Attachment 6

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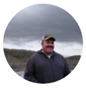

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Factors Influencing Winter Mortality Risk for Pronghorn Exposed to Wind Energy Development☆

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ABSTRACT

Evaluating the influence of energy development on pronghorn *(Antilocapra americana)* winter mortality risk is particularly critical given that northern populations already experience decreased survival due to harsh environmental conditions and increased energetic demands during this season. The purpose of our study was to evaluate pronghorn mortality risk over 3 winters (2010, 2010–2011, 2011–2012) on a landscape developed in 2010 for wind energy production (Dunlap Ranch) in south-central Wyoming, United States. We obtained locational data and survival status of 47 adult female pronghorn captured and equipped with Global Positioning System (GPS) transmitters. Overall, 17 pronghorn died during winter seasons, with 76.4% (13) of deaths occurring during the winter with highest snow accumulation (2010–2011). Survival ($\hat{S}$) was lowest in winter 2010–2011 ($\hat{S} = 0.53$, 90% confidence interval [CI]: 0.37–0.70) and highest in winters 2010 ($\hat{S} = 0.97$, 90% CI: 0.92–1.00) and 2011–2012 ($\hat{S} = 0.91$, 90% CI: 0.82–1.00). We modeled mortality risk for pronghorn using Cox's proportional hazards model inclusive of time-dependent and time-independent covariates within anthropogenic, environmental, and wind energy variable classes. Across winters, pronghorn winter mortality risk decreased by 20% with every 1.0-km increase in average distance from major roads (hazard ratio = 0.80, 90% CI: 0.66–0.98), decreased by 4.0% with every 1% increase in average time spent in sagebrush (*Artemisia* spp. L.; hazard ratio = 0.96, 90% CI: 0.95–0.98), and decreased by 92% with every 1 unit (VRM × 1000) increase in terrain ruggedness (hazard ratio = 0.08, 90% CI: 0.01–0.68). Pronghorn winter survival was not influenced by exposure to wind energy infrastructure; however, pronghorn survival may be impacted by larger-scale wind energy developments than those examined in our study. We recommend wildlife managers focus on conserving sagebrush stands in designated pronghorn winter range.

Introduction

Pronghorn *(Antilocapra americana)* winter range in northern latitudes is typified by harsh environmental conditions resulting in increased thermoregulatory costs and overall energy expenditure (Schwartz et al., 1977; Byers, 1997). Pronghorn may compensate for depleting fat reserves and higher energetic demands relative to body size by spending up to 55% of their time foraging in winter (Wesley et al., 1970; Byers, 1997). Nevertheless, malnutrition and starvation are prevalent among wintering pronghorn populations where exposure to severe weather often results in high mortality rates (Martinka, 1967; Barrett, 1982; Pyrah, 1987; O'Gara, 2004a). Pronghorn may reduce chances of mortality by utilizing more rugged terrain (ridges, draws, and swales) during local weather events (Richardson, 2006) or areas with less snow during harsh winters (Barrett, 1982). In addition, availability and nutritional quality of forage may influence survival for pronghorn during winter months.

While pronghorn winter survival is often impacted by severe environmental conditions, anthropogenic factors such as vicinity to fences and roads may also impact pronghorn mortality risk on winter range. Besides resulting in direct mortalities due to collisions with vehicles and entanglement in fences (Harrington and Conover, 2006), fences and roads may also act as barriers, increase risk of predation (Whittington et al., 2011), and increase perceived risk of predation (Frid and Dill, 2002), potentially resulting in increased energy expenditure and increased risk of mortality. Fences and roads have been known to inhibit pronghorn from reaching areas utilized during harsh weather events (Oakley and Riddle, 1974; O'Gara, 2004b). In addition, pronghorn closer to roads may be exposed to higher rates of poaching and predation by coyotes *(Canis latrans)*, a common predator of pronghorn fawns (Brown and Conover, 2011) and adults (deVos and Miller, 2005; Jacques et al., 2007). Finally, pronghorn may perceive high levels

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of disturbance as predation risk resulting in tradeoffs between fitness behavior and avoidance of disturbance (Frid and Dill, 2002). On winter landscapes where additional energy expended could result in energy deficits, increasing exposure to high levels of traffic, predation, and movement barriers may result in negative consequences to pronghorn survival.

The addition of anthropogenic disturbances associated with the recent increase in the demand for renewable energy has raised concerns about potential impacts to wildlife (Erickson et al., 2001). Response to novel infrastructure and increased human activity may have short- and long-term impacts to wildlife populations. Elk *(Cervus elaphus)*, caribou *(Rangifer tarandus)*, and mule deer *(Odocoileus hemionus)* have been known to avoid oil and gas developments or high levels of disturbance associated with these developments (Dyer et al., 2001; Sawyer et al., 2009; Buchanan et al., 2014); however, studies evaluating the impacts of wind energy development to wild ungulates are limited (e.g., Walter et al., 2006; Dzialak et al., 2011; Taylor, 2014).

To understand potential impacts wind energy may have on wintering pronghorn populations, we evaluated mortality risk for pronghorn exposed to wind energy development on winter range over winters 2010, 2010–2011, and 2011–2012 within the Dunlap Ranch and surrounding areas in south-central, Wyoming, United States. Dunlap Ranch was developed for wind energy from September 2009 to September 2010. Regulated hunting of pronghorn in this region occurred in fall, before the winter period included in our analyses. Specific objectives of our study were to identify environmental and anthropogenic predictor variables influencing pronghorn mortality risk. By analyzing findings from other studies, we evaluated five predictions relative to pronghorn winter survival in our study. This set of predictions provided us a framework within which we developed individual and combined regression models that best explained winter mortality risk for pronghorn in our study area. First, given that pronghorn experience high energetic demands on winter range (Schwartz et al., 1977; O'Gara, 2004a) and incur high mortality associated with winter weather events (Martinka, 1967; Barrett, 1982; Pyrah, 1987), we predicted that mortality risk would increase with increasing exposure to cold temperatures and increasing snow depth. Second, because it has been observed that fences may prevent pronghorn from accessing areas vital to survival during severe winter weather (Oakley and Riddle, 1974), we predicted that mortality risk would increase with decreasing distance to fences or increasing density of fences. Third, because roads may increase exposure to predation and perceived predation risk (Frid and Dill, 2002; Gavin and Komers, 2006; Whittington et al., 2011), as well as increase access for poachers, we predicted that mortality risk would increase closer to roads. Fourth, woody browse, in particular sagebrush (*Artemisia* spp. L.), is the primary dietary component for pronghorn on winter range in northern climates (Bayless, 1969; Beale and Smith, 1970; Mitchell and Smoliak, 1971); thus, we predicted that pronghorn spending greater proportions of time in sagebrush-dominated habitats would decrease mortality risk. Finally, it has been reported that other ungulate species avoid infrastructure associated with energy development (Sawyer et al., 2009; Buchanan et al., 2014). With the potential of avoidance behavior resulting in increased energy expenditure, we thus predicted that mortality risk would increase with increasing exposure to wind energy development.

Study Area

We evaluated mortality risk for pronghorn in the vicinity of the Dunlap Ranch, 11.8 km north of Medicine Bow in Carbon County, Wyoming, United States. Our study focused on a 36.5-km^2 wind energy facility completed on the Dunlap Ranch sited within a larger area that included 1452.3 km^2 of rangeland (22.6% Bureau of Land Management, 7.6% state of Wyoming, and 69.7% private ownership) delineated by the Wyoming Game and Fish Department as crucial winter range for pronghorn. PacifiCorp owned and operated the Dunlap Ranch wind-powered generation facility. Dunlap Ranch included the construction of wind energy infrastructure on pronghorn crucial winter range from September 2009 to September 2010. Construction of the Dunlap I wind-powered generation facility included installation of 74 General Electric Company 1.5-MW sle[1] wind turbine generators (119 m tall), 28.3 km of access roads, 3 meteorological towers (79.9 m tall), an onsite 34.5/230-kV substation, and onsite maintenance buildings. Construction began in fall 2009 and concluded with the erection of wind turbines from April 2010 to September 2010 (PacifiCorp Energy, 2009). Although construction of turbines did not begin until April 2010, access roads and other wind energy facilities were completed and wind turbine assembly was ongoing within the Dunlap Ranch during winter 2010. Thus, winter 2010 represented the Dunlap Ranch during development or construction phase, whereas winter 2010–2011 and winter 2011–2012 represented the Dunlap Ranch during operation phases. Highway 487 extended north and south through the center of the Dunlap Ranch and pronghorn crucial winter range. We began studying pronghorn in winter 2010 before wind turbines were erected at Dunlap I. In addition to Dunlap I, three other nearby wind energy facilities consisting of 347 turbines were potentially accessible by pronghorn in Carbon and Albany Counties. The Seven Mile Hill wind energy facility maintained production of 79 (1.5 MW) wind turbines (66 in Seven Mile Hill I and 13 in Seven Mile Hill II), the High Plains and McFadden Ridge wind energy project maintained production of 85 (1.5 MW) wind turbines (66 in High Plains I and 19 in McFadden Ridge I), and the Foote Creek Rim wind energy project maintained production of 183 (600 kW) wind turbines (69 in Foot Creek I, 3 in Foot Creek II, 33 in Foot Creek III, 28 in Foot Creek IV, and 50 in Rock River I) throughout the study period from January 2010 to May 2012.

Dunlap Ranch is located in the southern portion of the broad, intermontane Shirley Basin, dominated by arid shrublands and grasslands. The Little Medicine Bow and Medicine Bow Rivers run just south of the Dunlap Ranch with Muddy Creek, a tributary of the Medicine Bow River, flowing within the eastern border of the wind energy facility (PacifiCorp Energy, 2009). The region is marked by flats, high hills, and low mountains with Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young) as a prevalent cover type. The Freezeout Mountains to the west support alderleaf mountain mahogany (*Cercocarpus montanus* Raf.), aspen (*Populus tremuloides* Michx.), and limber pine *(Pinus flexilus)*. Elevations within the Dunlap Ranch range from 2 000 to 2 530 m. We acquired climate data from the nearest High Plains Regional Climate Center weather station in Medicine Bow, Wyoming. Total winter (November–April) snow fall for 2009–2010 was 136.6 cm, for 2010–2011 was 212.6 cm, and for 2011–2012 was 90.7 cm. Average minimum and maximum temperatures for winter (November–April) 2009–2010 were −10.2°C and 3.2°C, for winter 2010–2011 were −8.8°C and 2.9°C, and for winter 2011–2012 were −9.7°C and 5.4°C (HPRCC, 2012).

Methods

Capture and Monitoring

We contracted with Leading Edge Aviation, LLC (Lewiston, ID) to capture 35 adult female pronghorn in the Dunlap Ranch using helicopter net gunning in early January 2010 and an additional 17 adult female pronghorn in December 2011. The deaths of two pronghorn in 2010 and two in 2011 were attributed to capture stress and were not included in survival modeling. We also were unable to recover one transmitter either due to collar failure or the individual moving out of the area; we thus estimated survival and mortality risk for 47 females. Protocols were approved by the University of Wyoming Institutional Animal Care and Use Committee (protocol 01012010) and Wyoming Game and Fish Department (Chapter 33-742 Permit) to capture, handle, mark, and monitor female pronghorn. Each captured animal was fitted with an Advanced Telemetry System (Isanti, Minnesota 55040) storeon-board Global Positioning System (GPS) neck collar (model G2110B) in or within the general vicinity of the Dunlap Ranch study area. Collars were programmed to fix locations every 7 hours from 16 November to 15 May and every 11 hours from 16 May to 15 November. Locations were collected from January 2010 to April 2012. Aerial relocation flights were conducted four times annually to record the survival status of study animals. We recovered collars transmitting a mortality signal to download locational data collected up to time of death. We assessed the cause of mortality for each dead pronghorn; however, the delayed recovery of collars made this assessment difficult in most cases. The remaining collars detached from the animals in late April 2012 and were recovered by late May 2012.

Survival Analysis

We estimated survival rates of collared pronghorn by month over each winter (2010, 2010–2011, and 2011–2012) utilizing the Kaplan-Meier product-limit estimator (Kaplan and Meier, 1958), modified for staggered entry (Pollock et al., 1989). We computed the variance for Kaplan-Meier survival estimates following Greenwood (1926) and used a log-rank test to compare survival rates between winters (Cox and Oakes, 1984:105).

Mortality Risk Covariates

We used the Andersen–Gill (A–G) formulation of Cox's (1972) proportional hazards regression to evaluate pronghorn survival across all winters (2010, 2010–2011, and 2011–2012) for Dunlap Ranch pronghorn. This method evaluates survival time as intervals of risk where each individual may be represented by multiple observations (Cox, 1972; Andersen and Gill, 1982). Winter locations were defined separately for each individual pronghorn based on timing of movement to and from winter range. For resident individuals, winter locations were defined by the time frame in which the majority of nonresident pronghorn elicited movement to and from winter range for a given year. Mortality risk modeling included pronghorn locations ranging from 8 January to 26 May 2010 for winter 2010, from 24 October 2010 to 15 April 2011 for winter 2010–2011, and from 1 November 2010 to 26 April 2012 for winter 2011–2012.

We predicted pronghorn mortality risk using time-independent and time-dependent covariates of survivorship within three variable classes: environmental, anthropogenic, and wind energy. Time-independent covariates included age of pronghorn, fences, land cover, major roads, minor roads, average movement rate of pronghorn, percent exposure to wind energy development, and terrain (Table 1). Time-dependent covariates included snow depth, temperature, and a winter severity index (Brinkman et al., 2005; see Table 1). To account for exposure to covariates between location fixes (every 7 hours from 16 November to 15 May and every 11 hours from 16 May to 15 November), we summarized predictor variables within set spatial scales using a moving window. Average movement for pronghorn between 7-hour locations was 980 m, and for 11-hour locations it was 1085 m. Thus, we summarized predictor variables within 980 m of locations collected every 7 hours and 1085 m of locations collected every 11 hours. We

Table 1
Predictor variables considered in modeling mortality risk using Cox proportional hazards regression for pronghorn exposed to wind energy development in south-central Wyoming, United States, 2010–2012

Variable class	Covariate	Description
Environmental		
Age	Age class	2 age categories: pronghorn ≤ 5.5 yr (0) and pronghorn > 5.5 yr (1)
Movement rate	MovRateAvr	Distance moved between sequential locations for individual pronghorn averaged over all winters (meters · hr)
Terrain	VRMAvr	Mean Vector Ruggedness Measure (vector ruggedness index [VRM]; Sappington et al., 2007) scaled to 1 000 (VRM × 1 000) calculates terrain ruggedness within a 3−cell size neighborhood
	SlopeAvr	Mean slope of the landscape derived from a 30-m DEM
Temperature	Temp	Number of observations from the beginning of each respective winter to time *t* where daily low temperatures were <−12°C (HPRCC, 2012)
	Temp_wk	Number of observations within week before time *t* where daily low temperatures were <−12°C (HPRCC, 2012)
	Temp_mnth	Number of observations within month before time *t* where daily low temperatures were <−12°C (HPRCC, 2012)
Snow depth	Snowd	Daily snow depth average, accumulation and standard deviation (suffix: avr, acc, sd) from the beginning of each respective winter to time *t* (NOHRS, 2004; 30-m cell size)
	Snowd_wk	Daily snow depth average, accumulation and standard deviation (suffix: avr, acc, sd) from the week before time *t* (NOHRS, 2004; 30-m cell size)
	Snowd_mnth	Daily snow depth average, accumulation and standard deviation (suffix: avr, acc, sd) from month before time *t* (NOHRS, 2004; 30-m cell size)
Winter Severity Index (WSI)	WSI	Accumulation of WSI points from beginning of respective winter to time *t*, where 1 point was given when daily low temperatures were <−12°C (HPRCC, 2012) and 1 additional point was given when daily snow depth was ≥ 35 cm for each day
	WSI_wk	Accumulation of WSI points within week before time *t*, where 1 point was given when daily low temperatures were <−12°C (HPRCC, 2012) and 1 additional point was given when daily snow depth was ≥ 35 cm for each day
	WSI_mnth	Accumulation of WSI points within month before time *t*, where 1 point was given when daily low temperatures were <−12°C (HPRCC, 2012) and 1 additional point was given when daily snow depth was ≥ 35 cm for each day
Land cover	SagePerc	Percent of total locations for individual pronghorn found within sagebrush, derived from classified land cover data (sagebrush or other; USGS GAP, 2011)
Anthropogenic		
Fences	FenceDenAvr	Density of fences (km · km^2), digitized using NAIP imagery (2009)
	FenceDistAvr	Mean Euclidean distance to nearest fence (km; digitized using NAIP imagery [2009])
Major roads	MajorRdAvr	Mean Euclidean distance to nearest major road (U.S. highways, state highways, and interstate highways) derived from a 30-m DEM
	MajorRd_Decay	Decay distance at 3000 m of mean Euclidean distance to nearest major road (U.S. and state highways and Interstate highways) derived from a 30-m DEM
Minor roads	MinorRdAvr	Mean Euclidean distance to nearest county road derived from a 30-m DEM
Wind energy		
Percent exposure	ExpAccrd_1km	Percent of total locations for individual pronghorn found within 1 km of access roads associated with wind energy infrastructure
	ExpFac_1km	Percent of total locations for individual pronghorn found within 1 km of facilities (employee and maintenance buildings and substations) associated with wind energy infrastructure
	ExpTurb_1km	Percent of total locations for individual pronghorn found within 1 km of wind turbines associated with wind energy infrastructure
	ExpAccrd_2km	Percent of total locations for individual pronghorn found within 2 km of access roads associated with wind energy infrastructure
	ExpFac_2km	Percent of total locations for individual pronghorn found within 2 km of facilities (employee and maintenance buildings and substations) associated with wind energy infrastructure
	ExpTurb_2km	Percent of total locations for individual pronghorn found within 2 km of wind turbines associated with wind energy infrastructure

used three temporal scales to account for variable durations of exposure to time-dependent covariates on pronghorn mortality risk. For each observation or 7- to 11-hour time step in the model (time $= t$), time-dependent covariates were summarized (average, standard deviation, and sum): 1) over the week prior to time $= t$, 2) over the month prior to time $= t$, and 3) from the beginning of each respective winter to time $=$ t. Time-independent spatial variables were first averaged within their respective moving window for each observation and then averaged across locations for each respective winter for each individual.

Pronghorn age class was assessed at the time of capture via tooth eruption and wear. We grouped pronghorn into two age classes: 1) young (≤5.5 years) and 2) old (≥5.5 years). Due to conflicting documentation on lifespans for pronghorn in different regions (Byers, 1997; O'Gara, 2004c), we tested several different classifications of age; however, we found the most predictive classification of age to be "old" ≥ 5.5 years and "young" ≤ 5.5 years.

We categorized land cover types as 1) sagebrush or 2) other (including agriculture, marshland, mixed grassland, riparian, salt desert shrub, and rocky soils). We used the USGS GAP Land Cover dataset to categorize land cover types for survival modeling (U.S. Geological Survey GAP, 2011) because sagebrush is the primary component of winter diets for many pronghorn populations in northern latitudes (e.g., Bayless, 1969; Beale and Smith, 1970; Mitchell and Smoliak, 1971). Due to the low composition of riparian and agricultural lands (0.02%) within our study area, we did not designate separate categories for these land cover types as previous studies evaluating pronghorn resource selection have done (Beckmann et al., 2012).

We developed spatial layers in ArcGIS 10.0 for distance to nearest major road (interstate highways, U.S. highways, and state highways), distance to nearest minor road (county roads), slope, and vector ruggedness measure (VRM; Sappington et al., 2007) using a 1-arc-second (30-m) National Elevation Dataset (NED; U.S. Geological Survey). VRM, known as terrain ruggedness, accounts for variation in slope and aspect to measure heterogeneity in landscape terrain (Sappington et al., 2007). We used 2009 National Agriculture Imagery Program (NAIP) imagery to digitize and develop a spatial layer for distance to nearest fence and density of fences.

To represent the impact of wind energy development on pronghorn, we quantified percent exposure to energy infrastructure components. Following similar methods outlined by Harju et al. (2011), we calculated the percent of total locations per individual within 1 km of wind turbines, access roads, and wind energy facility buildings (i.e., substations and employee and maintenance buildings; see Table 1). We also calculated the percent of exposure within a 2 km buffer to account for potential impacts to pronghorn beyond 1 km.

We acquired daily snow depth measurements from the Snow Data Assimilation System (SNODAS; NOHRS, 2004). SNODAS integrates satellite and airborne platforms and ground stations to model snow cover—associated data. We acquired daily temperature lows for Chugwater, Medicine Bow, Rawlins, and Shirley Basin, Wyoming weather stations to represent weather conditions that pronghorn in the Dunlap Ranch study area may have encountered (HPRCC, 2012) and paired each individual's locations with the daily low temperature for the nearest weather station. We only considered temperatures at or below pronghorn lower critical temperatures identified as –12°C by Wesley et al. (1973) and assigned them a value of 1. We also calculated a winter severity index (WSI) value using a combination of snow depth and temperature. Each day was given a value of 1 if the snow depth was ≥ 35 cm or the temperature was ≤ –12°C. A value of 2 was given to days where both simultaneously occurred (Brinkman et al., 2005).

Mortality Risk Modeling

We examined mortality risk at hourly intervals for pronghorn on winter range in the Dunlap Ranch study area (winter 2010, 2010–2011, 2011–2012) as a function of covariates of survivorship. We utilized intervals of risk, rather than a single value for survival time, to accommodate discontinuous intervals of risk (Guo et al., 2008). Because we focused on winter locations specifically, time spent on summer 2010 and 2011 ranges was represented as discontinuous intervals of risk in the model, meaning summer locations were not used to predict mortality risk. In addition to accommodating discontinuous intervals of risk, the A-G model allows for left, right, and interval censoring (Andersen and Gill, 1982; Johnson et al., 2004). Pronghorn that survived the duration of the study period were right censored and pronghorn that died while on summer ranges were interval censored (Allison, 2010:103). We used staggered entry for left-truncated data (Allison, 2010:183) to accommodate pronghorn not introduced into the study until December 2011. Several locations were recorded daily for each pronghorn; thus, we evaluated survival on an hourly time scale to retain all locational data for use in the model. We conducted statistical modeling using the packages AICcmodavg, Dynpred, Regression Modeling Strategies (RMS), and Survival in Program R version 2.12.2 (Putter, 2011; R Core Team, 2012; Therneau, 2012; Harrell, 2013; Mazerolle, 2013).

We tested covariates of survivorship for correlation ($r > |0.6|$) and did not allow correlated covariates to be included in any same model. In addition, multiple scales of the same time-dependent covariates were not considered in the same model to avoid biased model estimates. We calculated the variance inflation factor for coefficients in all top models, which measures variance inflation caused by collinearity between variables. Variance inflation factor values ≤ 5 indicate that variance of coefficients is not inflated as a result of collinearity between variables in the model (Heiberger and Holland, 2004). Individual variables were considered uninformative and not included in model building if their respective 85% confidence intervals for hazard ratios overlapped 1 (Arnold, 2010). We tested all model combinations within each variable class. We identified the most supported model for each of the three variable classes using Akaike's Information Criterion (AIC; Burnham and Anderson, 1998, 2004). We calculated differences in AIC from the top model (ΔAIC). The model with the lowest AIC score was identified as being the most supported model; however, models within 4 AIC points of the most supported model were considered competitive models (Arnold, 2010). All competitive models within variable classes were considered top models and allowed to compete against top models for each of the other categories (Carpenter et al., 2010; Smith et al., 2014) to determine the overall most supported model for pronghorn survival at the Dunlap Ranch. Because our final top models were competitive ($\Delta AIC < 4$), we model averaged across the 90% confidence sets to estimate coefficients and standard errors for variables occurring in all competitive model subsets (Burnham and Anderson, 2002). We used the *c* (concordance) index to assess discrimination for all models within the 90% subset. The *c* index is capable of evaluating the predictive ability of survival models using time-dependent covariates and censored data (Harrell et al., 1996; Pencina and D'Agostino, 2004). A *c* value equal to 0.5 indicates no concordance between observed and predictive responses, *c* values equal to 1.0 indicate perfect concordance between observed and predictive responses (Harrell et al., 1996), and models with *c* values ≥ 0.8 are considered to have good predictive discrimination for the modeled data (Pencina and D'Agostino, 2004). We calculated relative importance for each variable within the 90% subset by summing the Akaike weights of the models in which each respective variable occurred.

Cox's proportional hazard regression assumes that hazard ratios are proportional over time (Cox, 1972); further, the effect of each covariate in the model should be the same throughout time (Allison, 2010:172). The proportional hazards assumption is satisfied when Schoenfeld residuals for a given covariate are not correlated with time (Schoenfeld, 1982). Schoenfeld residuals have a separate residual for each covariate and each individual that experiences an event (Allison, 2010:175). To test the proportional hazards assumption, we calculated Schoenfeld residuals for each covariate in the top model and plotted them against

Table 2
Model fit statistics for environmental, anthropogenic, and wind energy variable classes used to evaluate pronghorn winter mortality risk at the Dunlap Ranch, south-central Wyoming, United States, 2010–2012. Number of parameters in each model (*K*), log likelihood (LL), Akaike's Information Criteria (AIC), difference in AIC from the top model (ΔAIC), and Akaike's weights (w_i) are also reported. Refer to Table 1 for variable descriptions

Variable class model	K	LL	AIC	ΔAIC	w_i	Rank
Environmental (16 candidate models)						
SagePerc + SnowdSD_mnth + VRMAvr	3	−36.09	78.176	0.000	0.502	1
SagePerc + SnowdSD_mnth + Temp_mnth + VRMAvr	4	−35.98	79.954	1.778	0.206	2
SagePerc + Temp_mnth + VRMAvr	3	−37.58	81.159	2.982	0.113	3
SnowdSD_mnth + VRMAvr	2	−39.44	82.888	4.712	0.048	4
SagePerc + SnowdSD_mnth	2	−39.99	83.983	5.807	0.028	5
SagePerc + VRMAvr	2	−40.03	84.069	5.893	0.026	6
SnowdSD_mnth + Temp_mnth + VRMAvr	3	−39.19	84.377	6.200	0.023	7
SagePerc + SnowdSD_mnth + Temp_mnth	3	−39.41	84.814	6.638	0.018	8
Null	0	−61.68	123.354	45.178	0.000	16
Anthropogenic (3 candidate models)						
MajorRdAvr	1	−44.04	90.078	0	0.641	1
MajorRd_Decay3000	1	−44.62	91.236	1.158	0.359	2
Null	0	−61.68	123.354	33.276	0.000	3
Wind Energy (5 candidate models)						
ExpAccrd_1km	1	−47.29	96.572	0	0.281	1
ExpTurb_1km	1	−47.35	96.704	0.131	0.263	2
ExpTurb_2km	1	−47.05	96.941	0.369	0.234	3
ExpAccrd_2km	1	−47.53	97.054	0.482	0.221	4
Null	0	−61.68	123.354	26.782	0.000	5

survival time (Hess, 1995). We inspected residuals for uniform distribution and tested the fitted line for a nonzero slope (Johnson et al., 2004). All covariates examined within our model met the proportional hazards assumption.

Results

Survival

During our study (January 2010 to April 2012), 17 of 47 (36.2%) adult female pronghorn died. One female pronghorn died during winter 2010, 13 during winter 2010–2011, and 3 during winter 2011–2012. Causes of winter mortalities were unknown in all cases. We left censored two females with collars that detached early due to low battery. Survival ($\hat{S}$) in the Dunlap Ranch study area in winter 2010 was 0.97 (90% CI: 0.92–1.00), winter 2010–2011 was 0.53 (90% CI: 0.37–0.70), and winter 2011–2012 was 0.91 (90% CI: 0.82–1.00). Survival in the Dunlap Ranch was lower during winter 2010–2011 than winters 2010 ($X_1^2 = 14.46, P < 0.001$) and 2011–2012 ($X_1^2 = 5.37, P = 0.021$), whereas survival did not differ between winters 2010 and 2011–2012 ($X_1^2 = 0.81, P = 0.368$).

Mortality Risk

We evaluated mortality risk for 47 adult female pronghorn using 26 765 observations and 17 mortality events. Observations were acquired over 3 winters with 10 461 observations in winter 2010 ($n = 32$ females, mean locations per animal = 334, range: 92–466), 7 705 observations in winter 2010–2011 ($n = 27$ females, mean locations per animal = 293, range: 31–485), and 8 599 observations in winter 2011–2012 ($n = 23$ females, mean locations per animal = 381, range: 32–577). There were three top models for the environmental variable class, 2 for the anthropogenic class and 4 for the wind energy class (Table 2); however, we only considered a single best model for the anthropogenic and wind energy class due to variables across competing univariate models being highly correlated ($r = 0.71–0.99$) and their effect in combination with variables in other classes being similar. Thus, we selected the anthropogenic and wind energy model with the lowest AIC value to compete with the top models in the environmental class.

There were eight competitive models (ΔAIC ≤ 3.829) for pronghorn winter mortality risk (Table 3). Relative importance was highest for percent time spent in sagebrush (1.00) and terrain ruggedness (1.00) and lowest for locations within 1 km of wind facility access roads (0.37). In addition, relative importance was similar for number of

Table 3
Model fit statistics for subsets or combinations of environmental, anthropogenic, and wind energy variable classes predictive of pronghorn winter mortality risk in the Dunlap Ranch wind energy study area, south-central Wyoming, United States, 2010–2012. Predictor variables forming each variable class model appear in parentheses. Number of parameters in each model (*K*), log likelihood (LL), Akaike's Information Criterion (AIC), difference in AIC from the top model (ΔAIC), and Akaike's weights (w_i) are also reported. Refer to Table 1 for variable descriptions

Class model (predictor variables)	K	LL	AIC	ΔAIC	w_i
Anthropogenic + Environmental 3	4	−34.06	76.124	0.000	0.198
Anthropogenic + Environmental 2	5	−33.22	76.439	0.315	0.169
Anthropogenic + Environmental 1	4	−34.36	76.717	0.593	0.147
Anthropogenic + Environmental 3 + Wind	5	−33.72	77.432	1.308	0.103
Anthropogenic + Environmental 1 + Wind	5	−33.79	77.584	1.460	0.095
Anthropogenic + Environmental 2 + Wind	6	−32.98	77.956	1.832	0.079
Environmental 1 (SagePerc + SnowdSD_mnth + VRMAvr)	3	−36.09	78.176	2.052	0.071
Environmental 1 + Wind	4	−35.32	78.648	2.523	0.056
Environmental 2 (SagePerc + SnowdSD_mnth + Temp_mnth + VRMAvr)	4	−35.98	79.954	3.829	0.029
Environmental 2 + Wind	5	−35.29	80.576	4.451	0.021
Environmental 3 (SagePerc + Temp_mnth + VRMAvr)	3	−37.58	81.159	5.034	0.016
Environmental 3 + Wind	4	−36.60	81.192	5.067	0.016
Anthropogenic (MajorRdAvr)	1	−44.04	90.078	13.953	0.000
Anthropogenic + Wind	2	−43.53	91.054	14.930	0.000
Wind (ExpAccrd_1km)	1	−47.29	96.572	20.448	0.000
Null	0	−61.68	123.354	47.229	0.000

Table 4
Model-averaged parameter estimates for the 90% model subset predictive of pronghorn winter mortality risk in the Dunlap Ranch wind energy study area, south-central Wyoming, United States, 2010–2012

Variable	Coefficient	SE	Hazard ratio	Hazard ratio 90% CI	
			[*exp*(coefficient)]	Lower	Upper
SagePerc	−0.04	0.01	0.96	0.95	0.99
SnowdSD_mnth[a]	−0.20	0.17	0.81	0.62	1.08
Temp_mnth[a]	−0.04	0.03	0.96	0.91	1.01
VRMAvr	−2.53	1.30	0.08	0.01	0.68
MajorRdAvr	−0.22	0.12	0.80	0.66	0.98
ExpAccrd_1km[a]	0.02	0.02	1.02	0.99	1.05

[a] Uninformative predictor variable.

days ≤ –12°C within prior month (0.63), variation in snow depth within prior month (0.67), and average distance to major roads (0.79). Model fit for environmental, anthropogenic, and environmental + anthropogenic models did not improve with the addition of wind energy (see Table 3); rather, AIC values increased 0.033–1.517 with the addition of wind energy to these models (see Table 3). Model-averaged parameter estimates from 90% confidence sets indicated predictor variables for variation in snow depth within prior month (SnowdSD_mnth), number of days ≤ –12°C within prior month (Temp_mnth), and percent of locations within 1 km of wind energy facility access roads (ExpAccrd_1km) were uninformative (90% CI's for hazard ratios overlapped 1; Table 4). For model-averaged 90% model subsets, the hazard ratio for average distance to nearest major road was 0.80 (SE = 0.12, 90% CI: 0.66–0.98), for time spent in sagebrush was 0.96 (SE = 0.01, 90% CI: 0.95–0.98), and for terrain ruggedness (VRM × 1000) was 0.08 (SE = 1.30, 90% CI: 0.01–0.68). Pronghorn winter mortality risk decreased by 20.0% with every 1-km increase in distance from nearest major road. In addition, mortality risk for pronghorn on winter range decreased by 4.0% with every 1% increase in average time spent in sagebrush and decreased by 92.0% with every 1 unit (VRM × 1000) increase in terrain ruggedness (see Table 4, Fig. 1). All variance inflation factor values for coefficients within the eight competitive models were ≤ 5, indicating variance of coefficients did not increase as a result of collinearity between variables in the model (Heiberger and Holland, 2004). In addition, all *c* index values for the eight competitive models were ≥ 0.8, indicating our models had good concordance between observed and predictive survival of pronghorn on winter range (Pencina and D'Agostino, 2004).

Discussion

We examined mortality risk for pronghorn on a winter landscape that included wind energy development in south-central Wyoming. Because previous studies have attributed increased risk of mortality in other ungulate species to proximity to industrial development (Dzialak et al., 2011), construction of wind facilities on pronghorn crucial winter range is a relevant and major concern. Pronghorn on winter range already experience high energy demands and increased mortality rates (Barrett, 1982; Pyrah, 1987; Byers, 1997; O'Gara, 2004a); thus, the introduction of novel developments to these landscapes could lead to increased stress and avoidance behavior by pronghorn, potentially resulting in further energy losses and increased mortality risk. Assessing the impacts of wind energy development to pronghorn survival is particularly critical given the recent growth of the industry and the potential for these sites to coincide with suitable wintering habitats. We identified time spent in sagebrush habitats, average distance to major road, and terrain ruggedness as influential predictors for pronghorn winter mortality risk. Contrary to our predictions, exposure to wind energy infrastructure was not an informative predictor of pronghorn mortality risk on winter range in the Dunlap Ranch study area.

Little is known about the impacts of wind energy development on ungulate populations (Walter et al., 2006; Webb et al., 2013). If pronghorn avoided wind energy infrastructure at Dunlap Ranch as has been documented by other ungulate species in oil and gas fields (Sawyer et al., 2009; Buchanan et al., 2014), increased mortality risk may have

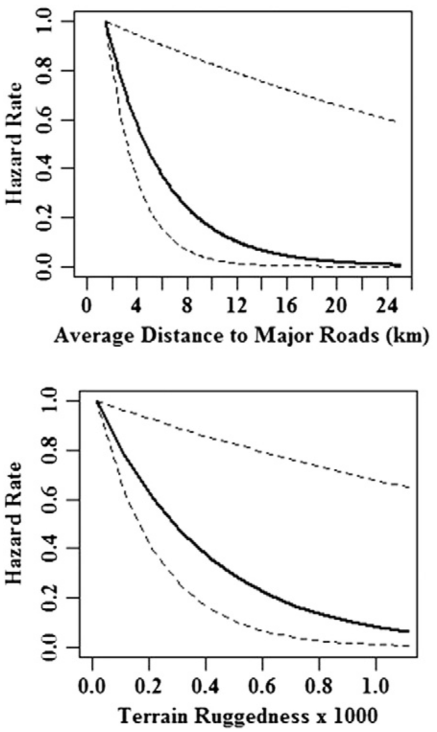

Figure 1. Hazard rates for the most supported model (average distance to major roads, percent of locations within sagebrush, and terrain ruggedness) predictive of adult female pronghorn survival in the Dunlap Ranch, south-central, Wyoming, United States. Hazard rates were plotted with 90% confidence intervals. Terrain ruggedness (Vector Ruggedness Measure) was rescaled by 1 000 to adjust for small units.

resulted for individuals with increased exposure to wind energy; however, we did not detect an influence of wind energy on pronghorn mortality risk. Model fit for anthropogenic and environmental models decreased with the addition of the wind energy variable class. Furthermore, wind energy had the lowest relative importance of all predictor variables within the top eight competitive models and was an uninformative predictor of pronghorn mortality risk (90% CI for hazard ratio overlapped 1; see Table 4). Thus, exposure to wind energy was not useful for predicting pronghorn mortality risk on winter range in our study area. This result may suggest adult pronghorn tolerance to wind development; however, other factors may have influenced the vulnerability of pronghorn to wind energy infrastructure.

Key differences between wind energy and oil and gas infrastructure may provide insights into why exposure to wind energy did not influence mortality risk in our study. Generally, density of wind turbines within wind facilities (2.03 turbines · km^2 at Dunlap Ranch) may be greater than well pads within oil and gas fields (Pinedale Anticline Project Area [PAPA] may allow up to 0.75 well pads · km^2; BLM, 2008); however, wind energy project areas are generally much smaller than oil and gas fields (e.g., the PAPA is 22× larger than the Dunlap Ranch wind energy facility). Pronghorn may more readily avoid wind-energy disturbed areas by using habitats beyond development perimeters, but large expanses of diffused oil and gas infrastructure could result in more individuals being relegated to negotiate terrain within these fields. A recently approved wind energy project in Carbon County, Wyoming plans to encompass up to 1 000 wind turbines within 889.1 km^2 (1.1 turbines · km$^{2\ -1}$; BLM, 2012). Although our study did not indicate that wind energy development negatively impacted mortality risk of adult female pronghorn on winter range, it is possible that larger-scale wind energy development could negatively affect pronghorn mortality risk. In addition, the length of our study period may have played a key role in determining the outcome of our study. For example, lag effects extending beyond the 3-year duration of our study may have prevented us from detecting an influence of wind energy exposure on pronghorn to survival.

Although previous studies have documented avoidance of fences by pronghorn and high mortality rates for animals using habitat closer to fences during harsh weather events (Oakley and Riddle, 1974; deVos and Miller, 2005; Sheldon, 2006), we found no evidence for distance to fences or density of fences being influential predictors for pronghorn mortality risk in our study. Distance to major roads, however, was an important anthropogenic and overall predictor variable for pronghorn mortality risk. Pronghorn mortality risk was elevated for individuals closer to major roads. Although we did not determine that any mortalities of collared pronghorn were due to collisions with vehicles, risk of mortality may have been elevated closer to major roads as a result of greater exposure to predators (Yoakum, 1957; Jacques et al., 2007; Brown and Conover, 2011) or pronghorn perceiving high levels of disturbance around highways as a predation risk (Frid and Dill, 2002). Perceived risk may result in tradeoffs being made between behavior leading to higher fitness and avoidance of disturbance. For example, Gavin and Komers (2006) observed pronghorn increasing vigilance and decreasing feeding time when exposed to roads with high traffic levels. If pronghorn on the Dunlap Ranch selecting habitats closer to major roads elicited these same behaviors, reduced foraging time and increased vigilance could have resulted in increased energy expenditure and increased mortality risk.

In addition to major roads, we note the importance of sagebrush in reducing pronghorn mortality risk. Lower mortality risk observed in individuals that spent more time within sagebrush substantiates previous studies identifying sagebrush as a primary component in pronghorn winter diets (Bayless, 1969; Beale and Smith, 1970; Mitchell and Smoliak, 1971) and by resource selection analyses documenting ungulate species' selection for sagebrush and shrub cover (Beckmann et al., 2012; Webb et al., 2013). A decrease in mortality risk for pronghorn spending more time within sagebrush not only signifies the prevalence of consumption of this shrub by pronghorn, but more importantly denotes its intrinsic value for survival. Further, assuming more rugged terrain encompassed steeper slopes, our findings corroborate previous studies identifying higher survival rates for migrant pronghorn in areas with steeper slopes (Barnowe-Meyer et al., 2010) and observations that pronghorn may utilize ridges, draws, and swales to avoid exposure to harsh weather events (Richardson, 2006), thus potentially reducing mortality risk.

Lower survival rates during winter 2010–2011 on the Dunlap Ranch likely resulted from harsh weather conditions. Total snowfall for Medicine Bow, Wyoming from December to February was 1.4–1.9× (30.2–53.1 cm) greater during winter 2010–2011 (114.6 cm) than winters 2010 (61.5 cm) and 2011–2012 (84.4 cm; HPRCC, 2012). Similarly, previous studies have identified lower survival rates for pronghorn during winters with increased snow accumulation (Barrett, 1982; Pyrah, 1987). In contrast, more recent studies documented high survival rates during winter months and attributed the leading cause of annual mortality to hunter kills; however, low snow accumulation and mild winter weather documented during these study periods may have resulted in high survival for these populations (Jacques et al., 2007; Kolar et al., 2012). Over the course of our study we documented two hunter kills and no unknown mortalities during hunting seasons. Although variables associated with winter severity (temperature or snow depth) were not supported in our mortality risk models, the timing of deaths (11 of 17 pronghorn that died did so in January–March 2011) suggests that winter severity, rather than hunting, was the primary factor limiting pronghorn survival in our study.

Although high mortality rates observed during winters with increased snow depth, documented here and in previous studies (Barrett, 1982; Pyrah, 1987), may suggest climate conditions influence survival, pronghorn mortality risk was not influenced by climate variables included within our study. Also, time scales other than weekly, monthly, and from the beginning of each winter that we examined may better represent the effect of snow depth and temperature on pronghorn mortality risk. Due to large variations in climatic conditions across years and seasons, examining survival separately by winter may offer more insights into the effects of weather conditions on pronghorn mortality; however, in the case of our study, limited mortality events during winters 2010 ($n = 1$) and 2011–2012 ($n = 3$) would have prevented us from adequately evaluating pronghorn mortality risk for these winters.

Implications

Our results suggest wind energy development did not influence pronghorn winter mortality; rather, pronghorn mortality on winter range was largely influenced by environmental (average time spent in sagebrush habitat and terrain ruggedness) and nonwind energy anthropogenic (distance to major roads) variables. We recommend managers focus on conservation strategies for environmental factors found to influence pronghorn mortality risk. Mitigating the effects of major roads for pronghorn survival may be difficult; however, maintaining large, continuous sagebrush stands in areas of development may be a more realistic management strategy. We suggest wildlife managers prioritize sagebrush conservation on pronghorn winter range, especially in areas being developed for energy resources. In addition, we suggest management strategies be implemented for maintaining connectivity between seasonal ranges and crucial wintering areas utilized during harsh weather events.

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References

[BLM] Bureau of Land Management, 2008. Record of decision. Final supplemental environmental impact statement for the Pinedale Anticline Oil and Gas Exploration and Development Project. Pinedale Field Office, Pinedale, WY, USA.

[BLM] Bureau of Land Management, 2012. Record of decision. Final Environmental Impact Statement for the Chokecherry and Sierra Madre Wind Energy Project. Rawlins Field Office, Rawlins, WY, USA.

[HPRCC] High Plains Regional Climate Center, 2012. High Plains Regional Climate CenterAvailable at: http://hprcc6.unl.edu/cgi-hpcc/home.cgi (Accessed 11 December 2012).

[NOHRS] National Operational Hydrologic Remote Sensing Center [digital media], 2004. Snow Data Assimilation System (SNODAS) Data Products at NSIDC [Jan 2010—May 2012]. National Snow and Ice Data Center, Boulder, CO, USA.

Allison, P.D., 2010. Survival analysis using SAS: a practical guide. 2nd ed. SAS Institute Inc., Cary, NC, USA.

Andersen, P.K., Gill, R.D., 1982. Cox regression model for counting processes: a large sample study. *The Annals of Statistics* 10, 1100–1120.

Arnold, T.W., 2010. Uninformative parameters and model selection using Akaike's information criterion. *Journal of Wildlife Management* 74, 1175–1178.

Barnowe-Meyer, K.K., White, P.J., Davis, T.L., Smith, D.W., Crabtree, R.L., Byers, J.A., 2010. Influences of wolves and high-elevation dispersion on reproductive success of pronghorn *(Antilocapra americana)*. *Journal of Mammalogy* 91, 712–721.

Barrett, M.W., 1982. Distribution, behavior and mortality of pronghorns during a severe winter in Alberta. *Journal of Wildlife Management* 46, 991–1002.

Bayless, S.R., 1969. Winter food habits, range use and home range of antelope in Montana. *Journal of Wildlife Management* 33, 538–551.

Beale, D.M., Smith, A.D., 1970. Forage use, water consumption, and productivity of pronghorn antelope in western Utah. *Journal of Wildlife Management* 34, 570–582.

Beckmann, J.P., Murray, K., Seidler, R.G., Berger, J., 2012. Human-mediated shifts in animal habitat use: sequential changes in pronghorn use of a natural gas field in Greater Yellowstone. *Biological Conservation* 147, 222–233.

Brinkman, T.J., Deperno, C.S., Jenks, J.A., Haroldson, B.S., Osborn, R.G., 2005. Movement of female white-tailed deer: effects of climate and intensive row–crop agriculture. *Journal of Wildlife Management* 69, 1099–1111.

Brown, D.E., Conover, M.R., 2011. Effects of large-scale removal of coyotes on pronghorn and mule deer productivity and abundance. *Journal of Wildlife Management* 75, 876–882.

Buchanan, C.B., Beck, J.L., Bills, T.E., Miller, S.N., 2014. Seasonal resource selection and distributional response by elk to development of a natural gas field. *Rangeland Ecology & Management* 67, 369–379.

Burnham, K.P., Anderson, D.R., 1998. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York, NY, USA.

Burnham, K.P., Anderson, D.R., 2002. Model selection and inference: a practical information-theoretic approach. 2nd ed. Springer-Verlag, New York, NY, USA.

Burnham, K.P., Anderson, D.R., 2004. Multimodel inference: understanding AIC and BIC in model selection. *Sociological Methods and Research* 33, 261–304.

Byers, J.A., 1997. American pronghorn: social adaptations and the ghost of predators past. University of Chicago Press, Chicago, IL, USA.

Carpenter, J., Aldridge, C., Boyce, M.S., 2010. Sage-grouse habitat selection during winter in Alberta. Journal of Wildlife Management 70, 1806–1814.

Cox, D.R., 1972. Regression models and life tables. *Journal of the Royal Statistical Society, Series B* 34, 187–220.

Cox, D.R., Oakes, D., 1984. Analysis of survival data. Chapman and Hall, New York, NY, USA.

deVos Jr., J.C., Miller, W.H., 2005. Habitat use and survival of Sonoran pronghorn in years with above-average rainfall. *Wildlife Society Bulletin* 33, 35–42.

Dyer, S.J., O'Neill, J.P., Wasel, S.M., Boutin, S., 2001. Avoidance of industrial development by woodland caribou. *Journal of Wildlife Management* 65, 531–542.

Dzialak, M.R., Webb, S.L., Harju, S.M., Winstead, J.B., Wondzell, J., Mudd, J.P., Hayden-Wing, L.D., 2011. The spatial pattern of demographic performance as a component of sustainable landscape management and planning. *Landscape Ecology* 26, 775–790.

Erickson, W.P., Johnson, G.D., Strickland, M.D., Young Jr., D.P., Sernka, K.J., Good, R.E., 2001. Avian collisions with wind turbines: a summary of existing studies and comparisons to other sources of bird collision mortality in the United States. National Wind Coordinating Committee (NWCC) Publication and Resource Document. Prepared for the NWCC by WEST, Inc., Cheyenne, WY, USA.

Frid, A., Dill, L.M., 2002. Human-caused disturbance stimuli as a form of predation risk. *Conservation Ecology* 6, 11.

Gavin, S.D., Komers, P.E., 2006. Do pronghorn *(Antilocapra americana)* perceive roads as a predation risk? *Canadian Journal of Zoology* 84, 1775–1780.

Greenwood, M., 1926. The natural duration of cancer. Reports on public health and medical subjects 33. His Majesty's Stationery Office, London, United Kingdom, pp. 1–26.

Guo, Z., Gill, T.M., Allore, H.G., 2008. Modeling repeated time-to-event health conditions with discontinuous risk intervals: an example of a longitudinal study of functional disability among older persons. *Methods of Information in Medicine* 47, 107–116.

Harju, S.M., Dzialak, M.R., Osborn, R.G., Hayden-Wing, L.D., Winstead, J.B., 2011. Conservation planning using resource selection models: altered selection in the presence of human activity changes spatial prediction of resource use. *Animal Conservation* 14, 502–511.

Harrell Jr., F.E., 2013. RMS: Regression Modeling Strategies [software program]. R Package Version 3.6-3.

Harrell Jr., F.E., Lee, K.L., Mark, D.B., 1996. Tutorial in biostatistics multivariable prognostic models: issues in developing models, evaluating assumptions and adequacy, and measuring and reducing errors. *Statistics in Medicine* 15, 361–387.

Harrington, J.L., Conover, M.R., 2006. Characteristics of ungulate behavior and mortality associated with wire fences. *Wildlife Society Bulletin* 34, 1295–1305.

Heiberger, R.M., Holland, B., 2004. Statistical analysis and data display: an intermediate course with examples in S-Plus, R, and SAS. Springer texts in statistics. Springer, New York, NY, USA.

Hess, K.R., 1995. Graphic methods for assessing violations of the proportional hazards assumption in Cox regression. *Statistics in Medicine* 14, 1707–1723.

Jacques, C.N., Jenks, J.A., Sievers, J.D., Roddy, D.E., Lindzey, F.G., 2007. Survival of pronghorns in western South Dakota. *Journal of Wildlife Management* 71, 737–743.

Johnson, C.J., Boyce, M.S., Schwartz, C.C., Haroldson, M.A., 2004. Modeling survival: application of the Anderson-Gill model to Yellowstone grizzly bears. *Journal of Wildlife Management* 68, 966–978.

Kaplan, E.L., Meier, P., 1958. Nonparametric estimation from incomplete observations. *Journal of the American Statistical Association* 53, 457–481.

Kolar, J.L., Millspaugh, J.J., Mong, T.W., 2012. Survival and cause-specific mortality of pronghorn in southwest North Dakota. *American Midland Naturalist* 167, 164–173.

Martinka, C., 1967. Mortality of northern Montana pronghorn in a severe winter. *Journal of Wildlife Management* 31, 159–164.

Mazerolle, M.J., 2013. AICcmodavg: model selection and multimodel inference based on (Q) AIC(c) [software program]. R Package Version 1.32.

Mitchell, G.J., Smoliak, S., 1971. Pronghorn antelope range characteristics and food habits in Alberta. *Journal of Wildlife Management* 35, 238–250.

O'Gara, B.W., 2004a. Mortality factors. In: O'Gara, B.W., Yoakum, J.D. (Eds.), Pronghorn: ecology and management. University Press of Colorado, Boulder, CO, USA, pp. 379–408.

O'Gara, B.W., 2004b. Behavior. In: O'Gara, B.W., Yoakum, J.D. (Eds.), Pronghorn: ecology and management. University Press of Colorado, Boulder, CO, USA, pp. 145–194.

O'Gara, B.W., 2004c. Physical characteristics. In: O'Gara, B.W., Yoakum, J.D. (Eds.), Pronghorn: ecology and management. University Press of Colorado, Boulder, CO, USA, pp. 110–143.

Oakley, C., Riddle, P., 1974. The impact of a severe winter and fences on antelope mortality in southcentral Wyoming. *Proceedings of the Antelope States Workshop* 6, 155–173.

PacifiCorp Energy, 2009. Wyoming industrial development information and siting act: section 109 permit application, Dunlap Wind Energy Project. Prepared by CH2M Hill, Englewood, CO, USA.

Pencina, M.J., D'Agostino, R.B., 2004. Overall C as a measure of discrimination in survival analysis: model specific population value and confidence interval estimation. *Statistics in Medicine* 23, 2109–2123.

Pollock, K.H., Winterstein, S.R., Bunck, C.M., Curtis, P.D., 1989. Survival analysis in telemetry studies: the staggered entry design. *Journal of Wildlife Management* 53, 7–15.

Putter, H., 2011. Dynpred: companion package to "Dynamic prediction in clinical survival analysis" [software program]. R Package Version 0.1.1.

Pyrah, D.B., 1987. American pronghorn antelope in the Yellow Water Triangle, Montana. Montana Division of Fish, Wildlife and Parks, Helena, MT, USA.

R Core Team, 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Richardson, C., 2006. Pronghorn habitat requirements. Proceedings: pronghorn symposium 2006. Texas A & M University Agricultural Research and Extension Center, Alpine, TX, USA, pp. 5–12.

Sappington, J.M., Longshore, K.M., Thomson, D.B., 2007. Quantifying landscape ruggedness for animal habitat analysis: a case study using bighorn sheep in the Mojave Desert. *Journal of Wildlife Management* 71, 1419–1426.

Sawyer, H., Kauffman, M.J., Nielson, R.M., 2009. Influence of well pad activity on winter habitat selection patterns of mule deer. *Journal of Wildlife Management* 73, 1052–1061.

Schoenfeld, D., 1982. Residuals for the proportional hazards regression model. *Biometrika* 69, 239–241.

Schwartz, C.C., Nagy, J.G., Rice, R.W., 1977. Pronghorn dietary quality related to forage availability and other ruminants in Colorado. *Journal of Wildlife Management* 41, 161–168.

Sheldon, D., 2006. Movement and distribution patterns of pronghorn in relation to roads and fences in Wyoming. Proceedings of the 22nd Biennial Pronghorn Workshop. Department of Fish and Game, Idaho Falls, ID, USA, p. 187.

Smith, K.T., Kirol, C.P., Beck, J.L., Blomquist, F.C., 2014. Prioritizing winter habitat quality for greater sage-grouse in a landscape influenced by energy development. *Ecosphere* 5, 15.

Taylor, K.L., 2014. Pronghorn *(Antilocapra americana)* response to wind energy development on winter range in south-central, Wyoming [M. S. thesis] University of Wyoming, Laramie, WY, USA.

Therneau, T., 2012. A package for survival analysis in S. Package version 2.36-14.

US Geological Survey, Gap Analysis Program (GAP), 2011. National land cover. Version 2. USGS Headquarters, USGS National Center, Moscow, ID, USA.

Walter, W.D., Leslie Jr., D.M., Jenks, J.A., 2006. Response of Rocky Mountain elk (*Cervus elaphus*) to wind-power development. *American Midland Naturalist* 156, 363–375.

Webb, S.L., Dzialak, M.R., Kosciuch, K.L., Winstead, J.B., 2013. Winter resource selection by mule deer on the Wyoming-Colorado border prior to wind energy development. *Rangeland Ecology & Management* 66, 419–427.

Wesley, D.E., Knox, K.L., Nagy, J.G., 1970. Flux and water kinetics in young pronghorn antelope. *Journal of Wildlife Management* 34, 908–912.

Wesley, D.E., Knox, K.L., Nagy, J.G., 1973. Metabolism of pronghorn antelopes. *Journal of Wildlife Management* 37, 563–573.

Whittington, J., DeCesare, N.J., Neufeld, L., Bradley, M., Wilmshurst, J., Musiani, M., 2011. Caribou encounters with wolves increase near roads and trails: a time-to-event approach. *Journal of Applied Ecology* 48, 1535–1542.

Yoakum, J.D., 1957. Factors affecting the mortality of pronghorn antelope in Oregon [M.S. thesis] Oregon State College, Corvallis, OR, USA.