# Supplementary Information to

**Displacement effects of conservation grazing on red deer (*Cervus elaphus*) spatial behaviour**

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## A) Supplementary tables

**Table SI.1** Conservation grazing terms at Glücksburger Heide, grazing sites listed together were used simultaneously; [a] for exact site location refer to Fig. 1 of the main article, [b] cut-off date for data included in the analysis, conservation grazing was still ongoing.

| Site[a] | From | To |
|---|---|---|
| South-west / south-east | 08.12.2016 | 21.12.2016 |
| North | 10.06.2017 | 23.07.2017 |
| South-west / south-east | 23.07.2017 | 26.09.2017 |
| South-west / south-east | 01.06.2018 | 03.09.2018 |
| North | 04.09.2018 | 16.10.2018[b] |

**Table SI.2** GPS collared red deer selected for analysis. Site affiliation refers conservation sites that are presented in Fig. 1 of the main article. Animals without end date were still transmitting at the time of data analysis.

| Animal ID | Sex | Age | Site affiliation | Start | End |
|---|---|---|---|---|---|
| 3 | f | Adult | South | 14.01.2015 | |
| 9 | f | Adult | South | 14.01.2015 | |
| 10 | f | Adult | South | 14.01.2015 | |
| 11 | f | Adult | South | 14.01.2015 | |
| 13 | f | Adult | South | 14.01.2015 | |
| 16 | f | Subadult (2016) | South | 14.01.2015 | 25.01.2018 |
| 40 | m | Adult | South | 19.09.2016 | |
| 20 | m | Adult | South | 26.09.2016 | |
| 5_2 | m | Adult | South | 26.09.2016 | 11.02.2017 |
| 34 | f | Adult | North | 05.03.2017 | |
| 37 | f | Adult | North | 05.03.2017 | |
| 44_3 | f | Subadult (2018) | North | 03.03.2017 | |

**Table SI.3** Overview of red deer GPS relocations selected for analysis. Treatment categories and time periods relate to conservation grazing on the northern site.

| | | | | GPS relocations | | |
|---|---|---|---|---|---|---|
| from | to | *treatment* | season | ID 34 | ID 37 | ID 44_3 |
| 18.05.2017 | 09.06.2017 | *pre-grazing* | summer | 258 | 260 | - |
| 10.06.2017 | 01.07.2017 | *early grazing* | summer | 249 | 250 | - |
| 02.07.2017 | 23.07.2017 | *ongoing grazing* | summer | 252 | 250 | - |
| 24.07.2017 | 14.08.2017 | *post-grazing* | summer | 269 | 248 | - |
| 13.08.2018 | 03.09.2018 | *pre-grazing* | summer | 140 | 257 | 54 |
| 04.09.2018 | 25.09.2018 | *early grazing* | summer | 151 | 140 | - |
| 26.09.2018 | 17.10.2018 | *ongoing grazing* | summer | 42 | 133 | - |
| - | - | *post-grazing* | summer | - | - | - |

**Table SI.4** Overview of red deer GPS relocations selected for analysis. Treatment categories and time periods relate to conservation grazing on two southern sites.

| | | | | GPS relocations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| from | to | *treatment* | season | ID 3 | ID 9 | ID 10 | ID 11 | ID 13 | ID 16 | ID 20 | ID 40 | ID 5_2 |
| 09.11.2016 | 07.12.2016 | *pre-grazing* | winter | 245 | 260 | 258 | 179 | 111 | 251 | 256 | 259 | 251 |
| 08.12.2016 | 21.12.2016 | *early grazing* | winter | 161 | 140 | 164 | 77 | 82 | 162 | 162 | 165 | 156 |
| - | - | *ongoing grazing* | winter | - | - | - | - | - | - | - | - | - |
| 22.12.2016 | 11.01.2017 | *post-grazing* | winter | 236 | 248 | 242 | 183 | 83 | 245 | 246 | 249 | 88 |
| 01.07.2017 | 22.07.2017 | *pre-grazing* | summer | 247 | 259 | 243 | 199 | 170 | 249 | 70 | 262 | - |
| 23.07.2017 | 14.08.2017 | *early grazing* | summer | 255 | 273 | 256 | 209 | 152 | 264 | - | 272 | - |
| 15.08.2017 | 05.09.2017 | *ongoing grazing* | summer | 240 | 260 | 248 | 205 | 191 | 252 | 76 | 258 | - |
| 27.09.2017 | 17.10.2017 | *post-grazing* | summer | 227 | 249 | 234 | 175 | 165 | 241 | 81 | 246 | - |
| 10.05.2018 | 31.05.2018 | *pre-grazing* | summer | 227 | 258 | 243 | 193 | 149 | - | - | 261 | - |
| 01.06.2018 | 22.06.2018 | *early grazing* | summer | 236 | 258 | 239 | 186 | 147 | - | - | 262 | - |
| 23.06.2018 | 14.07.2018 | *ongoing grazing* | summer | 225 | 260 | 237 | 195 | 166 | - | - | 260 | - |
| 04.09.2018 | 24.09.2018 | *ongoing grazing* | summer | 232 | 248 | 240 | 193 | 159 | - | - | 246 | - |

**Table SI.5** AIC-based model selection for the model describing red deer use during summer. Model candidates were considered supported if △ AIC ≥ 10 compared to the model candidate with the next lowest AIC value.

| | `glmer` model term | AIC | ΔAIC | $R_c^2$ | $R_m^2$ | supported |
|---|---|---|---|---|---|---|
| $\mathbf{m1}_{summer}$ | $Utilisation\ of\ grazing\ sites \sim time\ of\ the\ day + treatment + time\ of\ the\ day * treatment + (1 \mid animal\ ID)$ | 1665.480 | - | 0.305 | 0.550 | - |
| $\mathbf{m2}_{summer}$ | $\mathbf{m1}_{summer} + rut$ | 1643.562 | -21.918 | 0.322 | 0.554 | yes |
| $\mathbf{m3}_{summer}$ | $\mathbf{m2}_{summer} + calving$ | 1638.565 | -4.997 | 0.323 | 0.558 | no |

**Table SI.6** AIC-based model selection for the logistic regression used to derive coefficients of the summer RSF. Model candidates were considered supported if △ AIC ≥ 10 compared to the model candidate with the next lowest AIC value.

| | glmer model term | AIC | ΔAIC | $R_c^2$ | $R_m^2$ | supported |
|---|---|---|---|---|---|---|
| $\mathbf{m1}_{summerRSF}$ | $Selection\ of\ location\ \sim$ $cover$ $+\ NDVI$ $+\ distance\ to\ grazing\ site$ $+\ cover$ $\ldots *\ treatment\ *\ time\ of\ the\ day$ $+\ distance\ to\ grazing\ site$ $\ldots *\ treatment\ *\ time\ of\ the\ day$ $+\ (1\mid animal\ ID)$ | 111044 | - | 0.072 | 0.072 | - |
| $\mathbf{m2}_{summerRSF}$ | $\mathbf{m1}_{summerRSF}$ $+\ cover^2$ | 110919.9 | -124.1 | 0.080 | 0.080 | yes |
| $\mathbf{m3}_{summerRSF}$ | $\mathbf{m2}_{summerRSF}$ $+\ distance\ to\ grazing\ site^2$ | 110711 | -208.9 | 0.090 | 0.090 | yes |
| $\mathbf{m4}_{summerRSF}$ | $\mathbf{m3}_{summerRSF}$ $+\ NDVI^2$ | 110284.1 | -426.9 | 0.112 | 0.112 | yes |
| $\mathbf{m5}_{summerRSF}$ | $\mathbf{m4}_{summerRSF}$ $+\ cover\ *\ calving$ | 110073.2 | -210.9 | 0.118 | 0.118 | yes |
| $\mathbf{m6}_{summerRSF}$ | $\mathbf{m5}_{summerRSF}$ $+\ cover\ *\ rut$ | 110077.1 | +3.9 | 0.118 | 0.118 | no |

**Table SI.7** AIC-based model selection for the logistic regression used to derive coefficients of the winter RSF. Model candidates were considered supported if △ AIC ≥ 10 compared to the model candidate with the next lowest AIC value.

| | glmer model term | AIC | ΔAIC | $R_c^2$ | $R_m^2$ | supported |
|---|---|---|---|---|---|---|
| $\mathbf{m1}_{winterRSF}$ | $Selection\ of\ location\ \sim$ $cover$ $+\ NDVI$ $+\ distance\ to\ grazing\ site$ $+\ cover$ $\ldots *\ treatment\ *\ time\ of\ the\ day$ $+\ distance\ to\ grazing\ site$ $\ldots *\ treatment\ *\ time\ of\ the\ day$ $+\ (1\mid animal\ ID)$ | 36487.31 | - | 0.234 | 0.238 | - |
| $\mathbf{m2}_{winterRSF}$ | $\mathbf{m1}_{winterRSF}$ $+\ cover^2$ | 36306.36 | -180.95 | 0.248 | 0.251 | yes |
| $\mathbf{m3}_{winterRSF}$ | $\mathbf{m2}_{winterRSF}$ $+\ distance\ to\ grazing\ site^2$ | 35968.27 | -338.09 | 0.389 | 0.393 | yes |
| $\mathbf{m4}_{winterRSF}$ | $\mathbf{m3}_{winterRSF}$ $+\ NDVI^2$ | 35964.05 | -4.22 | 0.389 | 0.393 | no |

**B) Supplementary equations**

**Equations SI.1 and SI.2** Resource Selection Function for the summer; base function for the reference levels (equation SI.2) with the scenario-specific extensions (equation SI.2).

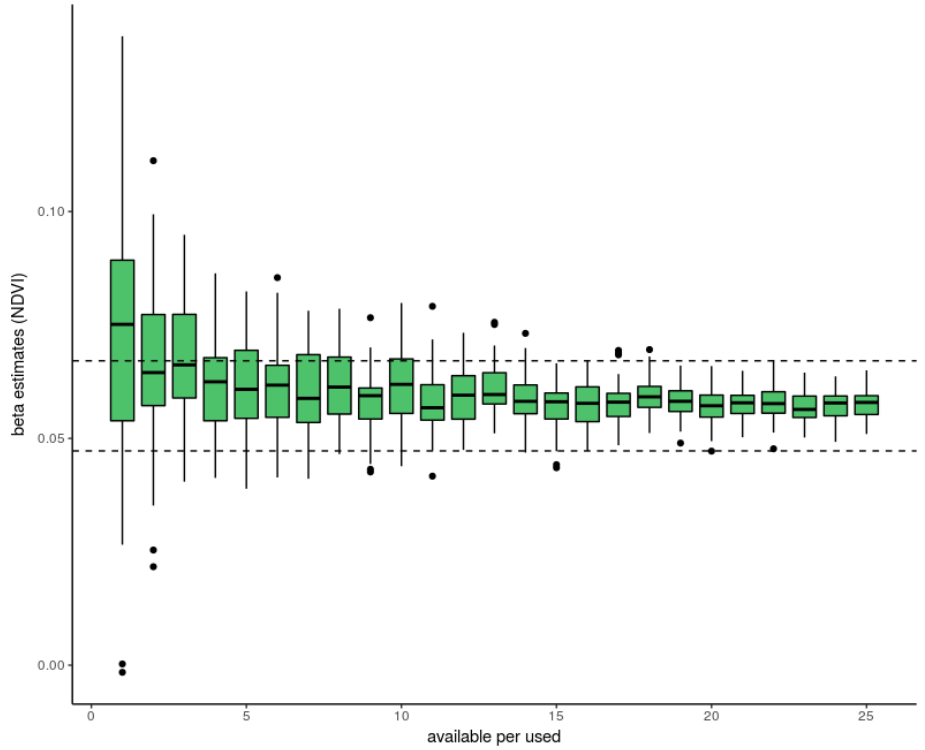
$$
\begin{aligned}
w = exp( \; & 0.063830 * cover \\
& - 0.105948 * cover^2 \\
& + 0.251224 * NDVI \\
& - 0.154700 * NDVI^2 \\
& - 0.383457 * distance\ to\ grazing\ site \\
& - 0.114533 * distance\ to\ grazing\ site^2 \qquad (1) \\
& \\
& - 0.079469 * aftergrazing \\
& + 0.092512 * night \\
& + 0.108984 * twilight \\
& - 0.134478 * calving \\
& + 0.297816 * cover * early\ grazing \\
& + 0.306423 * cover * ongoing\ grazing \\
& + 0.489362 * cover * aftergrazing \\
& - 0.562642 * cover * night \\
& - 0.290562 * cover * twilight \\
& - 0.188606 * ongoing\ grazing * night \\
& + 0.323440 * distance\ to\ grazing\ site * early\ grazing \\
& + 0.592911 * distance\ to\ grazing\ site * ongoing\ grazing \\
& + 0.530440 * distance\ to\ grazing\ site * aftergrazing \\
& + 0.502155 * distance\ to\ grazing\ site * night \\
& + 0.353136 * distance\ to\ grazing\ site * twilight \\
& + 0.424647 * cover * calving \\
& - 0.478894 * cover * early\ grazing * night \\
& - 0.465471 * cover * ongoing\ grazing * night \\
& - 0.341177 * cover * aftergrazing * night \\
& - 0.261897 * cover * early\ grazing * twilight \\
& - 0.279425 * cover * ongoing\ grazing * twilight \\
& - 0.240115 * distance\ to\ grazing\ site * early\ grazing * night \\
& - 0.341413 * distance\ to\ grazing\ site * ongoing\ grazing * night \\
& - 0.390236 * distance\ to\ grazing\ site * aftergrazing * night \\
& - 0.195044 * distance\ to\ grazing\ site * ongoing\ grazing * twilight) \qquad (2)
\end{aligned}
$$

**Equations SI.3 and SI.4** Resource Selection Function for the winter; base function for the reference levels (equation SI.3) with the scenario-specific extensions (equation SI.4).

$$
\begin{aligned}
w = exp( \; & 0.3096964 * cover \\
& - 0.3505960 * cover^2 \\
& + 0.2267749 * NDVI \\
& - 1.7420097 * distance\ to\ grazing\ site \\
& - 0.3897231 * distance\ to\ grazing\ site^2 \qquad (3) \\
\\
& + 0.5336198 * earlygrazing \\
& + 0.3694910 * aftergrazing \\
& + 0.7121565 * night \\
& + 0.2590906 * twilight \\
& - 1.0059007 * cover * night \\
& - 0.2882686 * cover * twilight \\
& - 0.3335367 * grazing * night \\
& + 0.6890899 * distance\ to\ grazing\ site * earlygrazing \\
& + 0.4668890 * distance\ to\ grazing\ site * aftergrazing \\
& + 1.3263162 * distance\ to\ grazing\ site * night \\
& + 0.2427902 * distance\ to\ grazing\ site * twilight \\
& + 0.2903048 * cover * earlygrazing * night \\
& + 0.5652130 * cover * aftergrazing * night \\
& - 0.4220144 * distance\ to\ grazing\ site * earlygrazing * night \\
& - 0.5319586 * distance\ to\ grazing\ site * aftergrazing * night \qquad (4)
\end{aligned}
$$

**C) Supplementary Fig.**


**Fig. SI.1** GPS relocations of 12 red deer in Glucksburger Heide analysed in this study. Lightgreen and darkgreen represent deciduous and coniferous forest, respectively (Foresttype product HRL, Copernicus Land Monitoring Service 2018). Black lines mark the limit of the DBU-managed conservation area, grazing sites are highlighted in purple.



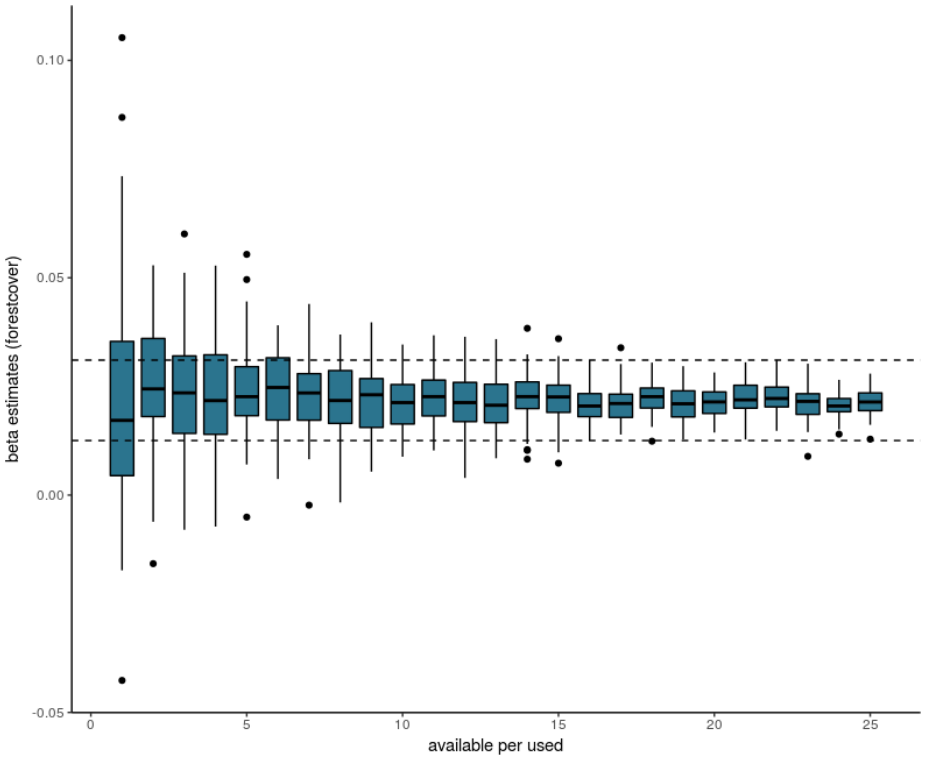




**Fig. SI.2 & SI.3** We performed a sensitivity analysis to assess the optimal ratio of used and available locations for the RSF. For that matter, a Generalized Linear Model (GLM) including NDVI and forest-cover as predictors was run for a subset of the data. The subset consisted of 1,783 used locations of one hind (ID 11) and available locations randomly sampled from its availability range. The GLM was run a total of 1,200 times - 50 runs each for 25 different used-available ratios (1:1 to 1:25) with each run of the same ratio sourcing from a new random draw of available locations. Presented Fig. show the results of the sensitivity analysis: **Fig. SI.2 (top)** shows beta-estimates for NDVI**; Fig. SI.3 (bottom)** shows beta-estimates for cover. Dotted lines mark the fluctuation of β estimates at the selected ratio of 1:16.

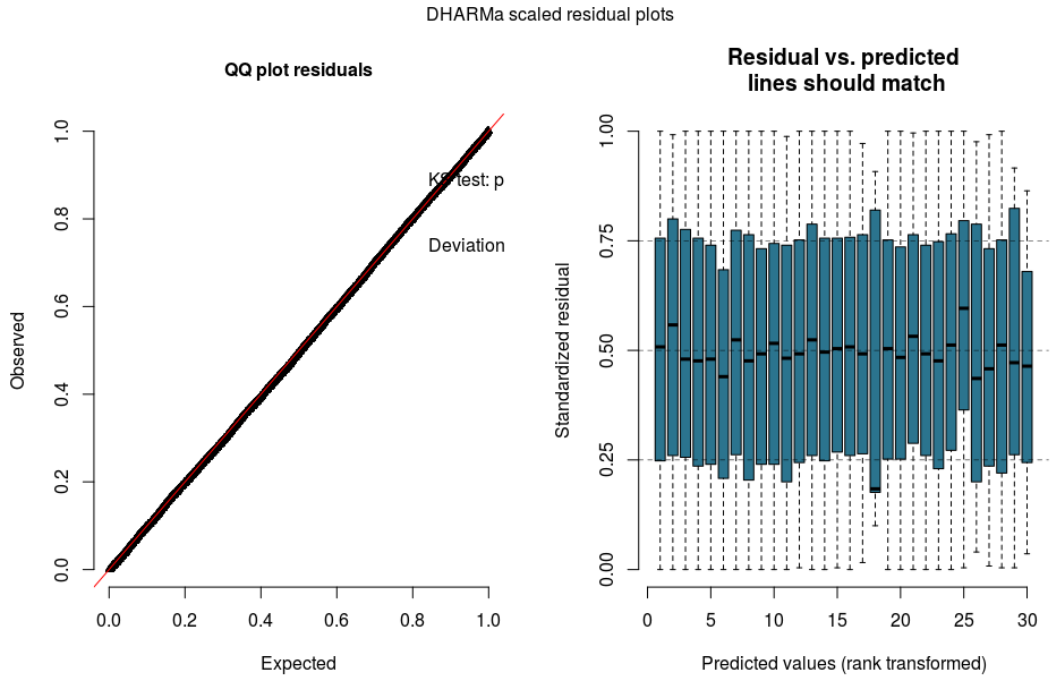



**Fig. SI.4** DHARMa diagnostic residual plots of the logistic regression modelling the red deer use of conservation grazing sites in summer.

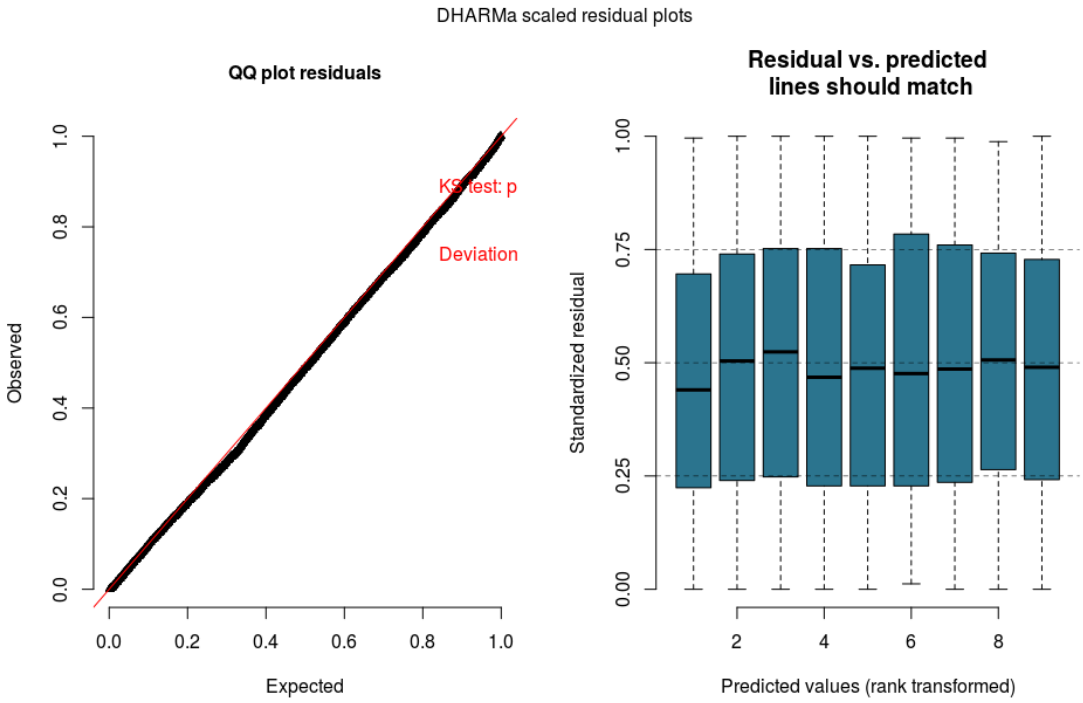



**Fig. SI.5** DHARMa diagnostic residual plots of the logistic regression modelling the red deer use of conservation grazing sites in winter.

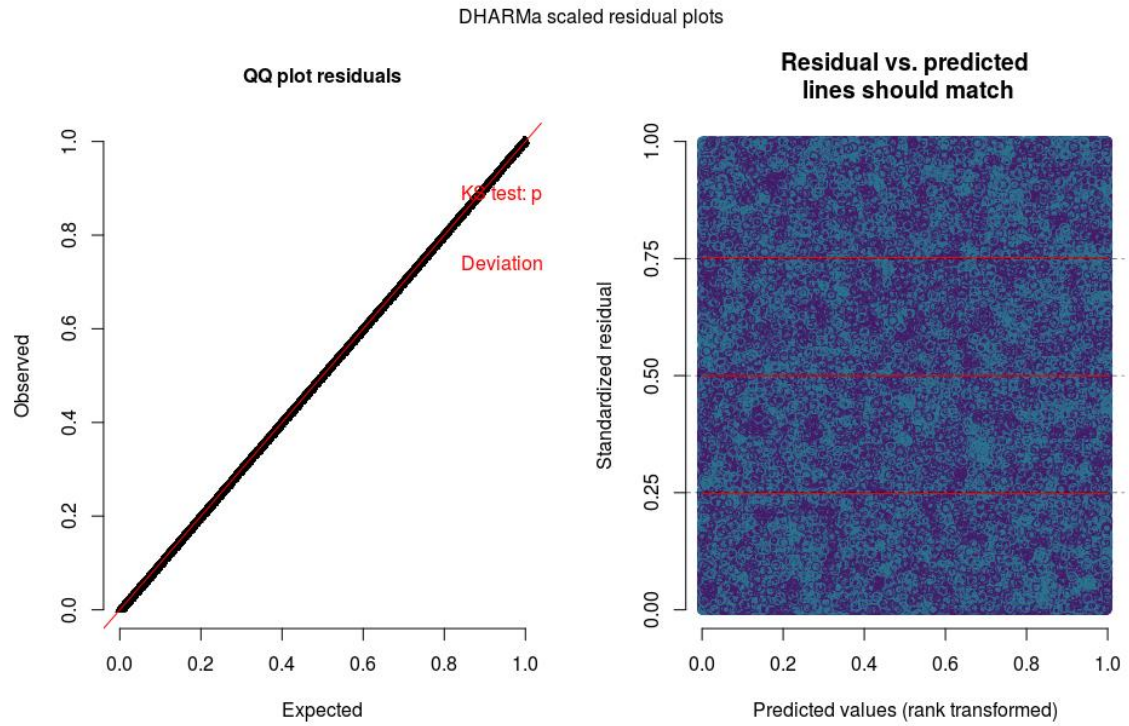



**Fig. SI.6** DHARMa diagnostic residual plots of the logistic regression used to derive coefficients of the summer RSF.

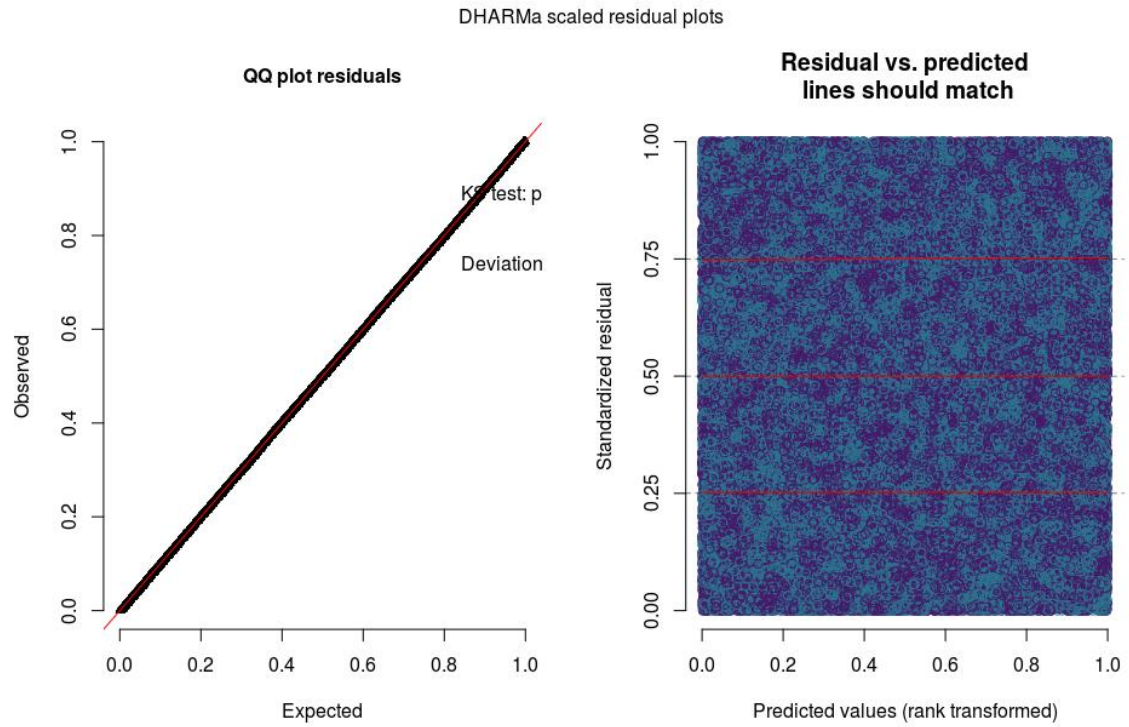



**Fig. SI.7** DHARMa diagnostic residual plots of the logistic regression used to derive coefficients of the winter RSF.

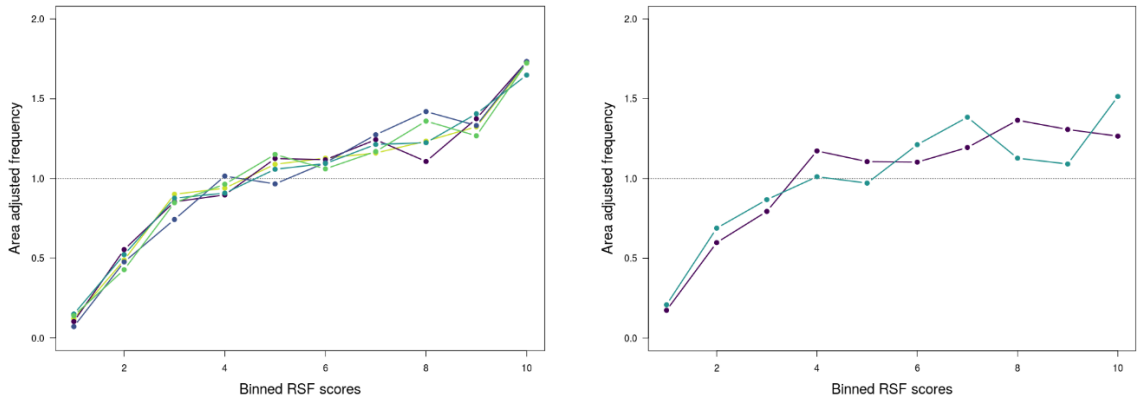



**Fig. SI.8 & SI.9** Cross-validation graphs of the summer RSF. **Fig. SI.8 (left)** 5-fold random cross-validation. **Fig. SI.9 (right)** 2-fold blocked cross-validation.

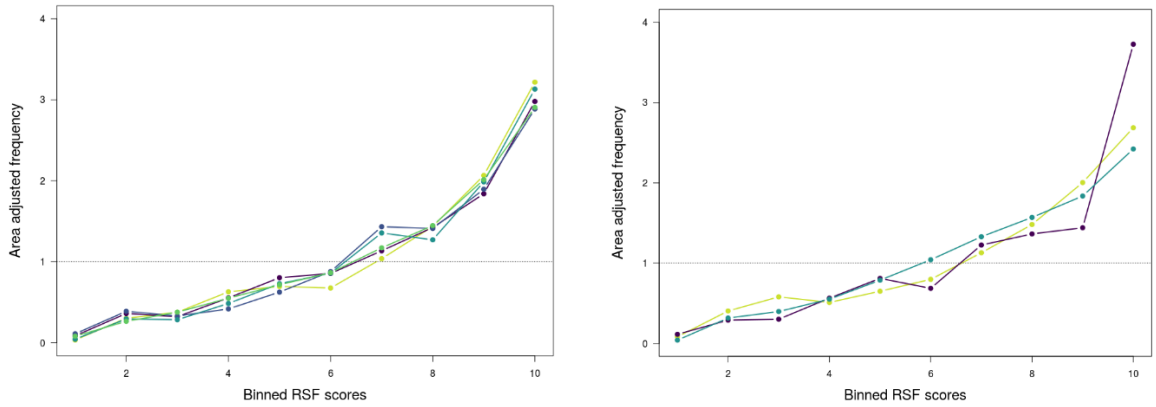



**Fig. SI.10 & SI.11** Cross-validation graphs of the winter RSF. **Fig. SI.10 (left)** 5-fold random cross-validation. **Fig. SI.11 (right)** 2-fold blocked cross-validation.

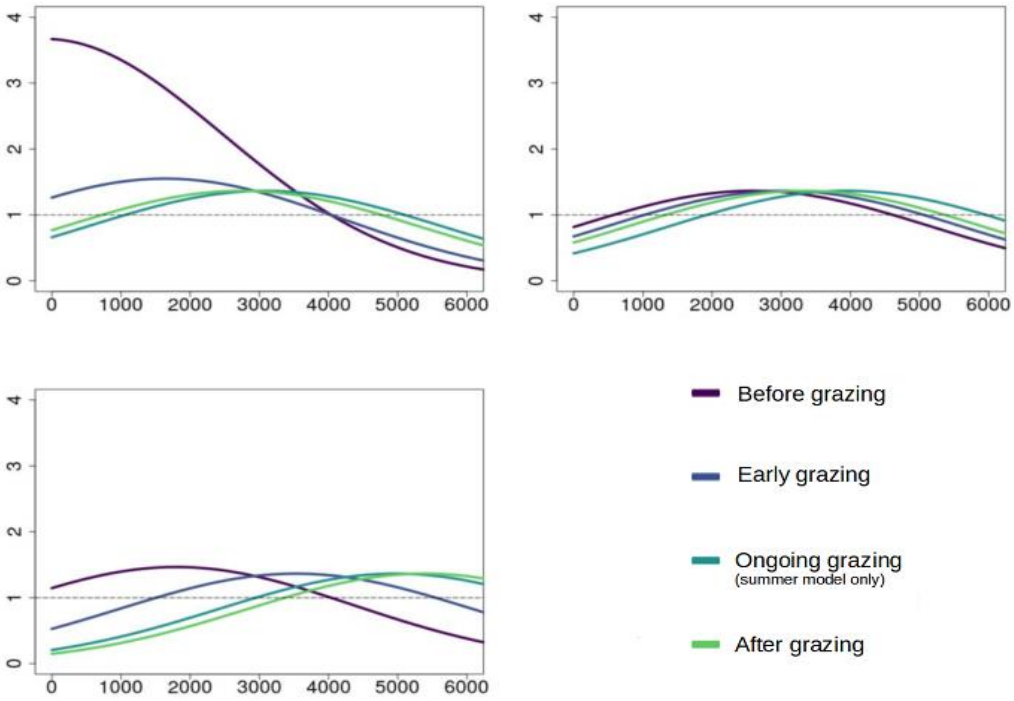



**Fig. SI.12** Resource selection for distance to conservation grazing sites during summer for day (**top-left**), night (**top-right**) and twilight (**bottom-left**) with distance (meters) on the x-axis and relative attractiveness (RSF score) on the y-axis.

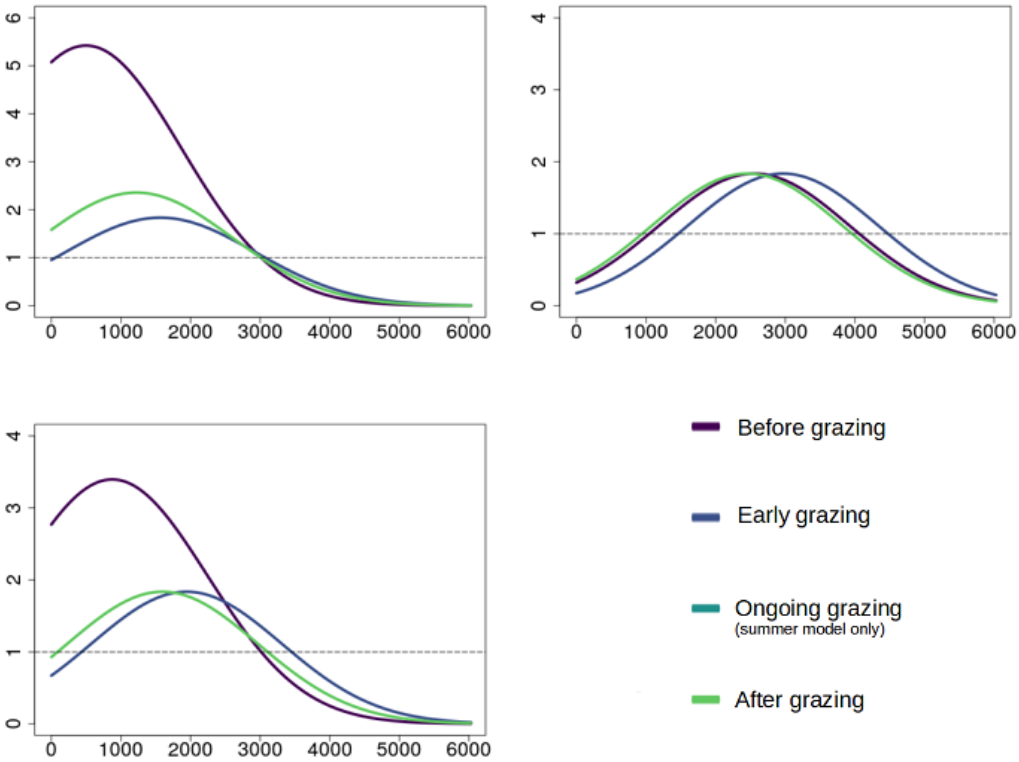



**Fig. SI.13** Resource selection for distance to conservation grazing sites during winter for day (**top-left**), night (**top-right**) and twilight (**bottom-left**) with distance (meters) on the x-axis and relative attractiveness (RSF score) on the y-axis.