmites australis*) and poison ivy (*Toxicodendron radicans*). Upland forests have a larger 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 consisted of red maple (*Acer rubrum*) and sweet gum with the understory being dominated by greenbrier (*Smilax* spp.) and poison ivy. The final dominant habitat type was the salt marsh which covered approximately ≈359 km^2 (MD DNR 2000). The dominant plant species include salt grass (*Distichlis spicata*), black needlerush (*Juncus roemarianus*), Olney's three-square (*Scirpus americanus*), cordgrass *(Spartina* spp.), and phragmites (Eyler 2001).

Chapter 3

METHODS

I captured sika deer between January and March, 2008 and January and April, 2009. I used drop net, clover trap, and darting methods described by Rhoads et al. (2010) as the means of capture. After I captured sika deer in either a drop net or a clover trap I used xylazine hydrochloride (HCL; 0.5 mg/kg) as the chemical restraint (Conner et al. 1987, Kilpatrick and Spohr 1999, Rhoads et al. 2010). While sedated, I fitted all sika deer with 2 medium plastic ear tags (white with black numbers, 4.5x5.1cm, Allflex USA, Inc. Dallas, TX) and 2 self-piercing metal ear tags (Model # 1005-49, National Band and Tag Company, Newport, KY), which were uniquely numbered for each individual. Additionally, I fitted juvenile males with an expandable VHF radio-collar (340g; Advanced Telemetry Systems, Isanti, MN) with a mortality sensor. I 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). I administered Vitamin E (30 units/kg of body weight; Eyler 2001 and Rhoads et al. 2010) to all deer that showed signs of capture myopathy. All my capture and handling procedures were approved by the University of Delaware's Institutional Animal Care and Use Committee (IACUC), approval number 1182.

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

In 2008, I conducted 2 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, I collected GPS locations of sites used annually for recreational hunting. Then using ArcView 3.2, I chose 15 camera sites spaced to represent ≈65-ha for a total coverage area of 975-ha.

I started with 4-kg of whole kernel corn per site and maintained that amount until all bait was consumed in one day. Once the bait placed at the site was consumed in a single day I increased the total amount placed at the site, by 2-fold. I 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 4-35 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 decay.

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

Once surveys were complete, I separated photographs by camera site, day, survey number, and year. I counted all deer within each picture tallying branch antler males, ear-tagged deer, unbranch-antlered deer, antlerless deer, and juveniles. I 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, Sweiter et al. 2000, Watts et al. 2008).

In 2009, after calculating abundance for both surveys using pictures taken at 1-minute intervals, I removed pictures that did not occur ≥5-minutes and ≥10-minutes from the preceding picture. After I limited the pictures to those taken at 5 and 10-

minute intervals, I used Bowden's estimator and the Jacobson method to generate additional population estimates. I then compared the 95% confidence interval overlap generated by Bowden's estimator to make inferences about the estimates. Finally, to determine if limiting the amount of bait had any affect on a 14-day camera survey, I used days 1-7 and 8-14 to generate separate abundance estimates for 1-minute picture intervals and compared those estimates to the estimates generated from the entire 14-day survey at 1-minute picture intervals.

For all surveys I noted days that individuals occurred at camera sites in order to determine the optimum survey length. I then plotted the survey days against the day that individual deer occurred at camera sites to determine the optimum survey length. I determined the detection probabilities for unique males, 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, I located deer within 2-km of the camera grid once daily during active camera days using 2 compass bearings, taken within 15-minutes, from fixed points on the landscape. I used the bearings as input data for program LOAS (Location of a Signal; Ecological Software Solutions, LLC) to calculate deer locations. I collected all locations during midday (between 1000-hrs and 1400-hrs) when deer were least active (Kalb 2010). I measured the distance from each deer's daily location to the nearest 8 camera sites. Limiting the number camera sites used in the analysis removed all sites that were unlikely to be visited by deer on a daily basis. I used SAS (version 9.2; SAS Institute, Cary, NC) to develop a logistic regression model of detection probability as a function of distance to a camera site. The model permitted me to assess the likelihood of camera site visitation based on distance to determine if my grid cell size was adequate.

Chapter 4

RESULTS

In 2008, I captured 84 sika deer; 30 juvenile males, 45 females, and 9 adult males. I captured 51 sika deer on Tudor Farm, including 21 juvenile males that received radio-collars, 18 adult females and 12 juvenile females. I took 18,354 photographs that contained sika deer during both camera surveys across 14 active camera days at 1-minute picture intervals (Table 1). The 2008 surveys yielded a total of 63 identifiable males, 10 adult females and 10 radio-collared males (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 (Figure 1). The population density estimates ranged from 17-42 deer/km^2 with an average of 33 deer/km^2 for both surveys and both estimators.

In 2009, I captured 96 sika deer; 30 juvenile males, 52 females and 14 adult stags. I captured 4 adult males, 24 juvenile males, 12 adult females and 27 juvenile females on Tudor Farm. I took 33,879 photographs and identified 133 adult males, 26 tagged females and 12 radio-collared males at 1-minute picture intervals (Table 1). Pictures were reduced by 66% at 5-minute intervals, and by 81% at 10-minute intervals (Table 1). Abundance estimates generated by both estimators were similar in all surveys, with the exception of Survey 2 in 2009 (Figure 2). The estimates were less in Survey 2 because of greater variance of occurrences of adult males during the survey (Figure 2). The abundance estimates for 1-minute, 5-minute, and 10-minute picture intervals generated by the Jacobson method and Bowden's estimator were similar within the estimators but varied between the estimators (Figure 2). The 95% confidence intervals generated by Bowden's estimator all over lapped one another, but the estimates generated by the Jacobson method were greater than the upper limits of Bowden's estimates in every survey. The population density estimates for both surveys were also similar for both estimators ranging from 32-35 deer/km^2 with an average of 32 deer/km^2 (Table 2). I separated the 2009 surveys into different survey lengths, Days 1-7 and Days 8-14 and then compared the estimates generated from those intervals to the population estimate for the entire survey (Figure 3). Using the different intervals produced inconsistent Bowden's estimates but the Jacobson estimates were similar to the estimates generated by the whole survey.

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 elapsed before a deer was detected at bait sites varied between years (Figures 4-9). Individual deer were detected earlier in the surveys in 2008 than in 2009, regardless of sex or age (Figures 4-9). The detection of available radio-collared male sika deer was also greater in 2008 than in 2009 (Figures 9 and 10). The detection probability of radio-collared male sika deer at 0 meters 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.

Tables and Figures

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.

	Survey 1 2008	Survey 2 2008	Totals 2008	Survey 1 2009	Survey 2 2009	Total 2009
Adult Males	29	35	64	75	55	133
All 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
Photos Taken 5-min	-	-	-	6,332	5,215	11,547
Photos Taken 10-min	-	-	-	3,527	2,905	6,432
Sex Ratio Female:Male	1:1	3:1	-	2:1	3:1	-

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

	Survey 1 2008	Survey 2 2008	Survey 1 2009	Survey 2 2009	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 (±2.4)	42 (±5.4)	32 (±3.7)	24 (±3.5)	29 (±3.6)
Bowden; 5-min	-	-	34 (±4.8)	24 (±3.2)	29 (±4.0)
Bowden; 10-min	-	-	35 (±6.3)	23 (±5.1)	29 (±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.

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

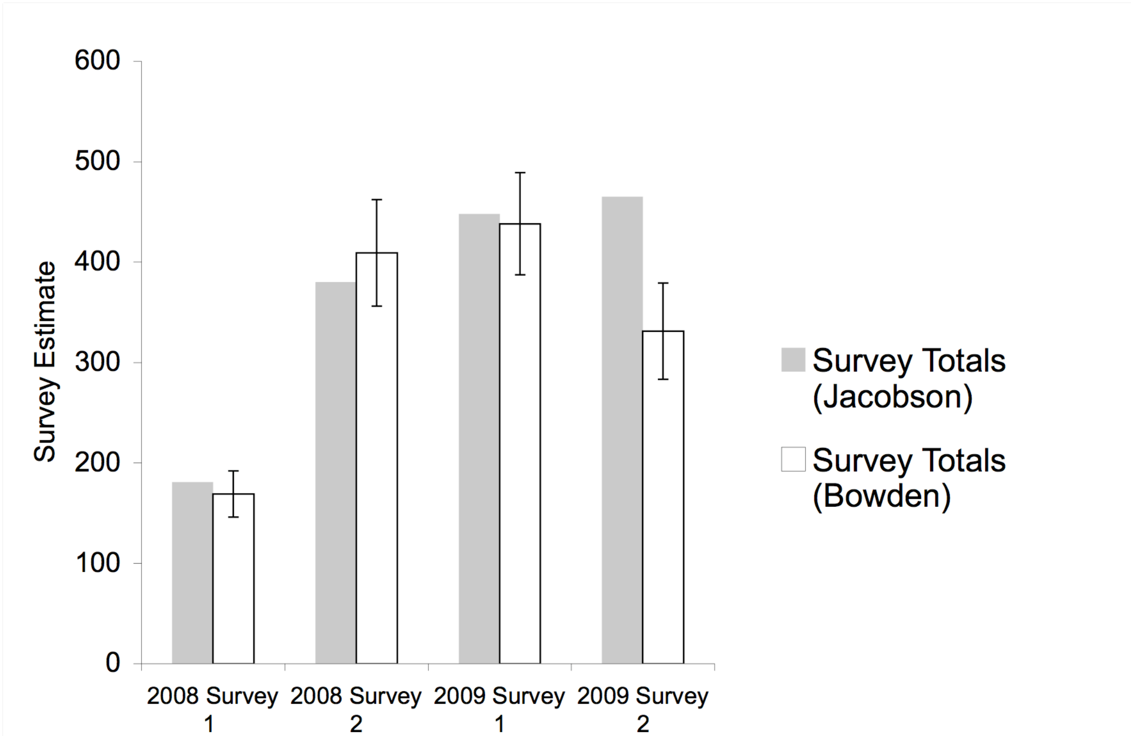

Figure 1. Population estimates for sika deer during 4 separate camera surveys using the Jacobson method and Bowden's estimator within program NOREMARK at Tudor Farms, LLC in Dorchester County, Maryland during 2008 and 2009.

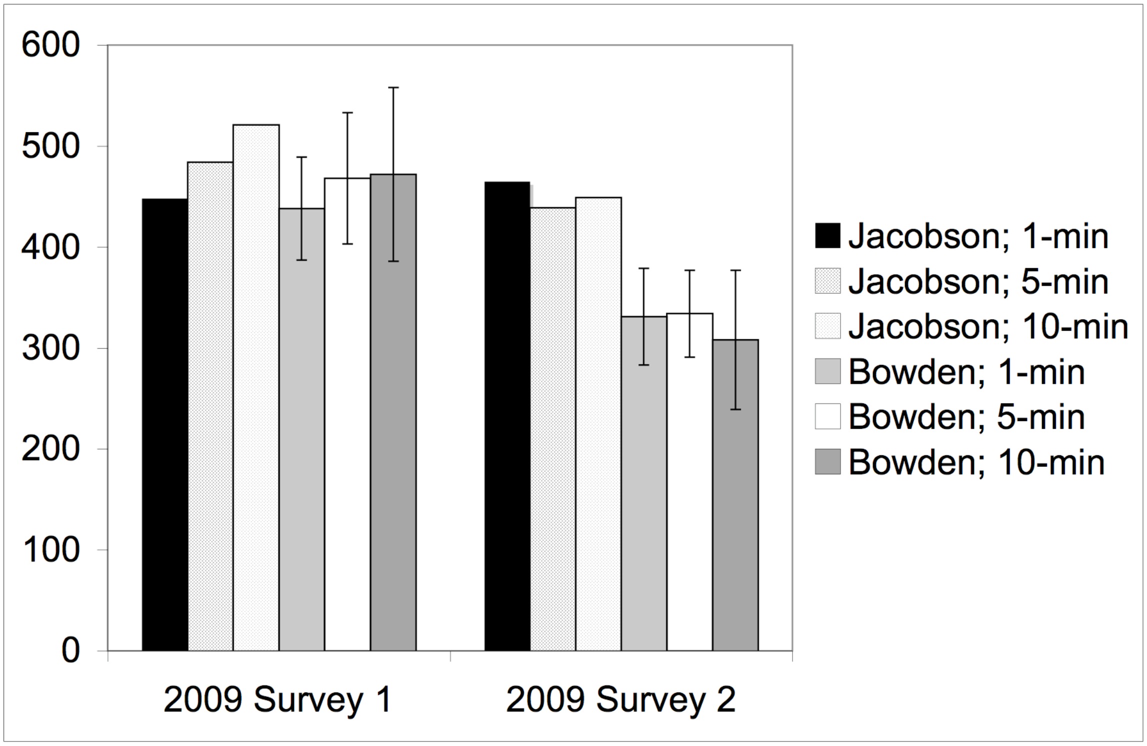

Figure 2. Population estimates for sika deer during 2 camera surveys using the Jacobson method and Bowden's estimator within program NOREMARK for 1-minute, 5-mintue and 10-minute picture intervals at Tudor Farms, LLC in Dorchester County, Maryland during 2009.

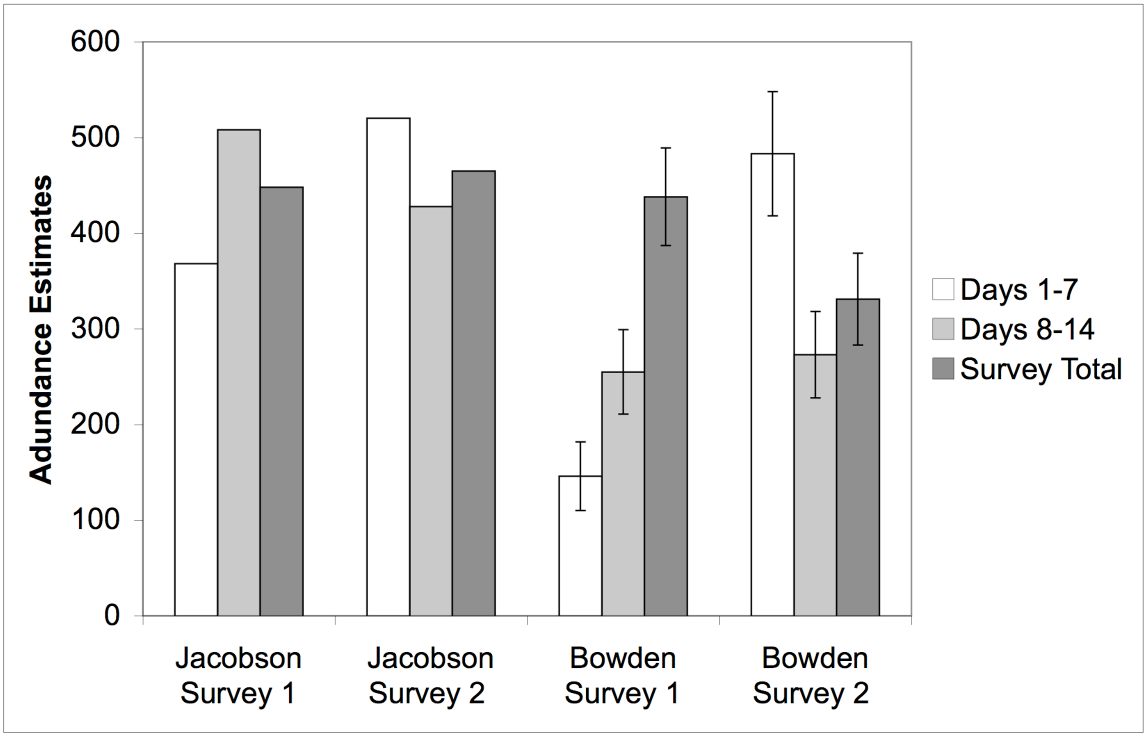

Figure 3. Population estimates for sika deer during a camera survey in 2009 comparing survey estimates using the Jacobson method and Bowden's estimator to determine difference in the estimates calculated for different lengths of time during a 14-day camera survey at Tudor Farm in Dorchester County, Maryland.

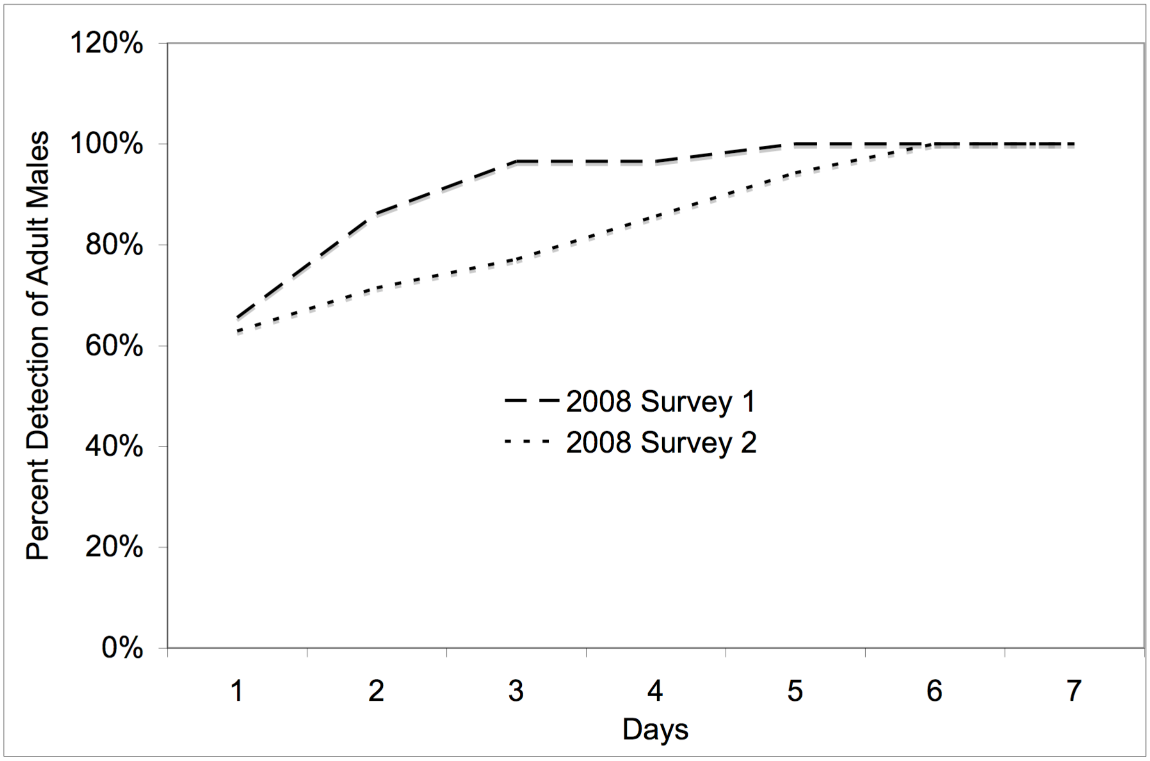

Figure 4. Percentage of unique sika deer adult males detected by day during 2 different camera survey in 2008 at Tudor Farm in Dorchester County, Maryland.

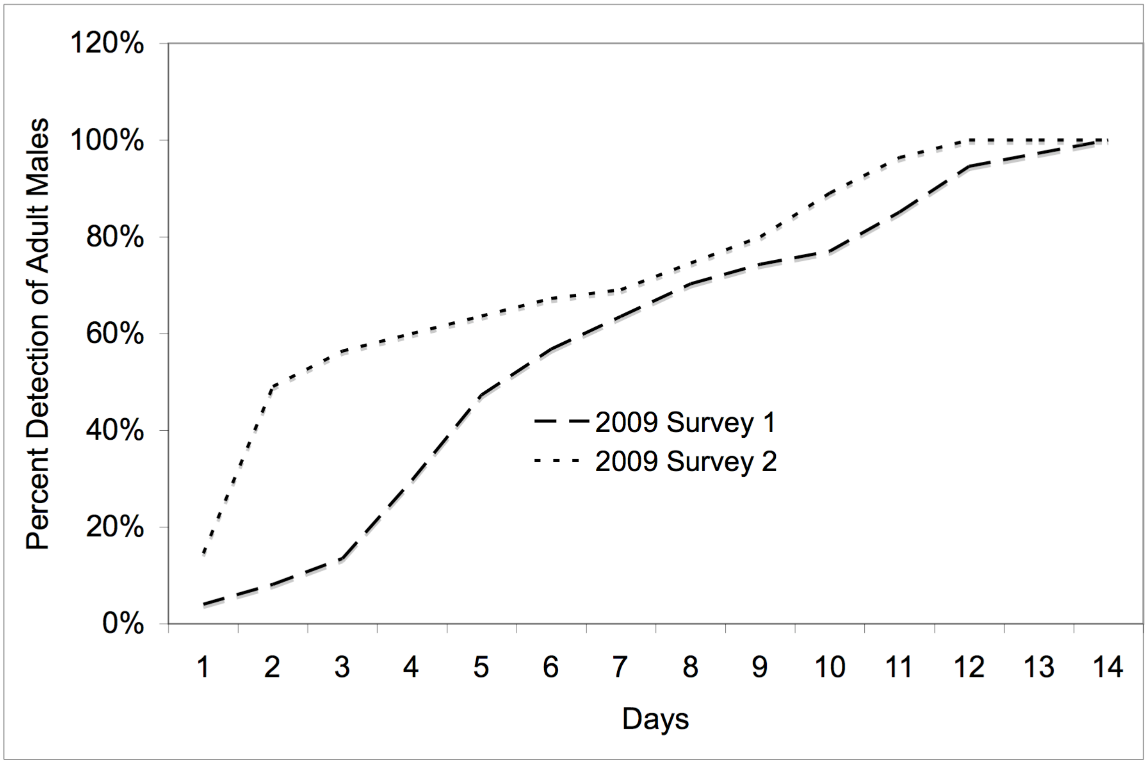

Figure 5. Percentage of unique sika deer adult males detected by day during 2 different camera survey in 2009 at Tudor Farm in Dorchester County, Maryland.

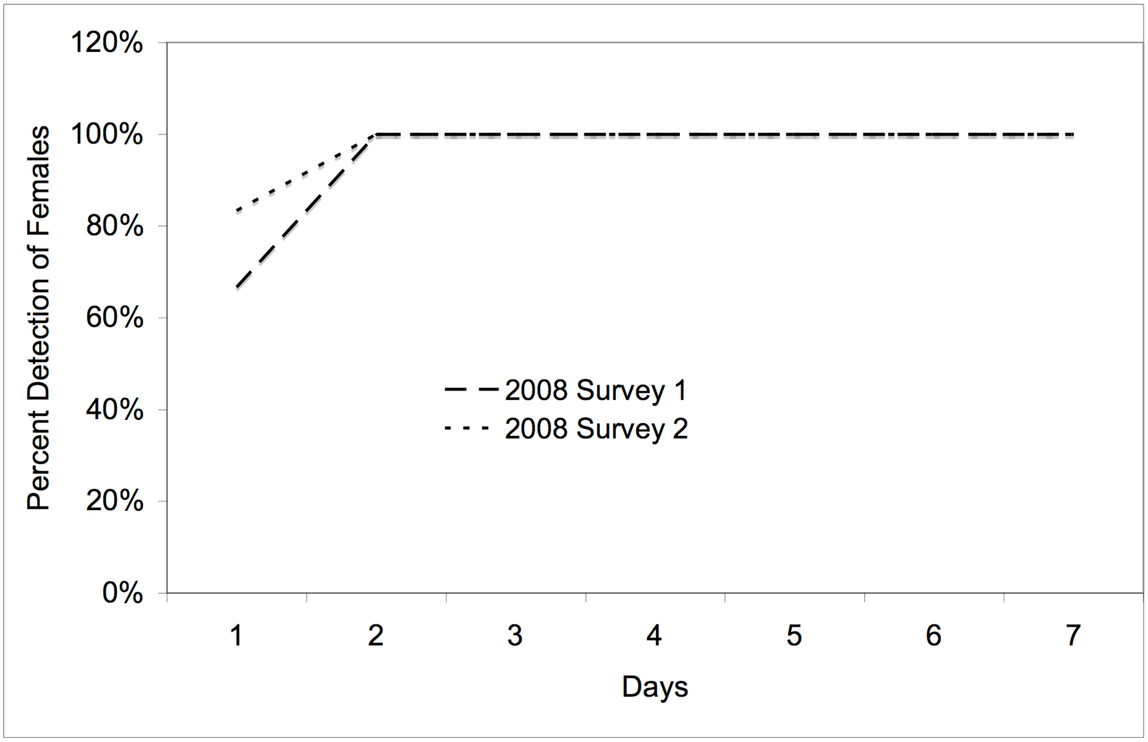

Figure 6. Percentage of tagged sika deer yearling and adult females detected by day during 2 different camera survey in 2008 at Tudor Farm in Dorchester County, Maryland.

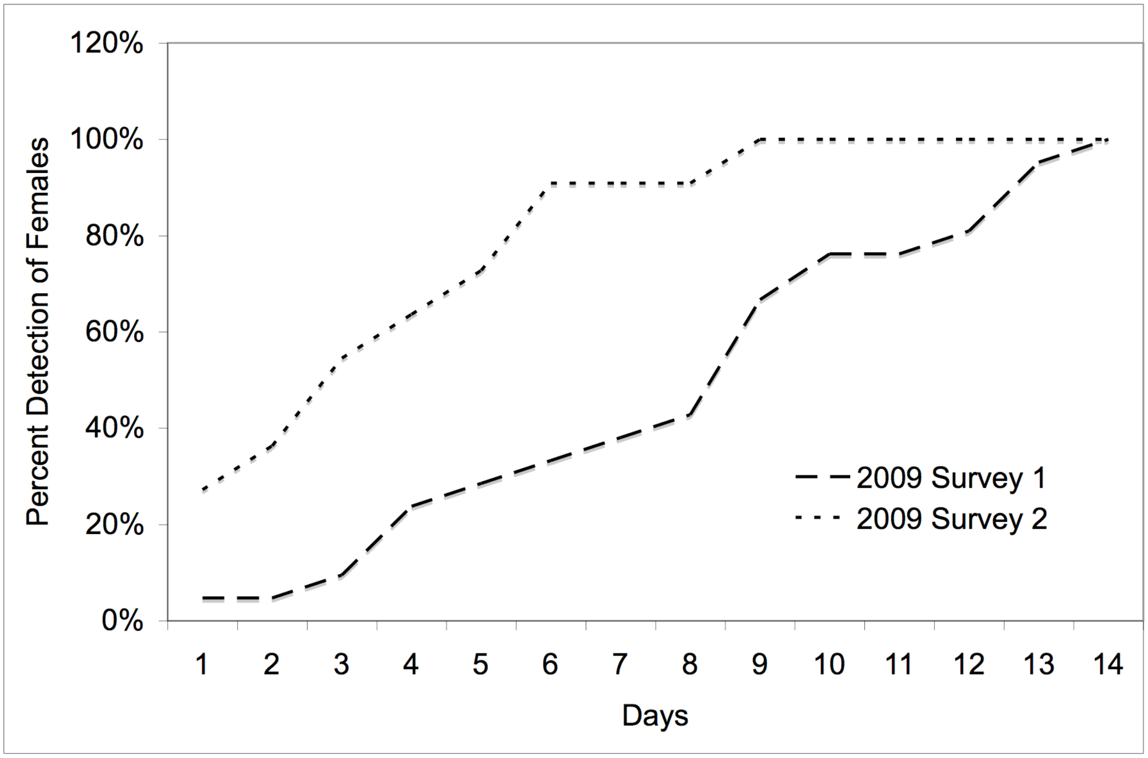

Figure 7. Percentage of tagged sika deer yearling and adult females detected by day during 2 different camera survey in 2009 at Tudor Farm in Dorchester County, Maryland.

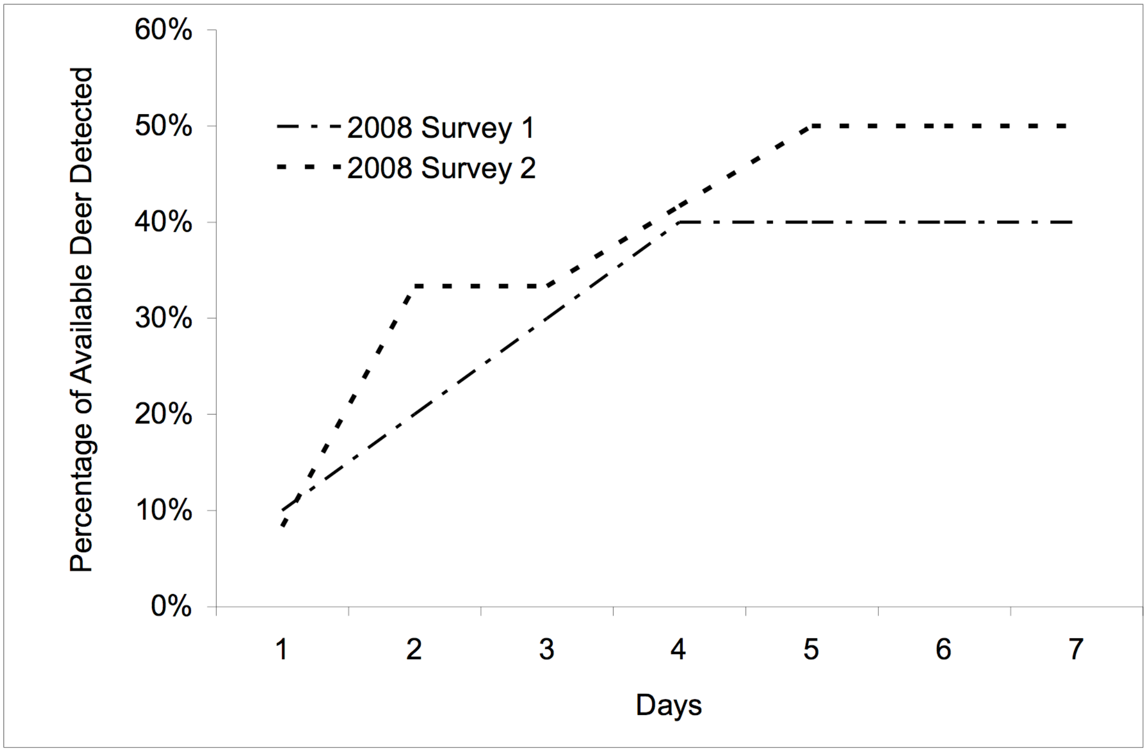

Figure 8. Percent of available juvenile sika deer males detected during 2008 camera surveys by day and survey at Tudor Farms, LLC in Dorchester County, Maryland.

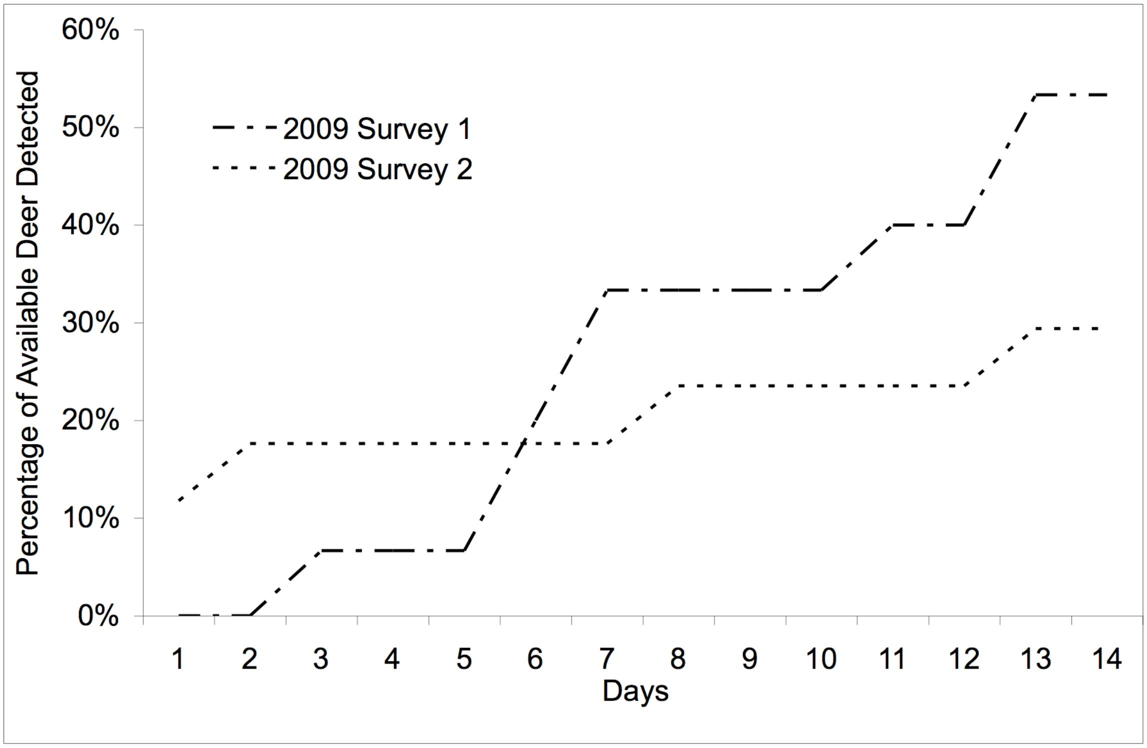

Figure 9. Percent of available juvenile sika deer males detected during 2009 camera surveys by day and survey at Tudor Farms, LLC in Dorchester County, Maryland.

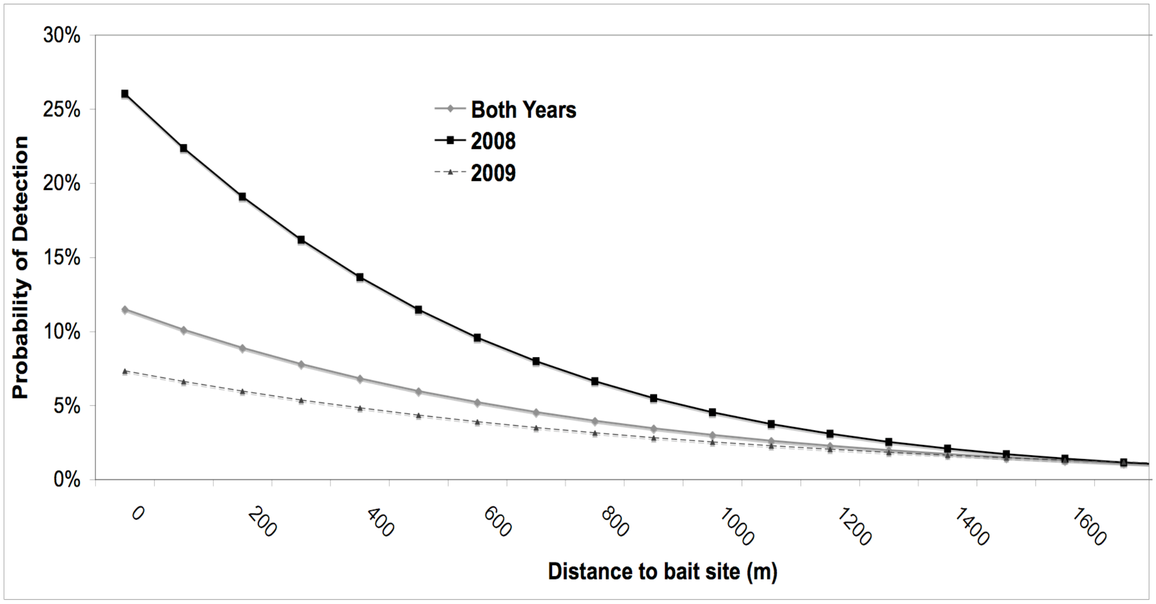

Figure 10. Probability of detection for juvenile male sika deer at camera sites during 2008-2009 camera surveys at Tudor Farms, LLC in Dorchester County, Maryland.

Chapter 5

DISCUSSION

The estimates generated from the camera surveys are 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- minute, 5- minute, and 10-minute intervals, respectively) are less than the estimates generated by the Jacobson method (448, 468, and 521; 1- minute, 5- minute, and 10-minute intervals, respectively). The upper limits of the confidence intervals from Bowden's estimates do not overlap the estimates generated by the Jacobson method. Considering the small differences between the estimates from all other surveys, there seems to be no discernable difference between the Jacobson method and 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, Figures 1 and 2). The low estimates in 2008 during Survey 1 resulted from fewer identifiable deer.

Program NOREMARK 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 observed in my study (Bowman et al. 1996, Sweitzer et al.

2000, Roberts et al. 2006, Watts et al. 2008, and 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.

Reducing costs when conducting population surveys is often a major concern (Jacobson et al. 1997, Koerth et al. 1997, McKinley et al 2006, Roberts et al. 2006, Watts et al. 2008). Increasing the picture intervals from 1-minute to 5 and 10-minutes had little effect on the population estimate except that Bowden's 10-minute estimates generated much wider confidence intervals (Figure 2). The greatest savings from increasing the photo interval comes from photo analysis. In this study increasing the photo interval reduced the total number of photos by 66% and 81% for pictures taken at 5 and 10-minute intervals, respectively (Table 2). When analyzing photos it took me an average of 1-hour to analyze 120 photos, for a total time of ≈282-hours for photos taken at 1-minute intervals. By increasing the photo interval to 5-minutes the total time required to analyze all photos was ≈96-hours and increasing the photo interval to 10-minute total time was reduced to ≈53-hours. Additionally, by increasing the photo intervals, camera surveys would use fewer batteries, require fewer pictures to be developed, and require less effort on behalf of the surveyor.

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 role in determining the optimum survey length (Figures 4-9). Limiting bait reduced the overall attractiveness of bait sites and therefore increased the amount of time needed for deer to be detected (Figures 4-9). In 2008 when bait was not limited, all deer were detected by day 3 during the active camera period; however in 2009, not all deer were detected until day 13, the 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 (Figures 8 and 9). An unlimited amount of bait allowed for greater detection probabilities and shorter lengths of time until identifiable sika deer were detected because bait placed at sites lasted throughout the day. When bait is available for longer sika deer have more time to be detected at bait sites and also more time during the day to approach baited sites, increasing detection probabilities. Limiting bait at sites reduces the bait availability to any deer in the area and causes competition for available bait amongst sika deer.

The use of baited camera sites could bias the abundance estimates generated from the camera surveys (Watts et al. 2008). In this study the use of bait did not bias surveys because of the increased detection rates throughout all camera surveys compared to unbaited camera surveys (Pei 2009). As with Jacobson et al. (1997), 14-days was the optimal amount of time for sika deer in Maryland 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 I conducted in 2008, all deer were consistently detected by the 10th overall day of the survey (Figure 4-9). A 10-day camera survey appears to be the optimum length of time if bait is not limited.

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. 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 in Maryland (Bartos 2009, Swanson and Putnam 2009, Tori and Tatsuzawa 2009).

Given the wide range of estimates for the sika deer population in Maryland, the density estimates generated from my camera surveys could be extrapolated to the entire range of sika deer in Maryland. My study area is representative of the sika deer range in Maryland and therefore the density estimates that I generated could be used to estimate the population in Maryland. Dorchester County has approximately 564.6-km^2 of sika deer habitat. Using the average density estimates generated by both estimators, the population estimates would be 17,503 and 16,373 individuals for the Jacobson method and Bowden's estimator, respectively. These estimates confirm some suspicions that population reconstruction could be severely underestimating the sika deer population in Maryland (T.B. Eyler, pers. comm.).

Chapter 6

MANAGEMENT IMPLICATIONS

Setting up a camera survey can be a good way to determine abundance of sika deer in areas with limited harvest. For a low-cost and precise camera survey, I recommend a 14-day survey maintaining a 12-kg of bait per site with pictures taken at 5-minute intervals and using Bowden's estimator. If unlimited bait is not cost prohibitive a 10-day camera survey with 1-minute picture intervals could be used effectively to estimate abundance. A camera survey with pictures taken at 5-minute intervals substantially reduces the costs associated with camera surveys and reduces the amount of time required to analyze photos. Camera site selection is important, so sites should be selected based on ease of access for the surveyor and attractiveness to sika deer (i.e. proximity to deer trails, proximity to road, water present at the site, nearby obstructions, etc.).

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Appendix A. Summary of total sika deer occurrences during 4 separate camera surveys at Tudor Farm LLC in Dorchester County, Maryland.

	Survey 1 2008	Survey 2 2008	Survey 1 2009	Survey 2 2009
Identifiable Males	3,204	2,393	5,478	3,542
Unidentifiable Males	3,915	2,008	1,964	1,518
All Tagged Females	490	650	1,561	1,210
Untagged Females	8,032	12,589	15,310	11,742
Radio-Collared Males	435	487	634	591
Juveniles	3,915	8,561	7,709	6,762