Supplementary Materials for article "Modeling wildlife-human relationships for social species with mixed-effects resource selection models" by Hebblewhite & Merrill

Appendix S1. Sample annotated STATA analysis code for analyzing a three-level generalized linear mixed-RSF models.

Herein is provided sample Stata 9.2 (StataCorp 2005) code for a three-level GLLAMM with a random coefficient at the pack level:

```
//* Modeling wolf RSF at the home range scale during
daytime only during the summer.
//*First need to define random intercept and random
coefficient equations
gen cons=1
eq wolfcons: cons
eq packcons: cons
eq packhuman: disthgh
//* MODEL IWPCPDAY - random intercept for wolf and pack,
random coefficient for pack DURING THE DAY
gllamm use distedg disthgh slope_a burn alpine shrub rock
oconif herb cutblock if day==1, i(wolfuid packid) nrf(1,2)
eqs(wolfcons packcons packhuman) fam(bin) link(logit)
nip(4) trace
matrix n=e(b)
gllamm use distedg disthgh slope_a burn alpine shrub rock
oconif herb cutblock if day==1, i(wolfuid packid) nrf(1,2)
eqs(wolfcons packcons packhuman) fam(bin) link(logit)
nip(10) from(n) adapt trace
estimate store iwpcpday
gllapred iwpcpdayreff, u
gen iwpcpday_wri = iwpcpdayreffm1 + _b[_cons]
gen iwpcpday_pri = iwpcpdayreffm2 + _b[_cons]
gen iwpcpday_prc = iwpcpdayreffm3 + _b[disthgh]
gllapred iwpcplinpred, linpred
gllapred iwpcpmarg, mu marg
gllapred iwpcpxb, xb
gllapred iwpcppears, pearson
gllapred iwpcpustd, ustd
```

The first step is to define the random intercepts `(wolfcons packcons)` as constants by setting them =1, the variable `cons`. Next, we defined the random coefficient for the variable disthhu (distance to high human use) at the pack level. The general approach we used was to first estimate the model using a reduced number of numerical integration points (nip) to speed up processing (e.g., `nip(4)`) during the first model iteration. We then saved the covariance matrix from this estimation using `matrix n=e(b)`, and for the second integration with more nip points (`nip(10)`) recalled this matrix n using `from(n)`, making estimation faster. In the

GLLAMM command, the two-levels of wolf and pack are identified by `i(wolfuid, packid)`, and the number of random effects at the two levels is specified by `nrf(1, 2)` to indicate the equations specified by `eqs(wolfcons packcons packhuman)` at the level of wolf and pack in the model. Following estimation, we stored the model using the `estimate store iwpcpday` command, and predicted the random intercepts and coefficients using `gllapred iwpcpdayreff, u.` This stored the estimate of the γ's, that is, the deviation for the random intercepts and random coefficients from the mean intercept and coefficient for each level. To calculate what the actual conditional coefficient value for a particular level was, we used the following three commands:

```
gen iwpcpday_wri = iwpcpdayreffm1 + _b[_cons]
gen iwpcpday_pri = iwpcpdayreffm2 + _b[_cons]
gen iwpcpday_prc = iwpcpdayreffm3 + _b[disthgh]
```

to "add" the γ's, `iwpcpdayreffm1`, to the fixed effect estimate of the intercept and coefficient for distance to high human use, and stored these as the wolf-level random intercept (wri), pack level random intercept (pri), and pack-level random coefficient (prc). Finally, various predictions are made using the command `gllapred`, including the linear predictor, the marginal population level prediction, the mean xb prediction, and the Pearson's and standardized Pearson's residuals.

Appendix A2. Conditional resource selection inferences and functional responses from the top three-level mixed-effects RSF models for the individual wolf level.

When the focus of a resource selection study is on consequences of individual variation in resource selection to fitness, it would be equally valid to consider only random effects at the individual wolf level and use the model with a random coefficient for inferences. In this example, one would use the following model:

$$\mathrm{Logit}(y_{\mathrm{ijk}}) = \gamma_{00} + \gamma^{(2)}_{jk} + \gamma^{(3)}_{k} + \gamma^{(2)}_{1jk}\, x_{1ijk} + \ldots + \mathbf{X}\boldsymbol{\beta} + \varepsilon_{\mathrm{ijk}} \qquad \text{eqn 1}$$

Unfortunately, this model failed to converge for the summer in this study for reasons that were biologically based (see Table S.1). However, this model converged during winter, and was the second ranked model and a reasonable challenger to the top model at night. Therefore, to illustrate conditional inferences given Eq. 1 for wolves in this study, we summarize individual level coefficients for wolf response to human activity in Table S.1.

Examining group means indicates some trends in age-sex-status classes in resource selection for proximity to human activity. We consider conservative wolf behavior as showing stronger avoidance of high human activity during the daytime (i.e., coefficient closer to 0 or positive during daytime relative to night). In this context, females, adults, and breeding wolves all showed more conservative behavior than males, yearlings, and non-breeding wolves during this study (Table S.1). Yearling males especially appeared less conservative, for example, wolf 77 who selected to be closer to human activity than any other ranch wolf during the study. Wolf 77 was often observed on the YHT grasslands during daytime in summer 2004 and was subsequently shot by a hunter in fall/winter 2004.

Moreover, one can still explore functional responses given individual inferences. Figure S.1 illustrates the individual coefficients plotted against pack-level home range availability of proximity to human activity. The general shape of the functional response remains the same as for the pack-level functional response, whereby wolves show an increasing aversion to select areas closer to human activity during daytime, but only at high human activity levels. Two further points are apparent. First, the strength of the relationship appears weaker than that for the pack-level functional response, and this is because of the wider variation present in individual wolf estimates. This latter observation brings us to the second major conclusion from this figure. Wolf response to human activity appears considerably more variable in areas of high human activity than at lower human activity. Thus, human disturbance may act to increase behavioral flexibility in wolves. However, this greater range of variation at high human activity levels likely comes with a fitness trade-off, for example, human-caused mortality as in the case of wolf 77. Based on these preliminary findings, we believe inferences from mixed-effects models will have important implications for the study of the consequences of resource selection to fitness.

Table S.1. Individual wolf coefficients for proximity to high human activity during night and day, winters 2002/03 and 2003/04, eastern slopes of BNP, Alberta, Canada.

Pack	Wolf #	Sex	Age	Status†	B – Day	SE	B – Night	SE
Cascade	42	Female	Adult	Breeding	0.139	0.029	0.174	0.016
Red Deer	45	Female	Adult	Breeding	0.057	0.027	0.099	0.016
Ranch	65	Male	Adult	Breeding	0.058	0.027	0.398	0.016
Ranch	77‡	Male	Yearling	Non-breeding	-0.577‡	0.274	-0.493	0.016
Wildhorse	78	Male	Yearling	Non-breeding	0.059	0.021	-0.122	0.016
Ranch	80	Male	Yearling	Non-breeding	-0.332	0.274	-1.010	0.016
Red Deer	81	Male	Yearling	Non-breeding	-0.040	0.071	0.015	0.016
Red Deer	82	Female	Yearling	Non-breeding	0.002	0.02	0.055	0.016
Wildhorse	83	Male	Adult	Breeding	-0.484	0.25	-0.748	0.016
Red Deer	84	Female	Yearling	Non-breeding	0.056	0.06	-0.122	0.016
Cascade	85	Female	Adult	Breeding	0.040	0.02	0.063	0.016
Bow Valley	87	Female	Adult	Breeding	-0.678	0.27	-1.441	0.016
Cascade	65††	Male	Adult	Non-breeding	-0.147	0.27	-0.174	0.016
Group means								
	Day	Night		Day	Night		Day	Night
Female	-0.083	-0.172	***Adult***	-0.191	-0.315	*Breeding*	-0.145	-0.243
Male	-0.239	-0.323	*Yearling*	-0.157	-0.256	*Non-breeding*	-0.221	-0.346

† - We follow (Mech and Boitani 2003) in using breeding and non-breeding instead of alpha.
†† - Wolf 65 switched wolf packs upon a new male dispersing into the Ranch pack, forcing wolf 65 to leave, when he subsequently joined the Cascade pack as a putative non-breeder.
‡ Wolf 77 selected areas closest to human activity during the daytime of all other wolves in the Ranch pack, and was subsequently shot during the fall (winter) hunting season Fall 2004.

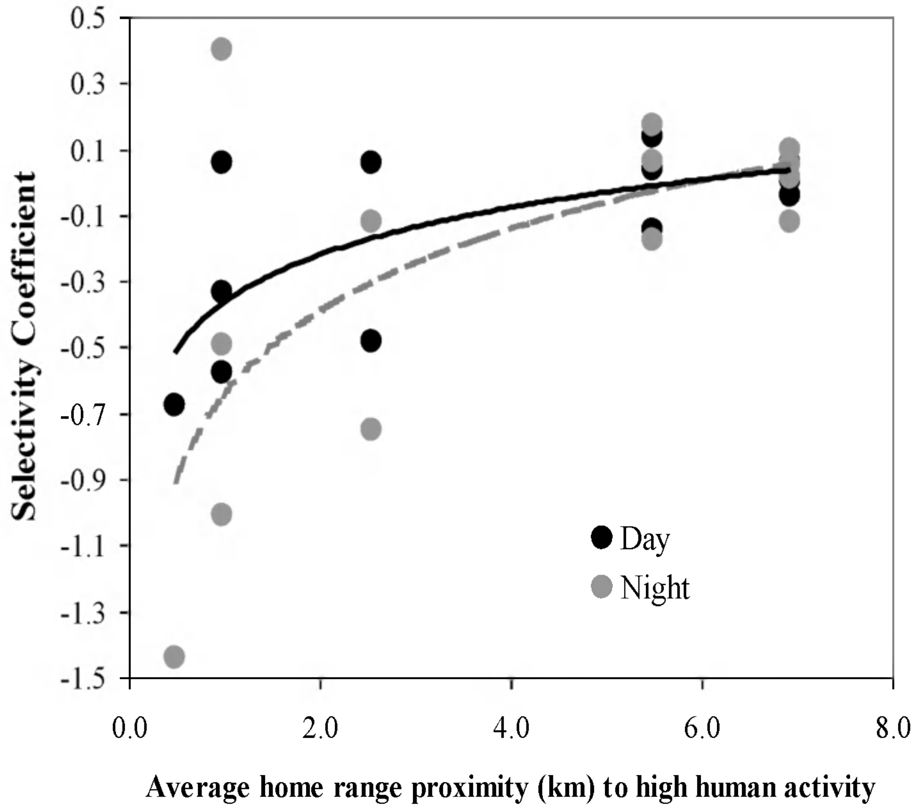

Figure S.1. Individual wolf functional response in selection as a function of proximity to average human activity at the wolf pack home-range level during night and day, winters 2002-2004.

References

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