SPATIAL ECOLOGY AND SURVIVAL OF SUBADULT MALE SIKA DEER ON MARYLAND'S EASTERN SHORE

by

David M Kalb

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David M Kalb

Approved: ____
Jacob L. Bowman, Ph.D.
Professor in charge of thesis on behalf of the Advisory Committee

Approved: ____
Douglas W. Tallamy, Ph.D.
Chair of the Department of Entomology and Wildlife Ecology

Approved: ____
Robin W. Morgan, Ph.D.
Dean of the College of Agriculture and Natural Resources

Approved: ____
Debra Hess Norris, M.S.
Vice Provost for Graduate and Professional Education

"Every farm woodland, in addition to yielding lumber, fuel and posts, should provide its owner a liberal education. This crop of wisdom never fails, but it is not always harvested. I here record some of the many lessons I have learned in my own woods."

Aldo Leopold

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CHAPTER 1

Introduction to Sika Deer on Maryland's Eastern Shore

Sika deer (*Cervus nippon)* are native to Asia and the Japanese islands, and were introduced to the Delmarva Peninsula in 1916. Since then, they have increased in number to an estimated 10,000 individuals. Although concentrated in Dorchester County, Maryland, sika deer are now found in Wicomico, Somerset, and Worcester Counties in Maryland (Maryland DNR 2009) as well as in Sussex County, Delaware (Delaware Department of Natural Resources and Environmental Control 2008) and Assateague Island, Virginia (Diefenbach and Christensen 2009). Sika deer are also reported from 31 other state wildlife agencies (Feldhamer and Marcus 1994).

Many states are concerned about sika deer being vectors for disease or competition with native populations of cervids (Feldhamer and Marcus 1994). Because sika deer eat a greater variety of plants (Keiper 1985), and are more aggressive, they are able to outcompete native deer where the 2 overlap (Bartos 2009). Maryland shares these concerns but also recognizes the important and unique sport hunting value of the species so the goal of the Maryland DNR is to maintain the current population level of sika deer (Eyler and Timko 2008).

Sika deer in Maryland are hunted for both meat and trophy antlers. Sika deer in general vary in size, coloration, and antler growth depending on the subspecies and native area. The *C. n. yakushimae*, the subspecies found in Maryland, is the smallest subspecies (Koda et al. 2008), with males reaching dressed weights of approximately 45 kg, whereas, females are smaller and have dressed weights of approximately 34 kg. Only male sika deer grow antlers, with growth beginning around mid-April as soon as the previous year's antlers are shed. Sika deer in Maryland will begin to grow antlers as yearlings, which will range in size from <1.3 cm of hard antler to spikes over 7.6 cm. No yearlings have been observed with branched antlers even in subspecies that produce larger antlers (Bennesten 1977). Often, adult males will have 3 points to a side although a few have been observed with 4 to a side (Maryland DNR 2009).

Sika deer consume a greater percentage of browse and a greater diversity of plants than native white-tailed deer in Maryland (*Odocoileus virginianus*) (Keiper 1985). Differences in diet may allow sika deer to take advantage of habitats that are not as heavily exploited by white-tailed deer. Sika deer may also be able to exploit habitats that currently have less dense populations of white-tailed deer by dispersing into them and taking advantage of food and space resources that are not sufficient for white-tailed deer.

Maryland separated sika deer harvest from white-tailed deer harvest in 1973 (Feldhamer et al. 1978). In 1976, managers hoped to change harvest trends by increasing bag limits on sika deer to 3 and decreasing white-tailed deer limits to 1 deer per season. Later managers reduced harvest pressure on sika deer to preserve the unique hunting opportunity. Currently sika deer regulations restrict harvest to 6 animals while hunters are allowed to take 30 white-tailed deer. Maryland has a growing population of sika deer (T. B. Eyler, Maryland Department of Natural Resources, personal communication) and management has the current goal of maintaining the population (Maryland DNR 2009).

CHAPTER 2

Spatial Ecology of Subadult Male Sika Deer on Maryland's Eastern Shore

ABSTRACT: Four or 5 (sexes unknown) Sika deer were introduced to the Delmarva Peninsula in 1916 (Flyger 1962). Since then their population has grown to an estimated 10,000 individuals (T. Brian Eyler, Maryland Department of Natural Resources and Wildlife Heritage, personal communication). The purpose of my study was to investigate dispersal and home range size of this growing population. I collected telemetry locations on 60 stags captured in their first winter from February 2008 through February 2010. Home range size was affected by seasons and deer movement types ($P = 0.0001$), averaging 464 ha-4,121 ha. Of 20 deer that dispersed, 19 did so at 1 year old. Dispersal distance and direction were random across the landscape ($P = 0.899$). Animals were classified into three movement groups; local, migratory, and nomadic. Local deer were the most common movement group and were characterized by short movements confined into a well established home range. I observed 14 deer migrations, which were round trip movements that were associated with seasons and direction ($P = 0.003$). Four deer I observed were classified as nomadic and had long distance movements across the landscape unassociated with seasons.

KEY WORDS: *Cervus nippon yakushimae*, dispersal, home range, Maryland, male, movements, nomadic, radio telemetry, sika deer

An increasing population of sika deer (*Cervus nippon*), an exotic species, in the Delmarva region is leading to concerns about conflicts with native species for space and food resources. Sika deer are more generalized in their feeding habits than species of native deer in many areas where they have been introduced, including Maryland

(Feldhamer and Marcus 1994, Swanson and Putman 2009). In areas with a niche overlap, sika deer are able to out-compete other species through aggression and using habitats that native species do not (Bartos 2009). The ability of sika deer to out-compete native white-tailed deer (*Odocoileus viginianus*) threatens to reduce native deer numbers where they cohabitate as well as lead to the spread of sika deer to new areas. In order to prevent the spread and further competition between introduced sika deer and native white-tailed deer, Maryland Department of Natural Resources (DNR) has set the goal of maintaining sika deer at their current population level (Eyler and Timko 2008). Understanding an animal's spatial ecology is integral to making management decisions to control a population. Insights into spatial ecology may provide information about where and how a population can be limited from expanding.

Understanding the spatial ecology of young males is imperative in managing the expansion of sika deer populations because they are the first cohort of animals to enter new areas (Swanson and Putman 2009), but a paucity of information is available for sika deer in Maryland. Published information regarding sika deer has focused on females or populations in their native range. For female sika deer in Maryland Eyler (2001) estimated annual home range size to be 161 ha. In Japan, home range sizes of male sika deer were estimated to be 4 and 10 ha for subdominant and dominant males, respectively (Endo 2009). In the British Isles, male sika deer had home ranges that ranged from 45-250 ha depending upon habitat and age (Swanson and Putman 2009). Because estimates of male home range size are highly variable for other areas and lacking for the eastern shore of Maryland, additional research is necessary to acquire these estimates.

Understanding spatial ecology of sika deer includes movement within and between home ranges. Deer move over the landscape in several ways. Sika deer can disperse which involves the movement of subadult deer (< 3 years old; Petersburg et al. 2000) from a baseline home range associated with their natal range (where they were born) to an area where they establish an adult home range (Petersburg et al. 2000, Long et al. 2008). Sika deer can also move across a landscape in ways that are not dispersals. These movements include : local movements, migrations, or nomadic movements. Local movements consist of day to day movements in a given area with little or no movement outside of an established home range. Migration is a seasonally associated movement between 2 home ranges with a predictable return to the same place. Nomadic deer move randomly across the landscape, unrelated to seasons, and do not establish a defined home ranges.. Nomadic sika deer in Europe were recorded to wander distances up to 160 km into areas lacking other sika deer (Bartos 2009). Male deer in Japan's Nara park had large, nomadic home ranges until they established an adult territory (up to 5 years:Miura 1984, Torii and Tatsuzawa 2009).

In an effort to better understand and manage the sika deer population, I conducted this study to fill the gaps in the literature regarding male sika deer movements and home range sizes. My objectives were to estimate home range sizes for subadult males and determine what proportion of the population dispersed (estimating average date, direction and distance). I hypothesized that male sika deer home range estimates would exceed those of female sika deer and white-tailed deer in size. I also hypothesized that male sika deer would disperse in both fall and spring during the first and second year of life in random directions and distances.

STUDY AREA

I conducted this research within greatest concentration of sika deer, Dorchester County, Maryland. The study area (1,542 km²) had an average elevation of 1 m above sea level (Feldhamer and Marcus, 1994) and was 41% forested, 30% agriculture, 25% wetlands, and 4% developed (Comprehensive Coastal Inventory Program 2003). Dorchester county was bordered on the west and south by the Chesapeake Bay, and on the east by the Nanticoke River. Blackwater National Wildlife Refuge along with Fishing Bay Wildlife Management Area (WMA) composed a large portion of the area south of Route 50. Trapping was conducted throughout the county on areas both north and south of these 2 major public land areas.

Dominant forest plants included loblolly pine (*Pinus taeda*), white oak (*Quercus alba*), northern red oak (*Quercus rubra*), willow oak (*Quercus phellos*), red maple (*Acer rubrum*), sweet gum (*Liquidambar styraciflua*), black gum (*Nyssa sylvatica*), poison ivy (*Toxicodendron radicans*), greenbriar (*Smilax* spp.), and American holly (*Ilex opaca*). Marshes were comprised of mostly three square rush (*Scirpus olnyi*), salt grass (*Distichlis spicata*), spikerush (*Eleocharis parvula*), cattail (*Typha* sp.), sedges (*Carex* spp.), common reed (*Phragmites australis*), and wax myrtle (*Myrica spp.*) (Feldhamer and Demarais 2009).

The daily average low and high temperature (1971-2001) were -3.0ºC and 7.1ºC in January, and 19.7ºC and 25.1ºC in July (National Oceanic and Atmospheric Administration 2009). Dorchester County averaged 120 cm of precipitation each year with <27 cm of it deposited as snow (National Oceanic and Atmospheric Administration

2009). Temperature and precipitation levels for 2008 and 2009 fell within the 30 year averages.

METHODS

I captured sika deer from January to April of 2008 and 2009 using drop nets, clover traps, and dart guns. For deer captured with drop nets or clover traps, I blindfolded and then sedated them with Xylazine (0.25 mg/kg; Eyler 2001, DeNicola et al. 1997, Rosenberry et al. 1999, Conner et al. 1987) via intramuscular injection. I darted deer with an intramuscular injection of Xylazine (4.4 mg/kg). For all sedated deer, I administered the antagonist Yohimbine hydrochloride (0.5 mg/kg; Eyler 2001, Rosenberry et al. 1999, DeNicola et al. 1997) intramuscularly within an hour of sedation. All deer received 2 medium 4.5 cm x 5.1 cm Allflex™ (Allflex USA, Inc. Dallas, TX) plastic ear tags (white with black numbering) and 2 self-piercing metal tags (Model # 1005-49, National Band and Tag Company, Newport, KY) uniquely numbered for each deer. I estimated each deer's age according to tooth replacement and wear for elk (United States Geological Survey 2006) and collected standard body measurements (hind foot length, front shoulder height, chest girth, and total body length; Rhoads 2006, Feldhamer et al. 1984). I monitored each deer until they left the capture site. All juvenile males (<1 year old) were fitted with expandable VHF radio collars (340g; Advanced Telemetry Systems, Isanti, MN). The University of Delaware's Institutional Animal Care and Use Committee approved my capture and handling procedures (Approval No. 1182).

I monitored deer via radio telemetry from time of capture as juveniles until February 2010 or until they lost their collar or died. I collected locations for each animal at least once per week from the ground using biangulation from fixed telemetry stations.

I used a Global Positioning System (GPS) handheld device to geo-reference each station. I took bearings with ATS R410 (Advanced Telemetry Systems, Isanti, MN) scanning telemetry receivers and a 3-element hand-held yagi antenna or H antenna. To obtain Universal Transverse Mercator (UTM) coordinates for each location, I entered the best 2 bearings (closest to 90º) into program LOAS™ 4.3 (Location of a Signal, Ecological Software Solutions, Urnäsch, Switzerland). I did not include any readings >15 minutes apart or with an interior angle outside of 60 and 120 degrees in my analysis. I visually located any deer with a collar that emitted a mortality signal to determine cause of the morality signal (i.e., cause of death or mortality signal on a live deer).

To estimate telemetry accuracy, I conducted an assessment of error for everyone that collected telemetry readings. I placed 10 radio collars on sugar solution bottles and placed them throughout the landscape where collared animals had been (Larkin et al. 1996). GPS locations were taken on the bottles and the location was unknown by the person taking the test. Average error polygon was 1.8 ha (SE = 0.48, range 0.0-9.1). Average time delay for all telemetry locations was 6.7 minutes between bearings with an average distance of 1049 m between telemetry station and estimated location (Saltz 1994).

I calculated seasonal home ranges for each deer for predetermined seasons. I defined seasons as 3 month periods that focused on biological activities of male sika deer. Parturition began in May (Feldhamer 1980) and appears to be extended in Maryland sika deer, with an unknown end date (Feldhamer and Marcus 1994). I expected to observe dispersal events (Long et al. 2008) just before and/or during calving so the spring season was March 1 – May 31 to capture these dispersal activities. Most parturition (70%) was completed by the end of May (Koizumi et al. 2009). Deer that moved from their natal range after May cannot be considered to have been influenced by maternal aggression, so I defined the summer season as the period without maternal aggression (June 1-August 31). Rut activity has been known to cause an increase in home ranges size and induce dispersal movements (Long et al. 2008). As in other cervids, the peak in rut activity for sika deer varied slightly but typically occurred around the second week in October (Feldhamer 1980), so I defined the fall season as 6 weeks on both sides of the anticipated peak (September 1 – November 30th). I defined the winter season (December 1 – February 28) based on when most sika deer mortality related to deer harvest occurred. Most of the 2 week rifle season in Maryland fell in December each year when the largest numbers of sika deer were harvested (Eyler and Timko 2008). The longest portion of Maryland muzzleloader season for sika deer ran from December into January. Both early and late muzzleloader season combined accounted for the second highest harvest rate for sika deer in Maryland.

I estimated seasonal home range sizes at both 50% and 95% utilization distribution using fixed kernel. I used fixed kernels because it provided the least biased estimates of home ranges (Seaman et al. 1999) and since I made all measurements regarding distance and direction from the centroid of the 50% range, it was more important that the center of these estimates be accurate rather than the tails (Worton 1989). I used the Animal Movement Extension (Hooge and Eichenlaub 1997) for ArcView 3.2 for any deer with at least 25 locations in a season (Blundell et al. 2001, Seaman et al 1999) to calculate a home range size.

I defined an animal's natal range as all locations taken prior to April 1st. Natal home ranges were used as the baseline for all movements. Deer were first separated into dispersers and non dispersers. I defined dispersal as the permanent emigration from a natal range (<5% overlap in the 95% kernel). When I determined that a deer had moved away from its natal range, I checked all seasons after the movement to ensure that none involved an overlap with the natal range.

I categorized all deer into 1 of 3 movement types: local, migratory, or nomadic based on 50% and 95% kernel home range estimates. I classified deer from a baseline home range, which was a natal range for non-dispersing deer or the first home range after dispersal for dispersing deer. I considered a deer with consistent home range (50% and 95% kernel) overlap of ≥50% between every season a local deer. I determined a deer to be migratory by movement away (<25% overlap) from a baseline winter or summer home range (95% kernel). Migrations involved a return to the established winter or summer home range (>50% overlap in 95% kernel). I defined nomadic deer as moving continually over the landscape. Unlike migratory deer that utilized 2 core areas in a year, nomadic deer utilized at least 3 non-overlapping 50% kernel areas within a year. Nomadic home ranges always overlapped the baseline home range at the 95% kernel in every season. The amount of overlap within deer varied by deer and season but ranged from 10-80%. To determine date of dispersal or migration, I used the last day that an animal was found in any home range as the movement date.

Once classified, I used the 50% kernel estimates of home ranges to make measurements of distance and direction of both dispersals and migrations. I used the center of the core use area because it provided a more consistent and concentrated area with which to estimate movements for each deer. I used ArcView Animal Movement extension to determine the centroid of the 50% kernel home range areas (Hooge and Eichenlaub 1997).

I investigated if dispersal distance and direction were random using Moore's modification to the Rayleigh test (Moore 1980). I determined average dispersal and migration dates by averaging Julian dates. Mean dispersal and migration directions were determined by converting bearings from degrees to radians (theta). I then averaged the vectors (average X, average Y) of the radians (by taking the sin and cosine of each theta) using:

$$\text{atan2}\left[\frac{\text{sum}(\sin(\text{theta}))}{\text{n}}, \frac{\text{sum}(\cos(\text{theta}))}{\text{n}}\right]$$

(H2NS Environmental 2006). I conducted home range analysis with SAS (version 9.1, Cary, NC) with an alpha level of 0.05. I used a 3-way ANOVA (analysis of variance: Sokal and Rohlf 1995) with main effects of movement (nomadic, local, or migratory), season, and age. If differences were detected, I used a least significant differences test to separate means.

RESULTS

I collected 12,994 locations from January 2008-February 2010 on 60 collared sika stags (average 216 locations per deer). One deer was lost shortly after it moved several km from its capture area and was therefore not included in any analysis. The interaction of movement and season and age ($F_{4,175} = 0.80$, $P = 0.528$), the interaction of movement and age ($F_{2,175} = 1.04$, $P = 0.357$), the interaction of season and age ($F_{3,175} = 0.44$ $P = 0.724$), and age ($F_{1,175} = 0.44$, $P = 0.509$) did not affect home range size. The interaction of movement and season affect home range size ($F_{6,175} = 6.27$, $P = <0.0001$; Table 1).

Home range sizes among the movement types and seasons varied from 464 ha to 6,810 ha.

I documented dispersal for 33% of deer (n = 60; 2008 30%, n = 30; 2009 37%, n = 30). All dispersal occurred as yearlings except one deer that dispersed as a 2-year old. Mean dispersal distance was 7.7 km (SE = 1.0; 2008: $\bar{x}$ = 7.3, SE = 0.9; 2009: $\bar{x}$ = 8.1, SE = 1.7). Fifty-five percent of the deer dispersed in the spring. The average date of spring dispersal was April 23rd (SE = 4 days, n = 11). Average dispersal date for the summer was June 19th (SE = 9 days, n = 5), and for the fall was September 30th (SE = 6 days, n = 4). No deer were observed dispersing in the winter. Average dispersal direction was 266 º (range 13 º-348 º). Distance and direction of dispersing deer was random (R_{20} = 0.202, P = 0.899).

Fourteen deer had seasonal migration movements. The average departure date from the winter home range was April 28th (SE = 8 days) and October 4th (SE = 6 days) for the summer home range. Migration direction in the spring averaged 20º (range 320º-62º) and direction for fall averaged 246º (range 253º-5º). Average migration distance was 6.2 km (SE = 0.6). Distance and direction of migrations were not random (R_{14}= 1.38 P = 0.003).

Nomadic deer home ranges were 50% greater than migratory and local home ranges in the spring, and 300-1000% greater in fall and winter, with the exception of summer where all groups had smaller home ranges (Table 1). Nomadic deer covered 6,800 ha during the rut which is the largest home range size observed during any season for any group (Table 1). Only 4 deer exhibited nomadic movements (7%, n = 60).

Nomadic deer varied in traveling direction from semi-circular movements to single directional long-distance movements (i.e., 45 km) with few local movements.

DISCUSSION

I observed most (55%) sika deer dispersal during spring, so maternal domination was likely the most influential factor in subadult male dispersal. My results were similar to research on white-tailed deer and elk in North America, but differed from research on sika deer in Japan. Minami et al. (2009) concluded that males remained with their mothers until 2 or 3 years of age, whereas all but 1 sika deer in my study dispersed at age 1. Dispersing deer can be used as an indicator of areas likely to see sika deer range expansion (Swanson and Putman 2009). Swanson and Putman (2009) stated that sika deer advancement was primarily done by the young males at 3-5 km per year. I found that dispersal by young males in Maryland could advance similar distances with an average dispersal distances of 7.7 km.

Increase in harvest rates have been observed in key deer, white-tailed deer, and elk during periods of dispersal (Lopez et al. 2003, Smith and Anderson 2001). I also observed a greater rate of dispersal mortality. More than a third of deer with dispersal movements were harvested. Some of the local or migratory deer may have been captured post-dispersal, but 57 of 60 deer were captured prior to the first date any deer moved outside of its natal range; therefore, I did not consider this to be a significant source of error.

I observed a mixture of migrations and local movements similar to sika deer behavior in Japan (Igota et al. 2009). I also observed nomadic home ranges like those of young sika deer in both Europe and Japan (Bartos 2009, Torii and Tatsuzawa 2009).

Regardless of movement type, the average sizes of home ranges were larger than all other reported sika home ranges. The smallest home range sizes on average were observed during the summer months, yet even the smallest home ranges observed in my study were larger than those observed in other sika deer studies; some were 20 times larger (Swanson and Putman 2009, Eyler 2001, Feldhamer et al. 1982). Sex and sample size differences could account for these differences. Home ranges observed were similar to those observed in elk (McCorquodale 2003, Tiller et al. 2000). These results follow the close phylogenetic relationship between sika deer and North American elk (Polziehn and Strobeck 1998).

Local deer had the most consistent home range sizes across seasons, but still had an increase in home range size during the rut. On average, local males had home ranges that were 3 times larger than females from the same area (Eyler 2001). When compared to male sika deer in the British Isles, I observed home ranges 2-10 times larger, and 25-100 times larger than male sika deer in Japan (Swanson and Putman 2009, Endo et al. 2009).

I observed more local deer than Diefenbach and Christensen (2009) which may be due to differences in study areas. Assateague Island has greater percentage of marsh and saltwater grass habitat, and less hardwood forested areas than Dorchester (Diefenbach and Christensen 2009). Dorchester County may also have more local deer than Assateague due to local landowner’s ability to bait year-round. In winter seasons when food resources are scarce, sika deer that are close to bait piles may not need to migrate to areas with better food availability.

Home range sizes of migratory deer increased each spring and fall which coincided with migration between winter and summer home ranges. Sika deer that migrated tended to have larger home ranges during the winter months than in summer which indicated that these animals had to cover a larger area to acquire the same basic resources. Unlike sika deer, elk tended to have larger summer home ranges than winter ranges (McCorquodale 2003). Elk and sika deer in their native range have habits that are often dependent on migratory movements across elevation gradients in connection with seasonal changes (Igota et al. 2009, McCorquodale 2003). Migrations are down to the valleys in the winter and up to the mountains in the summers which are associated with food availability (Igota et al. 2009, McCorquodale 2003). Based on the direction of migration that I observed, young males may be moving to the hardwood and agricultural habitats in the summer and possibly returning to the marshes in the winter. This migration pattern may be induced more by hunting pressure than food availability, these speculations will require further investigation to be confirmed. Change in home range size in Japan sika deer depended on migration movement. Deer that migrated had larger summer home ranges than winter, while local deer exhibited larger ranges in the winter than summer. Migration is uncommon in white-tailed deer on the Delmarva Peninsula. Rather than migrate, they shift their core use areas (Rhoads 2006), making migration unique to sika deer in Maryland.

The Delmarva Peninsula is characterized by the same physical attributes as seen in other areas where nomadic behavior is observed (i.e. large open areas with little change in elevation). Nomadic deer, as with the other 2 movement types had a marked increase in home range size during the rut. Nomadic deer during their first rut had the largest home range size that was observed during the entire study. Although nomadic deer traveled the greatest distance, none from this study moved close to the 160 km observed in Europe (Bartos 2009). Home ranges I observed where substantially larger (500 times) than those observed in Japan's Nara park (Miura 1984); however, the park was only 340 ha in size and average territory size for adults was substantially smaller (4.7 ha) than those observed in the US. Nomadism is important to species where food resources change quickly (Fryxell et al. 2004). Sika deer in Dorchester, even during winter should be able to find food within an area smaller than nomadic home range size that I observed. A possible explanation for nomadic home ranges could be dispersing deer that have not settled into an adult home range. Other factors (e.g., hunting pressure, geographical obstacles) could encourage deer to travel back to natal ranges where they are familiar, thereby interrupting movement that would naturally be migration or dispersal.

Eyler (2001) observed home ranges for female sika deer that were only 20% larger than home ranges observed for sympatric white-tailed deer. Home range sizes I observed followed Eyler (2001) in trend between sexes because sika deer home ranges were greater than those observed for white-tailed deer in similar studies (Brinkman et al. 2005, Smith 1991). Home range sizes for males of both species are larger than that of females. Male white-tailed deer tend to have seasonal home ranges up to 200 ha with some up to 550 ha (Nelson and Mech 1984, Rongstad and Tester 1969, Holzenbein and Marchinton 1992). Home range sizes observed in this study were consistently 3-10 times larger than those observed in white-tailed deer. This discrepancy is most likely is a synergistic result of differences in behavior of male and female and differences between species.

MANAGEMENT IMPLICATIONS

Dispersal data that I collected suggest that dispersal into new areas will primarily be observed in the spring. To better understand the distance that the population is advancing each year, surveys should be done in early summer, after young deer have dispersed and when migratory deer have moved north. Sika deer have been observed dispersing into new areas, and given their capacity to move long distances, an increased harvest rate of sika deer is recommended to reach Maryland's goals of maintaining the population level. By increasing harvest in the northern and eastern most extents of sika deer range, the population could be restricted. North and east are the primary directions of interest because spread of sika deer is naturally blocked by the Chesapeake Bay on the western and southern sides. By understanding sika deer spatial ecology more species specific management practices can be utilized. All but 5 sika deer had well established home range areas by age 2 therefore harvest can be focused in areas that will cause the desired population shift. Due to the directional shift of home ranges in migratory deer, it is unlikely that sika deer harvested in agricultural fields during hunting season are the same deer that cause crop damage in summer and early fall because these deer tended to migrate back to the marsh prior to the peak of hunting season. Managers who wish to change their population densities of sika deer most likely will be able to do so in areas as small as 400 ha. Nomadic deer would pose a difficulty in any area where deer are trying to be managed because of their large home range size, and continual movements within these ranges.

Table 1. Average male subadult sika deer home range size (ha) by movement type and season from 2008-2009 in Dorchester County, Maryland. All means for all seasons and movements were compared in the same analysis.

	Local			Migratory			Nomadic		
	n	$\bar{x}$ [a]	SE	n	$\bar{x}$	SE	n	$\bar{x}$	SE
Winter	15	727 CDE	145	9	479 E	49	2	3694 B	160
Spring	36	705 DE	101	11	1553 CDE	399	6	2058 C	1253
Summer	42	469 E	77	16	464 E	74	6	466 E	155
Fall	34	793 CDE	88	16	2020 CD	305	4	6810 A	4121

[a] Means with the same letter are not significantly different.

CHAPTER 3

Sika Deer Survival • Kalb et al.

Survival Rate of Subadult Male Sika Deer on Maryland's Eastern Shore

David M Kalb, Department of Entomology and Wildlife Ecology, University of Delaware, Newark, DE 19717, USA

ABSTRACT: The sika deer population in Maryland has been gradually increasing since their introduction in 1916. The purpose of my study was to determine a survival rate for subadult males, which are the segment of the population with the greatest harvest rate. I captured 60 male sika deer as juveniles (<1) and fitted them with radio telemetry collars. Survival rates did not differ among seasons (P = 0.060; spring = 0.98, SE = 0.019; summer = 1.00, SE = 0.000; fall = 0.93, SE = 0.034; and winter = 0.96, SE = 0.027) with a survival rate of 0.87 (SE=0.045). Survival was greater than previously reported in other native and introduced populations of sika deer, as well as many other populations of cervids. The greatest cause of mortality was hunting, and no animal deaths were attributed to natural causes or disease. Survival in sika deer was greater than in sympatric native white-tailed deer. I recommend an increase in harvest to achieve Maryland DNR deer management goals.

KEY WORDS: *Cervus nippon yakushimae,* Maryland, male, radio telemetry, sika deer, survival, subadult

Sika deer (*Cervus nippon*), an exotic species in the Delmarva region, has increased in abundance and expanded its range leading to concerns about conflicts with native species for space and food resources. Until the 1950's, the population of sika deer was small (<500; Flyger 1960). Introduced in 1916, the population has increased from <10 individuals to an estimated 10,000 individuals (T. Brian Eyler, Maryland Department of Natural Resources, personal communication). To prevent additional range expansion and further competition with native white-tailed deer, Maryland Department of Natural Resources (DNR) has set the goal of maintaining sika deer at their current population level (Eyler and Timko 2008). Because harvest of sika deer is the primary mortality cause and means of population control, understanding survival rates of sika deer is an important factor in designing an effective harvest regime.

Survival rates are necessary for understanding factors that affect population growth. Sika deer are not exposed to legal hunting in some parts of their native range (Takatsuki and Padmalal 2009). On Kinkazan Island females (55%) had greater survival rates than males (35%) including calf survival. Dominant males on the island lived on average 3 years longer than subdominant males despite the lack of predators and a ban on hunting (Minami et al. 2009). In the native range of sika deer where hunting was allowed, Uno and Kaji (2006) found an annual survival rate of 78% for females. The greatest cause of mortality was harvest (31%) followed by natural causes (13%) and unknown causes (6%). Miura and Tokida (2009) estimated survival from several populations of both hunted and non-hunted deer. The subadult (male and female) survival rate varied from 30-90% with greater survival rates as animals matured. Diefenbach and Christensen (2009) estimated 56% annual survival rate for male sika deer on Assateague Island, Maryland and harvest (legal and illegal) was the only cause of mortality. Eyler (2001) estimated an 82% survival rate for all captured female sika deer during his study in Maryland sika deer, and harvest accounted for all mortalities.

The male component of the sika deer harvest is dominated by subadults (<3 years old; Petersburg et al 2000, T.Brian Eyler, Maryland Department of Natural Resources and Wildlife Heritage, personal communication), but estimates of subadult survival are lacking. An understanding of subadult male survival rates will allow managers to better prescribe harvest regimes to manipulate sika deer populations and provide information for better population estimates. Currently Maryland DNR formulates their estimates for sika deer population size from population reconstruction models, and better estimates of survival could permit more precision population estimates. Knowledge of high population survival and increases in densities will allow managers to increase harvest to coincide with increased deer abundance. My objectives were to estimate survival and cause-specific mortality rates for subadult male sika deer. I hypothesized that male survival rates would be similar to survival from other areas with sika deer. I expected all mortalities to be from either hunter harvest or natural causes.

STUDY AREA

I conducted this research within greatest concentration of sika deer, Dorchester County, Maryland. The study area (1,542 km^2) had an average elevation of 1 m above sea level (Feldhamer and Marcus, 1994) and was 41% forested, 30% agriculture, 25% wetlands, and 4% developed (Comprehensive Coastal Inventory Program 2003). Dorchester county was bordered on the west and south by the Chesapeake Bay, and on the east by the Nanticoke River. Blackwater National Wildlife Refuge along with Fishing Bay Wildlife Management Area (WMA) composed a large portion of the area south of Route 50. Trapping was conducted throughout the county on areas both north and south of these 2 major public land areas.

Dominant forest plants included loblolly pine (*Pinus taeda*), white oak (*Quercus alba*), northern red oak (*Quercus rubra*), willow oak (*Quercus phellos*), red maple (*Acer rubrum*), sweet gum (*Liquidambar styraciflua*), black gum (*Nyssa sylvatica*), poison ivy (*Toxicodendron radicans*), greenbriar *(Smilax* spp.), and American holly (*Ilax opaca*). Marshes were comprised of mostly three square rush (*Scirpus olnyi*), salt grass (*Distichlis spicata*), spikerush (*Eleocharis parvula*), cattail (*Typha* sp.), sedges (*Carex* spp.), common reed (*Phragmites australis*), and wax myrtle (*Myrica spp.*) (Feldhamer and Demarais 2009).

The daily average low and high temperature (1971-2001) were -3.0ºC and 7.1ºC in January, and 19.7ºC and 25.1ºC in July (National Oceanic and Atmospheric Administration 2009). Dorchester County averaged 120 cm of precipitation each year with <27 cm of it deposited as snow (National Oceanic and Atmospheric Administration 2009). Temperature and precipitation levels for 2008 and 2009 fell within the 30 year averages.

METHODS

I captured sika deer from January to April of 2008 and 2009 using drop nets, clover traps, and dart guns. For deer captured with drop nets or clover traps, I blindfolded and then sedated them with Xylazine (0.25 mg/kg; Eyler 2001, DeNicola et al. 1997, Rosenberry et al. 1999, Conner et al. 1987) via intramuscular injection. I darted deer with an intramuscular injection of Xylazine (4.4 mg/kg). For all sedated deer, I administered the antagonist Yohimbine hydrochloride (0.5 mg/kg; Eyler 2001, Rosenberry et al. 1999, DeNicola et al. 1997) intramuscularly within an hour of sedation. All deer received 2 medium 4.5 cm x 5.1 cm Allflex™ (Allflex USA, Inc. Dallas, TX) plastic ear tags (white with black numbering) and 2 self-piercing metal tags (Model # 1005-49, National Band and Tag Company, Newport, KY) uniquely numbered for each deer. I estimated each deer's age according to tooth replacement and wear for elk (United States Geological Survey 2006) and collected standard body measurements (hind foot length, front shoulder height, chest girth, and total body length; Rhoads 2006, Feldhamer et al. 1984). I monitored each deer until they left the capture site. All juvenile males (<1 year old) were fitted with expandable VHF radio collars (340g; Advanced Telemetry Systems, Isanti, MN). The University of Delaware's Institutional Animal Care and Use Committee approved my capture and handling procedures (Approval No. 1182).

I monitored deer from time of capture as juveniles until February 2010 or until they lost their collar or died, via radio telemetry. I collected locations for each animal at least once per week from the ground using biangulation from fixed telemetry stations. I used a Global Positioning System (GPS) handheld device to geo-reference each station. I took bearings with ATS R410 (Advanced Telemetry Systems, Isanti, MN) scanning telemetry receivers and a 3-element hand-held yagi antenna or H antenna. To obtain Universal Transverse Mercator (UTM) coordinates for each location, I entered the best 2 bearings (closest to 90º) into program LOAS™ 4.3 (Location of a Signal, Ecological Software Solutions, Urnäsch, Switzerland). I did not include any readings >15 minutes apart or with an interior angle outside of 60 and 120 degrees in my analysis. I visually located any deer with a collar that emitted a mortality signal to determine cause of the morality signal (i.e., cause of death or mortality signal on a live deer).

Survival rates were determined annually as well as by predetermined seasons. I defined seasons as 3 month periods that focused on biological activities of male sika deer.

Survival of cervids has been shown to be reduced during periods of dispersal (Lopez et al. 2003), which is induced at different times of the year. Parturition began in May (Feldhamer 1980). I expected to observe dispersal events (Long et al. 2008) just before and or during calving so the spring season was March 1 – May 31 to capture these dispersal activities. Most parturition (70%) was completed by the end of May (Koizumi et al. 2009). Deer that moved from their natal range after May cannot be considered to have been influenced by maternal aggression, so I defined the summer season as the period without maternal aggression (June 1-August 31). Rut activity has been known to cause increase in home ranges size and induce dispersal movements (Long et al. 2008). As in other cervids, the peak in rut activity for sika deer varied slightly but typically peaked around the second week in October (Feldhamer 1980), so I defined the fall season as 6 weeks on both sides of the anticipated peak (September 1 – November 30th). I defined the winter season (December 1 – February 28) based on when most sika deer mortality related to deer harvest occurred. Most of the 2 week rifle season in Maryland fell in December each year, when the largest number of sika deer was harvested (Eyler and Timko 2008). The longest portion of Maryland muzzleloader season for sika deer ran from December into January and accounted for the second greatest harvest rate for sika deer in Maryland.

I center censored animals when the exact day of death was not known (DeLgiudice et al. 2002) I estimated annual and seasonal survival rates using the Kaplan-Meier estimator in SAS (version 9.1, Cary, NC; Heisey and Fuller 1985, Ebersole 2006). Survival rates among years were similar ($P<0.05$) and were pooled. I compared seasonal survival rates using the program Contrast (Hines and Sauer 1989).

RESULTS

From February 2008 to February 2010, I captured 195 sika deer and collared 60 juvenile males. The annual survival rate was 0.87 (SE = 0.045). Survival rates did not differ among seasons (χ^2_3 =7.413 P= 0.060; spring = 0.98, SE = 0.019; summer = 1.00, SE = 0.000; fall = 0.93, SE = 0.034; and winter = 0.96, SE = 0.027). One deer was censored at 194 days because it was euthanized at a land-managers request. Of the 8 collared deer that died, 6 had moved outside of their natal range and 2 were harvested inside their natal area. One deer was hit by a vehicle and 7 were harvested: 2 during bow season and 5 during gun season. Survival of tagged deer varied among age and sex cohorts (Appendix A).

DISCUSSION

I observed greater survival rates than hunted and non-hunted populations of sika deer in Japan. Survival rates for this study were 50% greater than that of males on Kinkazan Island despite a lack of predators and hunting, while in Maryland roughly 1,800 sika are harvested each year. Annual survival was 64% greater for sika deer in my study than those on Assateague Island (56%: Diefenbach and Christensen 2009). Survival for females in Maryland (82%) was similar to the annual rate I observed (Eyler 2001). Survival rates for subadult sika deer in this study were also greater than those observed in hunted populations of both elk (0.21-0.66; Bienderbeck et al. 2001, Petersburg et al. 2000, Smith and Anderson 1998, Sauer and Boyce 1983) and white-tailed deer (0.25-0.76; Bowman et al. 2007, Cambell et al. 2005, Nixon et al. 2001, Rosenberry et al. 1999). Three deer were reported harvested 43, 48 and 273 days after they were censored, which suggests that my survival estimates were greater than the actual rate.

High seasonal survival can be attributed to lack of natural predators and low density of roads throughout the study area. Although one death was attributed to vehicle, which is unique for sika deer, vehicle mortalities are common in both white-tailed deer and elk in North America suggesting that sika deer vehicle collisions may become more common. Additionally, hunters were not interested in harvesting males that had not matured to quality antlered deer. Hunters were able to opt not to harvest small males and still have opportunities to fill male sika deer tags with larger animals. An increase in selective pressure on older males is most likely balanced by experience. Young deer are able to learn about hunting leading to a decrease in mature male availability for harvest. High survival rates during the harvest seasons suggest that sika deer are able to find refuges from harvest pressure.

More than a third of sika deer that left their natal range died, while less than 10% of deer that remained local died. The lower survival of males outside of their natal range was also observed by Lopez et al. (2003) in key deer. Lower survival of dispersing portions of a population also follows observations in elk by Petersburg et al. (2000). Deer that disperse also have a greater chance of being harvested, because they are not familiar with the new habitat and do not have refuges. Deer that leave their home range face barriers that were unlikely to be part of a natal range such as roads and rivers which can be causes of mortality.

In order to prevent the continual growth of an exotic species, sika deer numbers must be limited. In habitat where there are limited predators, such as the Delmarva

Peninsula, sika populations must be controlled through hunting. Despite greater harvest pressure on sika deer on Assateague Island, white-tailed deer numbers on the island are decreasing (Diefenbach and Christensen 2009). Other data also suggests that the sika deer may be out-competing white-tailed deer for space and food resources (Harmel 1980, Keipler 1985) which can lead to greater survival rates for the more aggressive sika deer.

The subadult cohort of males appears to be an underutilized portion of the population. Current restrictions for sika deer harvest include all males with hard antler to be an antlered deer, whereas white-tailed deer in the area are not counted as an antlered deer unless the antler is longer than 7.64 cm (3 inches). This restriction, in conjunction with the bag limit restriction allowing a single antlered deer harvest per weapon, reduces the number of subadult males that are harvested because hunters will opt not to harvest a subadult in hopes of shooting an older animal. Previously, these animals could have been harvested and counted as a hind harvest, not affecting the hunter's ability to take a large male. Bowman et al. (2007) also observed a much greater survival rate among yearling white-tailed deer in their study, conducted in an area with antler restrictions limiting harvest of younger males.

Understanding survival is imperative for managers to make decisions about any species. Sika deer have a much higher survival rate than sympatric white-tailed deer. High survival rates have resulted in a continual growing population across their range. This growth in sika deer numbers is also leading to range expansion, exemplified by the first confirmed sika deer harvest in Delaware in 2007 (Delaware Department of Natural Resources and Environmental Control 2008).

MANAGEMENT IMPLICATIONS

Given their longevity and high survival rates, an increase in the harvest rate of sika deer is recommended to stem the population growth. Management should focus on the preservation of the native species which will include a balanced sika deer population available for harvest without hindering native deer. Limiting the range expansion of sika deer can be done by increasing the harvest of young males. I recommend an increase in the harvest of sika deer during the periods of early muzzleloader and rifle season when sika deer harvest is greatest. The high survival rates that I observed suggest that there is substantial room in the population for expanded harvest. To decrease survival, harvest pressure should be concentrated in the marsh areas where sika deer find refuge in the winter, and increased in the young male cohort when the deer are moving into unknown areas and are more susceptible to harvest pressure. I recommend that regulations return to previous standards where sika deer spike antlered animals would not count towards the hunters' male tags if an antler is <7.64 cm (3 inches).

LITURATURE CITED

Bartoš, L. 2009. Sika deer in continental Europe. Pages 573-594 *in* McCullough, D. R., S. Takatsuki, and K. Kaji. editors. Sika deer biology and management of native and introduced populations. Springer, New York, USA

Bennetsen, E. 1977. Some facts about sika deer in Denmark. Deer 4:153-157.

Biederbeck, H. H., M. C. Boulay, and D. H. Jackson. 2001. Effects of hunting regulations on bull elk survival and age structure. Wildlife Society Bulletin 29:1271-1277.

Blundell, G. M., J. A. K. Maier, and E. M. Debevec. 2001. Linear home ranges: effects of smoothing, sample size, and autocorrelation on kernel estimates. Ecological Monographs 71: 469-489.

Bowman, J. L., H. A. Jacobson, D. S. Coggin, J. R. Heffelfinger, and B. D. Leopold. 2007. Survival and cause-specific mortality of adult male white-tailed deer Managed under the quality deer management paradigm. The Proceedings of the Southeastern Association of Fish and Wildlife Agencies 61:76-81.

Brinkman, T. J., C. S. Deperno, J. A. Jenks, B. S. Haroldson, and R. G. Osborn. 2005. Survival of white-tailed deer in an intensively farmed region of Minnesota. Journal of Wildlife Management 69:1099-1111.

Campbell, T. A, B. R. Laseter, W. M. Ford, and K. V. Miller. 2005. Population characteristics of a central Appalachian white tailed deer herd. Wildlife Society Bulletin 33:212-221.

Comprehensive Coastal Inventory Program. 2003. Dorchester county Maryland shoreline situation report methods and guidelines. Center for Coastal Resources Management, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, USA.

Conner, M. C., E. C. Soutiere, and R. A. Lancia. 1987. Drop-netting deer: costs and incidence of capture myopathy. Wildlife Society Bulletin 15:434-438.

Delaware Department of Natural Resources and Environmental Concern Division of fish and Wildlife. 2008. Delaware Hunting and Fishing Guide. Online at <http://www.fw.delaware.gov/Hunting/Pages/Wildlife.aspx> Accessed 9 Feb 2009

DeLgiudice, G. D., M. R. Riggs, and P. J. Wei Pan. 2002. Winter severity, survival, and cause specific mortality of white-tailed deer in north-central Minnesota. Journal of Wildlife Management 66:698-717.

DeNicola, A. J., and R. K. Swihart. 1997. Capture-induced stress in white-tailed deer. Wildlife Society Bulletin 25:500-503.

Diefenbach, D. R., and S. A. Christensen. 2009. Movement and habitat use of sika and white-tailed deer on Assateague Island National Seashore, Maryland. United States Department of the Interior. National Park Service, Philadelphia Pennsylvania USA.

Ebersole, R. L., J. L. Bowman, T. B. Eyler. 2007. Efficiency of a controlled hunt for managing white-tailed deer on Fair Hill Natural Resource Management Area, Cecil County, Maryland. The Proceedings of the Southeastern Association of Fish and Wildlife Agencies 61:68-75.

Endo, A. 2009. Variations in mating behavior of sika deer: mating behavior of sika deer on Nozaki Island. Pages 287-296 *in* McCullough, D. R., S. Takatsuki, and K. Kaji. editors. Sika deer biology and management of native and introduced populations. Springer, New York, USA.

Eyler, T. B. 2001. Habitat use and movements of sympatric sika deer (*Cervus Nippon*) and white-tailed deer (*Odocoileus virginianus*) in Dorchester County, Maryland. Thesis, University of Maryland Eastern Shore the Graduate School, Princess Anne, Maryland, USA.

Eyler, T. B., and G. Timko. 2008. Maryland annual deer report 2007-2008. Maryland Department of Natural Resources, Wildlife and Heritage Service. Annapolis, Maryland, USA.

Feldhamer, G. A. 1980. Mammalian Species: Cervus nippon. The American Society of Mammalogists 128: 1-7.

Feldhamer, G. A., J. A. Chapman, and R. L. Miller. 1978. Sika deer and white-tailed deer on Maryland's eastern shore. Wildlife Society Bulletin 6:155-157.

Feldhamer, G. A. and S. Demarais. 2009. Free ranging and confined sika deer in North America: current status, biology and management. Pages 615-642 in McCullough, D. R., S. Takatsuki, and K. Kaji. editors. Sika deer biology and management of native and introduced populations. Springer, New York, USA.

Feldhamer, G. A., K. R. Dixon, and J. A. Chapman. 1982. Home range and movement of sika deer (*Cervus Nippon)* in Maryland. Zeitschrif fur Saugetierkunde 47:311-316 [In German.]

Feldhamer, G. A., and M. A. Marcus. 1994. Reproductive performance of female sika deer in Maryland. Journal of Wildlife Management 58:670-673.

Feldhamer, G. A., J. R. Stauffer, and J. A. Chapman. 1984. Body morphology and weight relationships of sika deer in Maryland. Zeitschrif fur Saugetierkunde 50:88-106 [In German.]

Flyger, V. 1960. Sika deer on islands in Maryland nad Virginia. Journal of Mammalogy 41:410.

Fryxell, J. M., J. F. Wilmshurst, and R. E. Sinclair. 2004. Predictive models of movement by Serengeti grazers. Ecological Society of America 85:2429-2435.

Harmel, D. E. 1980. The influence of exotic artiodactyls on white-tailed deer production and survival. Texas Parks and Wildlife Department. Austin, Texas, USA.

Heisey, D. M. and T. K. Fuller. 1985. Evaluation of survival and cause-specific mortality rates using telemetry data. Journal of wildlife Management 49: 668-674.

Hines, J. E. and J. R. Sauer. 1989. Program CONTRAST: a general program for the analysis of several survival or recovery rate estimates. U. S. Fish and Wildlife Service Technical Report 24.

Holzenbein, S., and R. L. Marchinton. 1992. Spatial integration of maturing-male white-tailed deer into the adult population. Journal of Mammalogy 73:326-334.

Hooge, P. N., and B. Eichenlaub. 1997. Animal movement extension to arcview. verison 1.1. Alaska Science Center - Biological Science Office, U.S. Geological Survey, Anchorage, Alaska, USA.

Igota, H., M. Sakuragi, and H. Uno. 2009. Seasonal migration of sika deer on Hokkaido Island, Japan. Pages 251-272 *in* McCullough, D. R., S. Takatsuki, and K. Kaji.

editors. Sika deer biology and management of native and introduced populations. Springer, New York, USA

Keiper, R. R. 1985. Are sika deer responsible for the decline of white-tailed deer on Assateague Island Maryland? Wildlife Society Bulletin 13:144-146.

Koda, R., N. Noma, R. Tsujino, K. Umeki, and N. Fujita. 2008. Effects of sika deer (*Cervus nippon yakushimae*) population growth on saplings in an evergreen broad-leaved forest. Forest Ecology and Management 256:431-437.

Koizumi, T., S. Hamasaki, M. Kishimoto, M. Yokoyama, M. Kobayashi, and A. Yasutake. 2009. Reproduction of female sika deer in western Japan. Pages 327-364 *in* McCullough, D. R., S. Takatsuki, and K. Kaji. editors. Sika deer biology and management of native and introduced populations. Springer, New York, USA.

Larkin, R. P., A. Raim, and R. H. Diehl. 1996. Performance of a non-rotating direction-finder for automatic radio tracking. Journal of Field Ornithology.67:59-71.

Long, E. S., D. R. Diefenbach, C. S. Rosenberry, and B. D. Wallingford. 2008. Multiple proximate and ultimate causes of natal dispersal in white-tailed deer. Behavioral Ecology 19:1235-1242.

Lopez, R. R., M. E. P. Vieira, N. J. Silvy, P. A. Frank, S. W. Whisenant, and D. A. Jones. 2003. Survival, mortality and life expectancy of Florida key deer. Journal of Wildlife Management 67: 34-45

Maryland Department of Natural Resources [DNR]. 2009. DNR home page. <http://www.dnr.state.md.us/>. Accessed 9 Feb 2009.

McCorquodale, S. A. 2003. Sex specific movement and habitat use by elk in the cascade range of Washington. Journal of Wildlife Management 67:729-741.

McCullough, D.R. 1985. Long range movements of large terrestrial mammals. Cited in Rankin. M.A. editor. Migration: mechanisms and adaptive significance. Marine Science Institute, Port Aransas, Texas, USA.

Minami, M., N. Ohnishi, and S. Takatsuki. 2009. Survival patterns of male and female sika deer on Kinkazan Island , north Japan. Pages 375-384 *in* McCullough, D. R., S. Takatsuki, and K. Kaji. editors. Sika deer biology and management of native and introduced populations. Springer, New York, USA.

Miura, S. 1984. Social behavior and territoriality in male sika deer (*Cervus nippon* Teminck 1838) during the rut. Zeitschrift Fur Tierpsychologie 64: 33-73.

Miura, S, and K. Tokida. 2009. Management strategy of sika deer based on sensitivity analysis. Pages 453-474 *in* McCullough, D. R., S. Takatsuki, and K. Kaji. editors. Sika deer biology and management of native and introduced populations. Springer, New York, USA.

Moore, B. 1980. A modification of the Rayleigh test for vector data. Biometrika 67:175-180.

National Oceanic and Atmospheric Administration, U. S. Department of Commerce [USNOAA] 2009. Climatography of the United States No. 20 1971-2000. Last updated 20 May 2009<http://cdo.ncdc.noaa.gov/cgi-bin/climatenormals/climatenormals.pl.>. Accessed 8 Jun 2009.

Nelson, M. E. and L. D. Mech. 1984. Home range formation and dispersal of deer in Northeastern Minnesota. Journal of Mammalogy 65:567-575.

Nixon C. M., L. P. Hansen, P. A. Brewer, J. E. Chelsvig, T. L. Esker, D. Etter, J. B. Sullivan, R. G. Koerkenmeier, and P. C. Mankin. 2001. Survival of white-tailed deer in intensively farmed areas of Illinois. Canadian Journal of Zoology 79:581-588.

Petersburg, M. L., A. W. Alldredge, and W. J. de Vergie. 2000. Emigration and survival of 2-year-old male elk in northwestern Colorado. Wildlife Society Bulletin 28:708-716.

Polziehn R.O., and C. Strobeck. 1998. Phylogeny of wapiti, red deer, sika deer, and other North American cervids as determined from mitochondrial DNA. Molecular Phylogenetics and Evolution 10: 249-258.

Rhoads, C. L. 2006. Spatial ecology and responses to a controlled hunt of female white-tailed deer in a exurban park. Thesis, University of Delaware, Newark, Delaware, USA.

Rongstad, O. J. and J. R. Tester. 1969. Movements and habitat use of white-tailed deer in Minnesota. Journal of Wildlife Management 33:366-379.

Rosenberry, C. S., R. A. Lancia, and M. C. Conner. 1999. Population effects of white-tailed deer dispersal. Wildlife Society Bulletin 27:858-864.

Sabine, D. L., S. F. Morrison, H. A. Whitlaw, W. B. Ballard, G. J. Forbes, and J. Bowman. 2002. Migration behavior of white-tailed deer under varying winter climate regimes in New Brunswick. Journal of Wildlife Management 62:205-213.

Saltz, D. 1994. Reporting error measures in radio location by triangulation: a review. Journal of Wildlife Management 58:181-184

Sauer, J. R., and M. S. Boyce. 1983. Density dependence and survival of elk in Norwestern Wyoming. Journal of Wildlife Management 47:31-37.

Seaman, D. E., J. J. Millspaugh, B. J. Kernohan, G. C. Brundige, K J. Raedeke, and R. A. Gitzen. 1999. Effects of sample size on kernel home range estimates. J. Wildlife Manage. 63:739-747.

Smith, B. L., and S.H. Anderson. 1998. Juvenile survival and population regulation of the Jackson elk herd. Journal of Wildlife Management 62:1036-1045.

Smith, B. L., and S.H. Anderson. 2001. Does dispersal help regulate the Jackson elk herd?. Journal of Wildlife Management 29:331-341.

Smith, W. P. 1991. *Odocoileus virginianus*. Mammalian Species 388:1-13.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry: the principles and practice of statistics in biological research. W. H. Freeman and Company. New York, NY, USA.

Swanson, G. M., and R. Putman. 2009. Sika deer in the British Isles. Pages 595-614 *in* McCullough, D. R., S. Takatsuki, and K. Kaji. editors. Sika deer biology and management of native and introduced populations. Springer, New York, USA.

Takiatsuki, S., and U. K. G. K. Padmalai. 2009. Food habits of sika deer on Kinkazan Island, northern Japan with reference to local variations, size effects, and comparison with the main island. Pages 113-123 *in* McCullough, D. R., S. Takatsuki, and K. Kaji. editors. Sika deer biology and management of native and introduced populations. Springer, New York, USA.

Tiller, B.L., L.L Cadwell, R. K. Zufelt, L. Bender, S. Turner, and G. K. Turner. 2000. Population characteristics and seasonal movement patterns of the Rattlesnake

Hills elk herd: status report 2000. U.S. Department of Energy. Richland, Washington, USA.

Torii, H. and S. Tatuzawa. 2009. Sika deer in Nara Park: unique human-wildlife relations. Pages 347-364 *in* McCullough, D. R., S. Takatsuki, and K. Kaji. editors. Sika deer biology and management of native and introduced populations. Springer, New York, USA.

United States Geological Servey [USGS]. 2006. Through the ages. <http//www.npwrc.usgs.gov/resources/mammals/agelk/ages.htm> accessed 3 April 2009.

Uno, H. and K. Kaji. 2006. Survival and cause specific mortality rates of female sika deer in eastern Hokkaido, Japan. Ecological Research 21:215-220.

Worton, B. J. 1989. Kernel methods for estimating the utilization distribution in home range studies. Ecology 70: 164-168.

APPENDIX A. Cause specific mortality for Maryland sika deer grouped by sex and age (total number caught). * includes the 60 animals that were collared. † Due to lose of their collar, 24 deer were censored (4 in their 1st year, 20 in their 2nd year), three were reported harvested and included in these counts.

	Capture	Vehicle	Gun	Muzzleloader	Bow	Total
Adult Males(9)	0	1	0	2	0	3
Subadult Males(70*†)	1	1	9	1	2	14
Adult Females(43)	1	0	4	0	0	5
Subadult Females(73)	0	1	5	3	2	11
All deer(195)	2	3	18	6	4	33