**Supplementary Material**

Guiding local-scale management to improve the conservation of endangered populations: the example of Bonelli’s Eagle *Aquila fasciata*

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Table S1. List of the territorial explanatory variables grouped in sets by tested hypothesis: species’ ecological requirements (H1), human disturbances (H2), mortality by power lines (H3), and individual and intraspecific characteristics (H4). For each explanatory variable, a variable code and a description of how each predictor variable was obtained is provided.

|  |  |  |
| --- | --- | --- |
| Set of variables | Original predictor variables | Description |
| Physical and orographic H1 | Altitude | Average altitude (m.a.s.l.) of the 15 m resolution pixels from the Digital Elevation Model of Catalonia (MET15). Source: Institut Cartogràfic i Geològic de Catalunya (<http://www.icgc.cat/>). |
| Roughness | Standard deviation of the altitude (m) of the 15 m resolution pixels from the Digital Elevation Model of Catalonia (MET15). Source: Institut Cartogràfic i Geològic de Catalunya (<http://www.icgc.cat/>). |
| Solar irradiation | Annual averaged-mean of solar irradiation (MJ/m2) of 100 m resolution pixels from the Solar Radiation Atlas of Catalonia. Source: Departament de Territori i Sostenibilitat, Generalitat de Catalunya (<http://territori.gencat.cat>). |
| Climatic H1 | Average temperature | Average temperature (°C) during the breeding season, from January to July. Source: Agencia Estatal de Meteorología (<http://www.aemet.es>). |
| Minimum temperature | Minimum temperature (°C) during the breeding season, from January to July. Source: Agencia Estatal de Meteorología (<http://www.aemet.es>). |
| Annual rainfall | Annual accumulated rainfall (L/m2). Source: Agencia Estatal de Meteorología (<http://www.aemet.es>). |
| April rainfall | April rainfall (L/m2). Source: Agencia Estatal de Meteorología (<http://www.aemet.es>). |
| Habitat and geology H1 | Shrubland | Shrubs (%) obtained by the reclassification of the land-use categories “Shrublands and grasslands”, “Soil with little or no vegetation” and “Burnt areas” from the Land-use map of Catalonia (Viñas and Baulies, 1995). Data from 1992, 1997 and 2002 were assigned to periods 1990-1994, 1995-1999 and 2000-2008 respectively. Source: Departament de Territori i Sostenibilitat, Generalitat de Catalunya (<http://territori.gencat.cat>). |
| Forest | Forests (%) obtained by the reclassification of the land-use categories “Sclerophyllous forests”, “Deciduous forests” and “Aciculifolia forests” from the Land-use map of Catalonia (Viñas and Baulies, 1995). Data from 1992, 1997 and 2002 were assigned to periods 1990-1994, 1995-1999 and 2000-2008 respectively. Source: Departament de Territori i Sostenibilitat, Generalitat de Catalunya (<http://territori.gencat.cat>). |
| Crops | Crops (%) obtained by the reclassification of different crop types from the Land-use map of Catalonia (Viñas and Baulies, 1995). Data from 1992, 1997 and 2002 were assigned to periods 1990-1994, 1995-1999 and 2000-2008 respectively. Source: Departament de Territori i Sostenibilitat, Generalitat de Catalunya (<http://territori.gencat.cat>). |
| Soft soils | Soft soils (%) derived from the Geological map of Catalonia 1:50 000. Soft soils were considered those from the Quaternary period, including clays, gravels, silts, loams and sands as predominant lithology. Source: Institut Cartogràfic i Geològic de Catalunya (<http://www.icgc.cat/>). |
| Burnt surface | Accumulated burnt surface (ha) during a period of 7 years, from 9 to 3 years before the considered year, assuming that forest fires have a positive effect on rabbit populations during this period (Rollan and Real, 2010). To do so, we used a database of fires in Catalonia. Source: Departament d’Agricultura, Ramaderia, Pesca i Alimentació, Generalitat de Catalunya (<http://agricultura.gencat.cat>). |
| Prey abundance H1 | European rabbit abundance | European rabbits captured every year (rabbits/km2) in private and local hunting areas, controlled hunting areas and national reserves. Captures were assumed to be an indirect estimate of real prey abundance. Source: Departament d’Agricultura, Ramaderia, Pesca i Alimentació, Generalitat de Catalunya (<http://agricultura.gencat.cat>). |
| Red-legged partridge abundance | Red-legged partridges captured every year (partridges/km2) in private and local hunting areas, controlled hunting areas and national reserves. Captures were assumed to be an indirect estimate of real prey abundance. Source: Departament d’Agricultura, Ramaderia, Pesca i Alimentació, Generalitat de Catalunya (<http://agricultura.gencat.cat>). |
| Wood pigeon abundance | Wood pigeons captured every year (pigeons/km2) in private and local hunting areas, controlled hunting areas and national reserves. Captures were assumed to be an indirect estimate of real prey abundance. Source: Departament d’Agricultura, Ramaderia, Pesca i Alimentació, Generalitat de Catalunya (<http://agricultura.gencat.cat>). |
| Human presence H2 | Regional population density | Annual average population (inhabitants/km2) of the counties where the vital area is located. Source: Institut d’Estadística de Catalunya, Generalitat de Catalunya (<https://www.idescat.cat/>). |
| Number of buildings | Number of buildings (buildings/km2), derived from the Topographic base of Catalonia 1:5000 (categories EDI01, EDI02 and EDI03). Source: Institut Cartogràfic i Geològic de Catalunya (<http://www.icgc.cat/>). |
| Length of paved roads | Length (km/km2) of paved roads, derived from the Topographic base of Catalonia 1:5000 (categories VIA01, VIA02, VIA03, VIA06, VIA07, VIA08, VIA09, VIA10 and VIA11). Source: Institut Cartogràfic i Geològic de Catalunya (<http://www.icgc.cat/>). |
| Length of trails | Length (km/km2) of unpaved trails suitable for 4WD vehicles, derived from the Topographic base of Catalonia 1:5000 (categories VIA16, VIA17 and VIA18). Source: Institut Cartogràfic i Geològic de Catalunya (<http://www.icgc.cat/>). |
| Length of footpaths | Length (km/km2) of unpaved footpaths, derived from the Topographic base of Catalonia 1:5000 (categories VIA21, VIA22 and VIA23). Source: Institut Cartogràfic i Geològic de Catalunya (<http://www.icgc.cat/>). |
| Power lines H3 | Distribution pylons | Number of distribution (25-66 kv) pylons (pylons/km2). Source: Power line companies (Endesa, Estabanell Energia and Electra Caldense Energia). |
| Distribution lines length | Length (km/km2) of distribution lines (25-66 kv). Source: Power line companies (Endesa, Estabanell Energia and Electra Caldense Energia). |
| Transmission lines length | Length (km/km2) of transmission lines ((≥ 110 kv). Source: Power line companies (Endesa and Red Eléctrica Española). |
| Power lines length | Length (km/km2) of both distribution (25-66 kv) and transmission lines ((≥ 110 kv). Source: Power line companies (Endesa, Estabanell Energia, Electra Caldense Energia, and Red Eléctrica Española). |
| Individual / intraspecific characteristics H4 | Couple's age | Whether the two members of the couple displayed adult plumage or not. Source: Long-term monitoring. |
| Age of the individual | Whether the individual displayed adult plumage or not. Source: Long-term monitoring. |
| Sex of the individual  | Sex of the individual (male or female). Source: Long-term monitoring. |
| Occupation of the territory in the previous year | Occupation status (occupied or not occupied) of the focal territory in the previous year. Source: Long-term monitoring. |
| Distance to the nearest neighbouring territories | Distance (km) to the nearest neighbouring territories. Source: Long-term monitoring. |

Viñas, O. and Baulies, X. (1995) 1:250000 Land-use map of Catalonia (32000 km2) using multi-temporal Landsat-TM data. *Int. J. Remote Sens.*, 16:1, 129-146.

Table S2.Preliminary GLMMs examining effect of predictor variables (Table 2) on territorial occupation. Models in bold indicates those selected for later model averaging procedure. Coefficient, standard errors (± SE), number of observations (n), AICc value of the null model (AICc null) and the model evaluated (AICc evl) are displayed for each of variable. AICc nul include the values of Occupation and random effects, except when the variable Occupation is compared with the models that only include the random factors.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Set of variables | Code | Coefficient (± SE) | n | AICc null | AICc evl |
| Physical and orographic H1 | **Altitude** | **-1.181 ± 0.234** | **1186** | **244.47** | **222.20** |
| Roughness | 0.083 ± 0.304 | 1186 | 244.47 | 246.39 |
| Irradiation | 0.227 ± 0.300 | 1186 | 244.47 | 245.80 |
| Climatic H1 | **Temperature\_1** | **0.990 ± 0.318** | **1186** | **244.47** | **235.48** |
| Temperature\_2 | 0.686 ± 0.256 | 1186 | 244.47 | 238.30 |
| Rainfall\_1 | -0.186 ± 0.262 | 1186 | 244.47 | 245.78 |
| Rainfall\_2 | -0.388 ± 0.272 | 1186 | 244.47 | 243.53 |
| Habitat and geology H1 | **Habitat\_1** | **0.363 ± 0.292** | **1186** | **244.47** | **244.67** |
| Habitat\_2 | 0.592 ± 0.399 | 1186 | 244.47 | 243.54 |
| **Burnt** | **0.214 ± 0.268** | **1186** | **244.47** | **245.59** |
| Prey abundance H1 | **Rabbit** | **0.554 ± 0.252** | **880** | **181.69** | **179.14** |
| Partridge | 0.156 ± 0.315 | 880 | 181.69 | 183.39 |
| **Pigeon** | **0.572 ± 0.292** | **876** | **181.56** | **179.27** |
|  Human presence H2 | **Human\_1** | **0.418 ± 0.343** | **1186** | **244.47** | **244.57** |
| **Human\_2** | **-0.444 ± 0.309** | **1186** | **244.47** | **244.00** |
| **Human\_3** | **0.065 ± 0.310** | **1186** | **244.47** | **246.42** |
| Power lines H3 | **Distribution\_1** | **-0.150 ± 0.299** | **1186** | **244.47** | **246.18** |
| **Distribution\_2** | **0.113 ± 0.315** | **1186** | **244.47** | **246.31** |
| **Transmission** | **-0.101 ± 0.310** | **1186** | **244.47** | **246.35** |
| Individual / intraspecific characteristics H4 | **Occupation** | **7.291 ± 0.599** | **1186** | **500.97** | **244.47** |
| **Neighbour** | **-0.231 ± 0.318** | **1186** | **244.47** | **245.85** |

Table S3.Preliminary GLMMs examining effect of predictor variables (Table 2) on territorial productivity. Models in bold indicates those selected for later model averaging procedure. Coefficient, standard errors (± SE), number of observations (n), AICc value of the null model (AICc null) and the model evaluated (AICc evl) are displayed for each of variable. AICc nul include the values of Occupation and random effects, except when the variable Occupation is compared with the models that only include the random factors.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Set of variables | Code | Coefficient (± SE) | n | AICc null | AICc evl |
| Physical and orographic H1 | **Altitude** | **-0.276 ± 0.147** | **865** | **1078.84** | **1077.39** |
| **Roughness** | **0.389 ± 0.134** | **865** | **1078.84** | **1072.79** |
| Irradiation | -0.136 ± 0.154 | 865 | 1078.84 | 1080.07 |
| Climatic H1 | Temperature\_1 | -0.012 ± 0.115 | 865 | 1078.84 | 1080.83 |
| **Temperature\_2** | **0.192 ± 0.091** | **865** | **1078.84** | **1076.63** |
| Rainfall\_1 | 0.100 ± 0.081 | 865 | 1078.84 | 1079.41 |
| **Rainfall\_2** | **0.123 ± 0.077** | **865** | **1078.84** | **1078.37** |
| Habitat and geology H1 | Habitat\_1 | 0.147 ± 0.142 | 865 | 1078.84 | 1079.81 |
| Habitat\_2 | 0.036 ± 0.137 | 865 | 1078.84 | 1080.77 |
| **Burnt** | **0.125 ± 0.086** | **865** | **1078.84** | **1078.78** |
| Prey abundance H1 | **Rabbit** | **0.281 ± 0.123** | **623** | **776.49** | **773.67** |
| **Partridge** | **0.299 ± 0.132** | **623** | **776.49** | **773.78** |
| Pigeon | -0.013 ± 0.133 | 623 | 776.49 | 775.09 |
|  Human presence H2 | **Human\_1** | **-0.239 ± 0.133** | **865** | **1078.84** | **1077.83** |
| **Human\_2** | **-0.111 ± 0.137** | **865** | **1078.84** | **1080.19** |
| **Human\_3** | **0.159 ± 0.139** | **865** | **1078.84** | **1079.57** |
| Power lines H3 | Distribution\_1 | -0.121 ± 0.134 | 865 | 1078.84 | 1080.06 |
| **Distribution\_2** | **0.135 ± 0.141** | **865** | **1078.84** | **1079.94** |
| Transmission | 0.034 ± 0.134 | 865 | 1078.84 | 1080.78 |
| Individual / intraspecific characteristics H4 | **Age** | **2.679 ± 0.231** | **844** | **1045.53** | **890.85** |
| **Neighbour** | **0.338 ± 0.126** | **865** | **1078.84** | **1073.97** |

Table S4. Preliminary GLMMs examining effect of predictor variables (Table 2) on survival of territorial individuals. Models in bold indicates those selected for later model averaging procedure. Coefficient, standard errors (± SE), number of observations (n), AICc value of the null model (AICc null) and the model evaluated (AICc evl) are displayed for each of variable. AICc nul include the values of Occupation and random effects, except when the variable Occupation is compared with the models that only include the random factors.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Set of variables | Code | Coefficient (± SE) | n | AICc null | AICc evl |
| Physical and orographic H1 | **Altitude** | **-0.270 ± 0.111** | **1639** | **1208.27** | **1204.58** |
| **Roughness** | **0.248 ± 0.110** | **1639** | **1208.27** | **1205.30** |
| Irradiation | -0.121 ± 0.121 | 1639 | 1208.27 | 1209.27 |
| Climatic H1 | **Temperature\_1** | **0.179 ± 0.100** | **1639** | **1208.27** | **1207.16** |
| Temperature\_2 | -0.045 ± 0.088 | 1639 | 1208.27 | 1210.03 |
| Habitat and geology H1 | Habitat\_1 | 0.092 ± 0.116 | 1639 | 1208.27 | 1209.64 |
| Habitat\_2 | 0.027 ± 0.111 | 1639 | 1208.27 | 1210.21 |
| Burnt | 0.083 ± 0.085 | 1639 | 1208.27 | 1209.32 |
| Prey abundance H1 | Rabbit | 0.141 ± 0.117 | 1240 | 907.06 | 907.64 |
| Partridge | -0.049 ± 0.125 | 1240 | 907.06 | 908.91 |
| Pigeon | -0.017 ± 0.124 | 1234 | 905.42 | 907.40 |
|  Human presence H2 | Human\_1 | 0.012 ± 0.111 | 1639 | 1208.27 | 1210.26 |
| Human\_2 | -0.041 ± 0.111 | 1639 | 1208.27 | 1210.14 |
| Human\_3 | 0.033 ± 0.113 | 1639 | 1208.27 | 1210.18 |
| Power lines H3 | **Distribution\_1** | **-0.086 ± 0.124** | **1623** | **1131.70** | **1133.24** |
| **Distribution\_2** | **0.040 ± 0.127** | **1623** | **1131.70** | **1133.61** |
| **Transmission** | **-0.073 ± 0.115** | **1619** | **1119.70** | **1121.31** |
| Individual / intraspecific characteristics H4 | **Age** | **0.987 ± 0.201** | **1625** | **1171.34** | **1153.10** |
| **Sex** | **-0.293 ± 0.155** | **1639** | **1208.27** | **1206.66** |
| Neighbour | 0.061 ± 0.108 | 1639 | 1208.27 | 1209.94 |

Table S5.Set of best-ranked GLMMs (ΔAICc i < 2) examining effect of selected predictor variables from Table S2 on territorial occupation.

|  |  |  |  |
| --- | --- | --- | --- |
| Candidate models | AICc | ΔAICc i | wi |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Distribution\_2 + Transmission + Pigeon + Neighbour  | 156.79 | 0 | 0.016 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Distribution\_2 + Transmission + Rabbit + Neighbour | 156.81 | 0.02 | 0.016 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 +Distribution\_2 + Transmission + Rabbit + Pigeon + Neighbour  | 156.99 | 0.20 | 0.015 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Burnt + Distribution\_2 + Transmission + Pigeon + Neighbour  | 157.68 | 0.89 | 0.010 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Burnt + Distribution\_2 + Transmission + Rabbit + Neighbour  | 157.98 | 1.19 | 0.009 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Human\_3 + Distribution\_2 + Transmission + Rabbit + Neighbour  | 158.15 | 1.36 | 0.008 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Burnt + Distribution\_2 + Transmission + Rabbit + Pigeon + Neighbour  | 158.22 | 1.43 | 0.008 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Distribution\_2 + Transmission + Neighbour  | 158.29 | 1.50 | 0.008 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Distribution\_2 + Distribution\_1 + Transmission + Pigeon + Neighbour  | 158.35 | 1.56 | 0.007 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Human\_3 + Distribution\_2 + Transmission + Rabbit + Pigeon + Neighbour  | 158.53 | 1.74 | 0.007 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Human\_3 + Distribution\_2 + Transmission + Pigeon + Neighbour  | 158.62 | 1.83 | 0.007 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Human\_1 + Distribution\_2 + Transmission + Rabbit + Pigeon + Neighbour  | 158.63 | 1.84 | 0.007 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Human\_1 + Distribution\_2 + Transmission + Pigeon + Neighbour  | 158.70 | 1.91 | 0.006 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Human\_1 + Distribution\_2 + Transmission + Rabbit + Neighbour  | 158.70 | 1.91 | 0.006 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Human\_2 + Distribution\_2 + Transmission + Pigeon + Neighbour  | 158.73 | 1.94 | 0.006 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Distribution\_2 + Distribution\_1 + Transmission + Rabbit + Pigeon + Neighbour  | 158.74 | 1.95 | 0.006 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Transmission + Rabbit  | 158.74 | 1.95 | 0.006 |
| Occupation + Altitude + Temperature\_1 + Habitat\_1 + Distribution\_2 + Distribution\_1 + Transmission + Rabbit + Neighbour  | 158.78 | 1.99 | 0.006 |

Table S6.Set of best-ranked GLMMs (ΔAICc i < 2) examining effect of selected predictor variables from Table S3 on territorial productivity.

|  |  |  |  |
| --- | --- | --- | --- |
| Candidate models | AICc | ΔAICc i | wi |
| Age + Roughness + Rainfall\_2 + Burnt + Rabbit + Neighbour  | 600.36 | 0 | 0.020 |
| Age + Roughness + Rainfall\_2 + Burnt + Rabbit  | 600.66 | 0.30 | 0.017 |
| Age + Rainfall\_2 + Burnt + Rabbit  | 601.49 | 1.13 | 0.011 |
| Age + Rainfall\_2 + Burnt + Rabbit + Neighbour  | 601.59 | 1.23 | 0.011 |
| Age + Roughness + Rainfall\_2 + Burnt + Human\_3 + Rabbit + Neighbour | 601.86 | 1.50 | 0.010 |
| Age + Roughness + Rainfall\_2 + Burnt + Human\_1 + Rabbit + Neighbour | 601.95 | 1.59 | 0.009 |
| Age + Roughness + Rainfall\_2 + Burnt + Human\_1 + Rabbit  | 602.08 | 1.72 | 0.009 |
| Age + Roughness + Rainfall\_2 + Burnt + Rabbit + Partridge | 602.12 | 1.76 | 0.008 |
| Age + Roughness + Temperature\_2 + Rainfall\_2 + Burnt + Rabbit + Neighbour  | 602.14 | 1.78 | 0.008 |
| Age + Roughness + Rainfall\_2 + Burnt + Rabbit + Partridge + Neighbour  | 602.27 | 1.91 | 0.008 |

Table S7.Set of best-ranked GLMMs (ΔAICc i < 2) examining effect of selected predictor variables from Table S4 on survival of territorial individuals.

|  |  |  |  |
| --- | --- | --- | --- |
| Candidate models | AICc | ΔAICc i | wi |
| Age + Altitude + Roughness + Sex | 1146.61 | 0 | 0.0573 |
| Age + Altitude + Roughness + Temperature\_1 + Sex | 1146.69 | 0.08 | 0.0550 |
| Age + Altitude + Roughness + Transmission + Sexe  | 1147.52 | 0.91 | 0.0363 |
| Age + Altitude + Roughness + Temperature\_1 + Transmission + Sex | 1147.68 | 1.07 | 0.0336 |
| Age + Altitude + Roughness  | 1147.69 | 1.08 | 0.0333 |
| Age + Altitude + Roughness + Temperature\_1  | 1147.76 | 1.15 | 0.0322 |
| Age + Roughness + Temperature\_1 + Sex | 1147.92 | 1.31 | 0.0298 |
| Age + Altitude + Roughness + Distribution\_2 + Sex | 1148.31 | 1.7 | 0.0244 |
| Age + Altitude + Roughness + Distribution\_1 + Sex | 1148.52 | 1.91 | 0.0220 |
| Age + Altitude + Roughness + Temperature\_1 + Distribution\_1 + Sex | 1148.57 | 1.96 | 0.0214 |