Ecography

ECOG-05251
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Supplementary material

Appendix 1 - Supplemental methods

Cache Site Analysis and variable creation:

- **Land-cover classifications** from NLCD 2016 (30 m^2) were assigned to "forest" (classes 40 – 45; also assigned as the reference category in resource selection models), "shrub" (classes 50 – 55), "developed" (classes 21 – 24), "crop" (classes 81 – 82), "water" (classes 11 – 12), "wetland" (classes 90 – 95), and "herbaceous/barren" (classes 71 – 74).

- **Distance to nearest habitat edge** was created by grouping the NLCD 2016 (30 m^2) land cover classes 41-43 as "forest, 50-55 as "shrub", and 71-85 as "open". For each grouping we used the "rasterToContour" function in the raster package (Hijmans 2019) to create a polyline that we considered the edge for each habitat grouping. We calculated the Euclidean distance between each location and each polyline edge group using the "nncross" function within the program R package spatstat (Baddeley & Turner 2005) and retained the minimum distance among the three estimates.

- **Road density** (resolution: 1 km^2) estimates were developed using road length [km]/area [km^2].

- The **terrain ruggedness index** used a 30 m^2 digital elevation model and the function "tri" in the spatialEco package (Evans 2019). The scale of the window covered within the function was 990 m (30 m X 33 cells).

- The values of log **nightlight radiance used to assign the study area light exposure categories** ("low", "medium", or "high") using k-means clustering were as follows: low: <= -0.720, medium: -0.719 – -0.176, high: > -0.176.

- We assessed the correlation among the continuous independent variables within each light exposure category using both the Pearson's r and variance inflation factors. We considered |r| <= 0.7 and VIF <= 2 thresholds for inclusion. All variables met these requirements, so each was retained for modeling (see Table S1 for |r| values).

Integrated step selection functions:

We used GPS-locations from both cougars and mule deer that were collected at either 2, 3, or 4 hour intervals between locations, and we classified each individual based on the interval length of their movement steps for the purposes of including it as a nuisance variable when modeling the SSF coefficients. In order to determine whether a location occurred in daytime, we used the "solarpos" function in package maptools (Bivand & Lewin-Koh 2019). Each movement step was assigned the sun's altitude associated with the timestamp and location at the origin of each movement step.

For the remainder of the SSF data preparation and modeling we followed Signer et al. (2019). First, we regularized timesteps to fall into one of the interval length categories (2, 3, or 4 hour) and created movement bursts consisting of movement steps. An animal's movement step consists of the recorded GPS-locations at times T_0 and T_1. Movement bursts are groups of GPS locations that were no more than the defined interval length that was assigned to the individual. From the bursts we assumed a straight-line trajectory to connect successive locations to estimate step lengths and turning angles (derived from the headings of 2 sequential steps). If a movement burst did not contain adequate locations to estimate a turning angle (three required), it was removed.

We generated 15 random steps per 1 actual movement step (Northrup *et al.* 2013) by drawing values from a gamma and von Mises distribution fit to each individual collared animal's step lengths and turn angles, respectively. SSF models were fit using conditional logistic regression using the "clogit" function from package survival (Therneau 2015). The strata were based on the movement step identification that grouped each actual movement step and the 15 random steps from the same origin point (T_0). The response variable was binary (0/1) with actual movement steps coded as a "1" and random as a "0". Some individual cougars and mule deer did not experience any variation among some variables. For example, several wildland individuals did not have locations in areas with housing density > 0. As a result, the iSSF models for these individuals could not contain the variable. Housing density was the variable where this issue occurred most frequently. We re-ran all models for these individuals with housing density removed. Because these individuals experienced no variation in housing density, the models would not have improved their fit even if they could be run with the variable included. For individuals with no variance for other variables, primarily road density and a few NLCD 2016 landcover, we removed them from the analysis entirely.

When scoring the top SSF model fits, if multiple models were within 2 AIC of the best-supported model, we assigned equal proportions of the point to each model within the 2 AIC threshold (We assessed the significance and the consistency of the directionality (+/-) of model coefficients that involved nightlight using bootstrapped 95% confidence intervals.

Functional response supplemental:

An individual was included in the model if it had at least 200 used GPS locations in a given season. Negative ratios were removed in order to model the selection ratio on the log scale. Because several deer only experienced a very small range of light levels due to limited ranges, we included only individuals with light exposure > .2 log radiance.

Predicted selection ratios for each light category and season were based on the population-level and plotted using the package 'ggeffects' (Lüdecke 2018).

Deer Activity Analysis:

A constant of 0.001 was added to all deer movement rates to remove any values of 0 prior to taking the log of all movement rates. The estimates of the sun's altitude were assigned periods of the day as follows: daytime: >= 20; crepuscular: < 20 & > -20; night: <= 20.

SI References

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Appendix 2 - Supplemental results

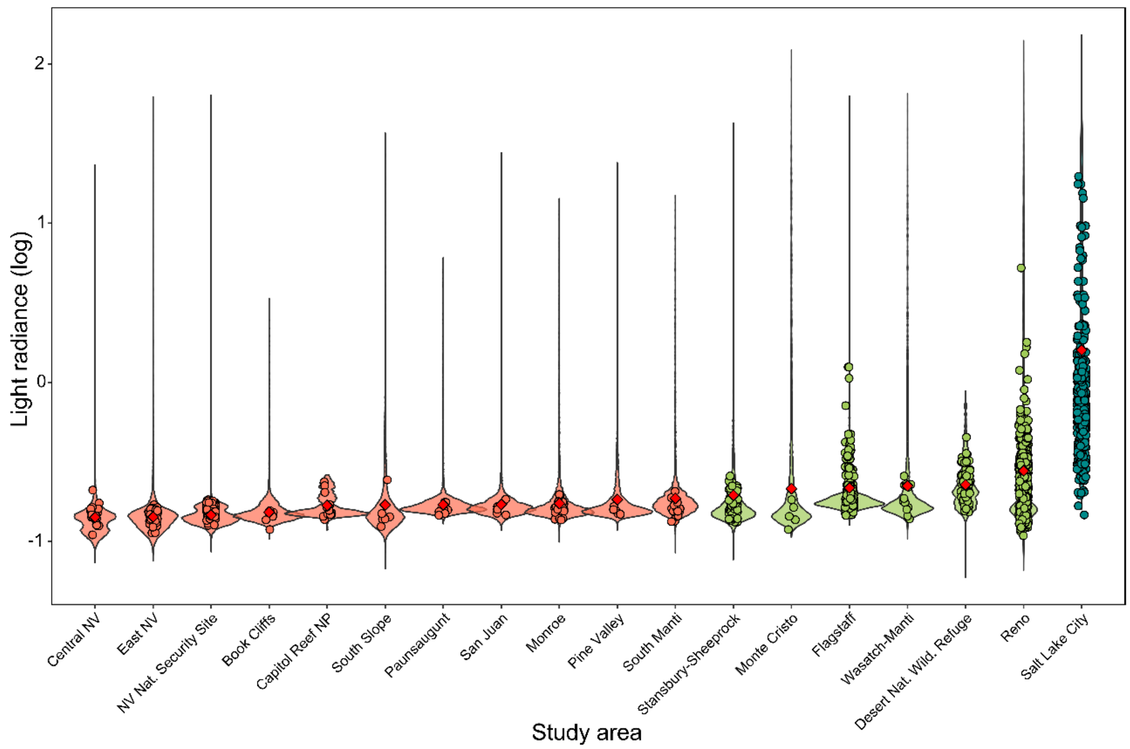

Fig. A1. VIIRS estimates of nightlight radiance (log scale) at 1,562 verified cougar-killed mule deer cache sites (points) for 18 study areas across the Intermountain West of the United States. Mean value per site is shown as a red diamond. Study areas were classified based on mean radiance into low (salmon), medium (green), and high (blue) nightlight exposure. The shapes of the violin plots are based off the random locations assigned to each study area. NV: Nevada. NP: National Park.

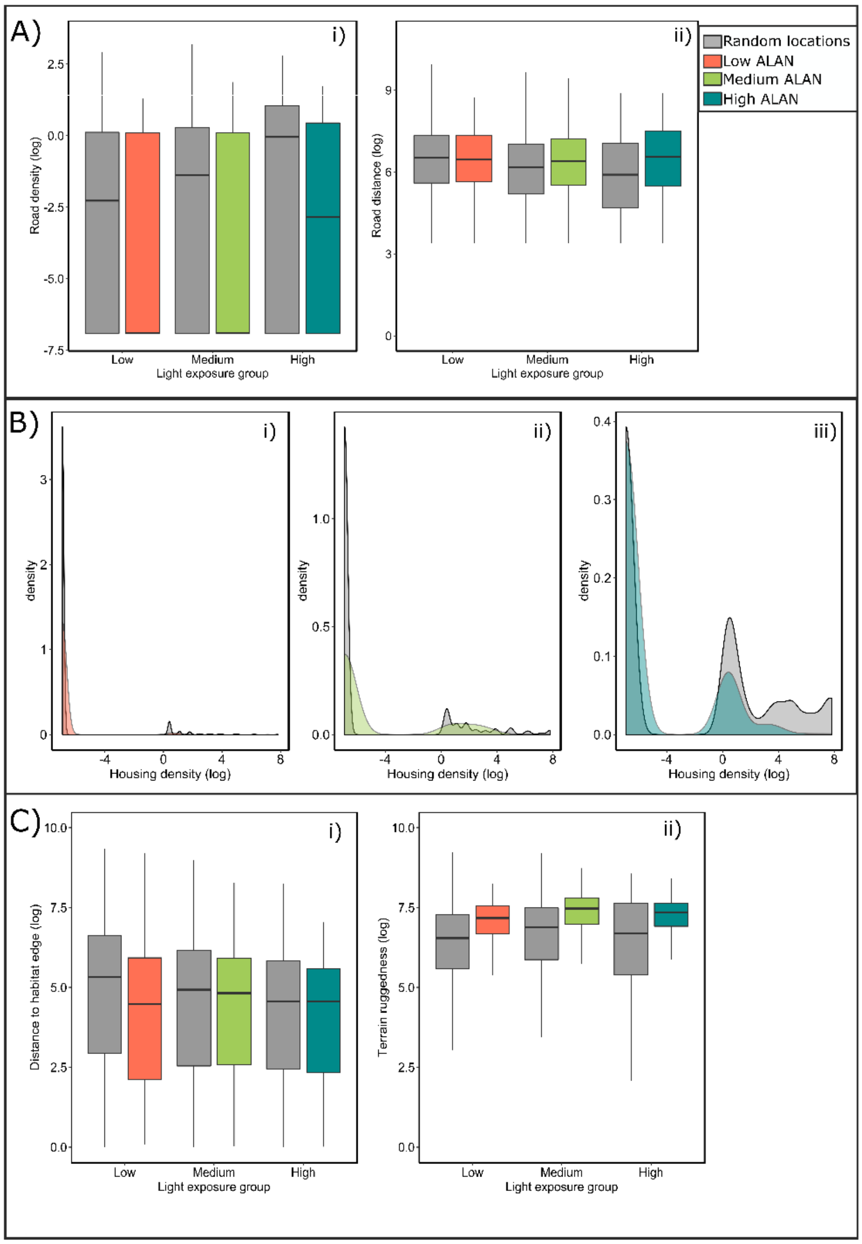

Fig. A2. Raw values of the variables considered in a resource selection function using 1,562 cougar-killed mule deer cache sites and random locations within the same study areas. We created three RSFs – one for each classification of nightlight exposure at each study area (low = salmon, medium = green, high = blue). Values shown here are on the log scale and a small constant was added to values (0.001). Outlier values from the boxplots were removed for visualization. Panel A) human footprint metrics (i = road density, ii = distance to the nearest road), B) housing density (i = low nightlight sites, ii = medium nightlight sites, iii = high nightlight sites), and C) landscape variables (i = distance to habitat edge, ii = terrain ruggedness). See Methods for list of all included variables in each light exposure RSF model. ALAN = artificial light at night

Table A1. Pearson's r correlation coefficients assessed between all quantitative variables included within the resource selection functions for cougar cache site selection. Values were derived from all cache sites and random points generated within study areas, and each area was classified as having Low, Medium, or High nightlight exposure.

Nightlight Exposure Class.	Pearson's r	Terrain Ruggedness	Nightlight	Dist. To Habitat Edge	Housing Density	Road Distance	Road Density
Low	Terrain Ruggedness		-0.06	-0.27	-0.02	0.13	-0.24
Low	Nightlight	-0.06		-0.15	0.21	-0.09	0.32
Low	Dist. To Habitat Edge	-0.27	-0.15		-0.01	-0.02	-0.01
Low	Housing Density	-0.02	0.21	-0.01		-0.02	0.14
Low	Road Distance	0.13	-0.09	-0.02	-0.02		-0.21
Low	Road Density	-0.24	0.32	-0.01	0.14	-0.21	
Medium	Terrain Ruggedness		-0.16	-0.19	-0.11	0.12	-0.26
Medium	Nightlight	-0.16		0.02	0.55	-0.12	0.62
Medium	Dist. To Habitat Edge	-0.19	0.02		0.01	0.27	-0.05
Medium	Housing Density	-0.11	0.55	0.01		-0.08	0.53
Medium	Road Distance	0.12	-0.12	0.27	-0.08		-0.26
Medium	Road Density	-0.26	0.62	-0.05	0.53	-0.26	
High	Terrain Ruggedness		-0.07	-0.25	-0.07	0.11	-0.23
High	Nightlight	-0.07		-0.09	0.49	-0.10	0.55
High	Dist. To Habitat Edge	-0.25	-0.09		0.00	0.03	-0.03
High	Housing Density	-0.07	0.49	0.00		-0.04	0.46
High	Road Distance	0.11	-0.10	0.03	-0.04		-0.20
High	Road Density	-0.23	0.55	-0.03	0.46	-0.20	

Table A2. The 13 integrated step selection function model specifications fit to GPS-location data from each cougar and mule deer in the Intermountain West of the United States. All models included strata based on each movement step and the associated random steps. Movement characteristics ("Char.") included the log of movement distance and the cosine of turning angle. Landcover used the NLCD 2016 landcover classes and included interactions with the movement characteristics. Landscape variables included distance to habitat edge and terrain roughness. The enhanced vegetation indices (EVI) and snow cover (SnowC) were derived from remotely-sensed data (see Methods). The Human Footprint consisted of distance to the nearest road, road density, and housing density. However, some individuals did not include housing density in their models because of a lack of any variability in the amount of housing density associated with their locations (see Methods Appendix for more detail). GPS locations were associated with the nearest season-year of nightlight estimates. For both the Human Footprint and nightlight, selection refers to the values at the end of each movement step, while movement refers to an interaction between the variable and the movement characteristics. See Appendix Table 5 for model selection results. ALAN = Artificial light at night

Model #	Model Specification
1	Movement Char. + Landcover
2	Movement Char. + Landcover + Landscape + EVI + SnowC
3	Movement Char. + Landcover + Landscape + EVI + SnowC + Human Footprint (selection)
4	Movement Char. + Landcover + Landscape + EVI + SnowC + Human Footprint (movement)
5	Movement Char. + Landcover + Landscape + EVI + SnowC + Human Footprint (selection & movement)
6	Movement Char. + Landcover + Landscape + EVI + SnowC + ALAN (movement)
7	Movement Char. + Landcover + Landscape + EVI + SnowC + ALAN (selection)
8	Movement Char. + Landcover + Landscape + EVI + SnowC + ALAN (selection & movement)
9	Movement Char. + Landcover + Landscape + EVI + SnowC + Human Footprint (selection) + ALAN (selection)
10	Movement Char. + Landcover + Landscape + EVI + SnowC + Human Footprint (movement) + ALAN (movement)
11	Movement Char. + Landcover + Landscape + EVI + SnowC + Human Footprint (selection & movement) + ALAN (selection & movement)
12	Movement Char. + Landcover + Landscape + EVI + SnowC + ALAN (selection & movement) + ALAN (selection)×EVI
13	Movement Char. + Landcover + Landscape + EVI + SnowC + Human Footprint (selection & movement) + ALAN (selection & movement) + Moon

Table A3. Coefficient values from three resource selection function models examining factors that influenced 1,562 cougar-killed mule deer cache sites across 18 study areas in the Intermountain West of the United States. The resource selection models were applied to study areas classified as either low, medium, or high exposure to artificial light at night (ALAN). NLCD: National Land Cover Data. NLCD data were factors and forest habitat was the reference category.

	ALAN Exposure: LOW				ALAN Exposure: MEDIUM				ALAN Exposure: HIGH			
Covariate	β Estimate	Std. Error	z value	p value	β Estimate	Std. Error	z value	p value	β Estimate	Std. Error	z value	p value
ALAN	0.11	0.06	1.65	0.10	0.25	0.05	5.23	< 0.01	-0.53	0.09	-5.99	< 0.01
Dist. To Habitat Edge	-0.36	0.11	-3.37	< 0.01	-0.08	0.06	-1.43	0.15	0.25	0.10	2.61	0.01
Dist. To Road	-0.38	0.13	-2.98	< 0.01	0.08	0.03	2.42	0.02	0.26	0.04	6.96	< 0.01
Housing Density	-23.19	9.55	-2.43	0.02	-0.83	0.40	-2.08	0.04	-0.32	0.30	-1.06	0.29
Intercept	-9.17	0.35	-26.12	< 0.01	-7.33	0.09	-84.27	< 0.01	-5.33	0.18	-30.17	< 0.01
NLCD:Crop	-2.07	1.02	-2.04	0.04	-2.08	0.71	-2.91	< 0.01	-2.46	0.73	-3.37	< 0.01
NLCD:Developed	-1.53	1.01	-1.51	0.13	-1.27	0.44	-2.90	< 0.01	-2.74	0.80	-3.41	< 0.01
NLCD:Herbaceous/Barren	-0.92	0.25	-3.64	< 0.01	-0.78	0.17	-4.54	< 0.01	1.20	0.18	6.83	< 0.01
NLCD:Shrub	-0.82	0.13	-6.38	< 0.01	0.15	0.08	1.79	0.07	0.91	0.15	6.11	< 0.01
NLCD:Water	-11.30	169.38	-0.07	0.95	-11.22	125.65	-0.09	0.93	-11.21	203.91	-0.06	0.96
NLCD:Wetland	-1.65	1.01	-1.64	0.10	0.84	0.27	3.15	< 0.01	1.05	0.35	3.03	< 0.01
Road Density	-0.05	0.07	-0.69	0.49	0.04	0.06	0.60	0.55	0.25	0.12	2.12	0.03
Terrain Ruggedness	0.14	0.06	2.51	0.01	0.45	0.03	13.01	< 0.01	-0.01	0.06	-0.24	0.81

Table A4. Model output from seasonal generalized additive mixed models fit to the movement rates of 263 GPS-collared mule deer living in the Great Basin of the United States. Deer were classified as low, medium or high light exposure based on the mean ALAN value of their GPS locations. Models included parametric fits and smoothing terms as well as random intercepts for deer ID. We were primarily interested in diel deer activity patterns (see Figure 3) while accounting for a suite of other factors potentially important to movement (EVI/greenness) and nuisance variables (GPS Time Interval).

	Summer Model				Winter Model			
Parametric Coefficient	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
Intercept	0.10	0.08	1.22	0.22	-0.06	0.10	-0.61	0.54
GPS Time Interval	0.00	0.00	-7.68	< 0.01	0.00	0.00	-6.12	0.00
Moon Phase	0.02	0.02	1.01	0.31	-0.03	0.02	-1.29	0.20
Light Classification [Low]	-0.05	0.09	-0.56	0.57	-0.13	0.10	-1.23	0.22
Light Classification [Medium]	-0.23	0.10	-2.33	0.02	-0.12	0.12	-0.99	0.32
Moon Phase × Light Classification [Low]	0.00	0.02	-0.05	0.96	0.07	0.03	2.71	0.01
Moon Phase × Light Classification [Medium]	0.01	0.02	0.46	0.65	0.00	0.03	0.05	0.96
Snow Cover	NA	NA	NA	NA	-0.12	0.01	-15.56	< 0.01
Smoothing Term	**edf**	**Ref.df**	***F***	**p-value**	**edf**	**Ref.df**	***F***	**p-value**
s(Julian Date)	8.93	8.93	916.56	< 0.01	8.65	8.65	266.70	< 0.01
s(Sun Position) × Light Classification [Low]	8.97	8.97	1138.52	< 0.01	8.93	8.93	1323.48	< 0.01
s(Sun Position) × Light Classification [Medium]	8.80	8.80	492.89	< 0.01	8.80	8.80	758.19	< 0.01
s(Sun Position) × Light Classification [High]	8.08	8.08	57.13	< 0.01	8.13	8.13	89.24	< 0.01
s(EVI) × Light Classification [Low]	8.62	8.62	43.17	< 0.01	5.81	5.81	53.58	< 0.01
s(EVI) × Light Classification [Medium]	7.22	7.22	45.47	< 0.01	5.12	5.12	14.71	< 0.01
s(EVI) × Light Classification [High]	6.73	6.73	25.07	< 0.01	4.34	4.34	12.27	< 0.01