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Movements of female white-tailed deer (*Odocoileus virginianus*) in relation to timber harvests in the central Appalachians

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Abstract

Deer movements in relation to timber harvests have not been studied within nonmigratory white-tailed deer (*Odocoileus virginianus*) populations. We compared home range and core area size and overlap, deer movements during timber harvests, and habitat use before and after harvests for deer associated and not associated with clearcuts. We radio-monitored 83 adult female deer pre- (3 months prior to), during, and post- (3 months after) timber harvest. Change in home range and core area size and overlap did not differ between control deer (home ranges comprised entirely of mature forest during all time periods) and treatment deer ($\geq$1 telemetry location within a harvested stand during any time period). During timber harvests, treatment deer were located outside their pre-harvest home ranges more often than control deer and generally were located closer to clearcuts than in other time periods. During both the pre- and post-timber harvest time periods, deer used clearcut habitats (stands $\leq$5-years-old) in greater proportion than availability. Lack of significant changes in white-tailed deer movements before, during, and after timber harvest suggests habitat management aimed at attracting deer away from problem areas (e.g., areas with low regeneration success) or toward browse supplies during severe winters would likely be unsuccessful in the central Appalachians of West Virginia.

Keywords: Clearcuts; Movement; Regeneration; Timber harvest; White-tailed deer

1. Introduction

The movements of cervids in relation to timber harvests have been documented (Peek et al., 1976; Skovlin et al., 1989; Armleder and Dawson, 1992; Appollonio et al., 1998). For example, elk (*Cervus elaphus*) in Montana are displaced by silvicultural disturbances (Edge and Marcum, 1985), but do not alter home range size or fidelity (Edge et al., 1985). Linnell and Andersen (1995) found similar behavior in roe deer (*Capreolus capreolus*) in central Norway and report minimal effects on deer habitat use.

The impact of timber harvests on white-tailed deer (*Odocoileus virginianus*) movements is less understood. In the Adirondack Mountains, Tierson et al. (1985) reported changes in white-tailed deer seasonal migrations and home ranges in response to timber harvests. Specifically, they observed deer arresting migrations to winter ranges when timber harvests occurred on summer ranges. Browse from felled trees and trails from logging equipment were suggested as

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causes for changes in movements and home ranges. Similarly, shifts in the spatial arrangement of white-tailed deer home ranges have been documented relative to agricultural crop availability (VerCauteren and Hygnstrom, 1998).

In nonmigratory white-tailed deer populations, movement responses to timber harvests have not been reported. Within these populations, however, other human disturbances (e.g., chasing by dogs, ranching operations, intensive hunting) caused short-term changes in deer behavior, with deer resuming pre-disturbance behavior shortly after disturbance (Sweeney et al., 1971; Hood and Inglis, 1974; Root et al., 1988). It is not clear whether silvicultural activities serve as an attractant or deterrent to white-tailed deer in nonmigratory populations in the central Appalachians. Herein, we compared home range and core area size and overlap, deer movements during timber harvests, and habitat use before and after harvests for deer associated and not associated with clearcuts in the central Appalachians.

2. Methods

In February 1999, we began a radio-telemetry study prior to a series of timber harvests on the MeadWestvaco Wildlife and Ecosystem Research Forest (MWWERF) in Randolph County, WV. The MWWERF is a 3360 ha research area located in the unglaciated Allegheny Mountain and Plateau physiographic province (Fenneman, 1938). Established in 1994 to assess the impacts of industrial forestry on ecological and ecosystem processes in the central Appalachians, the MWWERF is comprised of second growth, naturally regenerated Allegheny hardwood–northern hardwood forests originally cut in the early 1900's (Clarkston, 1993). Elevations range from 740 to 1200 m. The climate is moist and cool, with mean annual precipitation and temperatures >155 cm and <10 °C, respectively (Strausbaugh and Core, 1977). Soils on the MWWERF are well-drained, acidic inceptisols (Stephenson, 1993).

Forest cover at high elevations is dominated by American beech (*Fagus grandifolia*), yellow birch (*Betula allegheniensis*), red maple (*Acer rubrum*), sugar maple (*A. saccharum*), black cherry (*Prunus serotina*), mountain magnolia (*Magnolia fraseri*), cucumber magnolia (*M. acuminata*), and red spruce (*Picea rubens*). At lower elevations yellow-poplar (*Liriodendron tulipifera*), black birch (*B. lenta*), American basswood (*Tilia americana*), and northern red oak (*Quercus rubra*) are dominant. Dominant species in riparian areas include eastern hemlock (*Tsuga canadensis*), red spruce, and rosebay rhododendron (*Rhododendron maximum*). Striped maple (*A. pensylvanicum*), mountain laurel (*Kalmia latifolia*) and rosebay rhododendron form understory thickets in upland areas.

Regeneration silviculture on the MWWERF primarily involves even-aged techniques in the form of clearcutting and leave-tree harvests retaining <7 m^2 basal area/ha. Harvested stands regenerate naturally. Clearcuts, 0–5 years of age, comprise <7% of the MWWERF. Prior to the hunting season, white-tailed deer densities and sex ratios on our study area were 11–25 deer/km^2 and 6–18 adult males:100 adult females, respectively (Langdon, 2001). Abomasal parasite counts suggest the deer population is at or near nutritional carrying capacity (Fischer, 1996). The MWWERF was open to hunting under West Virginia Division of Natural Resources hunting regulations with access through foot-travel. The MeadWestvaco Corporation maintained approximately 56 km of roads on the MWWERF, thus facilitating our intensive radio-telemetry campaign.

Seven stands, ranging from 13.1 to 24.9 ha (Table 1), were harvested during our study and used as treatment areas. Our experimental design partitioned deer into two groups based on their behavior. Deer within the treatment group used one of seven harvested stands (i.e., they had $\geq$1 telemetry location (see below) within harvested stand during any time period). Deer within the control group did not use harvested stands (i.e., their home ranges (see below) were comprised entirely of mature forest). Sample sizes for treatment deer fluctuated by harvested stand (Table 1). We randomly matched our pool of control deer to a harvested stands on a temporal basis (i.e., only locations (see below) from 3 months pre- to 3 months post-harvest were used). We attempted to standardize sample sizes of control and treatment deer within harvested stand.

We used Clover traps (Clover, 1954) and rocket nets (Hawkins et al., 1968) baited with whole kernel corn to capture deer from January 1999 to April 2001. Our

Table 1
Stand size (ha), site index (m), harvest dates, number of white-tailed deer radio-monitored, and number of telemetry locations obtained for control and treatment deer, pre-, during, and post-timber harvest on the MeadWestvaco Wildlife and Ecosystem Research Forest, West Virginia, 1999–2002

Stand	Size (ha)	Site index[a]	Harvest dates	Control locations				Treatment locations			
				Deer (n)	Pre-	During	Post-	Deer (n)	Pre-	During	Post-
A	13.7	21.8	30 September 1999–11 November 1999	3	105	69	112	2	67	49	88
B	13.6	19.8	11 January 2000–5 April 2000	3	209	201	200	4	166	160	174
C	18.3	23.2	13 December 2001–3 January 2002	15	526	10	418	13	433	8	346
D	19.3	20.6	15 March 2000–17 April 2000	3	131	44	132	12	464	166	550
E	24.9	23.2	15 November 2000–24 February 2001	2	65	52	60	2	69	55	58
F	18.7	20.4	27 September 2000–25 October 2000	8	276	106	235	7	237	98	206
G	13.1	21.3	24 July 2001–20 October 2001	4	117	17	134	5	149	17	170

[a] Site index values (m) for northern red oak, base age 50.

capture sites were selected to include stands scheduled and not scheduled for harvest. Upon capture we immobilized and ear-tagged all deer. We used both physical restraint and chemical (2.2 mg xylazine hydrochloride/kg body weight) immobilization techniques. For deer chemically immobilized, we used 1/2 intravenous and 1/2 intramuscular injections of yohimbine hydrochloride (0.3 mg/kg body weight) as a reversal agent. We placed radio-collars (Advanced Telemetry Systems, Isanti, MN) on all female deer. We aged deer as fawns, yearlings or adults by tooth development and wear (Severinghaus, 1949). All capture and handling methods were approved by the University of Georgia's Institutional Animal Care and Use Committee (Permit No. A2002-10119-0).

We collected deer location data 3 months prior to the harvest of stands (i.e., pre-), during harvest (i.e., during), and 3 months after harvest (i.e., post-). Because of the staggered implementation of treatments (Table 1), our telemetry effort was continuous from 30 June 1999 to 3 April 2002. Ground-based deer locations were generated from 00:01 to 24:00 h using radio-receivers and hand-held, 4-element Yagi antennas. We obtained compass bearings from fixed geo-referenced telemetry stations. We recorded two simultaneous bearings yielding an angle of $90 \pm 40^\circ$ to generate estimated deer locations. Program CALHOME (Kie et al., 1996) was used to generate UTM coordinates of estimated deer locations. We attempted to locate each deer 3–4 times/week and we considered individual deer locations obtained = 10 h apart independent.

To assess the accuracy of our bearings, we randomly placed five radio-transmitters at geo-referenced points commonly used by deer. Each observer recorded five compass bearings to each transmitter from five telemetry stations (i.e., $n = 125$/observer; White and Garrott, 1990). Our observed mean bearing error of -0.65° (S.D. $= 8.41^\circ$) suggests minimum bias in our telemetry protocol. Mean distance from observer to deer was 352.8 m. Mean bearing error was 52.2 m. We omitted all location estimates = 3 km from observer to increase accuracy.

We used the fixed-kernel method (Worton, 1989) to generate 95% home range areas and 50% core areas using the Animal Movement extension (Hooge and Eichenlaub, 1997) of ARCVIEW® (ESRI, 1999). We used least square cross validation as the smoothing parameter on the kernel distributions (Silverman, 1986). Home range and core areas were generated from deer locations collected pre- and post-timber harvest. Only deer with $\geq$26 location estimates within each period (i.e., pre- and post-harvest) were used in analyses. Home range and core area polygons were overlaid onto a coverage map of the MWWERF using MeadWestvaco's Forest Research Information System (FRIS®) and ARCVIEW.

We quantified change in home range and core area size for each deer by subtracting pre- area from post-harvest area. We expressed this change as a percentage of pre-harvest area. We quantified overlap for each deer similar to Lesage et al. (2000) by calculating the percentage of home range and core areas that overlapped using ARCVIEW. We calculated the distance from the nearest edge of harvested stands to deer locations and their geographic mean pre-, during, and post-timber harvest using the Animal Movement extension (Hooge and Eichenlaub, 1997) of ARCVIEW.

We assessed habitat selection pre- and post-timber harvest. We used individual deer as the sampling unit (Aebischer et al., 1993). We defined the area available to each deer as its home range. We used ground-truthed FRIS coverages and aerial photographs to identify clearcut boundaries and quantified the area of clearcut ($\leq$5-years-old) within the available area using ARCVIEW. Area of forest available was determined via subtraction. We determined use for each deer by categorizing each deer location either as clearcut or forest.

We compared home range and core area change and overlap between control and treatment deer with a randomized block analysis of variance (ANOVA). We used stand as the blocking factor to reduce the experimental error variance (Kuehl, 1994) and group (control or treatment) as the main effect. Percentage data were square root transformed prior to analysis (Steel and Torrie, 1980). Similarly, we used a randomized block ANOVA to compare the percent of locations during timber harvests occurring within pre-harvest home ranges between control and treatment deer. Again, we used stand as the blocking factor and group as the main effect. For this model, deer were included if $\geq$12 locations were estimated during timber harvest. Consequently, we omitted 37 deer (both control and treatment) assigned to 2 stands (Table 1) from the analysis. Percentage values were square root transformed prior to analysis (Steel and Torrie, 1980).

For treatment deer, we compared the home range area (ha) overlapping harvested stands between pre- and post-harvest with a paired t-test. We compared distance (m) to the nearest edge of harvested stands among pre-, during, and post-timber harvest locations with a randomized block, repeated measure ANOVA. For this model, we used individual deer as the blocking factor and time period as the repeated factor (von Ende, 2001). Similarly, we compared distance (m) to the nearest edge of harvested stands among pre-, during, and post-timber harvest geographic means with a randomized block, repeated measure ANOVA. For this model, periods with less than three locations were considered missing values because ARCVIEW does not compute geographic means of less than three locations. Again, we used individual deer as the blocking factor and period as the repeated factor (von Ende, 2001).

We compared proportions of available and used habitats (clearcut or forested) within treatment deer both pre- and post-timber harvest with compositional analysis (Aebischer et al., 1993). If a habitat type was not available, thus resulting in a zero use value, we omitted the deer from analysis. If a habitat type was not used but was available, we employed a use value of 0.01 instead of 0.00 in the analysis (Aebischer et al., 1993).

For all analyses we considered individual deer the experimental unit (i.e., each deer is only represented once) and only adult ($\geq$1-year-old) females were included. When appropriate, Tukey's honestly significant difference was performed as a multiple range test. If not otherwise noted, means are reported with standard errors in parentheses. We used a Type I error rate of 10% for all analyses. All statistical procedures were performed using SAS software (SAS Institute, 1989).

3. Results

We monitored pre-, during, and post-timber harvest movements of 83 adult female deer (Table 1). The mean number of locations for control deer pre- and post-harvest were 40.0 (5.2) and 38.4 (5.2), respectively. The mean number of locations for treatment deer pre- and post-harvest were 35.0 (1.5) and 36.1 (3.1), respectively. Change in home range and core area size did not differ ($F_{1,75} = 0.73$, $P = 0.40$; and $F_{1,75} = 0.23$, $P = 0.63$, respectively) between control and treatment deer (Table 2). For both control and treatment deer, the positive change values indicate home range and core area sizes were less pre- than post-harvest (Table 2). Home range and core area overlap did not differ ($F_{1,75} = 0.04$, $P = 0.83$; and $F_{1,75} = 1.60$, $P = 0.21$, respectively) between control and treatment deer (Table 2).

Table 2
Mean (S.E.) percentage change in size and overlap in home range and core areas (from pre- to post-timber harvest) for control and treatment female white-tailed deer on the MeadWestvaco Wildlife and Ecosystem Research Forest, West Virginia, 1999–2002

Group	n	Home range size change[a] (%)	Core area size change[a] (%)	Home range overlap (%)	Core area overlap (%)
Control	38	72.5 (20.6)A[b]	88.8 (29.2)A	65.4 (3.5)A	55.8 (10.1)A
Treatment	45	69.8 (21.9)A	136.4 (40.0)A	66.5 (3.1)A	45.1 (4.8)A

[a] Positive percent indicates pre-harvest area < post-harvest area.
[b] Within column means followed by the same letter were not different ($P < 0.10$).

Mean number of locations for control and treatment deer during timber harvests were 28.8 (9.9) and 24.0 (4.9), respectively. During harvests, control deer were located inside their pre-harvest home range more frequently ($F_{1,40} = 5.04$, $P = 0.03$) than treatment deer. Mean percent of locations for control deer ($n = 19$) occurring within pre-harvest home range was 80.3 (5.0). Mean percent of locations for treatment deer ($n = 27$) occurring within pre-harvest home range was 69.0 (4.3).

Within treatment deer, home range area overlapping harvested stands did not differ ($t_{41} = -1.32$, $P = 0.19$) between pre- and post-timber harvest. Pre-harvest home ranges overlapped stands scheduled for harvest by 6.6 (0.8) ha and post-harvest home ranges overlapped harvested stands by 7.9 (0.9) ha. Mean distance to nearest edge of harvested stands was less ($F_{2,83} = 2.83$, $P = 0.07$) for during harvest locations than for the post-harvest locations (Table 3). Distance to nearest edge of harvested stands for pre-, during, and post-harvest geographic means did not differ ($F_{2,74} = 0.55$, $P = 0.58$).

We calculated percentage clearcut and forest habitat available versus used for 27 treatment deer pre-timber harvest and 41 treatment deer post-harvest (Table 4). During both periods, habitat selection differed from random (Table 4), indicating deer used clearcut habitats in greater proportion than their availability. Pre-timber harvest, percentage clearcut and forest available were 8.0 and 92.0, respectively; whereas percentage clearcut and forest used were 9.0 and 91.0, respectively. Post-harvest, percent clearcut and forest available were 13.7 and 86.3, respectively, whereas percent clearcut and forest used were 14.7 and 85.3, respectively. Within treatment deer, timber harvests from 1999 to early 2002 resulted in a 5.7% increase both in the availability and use of clearcut habitat.

Table 3
Mean (S.E.) distance (m) from pre-, during, and post-timber harvest radio-telemetry locations and their geographic means to harvested stands for treatment white-tailed deer on the MeadWestvaco Wildlife and Ecosystem Research Forest, West Virginia, 1999–2002

Period	Locations (m)	Geographic mean (m)
Pre-harvest[a]	413 (40)A	377 (44)A
During harvest	376 (43)AB	345 (50)A
Post-harvest	458 (52)AC	366 (54)A

[a] Within column means not followed by the same letter were different ($P < 0.10$).

Table 4
Compositional analysis data for habitat use based on telemetry locations and habitat availability based on fixed-kernel 95% home ranges of female white-tailed deer pre- and post-timber harvest on the MeadWestvaco Wildlife and Ecosystem Research Forest, West Virginia from 1999 to 2002

Period	n	D[a]		95% Confidence interval	
		$\bar{x}$	S.E.	Lower	Upper
Pre-harvest	27	−1.84	0.65	−3.18	−0.50
Post-harvest	41	−1.22	0.48	−2.19	−0.25

[a] Where D is the difference between the log-ratio proportion of clearcut/forest used minus the log-ratio proportion of clearcut/forest available.

4. Discussion

Cervid behavioral responses to timber harvests vary. For example, Pedersen et al. (1980) noted increased home range size for elk in response to timber harvests, concluding that silvicultural activities were a deterrent to elk. Conversely, in the Adirondack Mountains Tierson et al. (1985) observed that white-tailed deer were attracted to recently harvested stands and concluded that deer would arrest migration to winter ranges when timber harvests occurred during autumn–winter on or adjacent to their summer ranges. This response altered winter home ranges and was not observed when timber harvests occurred during summer (Tierson et al., 1985). Linnell and Andersen (1995) reported a neutral response in roe deer to timber harvests, with little change in home range size and overlap.

We found some evidence that timber harvests attracted deer short-term. During harvests, treatment deer were located outside their pre-harvest home ranges more often than control deer. Within treatment deer, estimated locations and geographic means during harvest generally were closer to harvested stands than in other periods, with location distances varying between the during and post-harvest periods. We believe deer may have ventured outside their home ranges toward stands being harvested to forage on browse from felled trees (Tierson et al., 1985). However, despite six of seven timber harvests (affecting 40 of 45 treatment deer) conducted during autumn or winter, we did not observe attraction to harvested sites as Tierson et al. (1985) did in the Adirondack Mountains. This was somewhat expected because deer in the central Appalachians are nonmigratory, display few seasonal movements, maintain high seasonal fidelity (Campbell, 2003), and experience less severe winter weather than deer in the Adirondacks. Our treatment deer maintained a high level of site fidelity (67% home range overlap) post-timber harvests.

We found no evidence that timber harvests diminished habitat quality (Campbell, 2003) or increased home range size of white-tailed deer. Post-harvest home ranges generally were larger than pre-harvest home ranges, but the percentage change did not differ between control and treatment deer. We attribute variation in pre- and post-harvest home ranges to the seasonality of the timber harvests. Winter (January–May) home ranges are larger on the MWWERF than during other seasons (Campbell, 2003). Post-harvest home ranges were generated from locations collected in portions of winter for all 83 deer. In contrast, pre-harvest home ranges were generated from locations collected in portions of winter for only 31 deer. We believe post-harvest home ranges were larger because they included more of the winter season.

Within cervids, altered home ranges and movements have been documented in response to military activity (Stephenson et al., 1996), snowmobile activity (Dorrance et al., 1975), and ranching activity (Hood and Inglis, 1974). However, most investigations of silvicultural activity suggest minimal long-term or permanent effects (Edge et al., 1985; Linnell and Andersen, 1995), with an exception of fallow deer (*Dama dama*) at breeding sites in Italy (Appollonio et al., 1998). Similarly, within our white-tailed deer population, timber harvests did not alter home ranges and movements 0–3 months post-harvest.

Stephenson et al. (1996), who found military activity altered long-term mule deer (*O. hemionus*) movements, suggest this may be a response to human harassment, altered security cover, and/or an altered forage base. In contrast, the almost universal lack of long-term negative effects on the movement of white-tailed deer associated with timber harvests suggests timber harvests do not influence their behavior through any of the above (or other) mechanisms and is comparatively benign. Long-term, timber harvests likely benefit most cervid populations by increasing forage availability and quality (Della-Bianca and Johnson, 1965; Blymyer and Mosby, 1977; Wentworth et al., 1990; Ford et al., 1994). However, due to the irruptive behavior of white-tailed deer populations (McCullough, 1979) and recent problems with white-tailed deer overabundance (McShea et al., 1997), this may not be desired.

The lack of changes in white-tailed deer movement in relation to timber harvests suggests that habitat management aimed at attracting deer away from problem areas (Miller, 1990; Mackey, 1995) or toward browse supplies during severe winters (Blouch, 1984) would likely be unsuccessful in the central Appalachians of West Virginia. However, due to the sedentary behavior of these deer, particularly when presented with large-scale habitat alteration, population management on localized (Porter et al., 1991) or regional (Van Deelen et al., 1998) scales may be successful. Furthermore, land managers can dismiss hunter concerns that clearcutting displaces deer during and immediately following timber harvest in the central Appalachians.

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