

Response of Rocky Mountain Elk (*Cervus elaphus*) to Wind-power Development

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ABSTRACT.—Wind-power development is occurring throughout North America, but its effects on mammals are largely unexplored. Our objective was to determine response (*i.e.*, home-range, diet quality) of Rocky Mountain elk (*Cervus elaphus*) to wind-power development in southwestern Oklahoma. Ten elk were radiocollared in an area of wind-power development on 31 March 2003 and were relocated bi-weekly through March 2005. Wind-power construction was initiated on 1 June 2003 and was completed by December 2003 with 45 active turbines. The largest composite home range sizes ($>80 \text{ km}^2$) occurred April–June and September, regardless of the status of wind-power facility development. The smallest home range sizes ($<50 \text{ km}^2$) typically occurred in October–February when elk aggregated to forage on winter wheat. No elk left the study site during the study and elk freely crossed the gravel roads used to access the wind-power facility. Carbon and nitrogen isotopes and percent nitrogen in feces suggested that wind-power development did not affect nutrition of elk during construction. Although disturbance and loss of some grassland habitat was apparent, elk were not adversely affected by wind-power development as determined by home range and dietary quality.

INTRODUCTION

Home-range has been correlated with forage availability, and ungulates in more productive habitats tend to have smaller home ranges (Schoener, 1981; Tufto *et al.*, 1996; Relyea *et al.*, 2000; Kie *et al.*, 2002). Rocky Mountain elk (*Cervus elaphus*) occupying a forested habitat with a concentrated food source in Washington had smaller home ranges than elk in more open shrub-steppe habitat (McCorquodale, 1991). Foraging and cover habitats, and proximity or isolation of such habitats, can influence home-range size of cervids (Schoener, 1981; Tufto *et al.*, 1996; Relyea *et al.*, 2000). Kie *et al.* (2002) found that distribution and abundance of various habitat types accounted for 57% of the variability in the home-range size of mule deer (*Odocoileus hemionus*) in California.

Among the numerous factors affecting home-range size, infrastructure development may effect habitat and forage availability to the greatest degree (Swihart *et al.*, 1988; Relyea *et al.*, 2000; Vistnes *et al.*, 2001; Kie *et al.*, 2002). Distribution of productive habitats relative to infrastructure development are integral to understanding wildlife use of a landscape

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(Turner, 1989; Wiens, 1989). Of 99 groups of caribou (*Rangifer tarandus granti*) that approached a road, pipeline and/or drill site, 10.1% reversed direction and left the study area in the Sagavanirktok River floodplain of Alaska (Fancy, 1983). Similarly, density of reindeer (*R. t. tarandus*) decreased with increasing infrastructure development (*i.e.*, power lines, roads, tourist resorts) in south-central Norway (Vistnes *et al.*, 2001). Assessments of forage quality and availability before and after infrastructure development are lacking. Vistnes *et al.* (2001) investigated changes in food quantity in areas with and without human disturbance; lichen availability was 71% lower in areas without infrastructure development. Caribou altered foraging behavior in response to development of an oil field region near Prudhoe Bay, Alaska as documented by intense foraging in the few remaining preferred habitats of rugged, elevated terrain (Nellemann and Cameron, 1998).

Wind energy provides <1% of electricity generated in the U.S., but may provide about 6% of the nation's energy by 2020 (<http://www.awea.org>). Most research on effects of wind-power on wildlife has focused on birds and volant mammals (Osborn *et al.*, 2000; Johnson *et al.*, 2002, 2003). Noises from wind-power generators were detectable by harbour porpoises (*Phocoena phocoena*) and harbour seals (*Phoca vitulina*) off the coast of Vancouver Island, Canada (Koschinski *et al.*, 2003), but research on effects of wind-power on terrestrial mammals is lacking. Studies on infrastructure development (*i.e.*, wind-power, oil-drilling, powerlines, ski trails) can elucidate effects on ungulate movements, behavior and habitat use (Fancy, 1983; Carruthers *et al.*, 1987; Vistnes *et al.*, 2001).

Understanding effects of wind-power development and operation on large terrestrial mammals would provide valuable information to wildlife managers and wind-energy companies to mitigate potential negative effects of wind-power facilities. We used radiotelemetry and fecal indices of dietary quality to assess the influence of wind-power development on Rocky Mountain elk. Our objectives were to determine: (1) effects of wind-power construction and operation on home-range size of elk; (2) if any avoidance of the wind-power facility caused elk to shift home range away from the wind-power facility; and (3) if construction of the wind-power facility resulted in a change in diet due to potential habitat loss.

METHODS

Our study occurred on private lands in southwestern Oklahoma, USA (34°47' to 34°57'N, 98°25' to 98°50'W), north of the Wichita Mountains Wildlife Refuge (WMWR). The study site contained agricultural fields of 1–251 ha, and state highways 19 and 115 intersected granite-derived private lands bordering WMWR on the north from limestone-derived private lands. Elevation was 444–645 m above mean sea level and was caused by Ordovician marine limestone and dolomite rising above redbed plains (Buck, 1964). Referred to locally as the Slick Hills, the area was classified as mixed-grass eroded plains and was used primarily for cattle grazing. Dominant tallgrasses included big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), switch grass (*Panicum virgatum*) and Indian grass (*Sorghastrum nutans*). Shortgrasses included buffalograss (*Buchloe dactyloides*), blue grama (*Bouteloua gracilis*) and sideoats grama (*B. curtipendula*) in a mesquite (*Prosopis glandulosa*) grassland (Tyril *et al.*, 2002). Forests were composed of sporadic post oak (*Quercus stellata*), blackjack oak (*Q. marilandica*) and eastern red cedar (*Juniperus virginiana*) at higher elevations and pecan (*Carya illinoensis*), American elm (*Ulmus americana*) and western walnut (*Juglans rupestris*) in riparian areas.

Residential homes and primary and secondary roads traverse the Slick Hills separating it into three unbroken tracts of land (Fig. 1). Access was limited to ranching operations, and brief permit-only hunting seasons occurred in October and December each year (Walter and Leslie, 2002). Herds of >50 elk used agricultural crops in the Slick Hills during

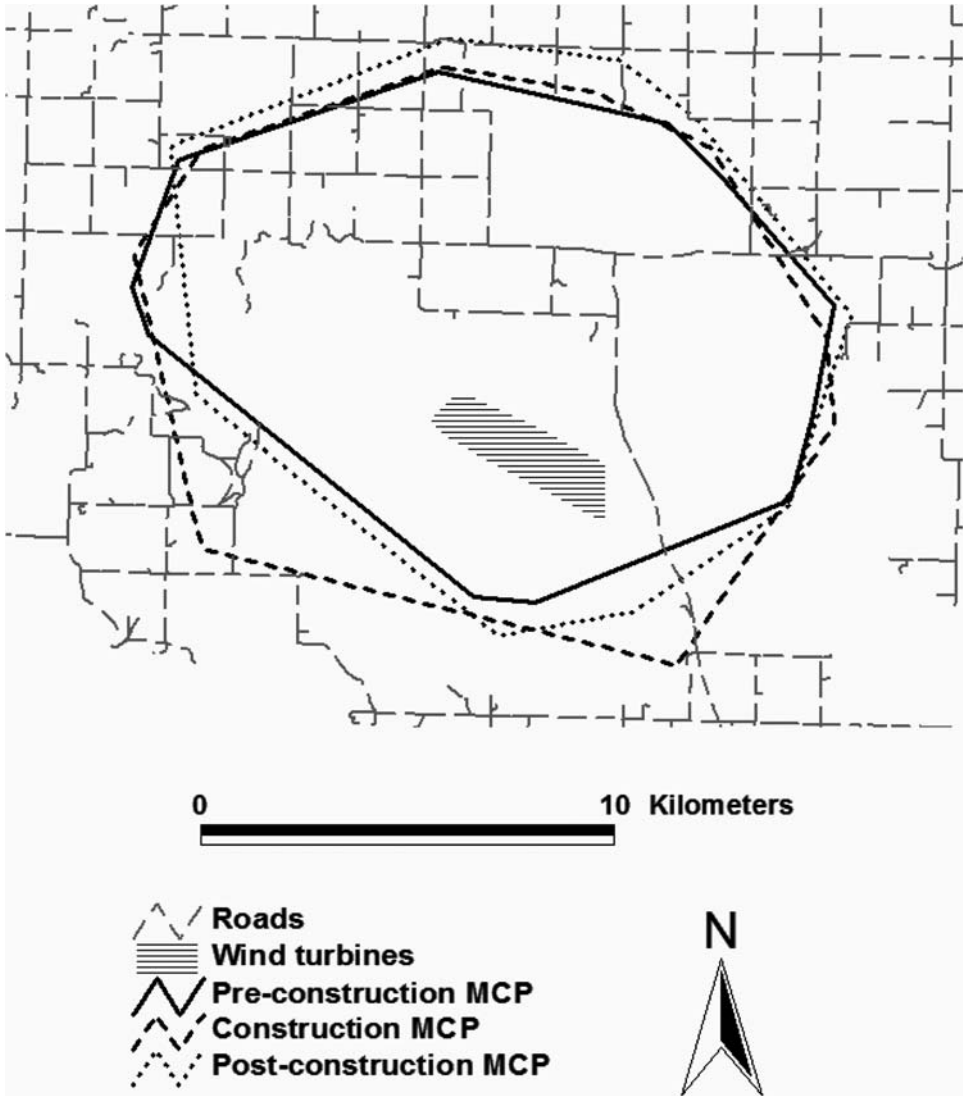


FIG. 1.—Minimum Convex Polygons (MCP) that encompasses 955 elk locations north of the Wichita Mountains Wildlife Refuge during pre-construction, construction and post-construction of the wind-power facility (2003–2005)

forage-limited winter months prior to construction of the wind-power facility (Walter, 2006). The largest tract (about 8000 ha) contained no primary roads and limited human activity prior to construction, but construction of a 2–3-km gravel road was initiated on 1 June 2003 to service the planned wind-power facility. The wind-power facility was completed by 31 December 2003 with 45 NEG Micon 1.65 MW turbines constructed and active. A 1.65 MW turbine reaches 100 m from the ground to the top of the blades with a blade diameter of

72 m. Large machinery was removed by December 2003, but wind-power personnel were present daily until 31 March 2004.

Prior to construction on 31 March 2003, 10 free-ranging elk were captured from a Bell 206 Series helicopter using net guns (Hawkins and Powers Aviation, Greybull, Wyoming) and were fitted with radiocollars (Advanced Telemetry Systems, Isanti, Minnesota, USA) and ear-tags. Elk were relocated 4–6 times per month from 1 April 2003 to 31 March 2005 using radiotelemetry triangulations, triangulations and direct observations (Walter, 2006); 1 radiocollared female elk was legally harvested in December 2003. Animal care and experimental procedures were approved by the Oklahoma State University's Institutional Animal Care and Use Committee. Radiolocations of elk were entered into LOCATE II to calculate telemetry intercepts from 2 or 3 receiver locations (Nams, 1990). Radiolocations and direct observations of radiocollared elk were plotted in ArcView 3.3 (ESRI, Redlands, California, USA) using U.S. Geological Survey 3.75-m digital orthophoto quadrangles in the Universal Transverse Mercator coordinate system. Telemetry error was assessed with transmitters at known locations resulting in a mean error distance of 476 m ($n = 76$) (Wallingford and Lancia, 1991; Zimmerman and Powell, 1995).

To understand effects of wind-power development on the elk herd using the Slick Hills, home-range size and distances from the wind-power facility were determined. Bootstrap sampling with 100 iterations was conducted on all elk locations combined by month using Animal Movement Analysis Extension (AMAE; Hooge and Eichenlaub, 1997). Monthly bootstrap sampling resulted in 100 datasets with 50 points selected randomly, with replacement, representing elk herd locations for each dataset. Bootstrap sampling of the monthly locations of all elk provided means and variances for the different home-range methods and permitted statistical testing of home-range size (Manly, 1997; Kernohan *et al.*, 2001; Kern *et al.*, 2003). Minimum Convex Polygons (MCP) were calculated for comparison with previous studies, and the 95% fixed kernel home ranges with least-squares cross-validation smoothing function (FXK) was calculated on each bootstrapped dataset using the Home Range Extension in ArcView 3.3 (Worton, 1989; Rodgers and Carr, 1998; Seaman *et al.*, 1999; Kernohan *et al.*, 2001).

Distances from wind turbines were measured in meters using the Spider Analysis function of AMAE (Hooge and Eichenlaub, 1997). To assess potential avoidance of the wind-power facility by elk, distances from all elk locations to the center of the wind-power facility were determined by month (SPIDER). To assess a potential change in home-range overlap due to the facility, distances from each wind turbine to the center of monthly MCP home range were determined (CENTER); monthly MCP's were calculated using all elk locations for a given month without outlier removal. When home-ranges and distances failed ($P < 0.05$) Levene's test for homogeneity of variance, data were rank-transformed. Mean (\pm SE) MCP, FXK, SPIDER and CENTER were compared monthly by year using a 2-way ANOVA with Tukey's multiple comparison to detect differences between month and year (Conover and Iman, 1981; Zar, 1996). Estimates of home-range size and distance measurements were compared during various phases of wind-power development: Pre-construction, 2 mo prior to construction (April–May 2003); Construction, 10 mo of construction (June 2003–March 2004); Post-construction, 12 mo (April 2004–March 2005) during the first year of operation of the 45-turbine wind-power facility.

To ascertain if construction of the wind-power facility affected elk nutrition, 10–15 fresh (<1 wk) elk fecal samples, free of insects, were collected opportunistically in areas where elk were known to occur. To prevent over-representation of diet by a group of elk, samples were collected from ≥ 3 locations in the study area during each month. Before construction, feces were collected in May–August 2002 and January–March 2003; during construction, feces

were collected in May–August 2003 and January–March 2004. Fecal samples were placed in paper bags and allowed to air dry before grinding to uniform consistency in a Wiley® Mini-Mill (Thomas Scientific, Swedesboro, New Jersey, USA). Subsequently, 2–3 mg from each sample were loaded into a 5 × 8-mm tin capsule for carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope analysis in an isotope ratio mass spectrometer (IRMS) at the Stable Isotopes Laboratory, University of California-Davis. Nitrogen content for each fecal sample was determined with a gas chromatograph prior to admission to the IRMS (Tieszen *et al.*, 1998). Isotope values were expressed in delta (δ) notation where δ was the ratio of heavy to light isotopes of the sample relative to the ratio of the Peedee Belemnite marine fossil limestone formation for $\delta^{13}\text{C}$ and atmospheric nitrogen for $\delta^{15}\text{N}$ (Peterson and Fry, 1987).

Standard deviations for replicated internal standards were 0.08 and 0.22‰ for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, respectively. When $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ failed Levene's test for homogeneity of variance ($P < 0.05$), statistical analyses were conducted on rank transformations of isotopic data. Differences in mean percent nitrogen and ranks of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in feces between months were analyzed individually using analysis of variance (ANOVA) with Tukey's multiple comparison test (Conover and Iman, 1981; Zar, 1996). Means \pm SE for non-transformed data are reported.

RESULTS

From 1 April 2003 to 31 March 2005, 955 radiolocations from 10 elk were collected for home-range and distance analyses. Mean home-range size differed for all monthly comparisons preventing pooling of monthly data by phase (Fig. 2). Pre-construction home range was smaller in April but larger in May compared with the construction period. Home-range size for all months during construction differed from their respective month post-construction (Fig. 2). Home-range sizes decreased from June to August during and post-construction. Home-range sizes increased in September comparable to those in April and May during and post-construction. Home range was larger in January–March during construction than respective months post-construction (Fig. 2).

Mean SPIDER distance pre-construction did not differ from SPIDER distance during construction for both months (Table 1). Mean SPIDER distance during construction differed from SPIDER distance post-construction only in August, December, and March (Table 1). Mean SPIDER distance during construction was shortest in November (1883 ± 143 m) and longest in December (5362 ± 206 m; Table 1). Mean SPIDER distance post-construction was shortest in January (1997 ± 121 m) and longest in June (5016 ± 471 m). Mean CENTER distance pre-construction differed from that during construction for both months (Table 1). Mean CENTER distance during construction was shortest in March (1539 ± 141 m) and longest in December (5519 ± 188 m; Table 1). Mean CENTER distance post-construction was shortest in January (1977 ± 162 m) and longest in March (5212 ± 116 m). Mean CENTER distance during construction differed from post-construction for all months except August (Table 1).

Mean carbon isotopes in feces ranged from -27.8 to -24.3 ‰ before construction and -26.8 to -23.9 ‰ during construction; highest values occurred in July and lowest values occurred in January and March (Fig. 3a). Mean nitrogen isotopes were 1.14 – 5.18 ‰ before construction and 3.24 – 4.76 ‰ during construction; highest values occurred in January and lowest values occurred in May and June (Fig. 3b). There were differences for $\delta^{13}\text{C}$ in January and $\delta^{15}\text{N}$ in June in monthly comparisons of before and during construction. Mean percent nitrogen in feces was 1.73 – 3.09 ‰ before construction and 1.80 – 2.78 ‰ during construction; highest values occurred in May and lowest values occurred in June and July (Fig. 3b). There were no differences in monthly percent nitrogen before and during construction (Fig. 3c).

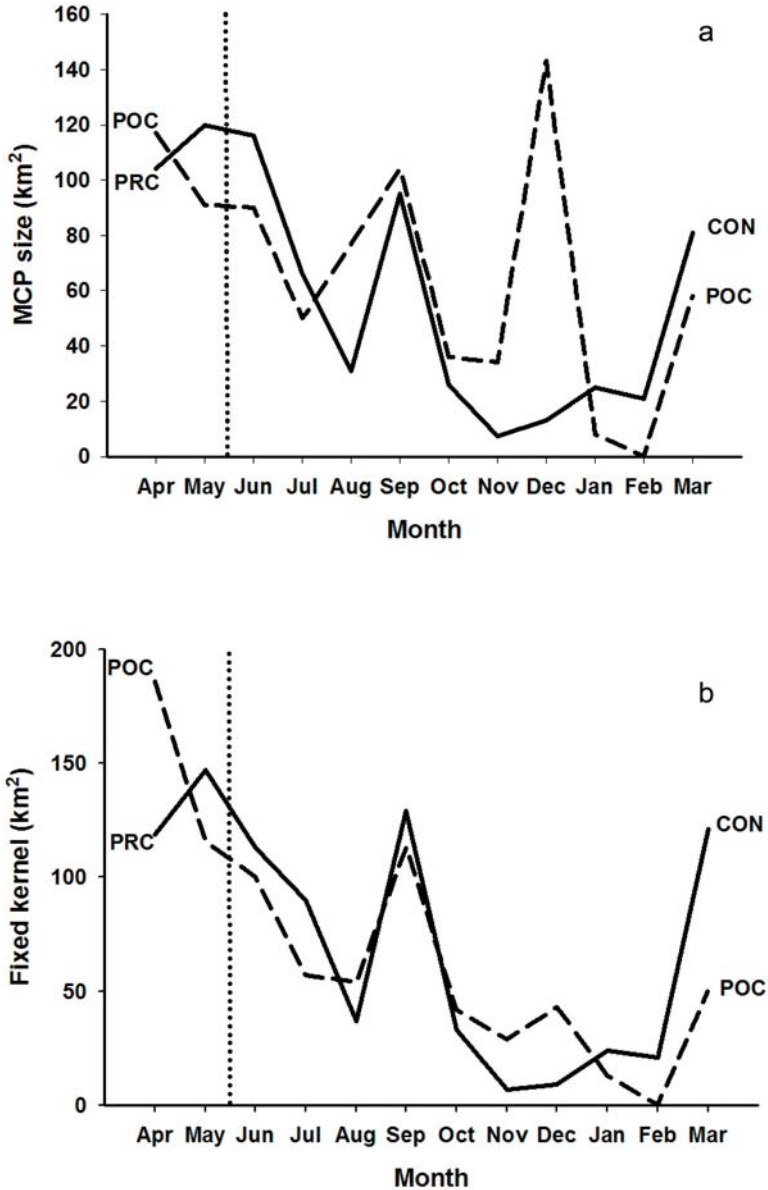


FIG. 2.—Mean monthly home ranges (km²) of elk in the Slick Hills pre-construction (PRC), during construction (CON) and post-construction (POC) of the wind-power development; (a) Minimum Convex Polygon (MCP) and (b) 95% fixed kernel using LSCV smoothing (Fixed Kernel). The dotted line indicates the comparison of 2 months pre-construction to the comparable months post-construction. All monthly comparisons were different at $P < 0.05$

TABLE 1.—Mean (\pm SE) distances (m) of elk locations in the Slick Hills during wind-power development and operation in southwestern Oklahoma, 2003–2005. Distances were from all elk locations to the center of the wind-power facility (SPIDER) and distances of all wind turbines from the center of monthly elk Minimum Convex Polygons (CENTER). Means within columns with different letters differed at $P < 0.05$

Month Year	SPIDER	CENTER
<i>Pre-construction</i>		
April 2003	3506 (355)b	3026 (175)b
May 2003	4809 (376)ab	3176 (133)b
<i>Construction</i>		
June 2003	5135 (410)ab	3630 (125)de
July 2003	4670 (289)ab	3292 (164)efg
August 2003	4462 (357)abcd	4352 (104)bc
September 2003	3974 (325)abcd	2850 (204)fgh
October 2003	2189 (168)ef	2839 (105)ghi
November 2003	1883 (143)f	4245 (207)cd
December 2003	5362 (206)a	5519 (188)a
January 2004	3054 (213)bcde	5031 (198)ab
February 2004	3219 (109)bcd	2629 (109)hi
March 2004	2976 (423)def	1539 (141)j
<i>Post-construction</i>		
April 2004	4427 (409)ab	2355 (195)c
May 2004	5292 (536)a	4768 (143)a
June 2004	5016 (471)abc	4958 (160)ab
July 2004	3839 (406)bcd	4917 (168)abc
August 2004	2448 (453)ef	5149 (186)ab
September 2004	3155 (373)def	2009 (149)ij
October 2004	3180 (444)cdef	3737 (107)de
November 2004	2025 (203)ef	2322 (81)ij
December 2004	2874 (259)def	3509 (113)def
January 2005	1997 (121)ef	1977 (162)ij
February 2005	2889 (28)bcdef	4667 (157)abc
March 2005	4323 (279)abc	5212 (116)a

DISCUSSION

Elk did not vacate the Slick Hills in response to construction or operation of the wind-power facility, and overall trends in home-range size were not affected. During and after construction, the largest elk home ranges were $>80 \text{ km}^2$ in April–June and September, which coincided with the greatest monthly rainfall during a typical year. The smallest home ranges each year were $<50 \text{ km}^2$ in October–February, and those months had the lowest precipitation and temperatures in typical years. Home-range data suggested that a concentrated food source (*i.e.*, winter wheat) in the Slick Hills resulted in smaller home ranges of elk in winter regardless of wind-power development. Similarity in largest and smallest home-range sizes during and post-construction indicated that climatic variables, and their effect on forage availability, likely influenced elk movements to a greater extent than construction of the wind-power facility. Precipitation and temperature influence forage production, and elk would be expected to search for high-quality forage because it is of greater nutritional value (Wilson and Hattersley, 1989; Van Soest, 1994; Taper and Gogan, 2002).

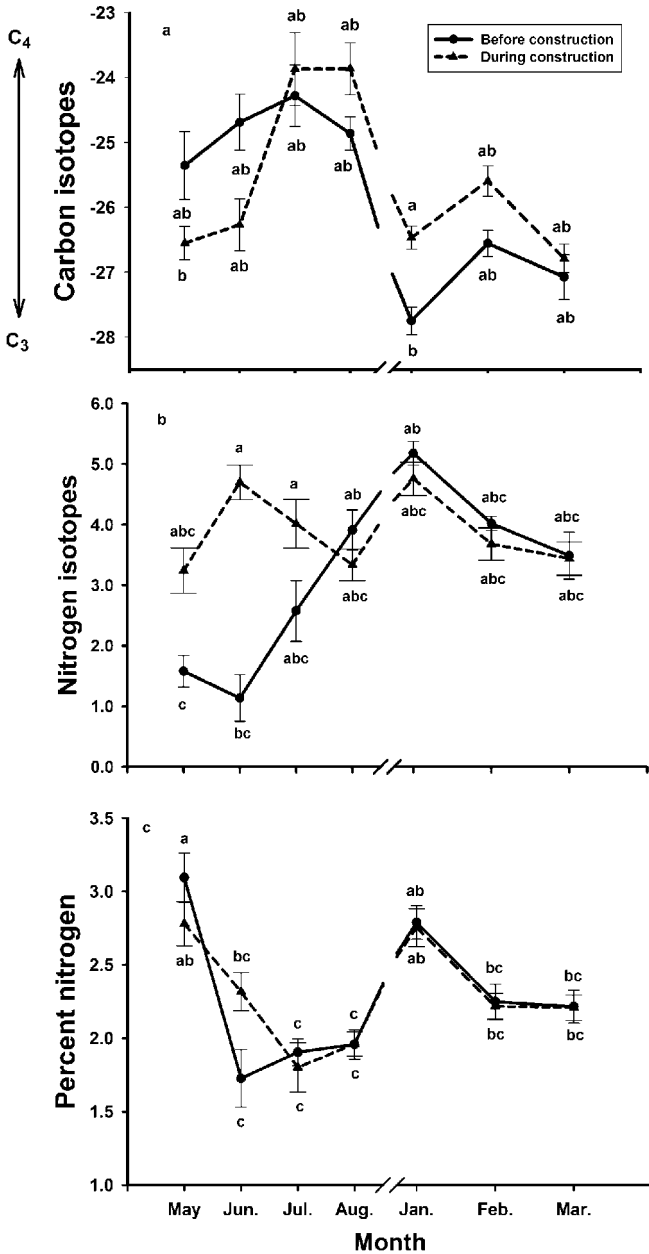


FIG. 3.—Means and standard error bars for (a) $\delta^{13}\text{C}$, (b) $\delta^{15}\text{N}$ and (c) percent nitrogen in feces collected before construction (May 2002–March 2003), and during construction (May 2003–March 2004) of the wind-power facility in southwestern Oklahoma. Error bars with different letters indicated monthly means were significantly different at $P < 0.05$

Disturbance from wind-power development did not displace elk from habitats surrounding the wind-power facility because SPIDER distances were similar to those for comparable months after construction was completed, except for August and December. The SPIDER distance indicated that elk were closer to the wind-power facility in August and December post-construction than the comparable months during construction. Behavioral acclimation to human disturbances has been documented for ungulates when that disturbance was within their home range (Edge *et al.*, 1985; Morrison *et al.*, 1995). For example, desert bighorn sheep (*Ovis canadensis nelsoni*) used the water source in closest proximity to the construction of a water pumping facility although use of alternate water sources was evident in Nevada (Leslie and Douglas, 1980). Future wind-power facilities will likely be constructed within home ranges of resident ungulates, and some studies suggest that ungulates will acclimate to infrastructure when the primary disturbance (*i.e.*, construction, human presence) is removed (Fancy, 1983; Carruthers *et al.*, 1987; Morrison *et al.*, 1995).

Interestingly, the CENTER distances differed for all months during construction compared with their respective months post-construction, except for August. The CENTER distances for 6 of 10 mo were greater post-construction than during construction indicating the center of elk home ranges shifted away from the wind-power facility after the disturbance (*i.e.*, turbine construction) was removed. The shift away from the wind-power facility could be in response to loss of habitat from the wind-power facility leading to an increased use of alternate areas. Development of power lines, ski trails and roads resulted in the intensive use of lichen by wild reindeer in the remaining habitat without human disturbance (Vistnes *et al.*, 2001). However, CENTER distances were closer to the wind-power facility in 4 of 10 mo, suggesting some other extrinsic factor may be controlling elk use of the area. Elsewhere, elk have adapted to habitat alterations and human disturbance if habitats able to fulfill requirements for survival and reproduction remained accessible (Geist, 1974; Edge *et al.*, 1985; Morrison *et al.*, 1995).

Plant phenology, and numerous interrelated factors that effect it, influence elk forage quality and, hence, elk movement to foraging areas (Nelson and Leege, 1982). Monthly trends in home-range sizes during and after construction and variability in SPIDER and CENTER distances suggested that some other extrinsic factors influenced elk movements. Fecal isotopes from before construction and during construction documented annual and monthly variability in dietary quality, regardless of the wind-power facility. Diets of bison (*Bison bison*) on the Konza Prairie Research Natural Area in Kansas changed as seasonal availability of forage changed based on fecal $\delta^{13}\text{C}$ (Post *et al.*, 2001). Similar to other ungulates, elk would be expected to search for C_3 plants because they are higher in dry matter digestibility than C_4 plants and, hence, of greater nutritional value (Wilson and Hacker, 1987; Wilson and Hattersley, 1989; Post *et al.*, 2001). The wind-power facility was constructed on the highest elevations along an east-west oriented ridge composed primarily of C_3 grasses during the cool season and C_4 grasses during the warm season. The $\delta^{13}\text{C}$ in elk feces before construction suggested that a similar mixture of C_3 and C_4 vegetation was consumed during construction of the wind-power facility. Although some habitat was removed for the wind-power facility, levels of $\delta^{13}\text{C}$ in feces paralleled results from radiotelemetry analyses that the heterogeneous landscape of the Slick Hills provided several sources of suitable forage for elk.

The $\delta^{15}\text{N}$ in elk feces documented the opportunistic foraging of elk from May to August despite construction of the wind-power facility. Plants can have $\delta^{15}\text{N}$ values ranging from -7 to 7‰ due to differential fractionation of nitrogen by N_2 -fixing and non- N_2 -fixing vegetation (Hoering, 1955; Virginia and Delwiche, 1982; Hobbie *et al.*, 2000). Feces also are typically enriched by 3‰ over the diet (Kelly, 2000; Sponheimer *et al.*, 2003). Therefore, $\delta^{15}\text{N}$ in feces

would be greater than the $\delta^{15}\text{N}$ of the diet and dependent on the $\delta^{15}\text{N}$ of dominant plants consumed, nitrogen content of overall diet ingested, and nitrogen content of endogenous sources (Steinhour *et al.*, 1982; Van Soest, 1994; Sponheimer *et al.*, 2003). No differences in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in May–August suggested that similar proportions of C_3 and C_4 plants were consumed before and during construction. However, differences in $\delta^{15}\text{N}$ between June before construction and June during construction may have been related to contrasting amounts of precipitation (84 vs. 208 mm, respectively; National Oceanic and Atmospheric Administration 2003) and the resulting forage quality. Elk foraged on alfalfa and wheat grain during the study, which may explain variability in summer fecal $\delta^{15}\text{N}$ when natural forage was unavailable. The $\delta^{15}\text{N}$ of alfalfa, wheat grain and natural forage depends on the N_2 -fixing mechanisms of the plant because N_2 -fixing legumes have different $\delta^{15}\text{N}$ than annual herbaceous plants dependent upon extraction of soil nitrogen (Virginia and Delwiche, 1982; Hobbie *et al.*, 2000).

Habitat loss and human disturbance from infrastructure development can change ungulate distribution and movement, lower fecundity and lower population density (Carruthers *et al.*, 1987; Nellemann and Cameron, 1998; Vistnes *et al.*, 2001). Percent nitrogen in feces indicated that elk nutrition was similar before and after construction for all months. Several researchers have used fecal nitrogen as an index to nutrition during similar seasons (Leslie and Starkey, 1985; Leslie and Starkey, 1987; Osborn and Jenks, 1998). Although monthly variability for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ was observed before and after construction, wind-power development did not adversely affect elk nutrition as determined by fecal percent nitrogen. Percent nitrogen also indicated that elk experienced higher nutrition during winter (Jan.–Mar.) from winter wheat than during late summer (*i.e.*, Jul.–Aug.; Fig. 3c). Regardless of the effects of wind-power development on habitat use and movements of elk, agricultural crops contributed to elk nutrition on a seasonal basis before and after construction.

Understanding effects of wind-power development on terrestrial mammals requires knowledge of changes in movement or behavior that adversely affect nutrition of resident wildlife. Annual climatic variability that determines forage quantity, quality and distribution caused monthly variability in elk movements, but nutrition and annual home range were not adversely affected. We agree with (Hoover and Morrison, 2005) that prior to development of wind-power facilities, site assessment should be made to investigate potential wildlife and habitat that may be affected. Radiotelemetry and direct observations showed that elk used riparian, forested habitat for calving and during summer months (Walter, 2006). Elk used riparian habitat during and after construction because this habitat was not altered by construction of the wind-power facility and provided a critical seasonal habitat. Although location of wind turbines is dictated by topography and wind speed, secondary structures such as access roads, power lines, storage platforms and business facilities should be constructed in areas that do not remove critical habitat or impact corridors vital to resident wildlife.

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