**Supplementary material**

**Table S1.** List of predictor variables used for the occupancy models. The resolution of the data is 1 km2

## S2. Results of Pearson correlation and Kruskal-Wallis test

## S3. Spatial autocorrelation of dependent variable

**Table S4**. Six occupancy models with site-varying predictor variables for brown bear, Balkan lynx and grey wolf.

**Table S5.** The summary of the best-fit (first ranked) occupancy models with site-varying predictor variables with occurrences (detection) one and pseudo-absences (non-detection) zero

**Table S1.** List of predictor variables used for the occupancy models. The resolution of the data is 1 km2. Mean elevation was calculated from the original data of 15 m × 15 m resolution. Forest and woodland cover 2010 included land classifications 1- Evergreen Needle leaf Forest, 2- Evergreen Broadleaf Forest, 3- Deciduous Needle leaf Forest, 4-Deciduous Broadleaf Forest, 5- Mixed Forests, 6- Closed Shrublands, 7-Open Shrublands, 8-Woody Savannas, 14- Cropland/Natural Vegetation Mosaic.

|  |
| --- |
| **Definition of the variable** |
| *Land cover 2001* |
| Beech pure and mixed with coniferous forests (percent, Km2) |
| Mixed broadleaved class (percent, Km2) |
| Coniferous forests (percent, Km2) |
| Cultivated land (percent, Km2) |
| Mediterranean *macchia* (percent, Km2) |
| Bare rocks and soil (percent, Km2) |
| Oak forests (percent, Km2) |
| *Land cover 2010* |
| Deciduous broadleaf forest as proxy of Beech pure and mixed with coniferous forests of the year 2001, Km2 |
| Mixed forests, Km2 |
| Evergreen needle leaf forest as a proxy of Coniferous forests of the year 2001, Km2 |
| Woody savannas used as a proxy of Mediterranean macchia of the year 2001, Km2 |
| *Forest cover*  |
| Forest & woodland cover 2000, (percent) |
| Forest and woodland cover 2010  |
| *Natural environment (abiotic) and biological (biotic) variables*  |
| Elevation (Meters) |
| Terrain ruggedness index, (Unitless) |
| Brown bear neighbour grid cells (10 km × 10 km) |
| Balkan Lynx neighbour grid cells (10 km × 10 km) |
| Grey wolf neighbour grid cells (10 km × 10 km) |
| *Anthropogenic variables* |
| Distance to nearest dwelling road (Meters) |
| Distance to nearest village (Meters) |
| Road density, (Km) |

## S2. Results of Pearson correlation and Kruskal-Wallis test

There were no correlation between predictor variables for brown bear and for wolf. There were correlation between forest cover in the years 2000 and forest cover in the year 2010, between distance to nearest village and elevation and between distance to nearest village and distance to nearest dwelling roads for lynx occupancy modelling.

Predictor variables of brown bear that remained after the Kruskal-Wallis test were as follows: forest and woodland cover 2000, elevation, cultivated land, mixed broadleaved forests, bare rocks and soil, terrain ruggedness index, *Mediterranean macchia*. Yet, distance to nearest village was exempted and used as an explanatory anthropogenicvariable for brown bear. Forest and land cover data of the year 2010 that passed the test with brown bear occurrence record data of the year 2010 were elevation and forest and woodland cover 2010.

For the Balkan lynx occurrence data of the year 2001, predictor variables that passed the Kruskal-Wallis test, were as follows: elevation, beech pure and mixed with coniferous forests, cultivated land, mixed broadleaved forests, distance to nearest dwelling road, forest and woodland cover 2000, terrain ruggedness index. Yet, bare rocks and soil and distance to nearest village was exempted and used respectively as explanatory land (natural conditions and resources) and anthropogenicvariables for Balkan lynx. Forest and land cover data of the year 2010 that passed the Kruskal-Wallis test with Balkan lynx occurrence data record of the year 2011 were mixed broadleaved forests and *Mediterranean macchia.*

For grey wolf models, predictor variables that passed the Kruskal-Wallis test are as follows: forest and woodland cover 2000, elevation, terrain ruggedness index, mixed broadleaved forests, coniferous forests, cultivated land, distance to nearest village. However, road density was exempted and used as an explanatory anthropogenicvariable for grey wolf. Forest and land cover of the year 2010 that passed the test with grey wolf species occurrence record data of the year 2011 were elevation and mixed broadleaved forests.

**S3. Spatial autocorrelation of dependent variable**

Spatial autocorrelation of dependent variables should be checked to decide whether to use samples or not; samples could be used to reduce the spatial autocorrelation of the dependent variable. The spatial autocorrelation of dependent variable jeopardize the results (Naves et al., 2003)⁠⁠, for this reason spatial autocorrelation of the dependent variable was checked using Geoda095i. The autocorrelation of large carnivore species occurrences (1 km2)is expected to be statistically insignificant (see May et al., 2008). ⁠

## S4. Model types derived from different hypothesis, based on available knowledge of carnivores’ biology: Occupancy models

Species models were composed of terrain ruggedness index and forest cover of the year 2000 for the initial occupancy and forest cover 2010 for species colonization and detection probabilities. Bared rocks and soil land type were used to investigate any effect of bared rocks and soil land type to the colonization process of Balkan lynx occupancy. The first rank (∆AIC < 2) large carnivore species occupancy models with site-varying predictor variables are shown in Table S5.

**Table S4**. Six occupancy models with site-varying predictor variables for brown bear, Balkan lynx and grey wolf. ψ1= initial occupancy probability γ=colonization probability, ε= extinction probability, and p=detection probability, Y=year, 14, 15=forest cover in the years 2000 and 2010. The summary of the best-fit (first ranked) occupancy models with site-varying predictor variables with occurrences (detection) one and pseudo-absences (non-detection) zero are in Table S5.

|  |  |  |
| --- | --- | --- |
| **No.** | **Sub-model** | **Models with site-varying predictor variables** |
| Brown bear  | Balkan lynx | Grey wolf  |
| 1 | ψ1: | 7, 10 | 7, 9, 1, 6 | 7, 10  |
|  | γ: | 8, 10 | 8, 9 | 8, 10  |
|  | ε: | 7, 8, 2, 15 | 7, 14, 2, 1 | 16  |
|  | p: | 8, 10  | 8, 10 | 8, 10  |
| 2 | ψ1: | 7, 1, 10, 2 | 7, 10, 14 | 7, 9, 10  |
|  | γ: | 8, 11, 10  | 8, 10 | 8, 9, 10  |
|  | ε: | 1, 15 | 7, 14, 1, 2 | 7, 8, 9, 10, 15 |
|  | p: | 11, 8, 10  | 10, 8  |  |
| 3 | ψ1: | 7, 10, 2  | 7, 10  | 7, 9, 10  |
|  | γ: | 8, 10, 11  | 8, 10, 12  | 8, 9, 10  |
|  | ε: | 7, 8, 1, 15  | 7, 14, 2, 1  | 7, 8, 9, 10, 15  |
|  | p: | 8, 10  | 10, 8  |  |
| 4 | ψ1: | 7, 9, 15  | 7, 10, 1  | 7, 10, 9  |
|  | γ: | 8, 10, 11  | 8, 10, 12 | 8, 10  |
|  | ε: | 7, 8, 15  | 7, 5, 15, 1, 2  | 7, 8, 9, 10, 15  |
|  | p: | 9, 10, 8  | 10, 8, 6 | 7, 8, 9, 10, 15  |
| 5 | ψ1: | 7, 10, 3  | 7, 10, 5  | 7, 10, 3  |
|  | γ: | 8, 10, 11  | 8, 10, 12  | 8, 10, 13  |
|  | ε: | 14, 5  | 7, 14, 15, 2, 1  | 8, 5, 16  |
|  | p: | 9, 10, 8 | 12, 10, 8 | 10, 8  |
| 6 | ψ1: | 7, 10, 5  | 7, 10, 15 | 7, 10, 3  |
|  | γ: | 8, 10, 11  | 8, 10, 12  | 8, 10, 13  |
|  | ε: | 7, 8, 15  | 7, 152, 2, 1 | 16 |
|  | p: | 8, 10  | 12, 10, 8 | 13, 10, 8  |

Notes: 1=beech pure and mixed with coniferous forests; 2=mixed broadleaved forests; 3= coniferous forests, 5 = *Mediterranean macchia*, 6=bare rocks and soil; 7= forest cover in the year 2000; 8= forest cover in the year 2010; 9=elevation; 10=terrain ruggedness index; 11 = brown bear neighbouring grid cells (10 km × 10 km), 12 = Balkan lynx neighbouring grid cells (10 km × 10 km), 13= grey wolf neighbouring grid cells (10 km × 10 km), 14 = distance to nearest dwelling road, 15= distance to nearest village, 16 = road density.

**Table S5.**  The summary of the best-fit (first ranked) occupancy models with site-varying predictor variables with occurrences (detection) one and non-detection zero shown in Figure 1 followed by the summary of results for initial occupancy, colonization, extinction and detection models, Akaike’s Information Criterion (AIC), predictor variables, estimated coefficients, standard errors (SE) of estimated coefficients, *p-value* of estimated coefficients, bootstrap standard errors (B SE) (B=1000) for the years 2001 and 2011 and percent of occupied grid cells in the years 2001 and 2011 for every large carnivore species. The assumptions on the correlations between species occupancy and predictor variables are in Table 1. The model number corresponds to the model number of Table S4.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Brown bear | Model | AIC | ΔAIC | AICwi,(%) | Predictor variables  | Coefficients | SE | *p-value* | B SE, 2001 | B SE, 2011 | Percent of occupied grid cells, 2001  | Percent of occupied grid cells, 2011 |
| Initial occupancy sub-model  | 4 | 162.2 | 0.0 | 72.0 | 7 | 0.18 | 0.21 | 0.38 | 0.04 | 0.04 | 38 | 61 |
|  |  |  |  |  | 9 | 0.84 | 0.31 | 0.006 |  |  |  |  |
|  |  |  |  |  | 15 | -0.18 | 0.26 | 0.48 |  |  |  |  |
|  |  |  |  |  | intercept | -0.55 | 0.21 | 0.009 |  |  |  |  |
| Colonization sub-model |  |  |  |  | 8 | 2.03 | 139.1 | 0.98 |  |  |  |  |
|  |  |  |  |  | 10 | 1.12 | 88.0 | 0.99 |  |  |  |  |
|  |  |  |  |  | 11 | 0.59 | 93.1 | 0.99 |  |  |  |  |
|  |  |  |  |  | intercept | 13.40 | 10.6.4 | 0.90 |  |  |  |  |
| Extinction sub-model |  |  |  |  | 7 | -0.002 | 41.0 | 1.00 |  |  |  |  |
|  |  |  |  |  | 8 | 2.01 | 127.4 | 0.98 |  |  |  |  |
|  |  |  |  |  | 15 | 0.60 | 43.5 | 0.98 |  |  |  |  |
|  |  |  |  |  | intercept | 10.9 | 43.6 | 0.80 |  |  |  |  |
| Detection sub-model |  |  |  |  | 9 | 0.34 | 47.2 | 0.99 |  |  |  |  |
|  |  |  |  |  | 10 | 0.22 | 51.1 | 0.99 |  |  |  |  |
|  |  |  |  |  | 8 | 1.47 | 124.3 | 0.99 |  |  |  |  |
|  |  |  |  |  | intercept | 12.3 | 53.8 | 0.81 |  |  |  |  |
| Balkan Lynx | Model | AIC | ΔAIC | AICwi,(%) | Variables | Coefficients | SE | *p-value* | B SE, 2001 | B SE, 2011 | Percent of occupied grid cells, 2001  | Percent of occupied grid cells, 2011 |
| Initial occupancy sub-model  | 2 | 39.8 | 0.0 | 38.1 | 7 | 2.29 | 1.52 | 0.13 | 0.11 | 0.10 | 47 | 52 |
|  |  |  |  |  | 10 | 6.37 | 3.72 | 0.08 |  |  |  |  |
|  |  |  |  |  | 14 | -0.0001 | 0.79 | 1.00 |  |  |  |  |
|  |  |  |  |  | intercept | -1.29 | 1.46 | 0.37 |  |  |  |  |
| Colonization sub-model |  |  |  |  | 8 | 0.41 | 124.5 | 0.99 |  |  |  |  |
|  |  |  |  |  | 10 | -2.11 | 80.0 | 0.97 |  |  |  |  |
|  |  |  |  |  | intercept | 9.43 | 43.1 | 0.82 |  |  |  |  |
| Extinction sub-model |  |  |  |  | 7 | 0.93 | 60.6 | 0.98 |  |  |  |  |
|  |  |  |  |  | 14 | 1.32 | 77.6 | 0.98 |  |  |  |  |
|  |  |  |  |  | 1 | 0.05 | 65.5 | 0.99 |  |  |  |  |
|  |  |  |  |  | 2 | -0.83 | 70.9 | 0.99 |  |  |  |  |
|  |  |  |  |  | intercept | 9.60 | 44.2 | 0.82 |  |  |  |  |
| Detection sub-model |  |  |  |  | 10 | 0.005 | 65.5 | 0.99 |  |  |  |  |
|  |  |  |  |  | 8 | 0.73 | 119.3 | 0.99 |  |  |  |  |
|  |  |  |  |  | intercept | 10.58 | 41.4 | 0.79 |  |  |  |  |
| Initial occupancy sub-model  | 3 | 39.8 | 0.0 | 38.0 | 7 | 2.29 | 1.49 | 0.12 |  |  |  |  |
|  |  |  |  |  | 10 | 6.38 | 3.70 | 0.08 |  |  |  |  |
|  |  |  |  |  | intercept | -1.29 | 1.33 | 0.33 |  |  |  |  |
| Colonization sub-model |  |  |  |  | 8 | 0.27 | 124.2 | 0.99 |  |  |  |  |
|  |  |  |  |  | 10 | -0.65 | 73.5 | 0.99 |  |  |  |  |
|  |  |  |  |  | 12 | 2.09 | 97.8 | 0.98 |  |  |  |  |
|  |  |  |  |  | intercept | 9.05 | 44.2 | 0.83 |  |  |  |  |
| Extinction sub-model |  |  |  |  | 7 | 0.73 | 58.2 | 0.99 |  |  |  |  |
|  |  |  |  |  | 14 | 0.96 | 72.2 | 0.98 |  |  |  |  |
|  |  |  |  |  | 2 | -0.52 | 69.0 | 0.99 |  |  |  |  |
|  |  |  |  |  | 1 | 0.01 | 51.1 | 1.00 |  |  |  |  |
|  |  |  |  |  | intercept | 9.60 | 43.9 | 0.82 |  |  |  |  |
| Detection sub-model |  |  |  |  | 10 | 0.01 | 40.7 | 1.00 |  |  |  |  |
|  |  |  |  |  | 8 | 0.65 | 117.3 | 0.99 |  |  |  |  |
|  |  |  |  |  | intercept | 10.55 | 40.7 | 0.79 |  |  |  |  |
| Grey wolf | Model | AIC | ΔAIC | AICwi,(%) | Variables | Coefficients | SE | *p-value* | B SE, 2001 | B SE, 2011 | Percent of occupied grid cells, 2001  | Percent of occupied grid cells, 2011 |
| Initial occupancy sub-model  | 3 | 30.1 | 0.0 | 38.1 | 7 | -2.45 | 45.0 | 0.95 | 0.04 | 0.04 | 42 | 57 |
|  |  |  |  |  | 9 | -0.29 | 38.7 | 0.99 |  |  |  |  |
|  |  |  |  |  | 10 | 23.7 | 67.0 | 0.72 |  |  |  |  |
|  |  |  |  |  | intercept | 5.52 | 51.4 | 0.91 |  |  |  |  |
| Colonization sub-model |  |  |  |  | 8 | 1.71 | 169.2 | 0.99 |  |  |  |  |
|  |  |  |  |  | 9 | -0.32 | 66.5 | 0.99 |  |  |  |  |
|  |  |  |  |  | 10 | -6.50 | 150.9 | 0.96 |  |  |  |  |
|  |  |  |  |  | intercept |  | 128.4 | 0.95 |  |  |  |  |
| Extinction sub-model |  |  |  |  | 7 | 1.96 | 177 | 0.99 |  |  |  |  |
|  |  |  |  |  | 8 | 1.77 | 186 | 0.99 |  |  |  |  |
|  |  |  |  |  | 9 | 5.41 | 165 | 0.97 |  |  |  |  |
|  |  |  |  |  | 10 | 8.93 | 188 | 0.96 |  |  |  |  |
|  |  |  |  |  | 15 | 0.95 | 166 | 0.99 |  |  |  |  |
|  |  |  |  |  | intercept | 16.11 | 193 | 0.93 |  |  |  |  |
| Detection sub-model |  |  |  |  | intercept | 13.5 | 57.1 | 0.81 |  |  |  |  |
| Initial occupancy sub-model  | 5 | 30.1 | 0.0 | 38.0 | 7 | -0.43 | 33.8 |  |  |  |  |  |
|  |  |  |  |  | 10 | 5.38 | 160.0 |  |  |  |  |  |
|  |  |  |  |  | 3 | -0.60 | 45.7 |  |  |  |  |  |
|  |  |  |  |  | intercept | -10.8 | -10.8 |  |  |  |  |  |
| Colonization sub-model |  |  |  |  | 8 | 0.41 | 147.5 |  |  |  |  |  |
|  |  |  |  |  | 10 | 0.00 | 159.2 |  |  |  |  |  |
|  |  |  |  |  | 13 | 2.21 | 81.1 |  |  |  |  |  |
|  |  |  |  |  | intercept | 9.82 | 52.2 |  |  |  |  |  |
| Extinction sub-model |  |  |  |  | 8 | 1.63 | 0.99 |  |  |  |  |  |
|  |  |  |  |  | 5 | 9.56 | 0.95 |  |  |  |  |  |
|  |  |  |  |  | 16 | 1.44 | 0.99 |  |  |  |  |  |
|  |  |  |  |  | intercept | 12.0 | 0.84 |  |  |  |  |  |
| Detection sub-model |  |  |  |  | 10 | 0.26 | 0.99 |  |  |  |  |  |
|  |  |  |  |  | 8 | 1.41 | 0.99 |  |  |  |  |  |
|  |  |  |  |  | intercept | 12.24 | 0.79 |  |  |  |  |  |

Notes: 1=beech pure and mixed with coniferous forests; 2=mixed broadleaved forests; 3= coniferous forests, 5 = *Mediterranean macchia*, 6=bare rocks and soil; 7= forest cover in the year 2000; 8= forest cover in the year 2010; 9=elevation; 10=terrain ruggedness index; 11 = brown bear neighbouring grid cells (10 km × 10 km), 12 = Balkan lynx neighbouring grid cells (10 km × 10 km), 13= grey wolf neighbouring grid cells (10 km × 10 km), 14 = distance to nearest dwelling road, 15= distance to nearest village, 16 = road density.

**References**

Naves, J. et al. (2003) ‘Endangered Species Constrained by Natural and Human Factors: The Case of Brown Bears in Northern Spain’, Conservation Biology. [Wiley, Society for Conservation Biology], 17(5), pp. 1276–1289. Available at: http://www.jstor.org/stable/3588953.

May, R. et al. (2008) ‘Habitat differentiation within the large-carnivore community of Norway’s multiple-use landscapes’, Journal of Applied Ecology. Blackwell Publishing Ltd, 45(5), pp. 1382–1391. doi: 10.1111/j.1365-2664.2008.01527.x.