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Research Article

Movements of White-Tailed Deer in Riparian Habitat: Implications for Infectious Diseases

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ABSTRACT Movements of male white-tailed deer (*Odocoileus virginianus*) are of great concern with respect to spread of chronic wasting disease (CWD) across landscapes because most yearlings males disperse and adult males have higher prevalence of CWD than do females and younger deer. We radiocollared and monitored 85 male white-tailed deer in the middle Missouri River Valley of eastern Nebraska and western Iowa, USA from 2004 to 2008. Average size (±SE) of fixed-kernel annual home ranges (95%) and core areas (50%) for resident deer were 449 (±32) ha and 99 (±7) ha, respectively. Resident deer exhibited a high-degree of fidelity to their home ranges. Mean overlap between consecutive annual home ranges and core areas was 81% and 74%, respectively. Average dispersal distance was 17.7 ± 4.5 km (range = 3–121 km) for 22 radio-marked and 6 ear-tagged yearlings. Mean spring dispersal distance (25 km) was 150% greater than fall (10 km). Dispersal direction from Desoto National Wildlife Refuge (DNWR) was bimodal on a northwest to southeast axis that followed the Missouri River corridor. Of 22 yearlings that dispersed 18 (82%) established adult home ranges within the river valley. Dispersal movements of yearling males represent the greatest risk for rapid spread of diseases from infected source populations. Disease management efforts in riparian habitats should target male fawns and yearling males for removal in areas within or immediately adjacent to river corridors. © 2011 The Wildlife Society.

KEY WORDS chronic wasting disease, dispersal, home range, male, migration, movements, *Odocoileus virginianus*, radio-telemetry, white-tailed deer.

White-tailed deer (*Odocoileus virginianus*) are known to play a role in the transmission of ecologically and economically important diseases in livestock (tuberculosis), humans (Lyme disease), and cervids (chronic wasting disease; Miller et al. 2000, O'Brien et al. 2002, Piesman 2002). Chronic wasting disease (CWD) is an infectious and fatal neurological prion disease found in cervids (Williams et al. 2002). Transmission of CWD likely occurs by direct contact among deer and from contaminated environments (Williams et al. 2002, Miller et al. 2004, Mathiason et al. 2006). Movements of male white-tailed deer are of great concern with respect to spread of CWD across the landscape because most male yearlings disperse (Hawkins and Klimstra 1970, Dusek et al. 1989, Nixon et al. 1991, Nelson 1993) and adult males have higher prevalence of CWD than females and younger deer (Gross and Miller 2001, Grear et al. 2006).

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Movement patterns of white-tailed deer in the Midwest generally consist of 4 types: local, temporary excursions, migratory, and dispersal. Home ranges of male white-tailed deer are generally larger than those of females and vary according to age, season, density, and habitat characteristics (Kammermeyer and Marchinton 1976, Nelson and Mech 1981, Gavin et al. 1984, Nixon et al. 1991, Webb et al. 2006). Temporary movements outside of home ranges have been documented for both yearling and adult male white-tailed deer (Hawkins and Klimstra 1970, Nelson and Mech 1981, Nixon et al. 1991, Skuldt et al. 2008). Migratory movements of male white-tailed deer in the Midwest are uncommon (Dusek et al. 1989, Nixon et al. 1991, Etter et al. 2002, Skuldt et al. 2008). Dispersal in white-tailed deer occurs predominantly among yearling males and usually is exhibited by ≥50% of these individuals (Nixon et al. 1994, Rosenberry et al. 1999, Long et al. 2005, Shaw et al. 2006). Yearling males typically disperse 8–12 km, but movements of >150 km have been reported (Nelson 1993, Kernohan et al. 1994, Nixon et al. 1994). Dispersal distances have been correlated with percent forest cover and are longer in highly fragmented habitats (Nixon et al. 1991, Long et al. 2005).

The highest densities of deer in the Midwest are often associated with riparian habitat and refuges where hunting is restricted (Gladfelter 1984). Several studies have shown that movements of white-tailed deer are directional and associated with watersheds (Sparrowe and Springer 1970, Kernohan et al. 1994, Nixon et al. 1994). Therefore, if transmission of CWD and other infectious diseases are affected by density-dependent functions, spread of diseases in the Midwest will likely occur along river corridors. Thus, information is needed on movements of male white-tailed deer in riparian habitats. To limit the spread of deer-transmitted diseases, managers need to understand local and long-distance movements along riparian corridors to assess the trade-offs between reducing the risk of disease spread versus the cost of delineating containment areas.

Our objectives were to quantify 1) home range size and fidelity, 2) rates of dispersal and migration, and 3) distances of movements of male white-tailed deer in the middle Missouri River Valley. We predicted that seasonal use areas would be smallest during the prebreeding season, largest during the breeding season, and that adult males would exhibit high site-fidelity to annual home ranges and core areas. We expected that rates of seasonal migration would be low for all age classes and that yearling males would be the primary cohort to make permanent, long-distance dispersal movements. We also expected that dispersal movements would relate closely to the Missouri River corridor.

STUDY AREA

We conducted our research in the Missouri River Valley (MRV) in eastern Nebraska and western Iowa, USA. We concentrated our efforts in and around the 3,385-ha DeSoto National Wildlife Refuge (DNWR), located 32 km north of Omaha, Nebraska.

Within DNWR, land cover consisted of 40% (1,355 ha) deciduous forest, which was dominated by mature eastern cottonwood (*Populus deltoides*). Understory included rough-leafed dogwood (*Cornus drummondii*), hackberry (*Celtis occidentalis*), mulberry (*Morus rubra*), and green ash (*Fraxinus pennsylvanica*). Poison ivy (*Rhus radicans*) and common scouring-rush (*Equisetum hyemale*) dominated the ground layer. An oxbow lake and wetland areas comprised 22% (745 ha) of DNWR. Native grass comprised 21% (700 ha) of DNWR and included big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), and sideoats grama (*Bouteloua curtipendula*). Local farmers leased 17% (580 ha) of the area for production of agricultural crops. Corn, soybeans, and a wheat-alfalfa mix were cultivated on a 3-year rotation and 10–30% of the corn was left standing through winter as food plots for wildlife. Topography was flat with slopes $\leq$2% (U.S. Department of Agriculture 1976). Average annual maximum and minimum temperatures were 15.4° C and 3.4° C, respectively (U.S. Department of Agriculture 2005). Average annual precipitation for the area was 760 mm; average snowfall was 750 mm (U.S. Fish and Wildlife Service 2001).

We estimated that the post hunt density of deer on DNWR was 27–35 deer/km^2 from 2004 to 2007 (G. Clements and J. Gilsdorf, University of Nebraska, unpublished data). We observed female/male ratios of 2.1:1, 2.1:1, 1.9:1, and 1.5:1 and fawn/adult female ratios of 1.2:1, 1.4:1, 1.3:1, and 1.2:1 during September–October for 2004, 2005, 2006, and 2007, respectively. Deer hunts on DNWR consisted of 4 2-day muzzleloader seasons and 92 days of archery hunting in designated areas of the refuge. Hunter harvest averaged 440 deer annually (range = 314–606) from 2004 to 2007.

METHODS

Deer Capture and Data Collection

We captured deer from January 2004 to August 2007 using netted cage traps (VerCauteren et al. 1999) and chemical immobilization with xylazine hydrochloride and Telazol® (Amass 2004). We marked all captured deer with a numbered cattle ear-tag and metal identification tag. We equipped males with expandable radio-collars with mortality sensors (150–152 MHz; Advanced Telemetry Systems, Inc., Isanti, MN). We classified the age of each deer as fawn (<12 months old), yearlings ($\geq$12 to <24 months old), and adults ($\geq$24 months old). For analyses, we assumed a 1 June birthday of each cohort. All capture and handling procedures were approved by the University of Nebraska's Institutional Animal Care and Use Committee (Permit no. 06-07-030C).

We determined locations of radiocollared deer using an integrated vehicle-mounted very high frequency telemetry system (Gilsdorf et al. 2008). Telemetry system tests from true and estimated bearings resulted in an average angular error of 2.63 $\pm$ 12.1° (SD) and mean location error distance of 128 $\pm$ 91.3 m (SD; Gilsdorf et al. 2008). We recorded direct observations of marked deer on-site using Geographic Information System (GIS) software ArcView 3.2 and a 1:24,000 scale United States Geological Survey digital aerial photo. We used a Cessna 172 airplane with 4-element antennas mounted on the wing struts 5 times to locate collared deer that we could not find from the ground. We located deer 3–5 times per week at random times throughout the day and night to ensure locations of deer were not biased towards periods of activity or inactivity. We recorded telemetry locations $\geq$4 hr apart to ensure independence. For each location, we collected 3–5 bearings consecutively in <10 min and solved them on-site using the maximum likelihood estimator from Location of a Signal software (LOAS) Version 4.0 (Ecological Software Solutions, Urnasch, Switzerland). We rejected locations that had error ellipses >1.0 ha.

To estimate deer density on DNWR we conducted helicopter surveys during winter (Jan–Mar) when snow depth was $\geq$15 cm. We used a Robinson R44 helicopter (Robinson Helicopter Company, Torrance, CA) with an experienced pilot and observer to fly transects over the DNWR at an altitude of 100–150 m. We estimated female/male and fawn/adult female ratios during September–October by observing agricultural fields throughout the study area. We used

binoculars and spotting scopes to identify sex and age (fawn or adult) of individual deer. We collected harvest data at check stations during all firearm hunts on DWNR. We recorded sex and weight and estimated the age of deer by tooth eruption, replacement, and wear (Severinghaus 1949).

Home Range Estimation and Fidelity

We divided the year into 3 seasons, based on deer behavior: postbreeding (1 Jan–31 May), prebreeding (1 Jun–14 Sep), and breeding (15 Sep–31 Dec). We defined annual home ranges as beginning on 15 March and ending 14 March of the following year to coincide with phenological periods. We imported location files into ArcView GIS 3.3 and integrated them with a covermap of the study area. We used the fixed kernel method (Rodgers and Carr 1998, Worton 1989) with unit variance style of standardization, h_ref smoothing factor automation, and 70-m × 70-m raster (grid) resolution to construct estimates of annual home ranges and seasonal use areas for each deer. We used 95% and 50% isopleths to delineate annual home ranges and core areas, respectively (Worton 1989). We estimated annual home ranges using ≥50 locations (Seaman et al. 1999) and a mean of 83 locations (SE = 3.76, range = 50–141) per deer. We estimated seasonal use areas using ≥30 (Seaman et al. 1999) and a mean of 40 locations (SE = 0.98, range = 30–64) per deer. We examined annual and seasonal variation in the size of home ranges and core areas using a mixed linear model (e.g., McLean et al. 1991), implemented in SAS Proc MIXED (Littell et al. 1996) with means estimated as least square means. We used Akaike's Information Criterion (AIC) to select the covariance structure that provided the best-fit model for the repeated measures analyses (Littell et al. 1996). We set statistical significance at $P \leq 0.05$ and presented estimates of data as mean 1 ± SE.

We quantified home range fidelity by calculating the area of home range and core areas that were reused (i.e., overlap) in the following year (Lesage et al. 2000). We determined percent overlap by dividing the overlap area by the mean of the associated home range or core area and multiplying by 100%. Additionally, we calculated home range and core area centroids using X Tools Pro in ArcGIS 9.1 and measured the distance between consecutive years or seasons.

Movements Analysis

We categorized deer as residents, dispersers, or migrators based on observed movement patterns. We defined residents as deer that remained in their annual home ranges and had overlapping seasonal ranges throughout the study. We defined migration as seasonal movement between established home ranges without overlap (Dusek et al. 1989, Van Deelen et al. 1997). We defined dispersal as a permanent movement to a new, non-overlapping range, such that predispersal locations did not overlap post-dispersal locations (Marchinton and Hirth 1984, Kenward et al. 2002). We estimated dates of dispersal and migration by using the midpoint of the dates for the last location in the original use area and the first location after dispersal or migration occurred (Sabine et al. 2002, McCoy et al. 2005). We calculated temporary excursions (occasional, temporary movements outside of the home range) as the cumulative distances moved between locations outside of the home range (Skuldt et al. 2008).

We estimated and modeled probability of dispersal using the known-fates (KF) procedure in Program MARK v. 4.2 (White and Burnham 1999). The procedure is based on the staggered-entry Kaplan–Meier survival model (Kaplan and Meier 1958, Pollock et al. 1989), because similar to mortality in survival studies, natal dispersal can occur only once. We estimated a philopatry rate, and the complement of this estimate was the dispersal rate. From the best model, we reported annual dispersal rates and standard errors as generated by MARK. We censored deer that died before dispersing and deer with which we permanently lost contact prior to dispersal.

We calculated dispersal distance as straight-line distance between median x- and y-coordinates of the 95% natal and adult use areas (Kenward et al. 2002). In 9 cases, only one adult location was available, typically resulting from ear tag return data or collar return data after transmitter failure. In these cases, we used a single-point estimate for adult range to calculate dispersal distance.

We calculated mean dispersal angles ($\bar{a}$) and angular deviation (s) following Zar (1984). We present mean angles and angular deviation as $(\bar{a}) \pm s$. We applied Rayleigh's test (Rayleigh's z) to determine if significant mean directions occurred within sampled dispersal distributions or whether dispersal directions were distributed randomly (Zar 1984). Finally, we used the nonparametric Watson's test to determine differences in dispersal directions between seasons (Zar 1984).

RESULTS

We captured 161 (95 M, 66 F) white-tailed deer between February 2004 and August 2007. We radio-marked 40 fawns, 20 yearlings, and 25 adult males. We generated 6,652 locations from 15 March 2004 to 14 March 2008. Location distribution by time period included: 0000–0600 hours (20%), 0600–1200 hours (27%), 1200–1800 hours (32%), 1800–0000 hours (21%). Direct observations accounted for 19% of locations. We tracked radiocollared males an average of 316 days (SE = 20.7; range = 27–750 days). Hunter harvest ($n = 22$), dropped radio collars ($n = 16$), and transmitter failure ($n = 15$) resulted in shortened tracking periods.

Annual home ranges and core areas of all males averaged 449 ha and 99 ha, respectively (Table 1). Comparison between yearling and adult males showed no difference in size of annual home ranges ($t_{31} = -0.50$, $P = 0.621$) or core areas ($t_{31} = -1.39$, $P = 0.173$). Size of home ranges ($F_{2,85} = 21.20$, $P < 0.001$) and core areas ($F_{2,85} = 15.8$, $P < 0.001$) varied by season and were larger during breeding than prebreeding and postbreeding periods (Table 1). Site fidelity was high among resident males, with a mean of 81% overlap ($n = 10$, range = 73–88%) and 74% overlap ($n = 10$, range = 58–89%) between consecutive annual home ranges and core areas, respectively. Distance between centers of core areas for consecutive years was 224 ± 534 m

Table 1. Size (ha) of fixed-kernel home ranges (95%) and core areas (50%) of male white-tailed deer relative to 3 behavioral periods, in eastern Nebraska and western Iowa, USA, 2004–2008.

Period[a]	Vol	n	$\bar{x}$	SE	Range
Annual	Home range	40	449	32	212–1,181
	Core area	40	99	7	41–261
Prebreeding	Home range	43	266	23	70–901
	Core area	43	65	6	16–177
Breeding	Home range	32	465	37	237–1,128
	Core area	32	116	10	53–309
Postbreeding	Home range	13	398	59	174–889
	Core area	13	90	14	28–206

[a] Annual (15 Mar–14 Mar), prebreeding (1 Jun–14 Sep), breeding (15 Sep–31 Dec), postbreeding (1 Jan–31 May).

($n = 10$). Distances between core area centers for seasonal periods were 428 ± 88 m ($n = 11$) for postbreeding to prebreeding, 499 ± 74 m ($n = 29$) for prebreeding to breeding, and 177 ± 45 m ($n = 7$) for breeding to postbreeding.

We identified movement patterns for 72 of 85 radio-marked deer, of which we classified 67% ($n = 48$) as residents with overlapping seasonal use areas, 30% ($n = 22$) as dispersers, and 3% ($n = 2$) as migrators. Of 31 yearling males (captured as fawns, moved into yearling age class) included in analysis, 71% ($n = 22$) dispersed, and 29% ($n = 9$) remained philopatric. Annual probability of dispersal for radio-marked yearling males was 0.83 ± 0.07 (range = 0.69–1.00) and did not differ among years (Table 2). Yearling males dispersed during spring ($n = 11$; 50%) and fall ($n = 11$; 50%). Mean dates of spring and fall dispersal were 4 June and 2 November, respectively. Departure dates in spring (SE = 7 days; range = 5 May to 29 Jun) were more variable than those in fall (SE = 3 days; range = 14 Oct to 15 Nov). We did not observe dispersal movements for males >18 months of age.

Yearling males dispersed average and median distances of 17.7 km and 9.5 km, respectively (SE = 4.5 km; range = 3–121 km). Mean spring dispersal distance ($n = 11$, 25.3 ± 9.5 km, range = 4–121 km) was 150% greater than fall dispersal distance ($n = 11$, 10.1 ± 2.2 km, range = 3–23 km). Fifty-five percent ($n = 6$) of spring dispersals, compared with 9% ($n = 1$) of fall dispersals, were >20 km (Fig. 1), including 1 deer that dispersed 121 km. Of 22 dispersers 18 (82%) remained in the Missouri River Valley and established adult home ranges in wooded habitat adjacent to the Missouri River. Four dispersers (18%) established adult home ranges in upland wooded habitat within 1–5 km of the edge of the river valley.

Mean dispersal direction was 155 ± 48°. Observed distribution of dispersal directions did not differ from random (Rayleigh's test, $z = 0.96$, $P > 0.05$, $r = 0.21$). However, a difference in dispersal direction occurred between spring and fall (Watson's test, $U^2 = 0.35$, $P < 0.05$). Mean dispersal direction was approximately 305 ± 48° for spring ($n = 11$) and 161 ± 45° for fall ($n = 11$; Fig. 2). Direction of dispersal during spring did not differ from random (Rayleigh's test, $z = 2.641$, $P > 0.05$, $r = 0.49$). Direction of dispersal during fall, however, differed from random (Rayleigh's test, $z = 5.324$, $P < 0.05$, $r = 0.70$), with most individuals dispersing to the southeast along the Missouri River corridor (Fig. 2). We classified 2 radio-marked adult males (≥2.5 years old) as migratory, with distinct, non-overlapping prebreeding and postbreeding use areas. Mean migration distance was 3.9 km (range = 3.1–4.7 km).

Temporary movements outside of home ranges ($n = 14$) were made by yearlings ($n = 10$) and adults ($n = 4$) and lasted from 1–6 days. Yearling males moved an average cumulative distance of 3.8 ± 0.8 km (range = 1.4–8.6 km). Temporary movements were made by 23% ($n = 5$) of yearling males prior to dispersing. Temporary excursions by adult males averaged 2.6 ± 0.6 km (range = 1.4–3.6 km).

Table 2. Annual probability of dispersal of radio-marked yearling male white-tailed deer captured on DeSoto National Wildlife Refuge in eastern Nebraska and western Iowa, USA, 2004–2008.

Yr	n	Rate	SE	95%CI
2004	7	1.00	<0.001	0.99–1.00
2005	7	0.85	0.14	0.57–1.00
2006	8	0.82	0.20	0.43–1.00
2007	9	0.69	0.17	0.36–1.00
Pooled	31	0.83	0.07	0.69–0.97

DISCUSSION

Sizes of annual home ranges in our study were similar to those reported in other riparian habitats in the Midwest (Dusek et al. 1989, Nixon et al. 1991). Seasonal use areas were largest during the breeding season and smallest during prebreeding, consistent with previous research (Nelson and Mech 1981, Marchinton and Hirth 1984, Beier and

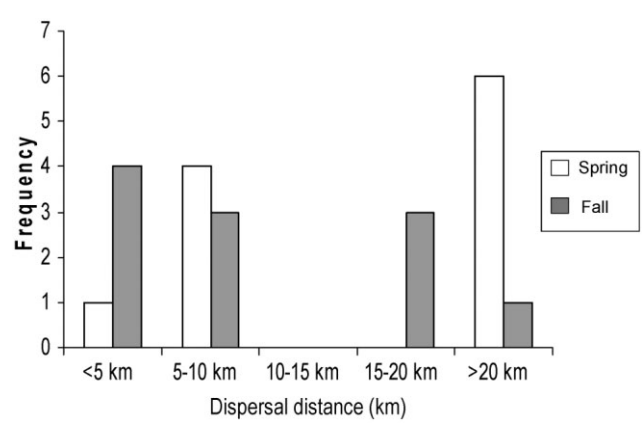

Figure 1. Histogram of dispersal distances by season for juvenile male white-tailed deer ($n = 22$) in eastern Nebraska and western Iowa, USA, 2004–2008.

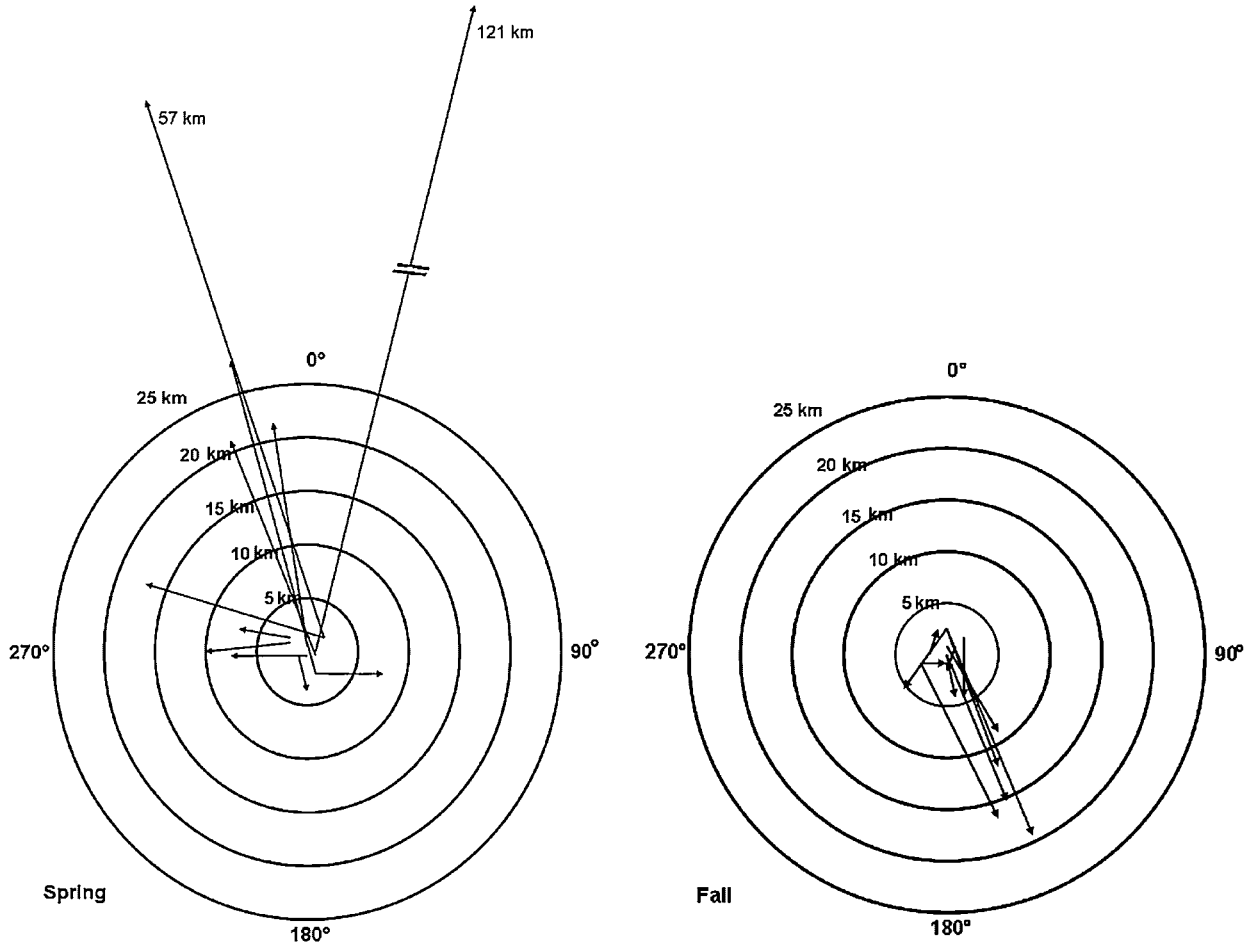

Figure 2. Dispersal directions and distances of yearling male white-tailed deer during spring ($n = 11$) and fall ($n = 11$) from DeSoto National Wildlife Refuge in eastern Nebraska and western Iowa, USA, 2004–2008.

McCullough 1990, Nixon et al. 1991). Deer in our study exhibited a high degree of fidelity to annual home ranges and core areas and seasonal shifts between centers of core areas were short.

Yearling males in our study dispersed during spring (50%) and fall (50%), a trend reported in other studies of juvenile male white-tailed deer (Nelson and Mech 1984, Holzenbein and Marchinton 1992, Nixon et al. 1994, Shaw et al. 2006, Long et al. 2008). Our estimate of annual dispersal rate (71%) based on the proportion of yearling males that dispersed was consistent with other populations of white-tailed deer (range 46–80%; Nelson 1993, Nixon et al. 1994, Rosenberry et al. 1999, Long et al. 2005, Skuldt et al. 2008). Analyses indicated no difference in probability of dispersal among years; however, we observed a decrease each year throughout the study. Though statistically similar, such a trend could be biologically important. Additional antlerless hunting seasons on DNWR were implemented in 2004 to reduce densities of deer. Average annual harvest of antlerless deer increased from 3/km^2 (1999–2003) to 14/km^2 (2004–2007). It is possible that the decrease of adult females resulted in reduced intensity of mother-offspring interactions and contributed to the decrease in dispersal rate among yearling males (Holzenbein and Marchinton 1992).

Mean dispersal distance of yearling males from DNWR (17.7 ± 4.5 km) was similar to other studies conducted in riparian habitat (18.5 km in eastern MT, Dusek et al. 1989; 18–20 km in western NE; W. D. Walter, University of Nebraska-Lincoln, unpublished data) but was shorter than reported in intensively farmed regions of Illinois (36–44 km; Nixon et al. 2007). We found that average dispersal distance in spring was 150% greater than in fall. Our results corroborate Long et al. (2008), who reported significantly greater distances for spring dispersal of yearling male white-tailed deer in eastern and western Pennsylvania. Variation in dispersal distances among populations has been shown to relate to landscape characteristics such as percent forest cover (Long et al. 2005). Within populations, however, variation in dispersal distances may relate more strongly to underlying causes of dispersal (Long et al. 2008). Intrasexual aggression prior to the breeding season is thought to reduce competition for mates, resulting in short dispersal (Pusey 1987). In contrast, avoidance of inbreeding may require longer dispersal distances to remove individuals from philopatric relatives of the opposite-sex (Ronce et al. 2001).

Analyses showed that distribution of dispersal directions from DNWR was random, however, the resulting frequency distribution was bimodal on a northwest–southeast axis that

conformed to the Missouri River corridor. Interestingly, dispersal direction between spring and fall was significantly different. In fall, dispersers traveled south to southeast from DNWR and established adult ranges that were within or south of DNWR. In spring, dispersers primarily traveled on a northerly axis from DNWR along the Missouri River corridor that resulted in establishment of adult ranges primarily to the north of DNWR. Though numerous studies have reported directional movements of deer associated with watersheds (Sparrowe and Springer 1970, Zwank et al. 1979, Dusek et al. 1989, Kernohan et al. 1994, Nixon et al. 1994), we know of no other research on deer that has documented a significant difference in direction of dispersal movements between spring and fall. In addition to using the river valley as a travel corridor, we found that most yearling males that dispersed stayed in the river valley and established adult home ranges in wooded habitat adjacent to the Missouri River. Dispersers that traveled outside of the river valley established adult home ranges in upland wooded habitat within 1–5 km of the edge of the river valley.

We did not document long-distance movements of male deer >18 months old. Reports of long-distance movements of male white-tailed deer were also uncommon in other studies (Dusek et al. 1989, Nixon et al. 1991, Van Deelen et al. 1997, Skuldt et al. 2008), however, long-distance movements outside of home ranges associated with the breeding season have been documented (8–22 km; Nelson and Mech 1987). We found that seasonal migration of male white-tailed deer in the middle Missouri River Valley was minimal and distances traveled were short, which is consistent with other studies conducted in the Midwest (Nixon et al. 1991, Skuldt et al. 2008).

MANAGEMENT IMPLICATIONS

The highest densities of white-tailed deer in the Midwest are often associated with riparian habitat; therefore, if transmission of CWD and other infectious diseases are affected by density-dependent functions, then spread of diseases in the Midwest will likely occur along river corridors. We found that adult males in the middle Missouri River Valley had a high degree of fidelity to their home range and temporary excursions and migratory movements occurred at low rates and distances traveled were short. Such movements would be unlikely to contribute to rapid expansion of infectious diseases. Yearling males, however, dispersed at high rates and were capable of traveling long distances, representing the greatest risk for rapid spread of diseases. Our results showed that most yearling males that dispersed followed the river corridor and established adult ranges within the river valley. This tendency may be strategically useful in controlling the spread of diseases from infected source populations. Management efforts in riparian habitats could be maximized by targeting male fawns and yearling males for removal in areas within or immediately adjacent to the river valley. Additionally, where feasible, construction of physical barriers, such as fences, could prevent or reduce long distance movements.

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