Supplementary Material 1.

Cain III, J.W., J.H. Kay, S.G. Liley, and J.V. Gedir. Mule deer (*Odocoileus hemionus*) resource selection: trade-offs between forage and predation risk

Spatially-explicit models of horizontal visibility, edible forage biomass, digestible energy and digestible protein for mule deer forage

We stratified the study area by aspect (north [north, northeast, northwest], south [south, southeast, southwest]), east, west, and flat) and vegetation community (grassland, pinyon-juniper woodland, ponderosa pine/mixed conifer forest and burned areas). We randomly generated four (north and south) and two (east, west, flat) replicate 100-m transects in each combined vegetation community-aspect strata for a total of 56 transects across the study area. We surveyed each transect in the middle of each season.

We collected horizontal visibility measurements at 0, 25, 50, and 100 meters along each transect to assess stalking cover for lions by recording concealment measurements from a fixed point looking out from the 8 cardinal and ordinal directions. We used a range finder to measure the distance from the observation point along a line of a specified azimuth to the closest point at which a crouched adult mountain lion could be fully concealed. We averaged all eight measurements for each point. We tested this method against a traditional cover board and correlated well ($r > 0.80$) and was considered to be more efficient and better represent predation risk. Horizontal visibility is inversely related to stalking cover for lions with areas with high visibility having low stalking cover and vice versa.

Our forage sampling focused on plant species that are known to contribute to mule deer diets, and was confirmed with microhistological analyses of fecal pellet samples collected seasonally from adult female mule deer on our study area (Kay, 2018). These forage species were the focus of our biomass and forage nutritional content sampling. Woody deciduous shrubs make up 53-86% of the seasonal diets during our study (Kay, 2018). Herbaceous grasses and forbs were mainly consumed during spring when they contributed 15% of the diet and only contributed 3-10% in summer and winter. Conifers were consumed primarily during winter and in spring (Kay, 2018).

We placed a 1-m^3 quadrat at 10-m intervals along each transect. Within each quadrat we used the modified comparative yield method and dry weight rank multipliers (Mazaika and Krausman 1991) to estimate the available edible biomass (i.e., leaves and twigs <5 mm in diameter) for browse (i.e., woody shrubs and trees) and composition for mule deer forage species (Haydock and Shaw 1975, Marshal et al. 2005). We assigned each plot a rank from 0 to 4 (in 0.25 increments from 0–1 and 0.5 increments from 1–4), where a rank of 0 represented a plot with no edible biomass, 1 = 25%, 2 = 50%, 3 = 75%, 4 = 100% (Marshal et al. 2005). We similarly estimated the biomass of herbaceous forage species (i.e., grasses and forbs) but with a maximum height of 0.5 m (Marshal et al. 2005). We clipped all edible biomass in a minimum of 10 plots per rank (including 0.25 and 0.5 ranks). We then dried all clipped biomass to a constant mass at 60˚C in a drying oven and estimated the relationship between rank and edible biomass using linear regression. We then used those results to estimate the biomass of unclipped plots (Marshal et al. 2005). Within each quadrat, we also ranked by dry weight the three most abundant forage species known to contribute significantly to mule deer diets using established multiplier values (1 = 0.70, 2 = 0.21, 3 = 0.09; t'Mannetje and Haydock 1963) to better estimate and model forage composition and subsequently biomass and quality.

To assess seasonal forage quality, we collected a composite grass sample and samples from each major browse and forb species from each transect and analyzed them for moisture, crude protein, neutral detergent fiber, acid detergent fiber, acid detergent lignin, ash (i.e., silica), and tannin (browse species only) content; tannins were estimated using the bovine serum albumin method. We then calculated digestible protein (%; Eqn. 1; Robbins et al. 1987a) and dry matter digestibility as a proxy for energy content (DMD; %; Eqn. 2; Robbin et al. 1987b) for each forage sample by plant species, season, aspect and vegetation community.

$$Digestible\ Protein = [-3.87 + 0.9283X - 11.82(T)], \quad (1)$$

where X is crude protein content (6.25 x total N; %) and T is tannin.

$$Dry\ Matter\ Digestibility\ (DMD) = [0.9231e^{-0.0451X} - 0.03(Z)]*(NDF)+[(-16.03 + 1.02NDS) - 2.8(11.82(T))], \quad (2)$$

where X is lignin and cutin content (% of NDF), Z is silica content of grasses (%), NDF is neutral detergent fiber (%), NDS is neutral detergent solubles (100 - NDF; %), P is digestible protein (%), and T is tannin.

For each transect, we weighted biomass by species-specific digestible energy and protein values to yield overall estimates of digestible energy and protein available (on a biomass basis) representing both forage quantity and quality (Proffitt et al. 2016).

We developed generalized linear models (GLM) in R 2.12.2 to estimate forage biomass, digestible energy and digestible protein (g/m^2) and horizontal visibility across the study area based on spatial and temporal attributes from the vegetation transects (R Core Team 2015). Covariates included vegetation type, elevation, canopy cover, NDVI, change in NDVI (ΔNDVI), ruggedness, topographic position, slope and aspect. Horizontal visbility data were pooled between the two years and divided into seasons (i.e., spring, summer, winter), whereas we ran separate forage models for each season in each year for edible forage biomass, digestible energy and digestible protein. We examined pair-wise correlations between covariates and did not include correlated variables (i.e., $r > |0.65|$) in the same model. We also examined variance inflation factors of a global model to help identify any collinear covariates before modeling, and we generated variance inflation factors for top models to ensure acceptable levels of collinearity (VIF <4.0). Because our goal was to generate more accurate predictor covariates for habitat selection models rather than comparing specific hypothesis on drivers of stalking cover and forage characteristics we did not use an a priori modeling approach. Rather we used forward and backward-stepwise model selection (Hebblewhite et al. 2008). We used Akaike's Information Criterion corrected for small sample size (AIC_c) to evaluate model support for each season and estimated model-averaged parameters when there was model uncertainty (i.e., > 1 model had $\Delta AIC_c \leq 2$; Burnham and Anderson 2002) averaged over all models in the model set. We then created GIS surfaces for horizontal visibility cover, forage biomass, and biomass-specific estimates of digestible energy and protein utilizing raster calculator based on topographical and vegetative spatial data and their respective coefficients included in top models. These raster layers were created at 30 m × 30 m resolution and used these as predictor variables for mule deer habitat selection. Ultimately, we only utilized biomass and digestible protein in deer RSFs because forage biomass was highly correlated with digestible energy and model performance for digestible energy were inadequate (Table 1.1).

Literature Cited

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodal inference: a practice information-theoretic approach, 2nd edition. Springer, New York, USA.

Haydock, K., and N. Shaw. 1975. The comparative yield method for estimating dry matter yield of pasture. Australian Journal of Experimental Agriculture 15:663–670.

Hebblewhite, M., E. Merrill, and G. McDermid. 2008. A multi-scale test of the forage maturation hypothesis in a partially migratory ungulate population. Ecological Monographs 78:141–166.

Marshal, J. P., P. R. Krausman, and V. C. Bleich. 2005. Dynamics of mule deer forage in the Sonoran Desert. Journal of Arid Environments 60:593–609.

Mazaika, R., and P. R. Krausman. 1991. Use of dry-weight rank multipliers for desert vegetation. Journal of Range Management 44:409–411.

Proffitt, K. M., M. Hebblewhite, W. Peters, N. Hupp, and J. Shamhart. 2016. Linking landscape-scale differences in forage to ungulate nutritional ecology. Ecological Applications 26:2156–2174.

R Core Team. 2018. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org

Robbins, C. T., S. Mole, A. E. Hagerman, and T. A. Hanley. 1987b. Role of tannins in defending plants against ruminants: reduction in dry matter digestion? Ecology 68:1606–1615.

Robbins, C. T., T. A. Hanley, A. E. Hagerman, O. Hjeljord, D. L. Baker, C. C. Schwartz, and W. W. Mautz. 1987a. Role of tannins in defending plants against ruminants: reduction in protein availability. Ecology 68:98–107.

t'Mannetje, L., and K. P. Haydock. 1963. The Dry-Weight-Rank method for the botanical analysis of pasture. Grass and Forage Science 18:268–275.

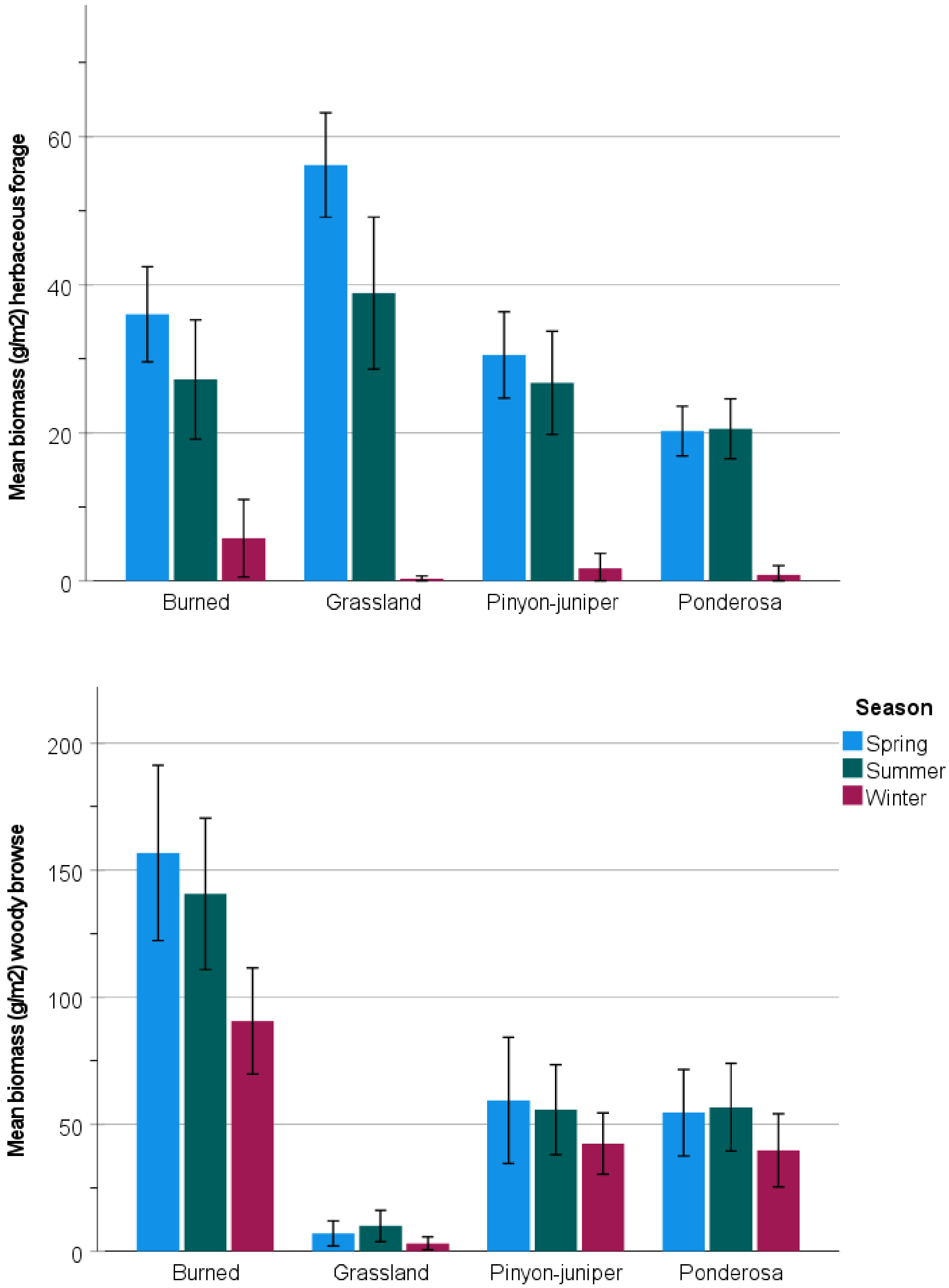

Figure 1.1. Mean seasonal edible biomass (g/m^2) of herbaceous forage (top panel) and woody browse (bottom panel) by vegetation type in the Gallinas Mountains, New Mexico, 2015-2016.

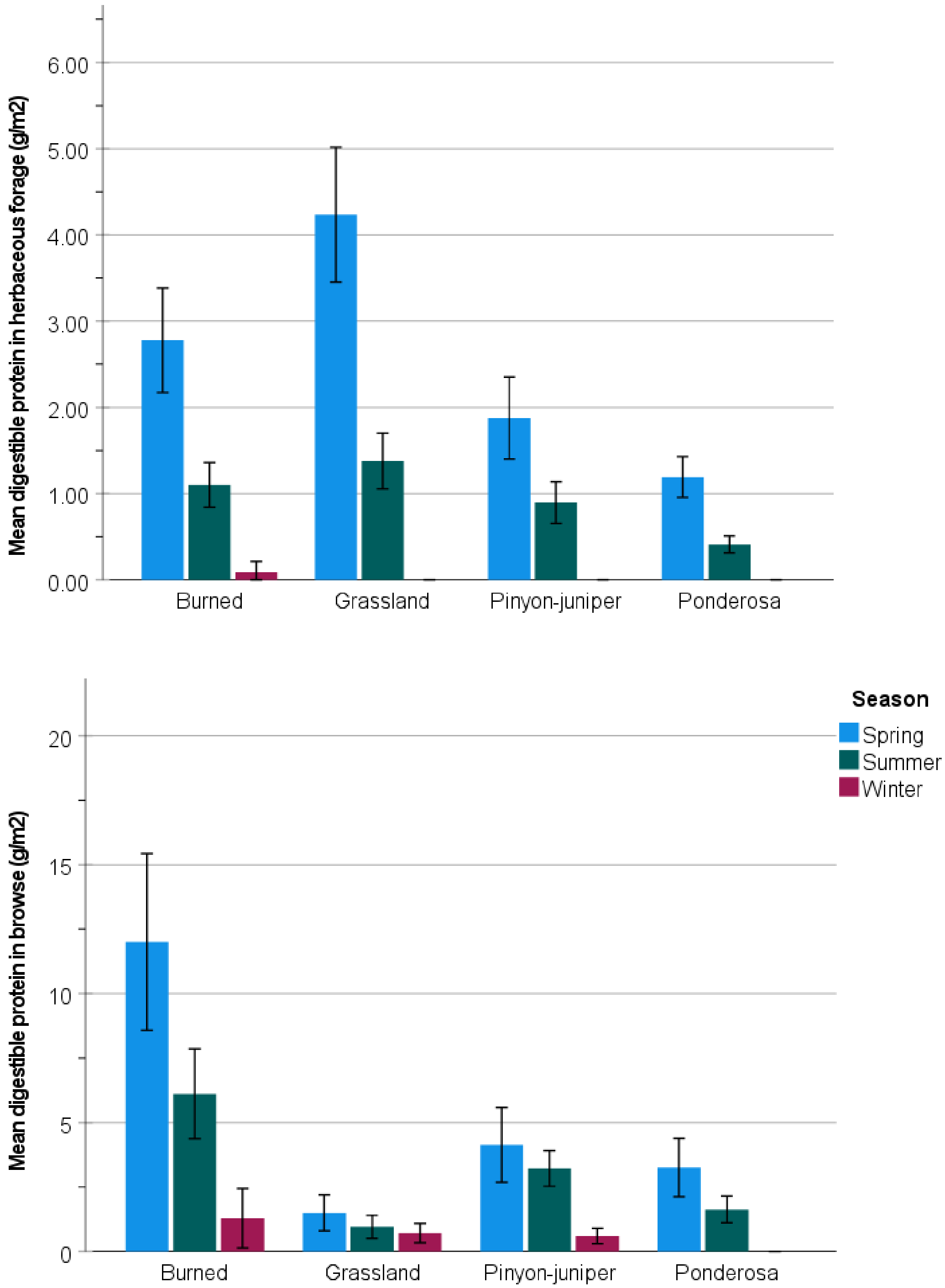

Figure 1.2. Mean seasonal digestible forage protein (g/m^2) of herbaceous forage (top panel) and woody browse (bottom panel) by vegetation type in the Gallinas Mountains, New Mexico, 2015-2016.

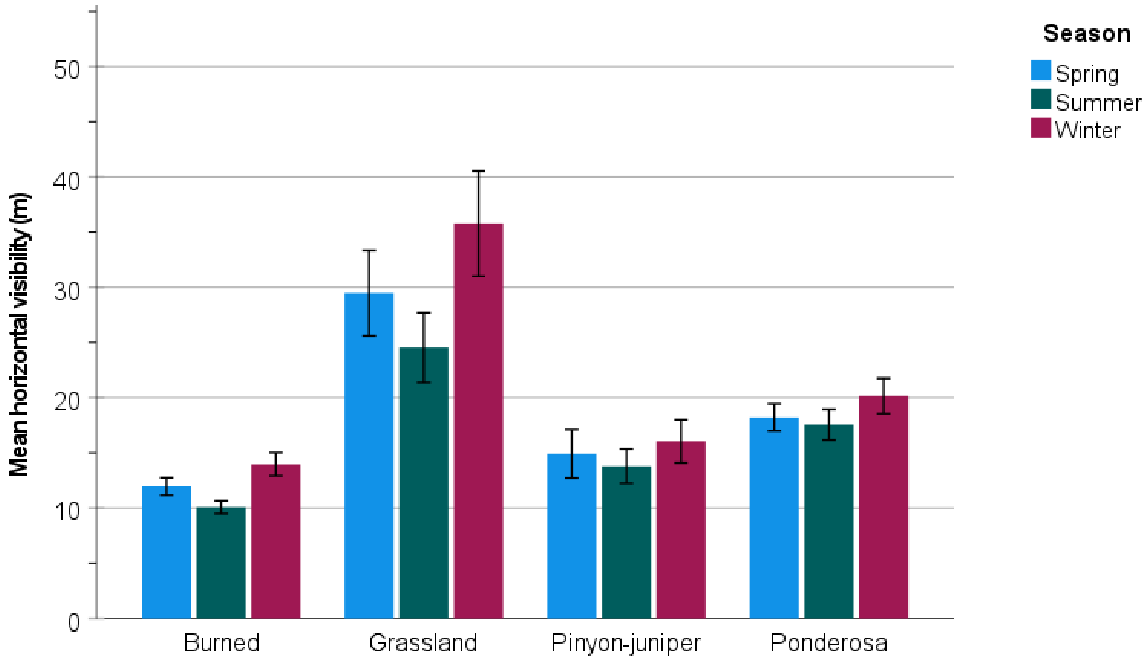

Figure 1.3. Mean seasonal horizontal visibility (m) by vegetation type in the Gallinas Mountains, New Mexico, 2015-2016.

Table 1.1. Five highest-ranking models predicting edible biomass, digestible energy, and digestible protein in mule deer forage in the Gallinas Mountains, New Mexico, 2015–2016. Model structures, number of parameters (*K*), Akaike's Information Criterion for small sample size (AIC_c), difference in AIC_c value between current model and top model (ΔAIC_c), AIC_c weight (w_i), and coefficient of determination (R^2) are given.

Model Structure[a,b]	***K***	**AIC_c**	**ΔAIC_c**	**w_i**	**R^2**
Edible biomass					
Veg × Season + North + TPI^2	28	1059.7	0.0	0.830	0.703
Veg × Season	25	1063.2	3.5	0.150	0.693
Veg × Season + North + ΔNDVI	27	1067.5	7.7	0.020	0.693
Veg × Season + North + ΔNDVI × Veg	30	1070.6	10.9	0.000	0.697
Veg + North + ΔNDVI	7	1269.2	209.5	0.000	0.361
Digestible energy					
Veg × Season + North + TPI^2	28	1137.6	0.0	0.350	0.444
Veg × Season + North + ΔNDVI × Veg	30	1138.2	0.6	0.260	0.451
Veg × Season + North + ΔNDVI	27	1138.7	1.2	0.200	0.438
Veg × Season	25	1138.8	1.2	0.190	0.430
Veg + North + ΔNDVI	7	1178.8	41.2	0.000	0.277
Digestible protein					
Veg × Season + North + TPI^2	28	897.0	0.0	0.910	0.730
Veg × Season + North + ΔNDVI	27	901.8	4.8	0.080	0.724
Veg × Season + North + ΔNDVI × Veg	30	906.9	9.9	0.010	0.726
Veg × Season	25	907.2	10.2	0.010	0.716
Veg + North + ΔNDVI	7	1139.7	242.7	0.000	0.359

[a] Covariates: Veg = vegetation type (Grassland [reference], Burned, Ponderosa Pine, Pinyon-Juniper); Season = season of study (Spring 2015 [reference], Summer 2015, Winter 2015/16, Spring 2016, Summer 2016, Winter 2016/17); North = northness index; TPI = topographical position index; ΔNDVI = change in Normalized Difference Vegetation Index.

[b] Models with quadratic terms also include the linear term (e.g., a^2 refers to $a + a^2$ as fixed effects). Models with interaction terms also include main effects (e.g., a × b refers to a + b + a × b as fixed effects).

Table 1.2. Scaled parameter estimates, standard error (SE), z statistic, and *P*-value for predicting edible biomass (g/m^2; log transformed) of mule deer forage in the Gallinas Mountains, New Mexico, 2015–2016.

Parameter[a,b]	Estimate	SE	z-*value*	*P*-value
Intercept	4.33	0.30	14.33	< 0.001
Burned	0.88	0.44	2.02	0.045
Ponderosa	-0.02	0.43	-0.05	0.960
Pinyon-Juniper	0.29	0.42	0.68	0.499
Summer 2015	-0.04	0.42	-0.10	0.923
Winter 2015/16	-4.74	0.42	-11.20	< 0.001
Spring 2016	-0.34	0.42	-0.79	0.428
Summer 2016	-1.24	0.42	-2.93	0.004
Winter 2016/17	-6.23	0.42	-14.71	< 0.001
North	0.02	0.13	0.15	0.877
TPI	-0.26	0.13	-2.05	0.041
TPI^2	0.37	0.15	2.54	0.012
Burned × Summer 2015	-0.16	0.60	-0.27	0.787
Ponderosa × Summer 2015	0.03	0.60	0.06	0.956
Pinyon-Juniper × Summer 2015	0.00	0.60	0.00	0.997
Burned × Winter 2015/16	3.72	0.60	6.22	0.000
Ponderosa × Winter 2015/16	3.03	0.60	5.07	0.000
Pinyon-Juniper × Winter 2015/16	3.46	0.60	5.78	0.000
Burned × Spring 2016	-0.03	0.60	-0.05	0.960
Ponderosa × Spring 2016	0.04	0.60	0.08	0.940
Pinyon-Juniper × Spring 2016	-0.23	0.60	-0.39	0.699
Burned × Summer 2016	0.68	0.60	1.14	0.257
Ponderosa × Summer 2016	0.97	0.60	1.63	0.105
Pinyon-Juniper × Summer 2016	0.67	0.60	1.13	0.261
Burned × Winter 2016/17	5.25	0.60	8.77	< 0.001
Ponderosa × Winter 2016/17	4.40	0.60	7.36	< 0.001
Pinyon-Juniper × Winter 2016/17	5.12	0.60	8.56	< 0.001

[a] Covariate definitions: Burned = burned areas; Ponderosa = Ponderosa pine; Pinyon-Juniper = Pinyon-Juniper woodland; North = northness index; TPI = topographical position index.

[b] Reference categories: Grassland; Spring 2015.

Table 1.3 Scaled parameter estimates, standard error (SE), z statistic, and *P*-value for predicting digestible energy content (log transformed) of mule deer forage in the Gallinas Mountains, New Mexico, 2015–2016.

Parameter[a,b]	Estimate	SE	z-*value*	*P*-value
Intercept	4.33	0.34	12.77	< 0.001
Burned	0.48	0.49	0.98	0.329
Ponderosa	-0.49	0.48	-1.03	0.306
Pinyon-Juniper	0.38	0.48	0.80	0.424
Summer 2015	-0.34	0.48	-0.71	0.479
Winter 2015/16	-2.94	0.48	-6.19	< 0.001
Spring 2016	-0.93	0.48	-1.97	0.050
Summer 2016	-1.43	0.48	-3.00	0.003
Winter 2016/17	-3.37	0.48	-7.09	< 0.001
North	0.29	0.14	2.05	0.041
TPI	-0.11	0.14	-0.74	0.459
TPI^2	0.31	0.16	1.89	0.060
Burned × Summer 2015	-0.41	0.67	-0.62	0.538
Ponderosa × Summer 2015	-0.05	0.67	-0.07	0.941
Pinyon-Juniper × Summer 2015	0.03	0.67	0.04	0.967
Burned × Winter 2015/16	1.65	0.67	2.46	0.014
Ponderosa × Winter 2015/16	0.65	0.67	0.97	0.333
Pinyon-Juniper × Winter 2015/16	1.72	0.67	2.57	0.011
Burned × Spring 2016	0.30	0.67	0.45	0.652
Ponderosa × Spring 2016	0.01	0.67	0.01	0.991
Pinyon-Juniper × Spring 2016	0.33	0.68	0.48	0.629
Burned × Summer 2016	0.94	0.67	1.40	0.162
Ponderosa × Summer 2016	0.99	0.67	1.47	0.143
Pinyon-Juniper × Summer 2016	0.87	0.67	1.29	0.198
Burned × Winter 2016/17	2.31	0.67	3.44	0.001
Ponderosa × Winter 2016/17	1.63	0.67	2.43	0.016
Pinyon-Juniper × Winter 2016/17	2.84	0.67	4.23	< 0.001

[a] Covariate definitions: Burned = burned areas; Ponderosa = Ponderosa pine; Pinyon-Juniper = Pinyon-Juniper woodland; North = northness index;
[b] Reference categories: Grassland; Spring 2015.

Table 1.4 Scaled parameter estimates, standard error (SE), z statistic, and *P*-value for predicting digestible protein content (log transformed) of mule deer forage in the Gallinas Mountains, New Mexico, 2015–2016.

Parameter[a,b]	Estimate	SE	z-*value*	*P*-value
Intercept	1.98	0.24	8.37	< 0.001
Burned	0.75	0.34	2.20	0.028
Ponderosa	-0.35	0.33	-1.04	0.299
Pinyon-Juniper	0.06	0.33	0.19	0.850
Summer 2015	-1.02	0.33	-3.06	0.002
Winter 2015/16	-2.55	0.33	-7.69	< 0.001
Spring 2016	-0.59	0.33	-1.78	0.076
Summer 2016	-1.55	0.33	-4.68	< 0.001
Winter 2016/17	-3.26	0.33	-9.81	< 0.001
North	0.29	0.10	2.93	0.004
TPI	-0.27	0.10	-2.67	0.008
TPI^2	0.21	0.11	1.86	0.063
Burned × Summer 2015	-0.03	0.47	-0.06	0.952
Ponderosa × Summer 2015	-0.18	0.47	-0.38	0.703
Pinyon-Juniper × Summer 2015	0.53	0.47	1.14	0.257
Burned × Winter 2015/16	-1.03	0.47	-2.19	0.029
Ponderosa × Winter 2015/16	-1.05	0.47	-2.23	0.026
Pinyon-Juniper × Winter 2015/16	0.16	0.47	0.33	0.741
Burned × Spring 2016	-0.04	0.47	-0.08	0.940
Ponderosa × Spring 2016	-0.03	0.47	-0.07	0.941
Pinyon-Juniper × Spring 2016	-0.33	0.47	-0.69	0.489
Burned × Summer 2016	-0.05	0.47	-0.11	0.911
Ponderosa × Summer 2016	0.49	0.47	1.04	0.299
Pinyon-Juniper × Summer 2016	0.66	0.47	1.40	0.164
Burned × Winter 2016/17	-0.71	0.47	-1.52	0.130
Ponderosa × Winter 2016/17	-0.56	0.47	-1.19	0.234
Pinyon-Juniper × Winter 2016/17	0.07	0.47	0.16	0.877

[a] Covariate definitions: Burned = burned areas; Ponderosa = Ponderosa pine; Pinyon-Juniper = Pinyon-Juniper woodland; North = northness

[b] Reference categories: Grassland; Spring 2015.

Table 1.5. Five highest-ranking models predicting horizontal visibility from generalized linear models by season in the Gallinas Mountains, New Mexico, 2015–2016 Model structures, number of parameters (*K*), Akaike's Information Criterion for small sample size (AIC_c), difference in AIC_c value between current model and top model (ΔAIC_c), AIC_c weight (w_i), and coefficient of determination (R^2) are given.

Model Structure[a,b]	***K***	**AIC_c**	**ΔAIC_c**	**w_i**	**R^2**
			Spring		
Veg × Can + North	10	683.53	0.00	0.591	0.714
Veg × Can + North + VRM	11	685.88	2.35	0.182	0.714
Veg × Can + North + ΔNDVI	11	685.97	2.44	0.175	0.714
Veg × Can + North + ΔNDVI + VRM	12	688.37	4.84	0.052	0.713
Veg + North + $Slope^2$	8	707.60	24.08	0.000	0.629
			Summer		
Veg × Can + North + ΔNDVI	11	650.14	0.00	0.60	0.700
Veg × Can + North + ΔNDVI + VRM	12	652.44	2.30	0.19	0.701
Veg × Can + North	10	652.89	2.76	0.15	0.687
Veg × Can + North + VRM	11	655.16	5.02	0.05	0.687
Veg × North + $Slope^2$	8	661.05	10.91	0.00	0.672
			Winter		
Veg × North	9	743.98	0.00	0.349	0.690
Veg × Can + North	10	745.42	1.43	0.170	0.693
Veg × North + ΔNDVI	10	745.75	1.77	0.144	0.692
Veg × North + $Slope^2$	11	746.54	2.56	0.097	0.696
Veg × Can + North + VRM	11	747.28	3.30	0.067	0.694

[a] Covariates: Veg = vegetation type (Grassland [reference], Burned, Ponderosa Pine, Pinyon-Juniper); Elev = Elevation (m); North = northness index; Can = canopy cover; ΔNDVI = change in Normalized Difference Vegetation Index; VRM = vector ruggedness measure; Slope = Slope.

[b] Models with quadratic terms also include the linear term (e.g., a^2 refers to $a + a^2$ as fixed effects). Models with interaction terms also include main effects (e.g., a × b refers to a + b + a × b as fixed effects).

Table 1.6. Scaled parameter estimates, standard error (SE), *z* statistic, and *P* value for horizontal visibility by season in the Gallinas Mountains, New Mexico, 2015–2016.

Parameter[a,b]	**Estimate**	**SE**	**z-*value***	***P*-value**
		Spring		
Intercept	12.57	3.16	3.98	< 0.001
Burned	0.84	3.40	0.25	0.806
Ponderosa	4.03	3.95	1.02	0.311
Pinyon-Juniper	4.28	3.36	1.27	0.206
Can	-30.43	5.54	-5.49	< 0.001
North	-3.84	1.00	-3.85	< 0.001
Burned × Can	34.79	6.57	5.29	< 0.001
Ponderosa × Can	32.79	6.56	5.00	< 0.001
Pinyon-Juniper × Can	19.62	6.76	2.90	0.005
		Summer		
Intercept	11.37	2.68	4.24	< 0.001
Burned	-0.32	2.88	-0.11	0.912
Ponderosa	4.32	3.36	1.29	0.201
Pinyon-Juniper	3.63	2.84	1.28	0.204
Can	-23.74	4.70	-5.05	< 0.001
North	-2.87	0.83	-3.45	0.001
Burned × Can	26.51	5.58	4.75	< 0.001
Ponderosa × Can	26.61	5.57	4.78	< 0.001
Pinyon-Juniper × Can	16.30	5.70	2.86	0.005
		Winter		
Intercept	34.68	1.22	28.35	< 0.001
Burned	-20.83	1.74	-12.00	< 0.001
Ponderosa	-14.63	1.72	-8.51	< 0.001
Pinyon-Juniper	-18.59	1.72	-10.84	< 0.001
North	-13.73	2.74	-5.02	< 0.001
Burned × North	14.92	3.62	4.12	< 0.001
Ponderosa × North	10.71	3.49	3.07	0.003
Pinyon-Juniper × North	9.85	3.75	2.62	0.010

[a] Covariate definitions: Grassland (reference); Burned = burned areas; Ponderosa = Ponderosa pine; Pinyon-Juniper = Pinyon-Juniper woodland; North = northness index; Can = canopy cover.