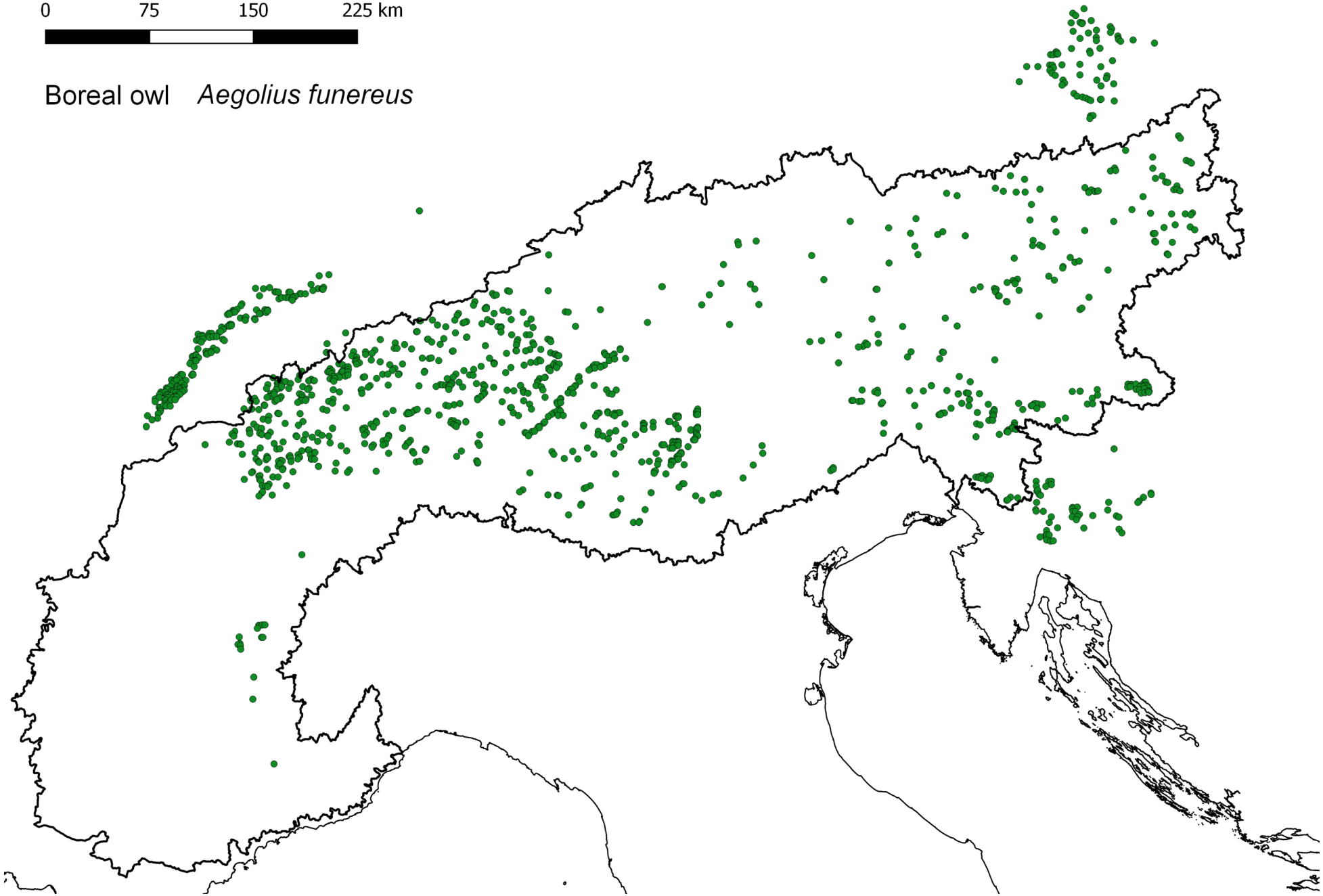
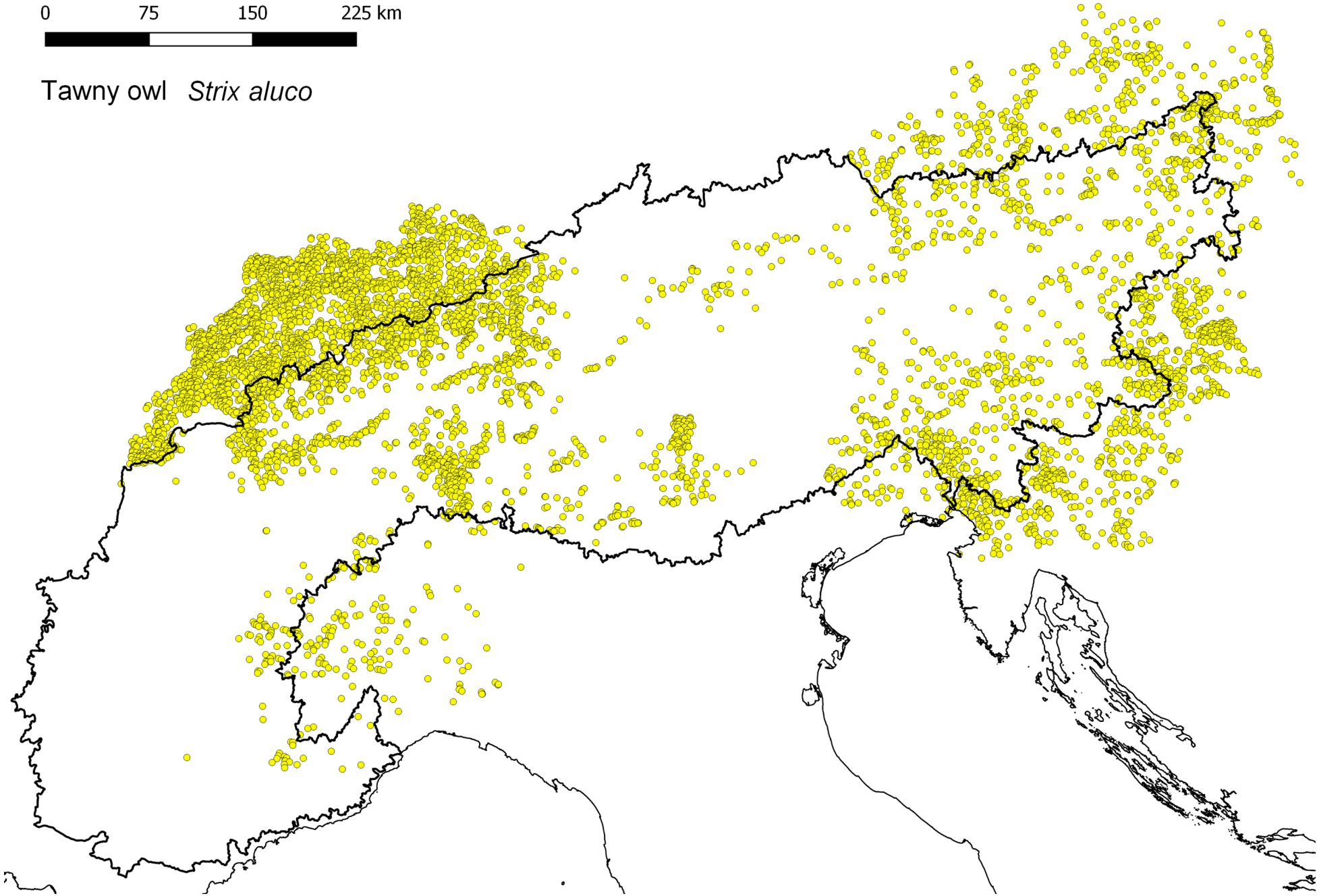
Supplementary material for the paper

Species interactions and climate change: how the disruption of species co-occurrence will impact on an avian forest guild

Mattia Brambilla, Davide Scridel, Gaia Bazzi, Luca Ilahiane, Aaron Iemma, Paolo Pedrini, Enrico Bassi, Radames Bionda, Luigi Marchesi, Fulvio Genero, Norbert Teufelbauer, Remo Probst, Al Vrezec, Primož Kmecl, Tomaž Mihelič, Giuseppe Bogliani, Hans Schmid, Giacomo Assandri, Renato Pontarini, Veronika Braunisch, Raphaël Arlettaz, Dan Chamberlain

Figure S1. Maps of species records used for distribution modelling after excluding duplicated occurrence (i.e. records within the same modelling cell). The study area is shown in black; records outside it where also used for modelling. Occurrence of Ural owl *Strix uralensis* is not shown because of conservation reasons (rare species in the region, potentially sensitive to disturbance)


0
75
150
225 km
Boreal owl *Aegolius funereus*


0
75
150
225 km
Tawny owl *Strix aluco*

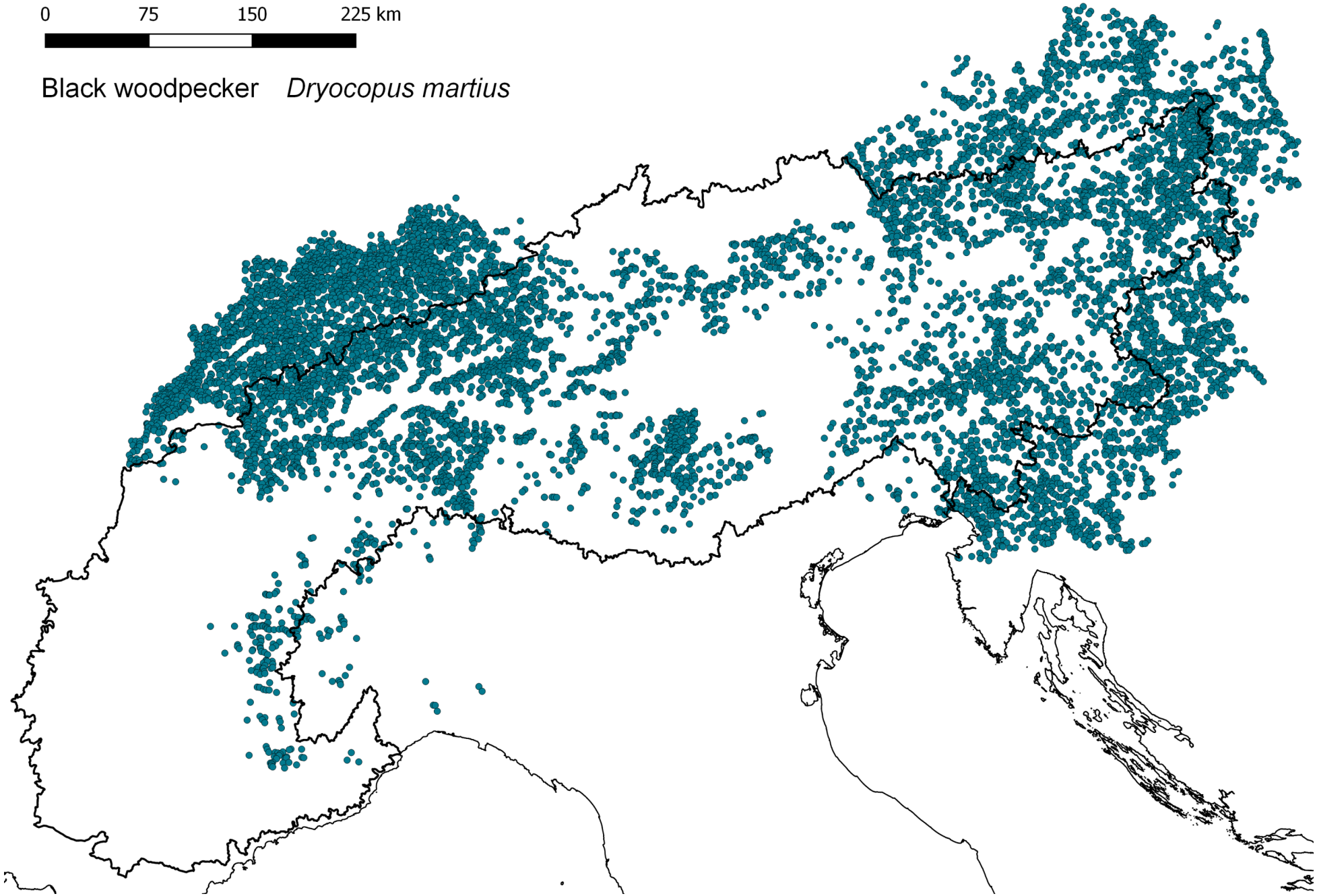

0
75
150
225 km
Black woodpecker *Dryocopus martius*

Table S1. Full list of environmental factors used to model species distribution, relative importance (percentage contribution/permutation importance) and short description of the effect (within brackets; relative to the model including all the selected predictors) according to final models for each species. Numerical codes for land cover variables represent CORINE categories. Symbols used for effects: +: positive, -: negative, +/-: quadratic (hump-shaped), -/+: quadratic (U-shaped), +/--: quadratic (hump-shaped)/negative, 0: nearly null.

Variable	Description	Boreal owl	Tawny owl	Ural owl	Black woodpecker
bio_1	Annual Mean Temperature	76.60/81.27 (+/--)	31.93/54.68 (+)		16.91/20.23 (+/--)
bio_12	Annual Precipitation		1.47/2.67 (+)	17.61/2.80 (+)	14.17/36.82 (-)
bio_15	Precipitation Seasonality (Coefficient of Variation)	2.96/4.21 (-)	5.93/0.00 (-)	12.47/22.94 (-)	
bio_19	Precipitation of Coldest Quarter	2.64/0.37 (-/+)		4.05/0.00 (0)	
bio_7	Temperature Annual Range (BIO5-BIO6)	2.23/5.66 (-)	24.01/35.13 (-)	15.99/14.94 (+)	
solarMay	Global solar radiation for May		1.66/4.49 (+)	0.86/0.78 (+)	8.24/13.22 (+/--)
X10	1.4.1 Green urban areas				
X11	1.4.2 Sport and leisure facilities				
X14	2.1.3 Rice fields				
X15	2.2.1 Vineyards				0.64/0.66 (-)
X16	2.2.2 Fruit trees and berry plantations				
X17	2.2.3 Olive groves				
X18	2.3.1 Pastures		1.02/0.43 (+)	0.61/0.22 (-)	0.20/0.69 (-)
X1.1	1.1.2 Continuous urban fabric			0.38/0.94 (+)	0.90/0.25 (-)
X2.1	1.1.1 Discontinuous urban fabric	0.29/1.05 (-)	0.85/0.77 (+)	1.03/0.94 (+)	1.60/0.0 (-)
X20	2.4.2 Complex cultivation patterns		0.25/1.21 (+)		0.65/3.33 (-)
X21	2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation			0.62/0.42 (-)	
X25	3.1.3 Mixed forest			4.75/0.00 (+)	

X26	3.2.1 Natural grasslands		9.44/0.00 (-)		
X27	3.2.2 Moors and heathland				
X28	3.2.3 Sclerophyllous vegetation				
X29	3.2.4 Transitional woodland-shrub				
X3	1.2.1 Industrial or commercial units				
X30	3.3.1 Beaches, dunes, sands				
X31	3.3.2 Bare rocks		2.79/0.44 (-)		
X32	3.3.3 Sparsely vegetated areas	0.75/0.48 (-)	6.03/0.00 (-)	1.55/1.50 (-)	
X34	3.3.5 Glaciers and perpetual snow				
X35	4.1.1 Inland marshes				1.61/2.97 (+)
X36	4.1.2 Peat bogs				
X4	1.2.2 Road and rail networks and associated land				0.49/2.31 (-)
X40	5.1.1 Water courses				1.03/3.43 (+)
X41	5.1.2 Water bodies				
X44	5.2.3 Sea and ocean				
X6	1.2.4 Airports				
X7	1.3.1 Mineral extraction sites				
X9	1.3.3 Construction sites				
x2632_TCD_TCD_20m	Tree cover density	0.72/1.63 (+)		25.89/0.22 (-)	18.07/11.02 (+/-)
X2.2	x2632_TCD_FTY_20m Coniferous forest	13.83/5.33 (+)	14.62/0.19 (-)	5.16/17.55 (+)	33.63/2.00 (+)
X1.2	x2632_TCD_FTY_20m Deciduous forest			9.14/36.75 (+)	1.84/3.07 (+)

Table S2. Model statistics. List of abbreviations: RM: the selected value of regularization multiplier (for each species, we tested the following options: 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4; at higher values correspond more uniform distributions); Var: variation; OR10: omission rate at 10th percentile (this value should be as close as possible to 0.10; mean and variation are reported); ORmin: omission rate at minimum training occurrence value (this value should be as low as possible; mean and variation are reported); AUC: area under the curve of the ROC (receiver operating characteristic) plot; DIFF: difference; nparam: number of parameters; bin.1 and bin.2: the two spatially non-overlapping data partitions; N: sample size (occupied cells used for distribution modelling).

Please note that AUC values per se are not particularly meaningful (rare species invariably have high values, widespread species low ones); what is really important is that they do not show large variations across bins, and that the omission rates are close to the expected values (0.10 for OR10 and 0.00 for ORmin) for all bins.

Species	RM	full.AUC	Mean.OR10	Var.OR10	Mean.ORmin	Var.ORmin	nparam	AUC_bin.1	AUC_bin.2	AUC.DIFF_bin.1	AUC.DIFF_bin.2	OR10_bin.1	OR10_bin.2	ORmin_bin.1	ORmin_bin.2	N
B. woodpecker	1	0.54	0.10	0.00	0.00	0.00	75	0.54	0.53	0.00	0.01	0.10	0.10	0.00	0.00	9323
Boreal owl	3.5	0.83	0.11	0.00	0.00	0.00	12	0.84	0.83	0.00	0.01	0.09	0.13	0.00	0.00	1207
Tawny owl	4	0.62	0.10	0.00	0.00	0.00	16	0.62	0.62	0.00	0.00	0.09	0.11	0.00	0.00	5791
Ural owl	1.5	0.94	0.11	0.00	0.00	0.00	22	0.94	0.94	0.00	0.01	0.09	0.13	0.00	0.00	436

Figure S2. Predicted future distribution (RCP85 for 2050) for boreal owl (upper left), tawny owl (upper right), Ural owl (lower left) and black woodpecker (lower right). The darker the colour, the higher the environmental suitability.

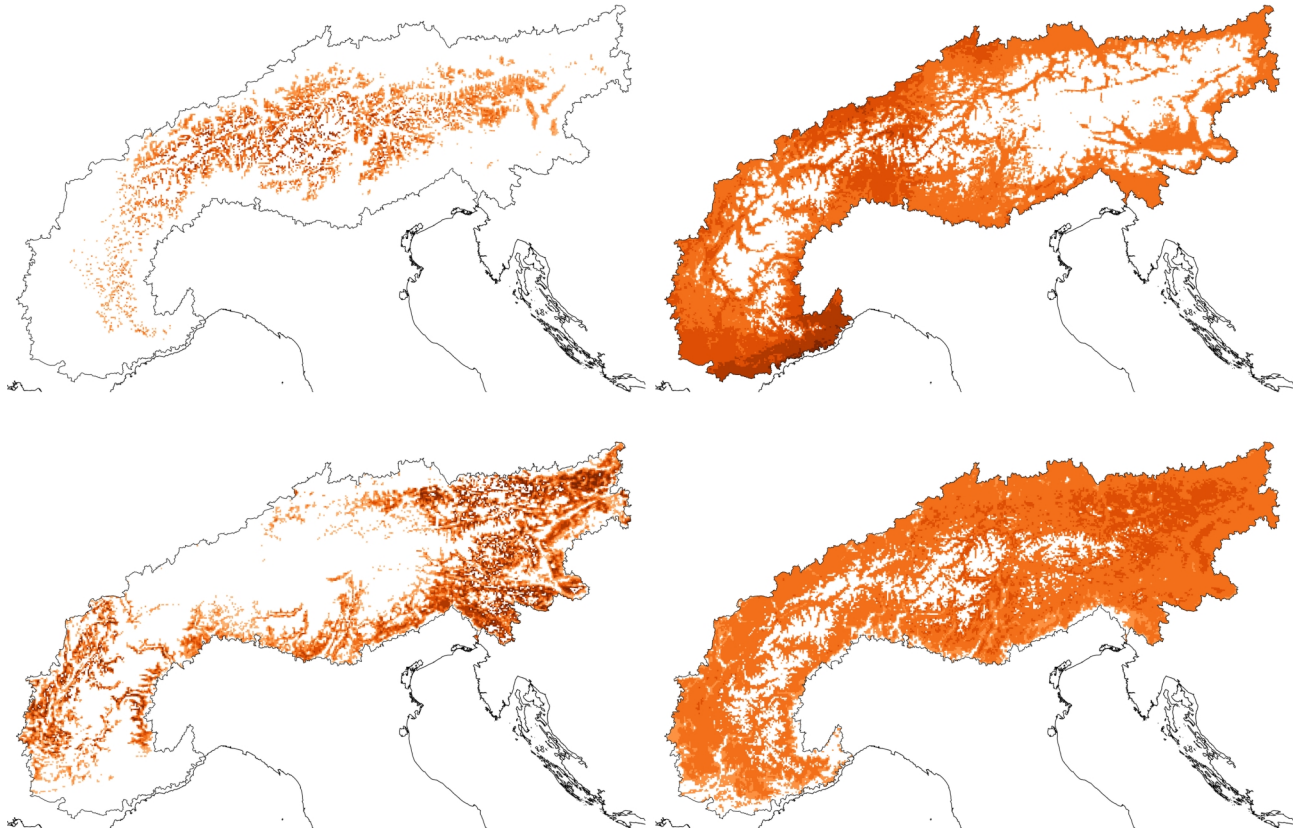


Table S3. The most supported models (ΔAICc < 2) for boreal owl abundance at sampling sites (all non-factorial variables were scaled before analyses). For factorial variables: “black woodp.” means black woodpecker occurrence; for “disturb”, weak/moderate disturb had a slightly negative effect on the species detectability, strong disturb had a very negative impact on detectability. “envir. suitability” is environmental suitability as calculated by the current MaxEnt model for the species. Model was re-run considering only 122 well-spaced points from Lombardy (see text). Results from the Lombardy subset substantially confirmed the general pattern, but suggested a slightly higher effect of environmental suitability, and a reduced importance of date and, especially, time of the day (hour) on detection. A goodness-of-fit test was performed on a ‘full’ model including all the variables included in the most supported models (not significant).

lambda intercept	psi intercept	black woodp.	tawny owl max.	envir. suitability	date	disturb	hour	df	logLik	AICc	delta	weight
1.27	-3.01	+			-0.33	-	0.31	7	-194.04	402.7	0.00	0.26
1.74	-3.43				-0.34	-	0.31	6	-195.34	403.1	0.44	0.21
2.10	-3.87	+	-0.17		-0.37	-	0.33	8	-193.25	403.3	0.61	0.19
3.25	-4.97		-0.16		-0.37	-	0.33	7	-194.57	403.7	1.06	0.16
1.46	-3.21	+		0.06	-0.36	-	0.32	8	-193.93	404.6	1.96	0.10

Only Lombardy:

lambda intercept	psi intercept	black woodp.	tawny owl max.	envir. suitability	date	disturb	df	logLik	AICc	delta	weight
4.27	-5.52	0.00		0.25		-	6	-126.47	265.7	0.00	0.19
2.55	-3.89	0.00				-	5	-127.85	266.2	0.56	0.14
4.50	-5.80	0.00	-0.21			-	6	-126.89	266.5	0.83	0.12
4.57	-5.70			0.24		-	5	-128.07	266.6	0.98	0.12
4.52	-5.74					-	4	-129.3	266.9	1.27	0.10
4.21	-5.44	0.00		0.30	-0.14	-	7	-125.98	266.9	1.28	0.10
4.26	-5.50	0.00	-0.13	0.21		-	7	-126.09	267.2	1.50	0.09
4.83	-6.01		-0.19			-	5	-128.42	267.3	1.67	0.08

Table S4. The most supported models (ΔAICc < 2) for tawny owl abundance at sampling sites (all non-factorial variables were scaled before analyses). For “disturb”, weak/moderate disturb had a negligible effect on the species detectability, strong disturb had a very negative impact on detectability; for “wind”, weak wind had a negligible effect, moderate or strong wind a negative effect on the species detectability. “envir. suitability” is environmental suitability as calculated by the current MaxEnt model for the species. Model was re-run considering only 122 well-spaced points from Lombardy (see text); models were substantially identical. A goodness-of-fit test was performed on a ‘full’ model including all the variables included in the most supported models (not significant).

lambda intercept	psi intercept	envir. suitability	disturb	wind	df	logLik	AICc	delta	weight
-0.31	-0.59	0.84	-		5	-236.7	483.7	0.00	0.40
-0.26	-0.61	0.83	-	-	7	-235.5	485.6	1.88	0.16

Only Lombardy:

lambda intercept	psi intercept	envir. suitability	disturb	wind	df	logLik	AICc	delta	weight
0.43	-1.17	0.76	-		5	-166.92	344.3	0.00	0.34
0.55	-1.29	0.77	-	-	6	-166.39	345.5	1.15	0.19
0.60	-1.36	0.74			3	-169.94	346.1	1.73	0.14

Table S5. Predicted extent of overlap between species, as absolute values and as a share of the species range (focal species: tawny owl for tawny-Ural owl interaction, boreal owl in all other cases).

	current extent of overlap (km^2)	**future extent of overlap (km^2)**	**change (%)**	**current share (%)**	**future share (%)**
boreal owl-black woodpecker	84824	29320	-65	99	98
boreal-tawny owls	21640	16072	-26	25	54
boreal-Ural owls	10616	4344	-59	12	14
tawny-Ural owls	14080	43340	+208	15	36
boreal-tawny-Ural owls	5188	492	-91	6	2