Effects of functional traits on the prediction accuracy of species richness models

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Appendix S1. Supporting tables and figures

Content

Tables

Table S1. Predictor variables used for prediction of Swiss avian species distributions and richness.

Abbreviation	Range	Unit	Description
Climate variables:			
TAVEwinter	-8.49 – 3.85	°C	Mean winter temperature (December – February)
TAVEsummer	5.95 – 20.62	°C	Mean summer temperature (June – August)
TAVEyear	-1.10 – 12.13	°C	Annual mean temperature
RADyear	9552 – 22482	kJ/(m^{2}d)	Annual mean potential solar radiation
RADsummer	19210 – 30512	kJ/(m^{2}d)	Mean potential solar radiation in Summer (June – August)
RADwinter	1641 – 13755	kJ/(m^{2}d)	Mean potential solar radiation in winter (December – February)
PRECyear	524.2 – 2384.1	mm	Annual precipitation sum
PRECsummer	47.6 – 264.2	mm	Summer precipitation sum
PRECwinter	31.8 – 190.4	mm	Winter precipitation sum
MINDsummer	-116.56 – 144.79	-	Mean summer moisture index (precipitation – potential evapotranspiration; June – August)
GDD0	7318 - 44393	-	Growing degree days above 0°C
Topographic variables:			
min_alt	188 – 2488	m	Minimum altitude within 1 km^2 cell
med_alt	193 – 2544	m	Median altitude within 1 km^2 cell
max_alt	195 - 2805	m	Maximum altitude within 1 km^2 cell
range_alt	0 - 1028	m	Altitudinal range within 1 km^2 cell
Slope	0.01 – 33.04	degrees	Slope
Aspect	0.0 – 359.9	degrees	Aspect
sin_aspect	-1.0 – 1.0	-	Sinus of aspect
cos_aspect	-1.0 – 1.0	-	Cosinus of aspect
Beers	0.0 – 2.0	-	Beers aspect transformation
Streampower	-1.39 – 13.8	-	Streampower index
TWI	7.34 – 22.39	-	Wetness index
Habitat variables:			
BN9725_1	0 – 99	%	Closed forest (category 1 from Swiss land use statistics aggregation NOAS92_25)
BN9725_2	0 – 40	%	Open forest (category 2 from NOAS92_25)
DZ3	0 – 53	%	Brush forest, brush meadows and brush alpine

			pastures (category 3 from NOAS92_25 + categories 84 and 86 from NOAS92 basic categories)
BN9725_4	0 – 21	%	Woods (category 4 from NOAS92_25)
DZ5	0 – 100	%	Vineyards, intensive orchards, horticulture, intensive arable land and meadows, surroundings of agricultural buildings (categories 5 and 7 from NOAS92_25 + categories 75, 76, 81, 82, 48 from NOAS92 basic categories)
DZ8	0 – 99	%	Extensive agriculture and gardens (NOAS92 basic categories 77, 73, 83, 85, 88, 89, 87, 45, 47)
BN9725_12	0 – 74	%	Lakes (category 12 from NOAS92_25)
BN9725_13	0 – 32	%	Rivers (category 13 from NOAS92_25)
BN9725_14	0 – 74	%	Unproductive vegetation (category 14 from NOAS92_25)
DZ15	0 – 80	%	Bare land incl. rocks, sands, glaciers (categories 15 + 16 from NOAS92_25)
DZ17	0 – 44	%	Buildings (category 17 from NOAS92_25 + categories 46, 49, 20 from NOAS92 basic categories)
DZ19	0 – 53	%	Industrial and special urban areas (categories 19 + 20 from NOAS92_25 + categories 24 and 61-66 from NOAS92 basic categories)
BN9725_22	0 – 31	%	Recreational areas and cemeteries (category 22 from NOAS92_25)
DZ23	0 – 33	%	Transportation areas incl. roads, railways and airports (categories 23-25 from NOAS92_25)

Table S2. Trait variables representing trophic and habitat niche and migratory status. All variables were binary, meaning scored as used (1) or not used (0) by the bird species, except body size (continuous body length). Categories for nest position and migratory status were exclusive, all other variables were non-exclusive.

Abbreviation	Description
Diet:	
e.seeds.nuts.grain	Seeds, nuts, grain
e.fruits.frugivory	Frugivory
e.vegitative	Vegetative parts
e.invert	Invertebrates
e.fish	Fish
e.v.sm.mammals	Small mammals
e.lg.mammals	Large mammals
e.herptiles	Herptiles
e.sm.birds	Small birds
e.lg.birds	Large birds
e.vert	Vertebrates (unspecified)
e.carrion	Carrion
Acquisition behaviour:	
e.pursuit.air.aquatic	Pursuit (air, aquatic)
e.sally	Sally
e.foliage.glean	Foliage glean
e.pounce	Pounce
e.graze	Graze
e.pick.peck.stab	Pick, peck, stab
e.dig	Dig
e.overturn.obj	Overturn objects
e.probe	Probe
Substrate:	
e.watersurface	Water surface
e.underwater	Under water
e.water	Water (unspecified)
e.ground	Terrestrial ground
e.canopy	Canopy
e.shrub.low.high	Shrub
e.vegitation	Vegetation (unspecified)
e.air	Air
Foraging habitat:	
f.wet.grslnd.fens.edges.tundra	Wet grassland, fens, tundra
f.dry.grassland	Dry grassland
f.rocky.slope	Rocky slope
f.fast.lotic	Fast lotic
f.still.slow.lotic	Still or slow lotic
f.saltmarsh	Salt marsh
f.mud.silt.flat	Mud or silt flat
f.sandy.gravel.beach	Sand or gravel beach

f.reed.marsh	Reed marsh
f.conifer	Conifer forest
f.mixed	Mixed forest
f.deciduous	Deciduous forest
f.mediterranean.oak.other	Mediterranean or oak
f.open.or.low.forest	Open or low forest
f.forest.or.habitat.edge	Forest edge
f.shrub.bush	Shrub, bush, or brush
f.urban	Urban
f.garden	Garden
Breeding habitat:	
b.wet.grslnd.meadows.fens.sedges.tundra	Wet grassland, fens, tundra
b.dry.grassland	Dry grassland
b.banks.sand.mud	Banks of sand or mud
b.rockfaces.outcrops.structures	Rock faces, outcrops, structures
b.nr.water.lkshr.island	Near water, lakeshore, island
b.sand.gravel.beach	Sand or gravel beach
b.reed.marsh	Reed marsh
b.conifer	Conifer forest
b.mixed	Mixed forest
b.deciduous	Deciduous forest
b.mediterranean.oak.other	Mediterranean or oak
b.open.low.forest	Open or low forest
b.shrub.bush	Shrub, bush, or brush
b.urban	Urban
b.garden	Garden
Nest position:	
nest.cavity	Cavity, tree hole
nest.elevated	Elevated
nest.ground	Ground
Migratory status:	
mig.long	Long-distance migrant
mig.sed	Sedentary
mig.short	Short-distance migrant
Morphology:	
log(Size)	Body Size (length from beak to tail), proxy for resource requirement and home range size

Table S3. Species groups as defined by hierarchical clustering. Please see Table S4 for average, within-group trait values.

Group ID	Species (English names)	Common characteristics
1 (*n*=21)	Northern Goshawk, Marsh Warbler, European Goldfinch, Lesser Redpoll, European Greenfinch, Hawfinch, Feral Pigeon, Common Wood Pigeon, Northern Raven, Northern Raven, Carrion Crow, Common Kestrel, Common Chaffinch, Eurasian Jay, Red Kite, Spotted Nutcracker, Eurasian Magpie, Eurasian Bullfinch, Goldcrest, Citril Finch, Eurasian Collared Dove, Eurasian Blackbird	Sedentary; breed on elevated nests; breed and forage in forests of all kinds, shrubland, parks and gardens; feed mainly on seeds, fruits and invertebrates, some carnivorous and omnivorous; forage mainly by picking and stabbing, on the ground or in vegetation
2 (*n*=16)	Eurasian Sparrowhawk, Eurasian Reed Warbler, Common Swift, Common Cuckoo, Common House Martin, Eurasian Hobby, Barn Swallow, Red-backed Shrike, Black Kite, Spotted Flycatcher, Eurasian Golden Oriole, European Honey Buzzard, European Turtle Dove, Garden Warbler, Common Whitethroat, Lesser Whitethroat	Long-distance migrants; breed on elevated nests; breed mainly forests, forage also in grasslands and marshes, outside settlements; feed mainly on invertebrates, some carnivorous; forage by picking and stabbing, also pursuit and pounce, mainly on ground, in vegetation, or air
3 (*n*=12)	Long-tailed Bushtit, Eurasian Siskin, European Robin, Red Crossbill, Dunnock, Firecrest, European Serin, Eurasian Blackcap, Song Thrush, Fieldfare, Ring Ouzel, Mistle Thrush	Small short-distance migrants; breed on elevated nests; forage and breed in (coniferous) forests, also in parks and gardens; feed on seeds, fruits and invertebrates; forage mainly in vegetation by picking and stabbing
4 (*n*=11)	Eurasian Skylark, Water Pipit, Tree Pipit, Common Quail, Common Reed Bunting, Common Nightingale, Western Bonelli's Warbler, Common Chiffchaff, Wood Warbler, Willow Warbler, Whinchat	Mainly long-distance but also short-distance migrants; ground breeders; breed and forage in (wet) grasslands and forests, outside settlements; feed mainly on invertebrates; forage by picking and stabbing, and pursuit in air, in vegetation and on the ground

5 (*n*=7)	Common Kingfisher, White Wagtail, Grey Wagtail, Black Redstart, Eurasian Crag Martin, Common Starling, Winter Wren	Short-distance migrants; breed in cavities in banks or on rock faces and structures; forage in diverse habitats; feed on invertebrates (Kingfisher also on fish)
6 (*n*=9)	Rock Partridge, Mallard, Common Linnet, Yellowhammer, Eurasian Coot, Common Moorhen, Rock Ptarmigan, Great Crested Grebe, Black Grouse	Large birds; sedentary; ground breeders; breed near water, in reed marshes and in grasslands at forest edges; forage in/near water, marshes and grasslands; vegetarian and invertebrate food
7 (*n*=28)	Common Buzzard, Short-toed Treecreeper, Eurasian Treecreeper, White-throated Dipper, Stock Dove, Great Spotted Woodpecker, Lesser Spotted Woodpecker, Black Woodpecker, Rock Bunting, European Pied Flycatcher, Eurasian Wryneck, White-winged Snowfinch, Northern Wheatear, Coal Tit, Blue Tit, European Crested Tit, Great Tit, Willow Tit, Marsh Tit, House Sparrow, Eurasian Tree Sparrow, Common Redstart, Grey-headed Woodpecker, European Green Woodpecker, Alpine Accentor, Alpine Chough, Eurasian Nuthatch, Tawny Owl	Mostly sedentary, some long-distance migrants; breed in cavities/tree holes; breed in closed to open forests, also in parks and gardens; forage in forests, shrubland, parks and gardens; feed mainly on invertebrates; forage in vegetation or on ground mainly by picking and stabbing;

Table S4. Average trait values within functional groups (clusters) compared to average values for all species. Significant differences between the group and overall means are indicated by grey shading and were assessed using the Mann-Whitney test (except for niche sizes). Significance levels are: **(p<0.01); *(p<0.05); '(p<0.1). Niche size for the different trait categories was calculated as the area of the inertia (covariance) ellipse that describes the point cloud covered by each group along the first two axes of a principal component analysis on these traits. For more information on bird functional groups, cf. Table S3 and Figure S1.

	Functional group / Cluster							
Traits	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**All**
Morphology								
log(Size)	3.29	3.13	**2.83'**	2.7	2.8	**3.55***	2.94	3.05
Diet								
e.seeds.nuts.grain	**0.67****	**0.06***	0.33	0.27	**0'**	**0.78***	0.25	0.35
e.fruits.frugivory	0.38	0.38	0.42	0.09	0.14	0.44	**0.11'**	0.27
e.vegitative	0.33	0.06	0.08	0.09	0	**0.67****	0.11	0.18
e.invert	**0.71'**	0.88	0.83	1	1	**0.67'**	**1'**	0.88
e.fish	0.05	0.06	0	0	0.14	**0.22***	0	0.05
e.v.sm.mammals	0.19	**0.25'**	0	0	0	0	0.04	0.09
e.lg.mammals	0.14	0.12	0	0	0	0	0.04	0.06
e.herptiles	0	0.06	0	0	0	0	0.04	0.02
e.sm.birds	**0.24'**	**0.25'**	0	0	0	0	0.04	0.1
e.lg.birds	0.1	0.06	0	0	0	0	0	0.03
e.vert	0.29	**0.31'**	0	0	0.14	0.22	0.04	0.14
e.carrion	**0.24***	0.12	0	0	0	0	0.04	0.08
Diet niche size	*55.07*	*48.66*	*0.03*	*0.005*	*0.17*	*4.17*	*6.76*	*17.15*
Acquisition behaviour								
e.pursuit.air.aquatic	0.19	**0.5'**	0.08	**0.64***	0.57	0.11	0.18	0.29
e.sally	0.05	0.25	0.25	0.36	0.29	0.11	0.11	0.17
e.foliage.glean	0.33	0.38	0.5	0.55	0.29	**0***	0.39	0.37
e.pounce	0.19	**0.31***	0	0	0	0	0.04	0.1
e.graze	0	0	0	0	0	**0.22****	0	0.02
e.pick.peck.stab	0.81	**0.56***	0.92	1	0.71	0.89	0.93	0.84
e.dig	0.05	0.06	0	0.09	0	0.11	0.14	0.08

e.overturn.obj	0.14	0	0.08	0	0	0	0.07	0.06
e.probe	0.19	0	0.08	0	0.14	0	**0.29'**	0.13
Acquisition niche size	*16.43*	*11.71*	*1.42*	*0.87*	*8.13*	*3.65*	*5.9*	*10.12*
Substrate								
e.watersurface	0.05	0.06	0.08	0	**0.43****	**0.33***	0.04	0.1
e.underwater	0	0	0	0	0.14	**0.33****	0.04	0.05
e.water	0.05	0.06	0	0	**0.43***	**0.44****	0.07	0.11
e.ground	**0.95***	0.62	0.75	0.73	0.71	0.78	0.61	0.73
e.canopy	0.43	0.38	0.42	0.36	**0'**	**0***	0.32	0.32
e.shrub.low.high	0.62	0.5	0.83	0.45	0.29	0.33	0.75	0.6
e.vegitation	0.76	0.56	**1***	0.73	0.43	**0.33***	0.82	0.71
e.air	0.19	0.5	0.33	**0.73***	0.57	0.11	0.21	0.34
Substrate niche size	*2.62*	*6.89*	*0.80*	*1.48*	*23.11*	*20.58*	*8.53*	*13.74*
Foraging habitat								
f.wet.grslnd.fens.sedges.tundra	0.33	0.25	0.17	**0.55'**	0.14	0.33	0.21	0.28
f.dry.grassland	0.48	0.31	**0.08'**	0.18	0.29	0.44	0.36	0.33
f.rocky.slope	0.05	0.06	0.17	0.09	0.29	0.22	0.18	0.13
f.fast.lotic	0	0	0	0	0	0.11	0.04	0.02
f.still.slow.lotic	0	0.12	0	0	0.14	**0.44****	0	0.07
f.saltmarsh	0.1	0	0	0	0.14	0.11	0	0.04
f.mud.silt.flat	**0.1'**	0	0	0	0	0	0	0.02
f.sandy.gravel.beach	0.14	0	0	**0.18'**	0	0	0	0.05
f.reed.marsh	0.1	**0.38***	0	0.18	0.14	**0.44***	**0.04'**	0.15
f.conifer	0.67	0.38	**0.92****	0.36	0.29	**0.11***	0.39	0.47
f.mixed	0.52	0.44	0.58	0.36	0.43	**0****	0.64	0.48
f.deciduous	0.48	0.38	0.67	0.55	0.14	**0.11***	0.57	0.46
f.mediterranean.oak.other	0.24	0.25	0.17	0.36	0	**0'**	0.36	0.24
f.open.or.low.forest	0.67	0.75	0.75	0.55	0.57	**0.22***	0.57	0.61
f.forest.or.habitat.edge	0.48	0.44	0.42	0.18	0.29	0.22	0.21	0.33
f.shrub.bush	0.48	0.56	0.42	0.64	0.43	0.33	0.29	0.43

f.urban	0.33	0.12	0.25	0	0.43	0.11	0.14	0.19
f.garden	0.38	0.19	0.5	0.09	0.29	0.11	0.43	0.32
Foraging niche size	*83.17*	*4.11*	*2.22*	*11.56*	*15.05*	*15.3*	*4.69*	*34.08*
Breeding habitat								
b.wet.grslnd.meadows.fens.sedges .tundra	0.14	0	0.17	**0.55****	0	0.22	0.04	0.13
b.dry.grassland	0.05	0.06	0	0.18	0	**0.33***	0.11	0.1
b.banks.sand.mud	0.05	0	0.17	0	**0.43****	0	0.11	0.09
b.rockfaces.outcrops.structures	0.29	0.25	0.17	0.09	**0.86****	**0'**	0.43	0.3
b.nr.water.lkshr.island	0.1	0.06	0	0.09	0.29	**0.44****	0.04	0.11
b.sand.gravel.beach	0	0	0	0.09	0	0.11	0	0.02
b.reed.marsh	0	0.12	0	0.09	0	**0.44****	0.04	0.08
b.conifer	**0.76***	0.5	**0.92****	0.36	**0.14'**	**0.22'**	0.43	0.52
b.mixed	0.57	0.56	0.58	0.36	0.29	**0****	0.68	0.51
b.deciduous	0.38	0.44	0.58	0.55	0.14	**0.11***	0.61	0.45
b.mediterranean.oak.and.other	0.24	0.31	0.17	0.36	0	**0'**	0.36	0.25
b.open.low.forest	0.33	0.44	0.5	0.45	0.29	0.33	0.5	0.42
b.shrub.bush	0.57	0.44	0.42	0.64	0.14	0.56	**0.11****	0.38
b.urban	**0.43***	0.06	0.17	0	0.43	0.22	0.14	0.2
b.garden	0.38	0.12	0.42	0.09	0.29	0.22	0.39	0.3
Breeding niche size	*15.83*	*4.15*	*13.58*	*5.06*	*9.79*	*8.08*	*16.04*	*17.15*
Nest position								
nest.cavity	**0****	**0****	**0***	**0***	**1****	**0***	**1****	0.34
nest.elevated	**1****	**1****	**1****	**0****	**0***	**0****	**0****	0.47
nest.ground	**0***	**0'**	**0'**	**1****	0	**1****	**0***	0.19
Migratory status								
mig.long	**0****	**1****	**0***	**0.64****	0	**0'**	0.14	0.26
mig.sed	**1****	**0****	**0****	**0****	**0****	**1****	**0.86****	0.52
mig.short	**0***	**0***	**1****	0.36	**1****	0	**0****	0.22
Range size								

Prevalence	0.38	0.23	0.51’	0.24	0.5	0.16	0.32	0.33

Table S5. Effects of ecological traits on species richness residuals, over- and underprediction patterns in MEMs and S-SDMs, and on assemblage prediction success in bS-SDMs (using sensitivity-specificity equality threshold). Spatial (positive and negative) species richness residuals and assemblage prediction success per site were regressed against community average traits using AIC-based variable selection. Presented are the slope estimates of the most parsimonious models. Please note that for bS-SDM the effects on overprediction and underprediction are not presented because of unbalanced sample sizes due to general tendency towards overprediction. Predictions are made by a simple average consensus over the three algorithms BRTs, MARS and GAMs. For description of traits see Table S2.

	SR residuals			SR overprediction		SR underprediction		Assemblage prediction success
Traits	***MEM***	***pS-SDM***	***bS-SDM***	***MEM***	***pS-SDM***	***MEM***	***pS-SDM***	***bS-SDM***
Morphology								
log(Size)	18.06	12.06	16.23	-10.08	-7.26	-	13.27	-0.11
Diet								
e.seeds.nuts.grain	33.64	27.72	35.14	-	-	16.65	26.09	-0.10
e.fruits.frugivory	-10.24	-19.15	-	-	-	-	-	0.08
e.vegitative	14.77	17.63	-	15.86	21.73	-	-15.22	0.11
e.invert	46.84	53.69	42.65	36.65	27.96	-	-	-0.33
e.fish	-	-	-	-50.98	-47.54	-	-	-
e.v.sm.mammals	-	-	-	-	-	-	-	-
e.lg.mammals	102.25	75.94	103.65	-	-	-	-	-
e.herptiles	38.27	57.35	-	-	-	-	-	-
e.sm.birds	-	-	-	37.24	22.68	-	-	-
e.lg.birds	-	-	-	44.95	59.24	-	-	-
e.vert	-22.03	-43.57	-	-	-	-	-	-
e.carrion	-64.79	-53.45	-66.22	-17.54	-17.31	-	-	0.13
Acquisition behaviour								
e.pursuit.air.aquatic	-	-	-	-	-	-	-	0.14
e.sally	-	11.94	-	-	-	-	-21.28	0.13
e.foliage.glean	-	-	-	-12.57	-	-13.48	-12.69	-0.08

e.pounce	-	-	-	-	-	-	-	-
e.graze	-	-	-	-	-	-	-	-
e.pick.peck.stab	23.83	17.54	34.52	22.48	21.24	-	18.07	-
e.dig	-	-	-	-	-	-	-	0.19
e.overturn.obj	-	-	-	-	-	-	-18.71	-0.16
e.probe	-	15.19	-	-12.73	-11.50	-	-	-
Substrate								
e.watersurface	-	-	-	-	-	-	-	-0.20
e.underwater	-	-	-	-	-	18.74	39.21	-
e.water	-	-	-	-	-	-	-	-
e.ground	-	-	-	-	-	19.98	13.79	-
e.canopy	-	-	-14.71	-	-	-	-	0.27
e.shrub.low.high	-	-	-	6.68	-	-	-	-0.27
e.vegitation	-	-	-	-	-	-	-	-
e.air	12.01	-	-	-	-	12.81	17.35	-
Foraging habitat								
f.wet.grslnd.fens.sedges.tundra	-	-21.09	-	-	-	-	-	0.21
f.dry.grassland	-25.43	-	-25.42	-	-	-35.79	-33.09	-
f.rocky.slope	17.28	35.37	11.02	-13.04	-7.18	-	-	0.17
f.fast.lotic	-	-	-	-	-	-	-	-
f.still.slow.lotic	-	-	-	-	-	-	-24.81	-
f.saltmarsh	-	-	-	-	-	-	-	-
f.mud.silt.flat	-	-	-	-	-	43.94	-	-
f.sandy.gravel.beach	25.65	23.62	-	-	24.28	-	-	0.29
f.reed.marsh	-	-	-	-28.50	-26.34	-	-	-
f.conifer	-	-	-	-	-	-	-	0.15

f.mixed	-	-	-	-	-	-17.90	-	-0.13
f.deciduous	-	-	-	-	-	-	-11.39	-
f.mediterranean.oak.other	-17.60	-25.47	-	-20.70	-22.49	16.31	-	-
f.open.or.low.forest	-	18.36	-	-	-	10.86	-	-
f.forest.or.habitat.edge	28.96	31.90	42.90	13.36	20.75	-9.25	-	-0.21
f.shrub.bush	29.49	26.62	28.15	-	-	-8.67	-	-
f.urban	-	30.34	26.52	-	-	-	-	-0.27
f.garden	-	-	-	-	-	-10.13	-	-
Breeding habitat								
b.wet.grslnd.meadows.fens.sedges.tundra	-	-	-24.16	-	-13.89	-	-	-
b.dry.grassland	-	-	14.90	-	9.92	11.47	-	-0.09
b.banks.sand.mud	-27.71	-24.83	-17.18	-	-	-30.87	-21.44	0.19
b.rockfaces.outcrops.structures	-	-17.75	-10.29	-	-	19.23	31.61	-
b.nr.water.lkshr.island	-	-	-	-	-	-	-	-
b.sand.gravel.beach	-	-	-35.83	-20.57	-42.42	-	26.01	0.50
b.reed.marsh	-56.68	-63.35	-65.13	-	-	-	-	0.47
b.conifer	-25.42	-37.99	-28.73	-	-	-13.10	-25.59	-
b.mixed	-	18.73	-	-	-	-	-	-
b.deciduous	-	-	-	-	-	-	-	-
b.mediterranean.oak.and.other	-	-	-	-	-	-	23.00	-0.08
b.open.low.forest	-15.14	-28.93	-19.35	-	-	-	-	0.19
b.shrub.bush	-	-	-	15.04	7.98	20.52	10.05	-0.14
b.urban	11.86	-	-	18.68	22.72	-14.28	-31.54	-
b.garden	-	-	-	-	-	-	-	-
Nesting position								
nest.cavity	13.19	-	-	-	-	18.40	-	0.24

nest.elevated	-	-	-15.68	-9.36	-9.49	-	-	0.25
nest.ground	-	-	-	-	-	-	-	-
Migratory status								
mig.long	-	-	-	-	-	-	-	-
mig.sed	16.40	15.16	13.34	12.28	14.09	-	-	-
mig.short	-	-	-	-	-	-	-	-
Range								
prevalence	79.81	47.39	65.82	-	-	104.01	112.30	0.43
Community assembly/Environmental stress								
MFD_{SES}	3.08	4.71	4.38	4.95	5.07	-	-	-0.04
Explained variance – adjusted r^2	**0.40**	**0.42**	**0.36**	**0.38**	**0.37**	**0.31**	**0.35**	**0.42**

Table S6. Effects of mean traits within functional groups (cf. Tables S3-S4 and Figure S1) on prediction error (NRMSE) of species richness predictions, and mean assemblage prediction success (using sensitivity-specificity equality threshold in bS-SDMs). Prior to modelling, the within-group average traits were standardised by the within-group standard deviation (except for niche sizes). Shown are coefficient estimates for the traits and the variance explained (adjusted r^2) of the single-trait models (coefficients estimates from models with negative r^2 were omitted). Significance is indicated by **(p<0.01), *(p<0.05) and '(p<0.1). Parameter estimates in bold remained significant (p<0.05) after Holm's adjustment for multiple tests.

Trait	NRMSE						Ass. Success	
	MEM		*pS-SDM*		*bS-SDM*		*bS-SDM*	
	coef	r^2	coef	r^2	coef	r^2	coef	r^2
Morphology								
Size	-0.002*	0.22	-0.002*	0.25	0.003	0.01	-	-
Diet								
e.seeds.nuts.grain	-	-	-0.01	0.06	-	-	0.01	0.07
e.fruits.frugivory	-	-	-	-	-	-	-0.02	0.01
e.vegitative	-	-	-	-	0.06*	0.15	0.02'	0.10
e.invert	-	-	-	-	-	-	0.00	0.04
e.fish	0.02'	0.12	0.02'	0.13	0.12*	0.16	0.04'	0.11
e.v.sm.mammals	-0.02*	0.19	-0.02*	0.17	-	-	-0.05**	0.31
e.lg.mammals	-0.04**	0.34	-0.03**	0.33	-0.07	0.01	-0.06*	0.19
e.herptiles	-0.03	0.02	-	-	-	-	-0.09*	0.18
e.sm.birds	-0.02*	0.22	-0.02*	0.21	-	-	-0.05**	0.27
e.lg.birds	-0.03'	0.12	-0.03'	0.12	-	-	-0.08*	0.24
e.vert	-	-	-	-	-	-	-	-
e.carrion	-0.03**	0.39	-0.03**	0.39	-0.08	0.06	-0.04'	0.12
Diet niche size	-0.0002'	0.14	-0.0002'	0.14	-	-	-0.00*	0.24
Acquisition behaviour								
e.pursuit.air.aquatic	0.01*	0.16	0.01*	0.24	0.04	0.04	-0.01	0.03
e.sally	0.04**	0.42	**0.04****	**0.48**	0.08	0.02	-0.04*	0.10
e.foliage.glean	-0.01	0.002	-	-	-0.07*	0.2	-0.04**	0.30
e.pounce	-0.02'	0.12	-0.02'	0.11	-	-	-0.05**	0.37
e.graze	0.02	0.06	0.01	0.02	0.18**	0.4	0.06*	0.21
e.pick.peck.stab	-	-	-	-	0.004	0.01	-	-

e.dig	-0.03	0.07	-0.02’	0.09	0.16*	0.19	-	-
e.overturn.obj	**-0.06****	**0.66**	**-0.05****	**0.75**	**-0.25****	**0.67**	-	-
e.probe	**-0.03****	**0.5**	**-0.03****	**0.46**	**-0.17****	**0.67**	0.03	0.08
Acquisition niche size	-0.001*	0.17	-0.001’	0.14	-0.003	0.06	-	-
Substrate								
e.watersurface	0.02*	0.17	0.02*	0.2	-	-	0.04**	0.31
e.underwater	0.02	0.09	0.01	0.08	0.1*	0.19	**0.06****	**0.58**
e.water	0.01	0.08	0.01’	0.11	0.05	0.09	0.04’	0.43
e.ground	-0.01*	0.22	-0.01**	0.28	-0.02*	0.17	-	-
e.canopy	-0.02**	0.27	-0.02**	0.31	-0.06*	0.15	**-0.04****	**0.48**
e.shrub.low.high	-0.01*	0.24	-0.01**	0.29	-0.06**	0.37	-0.00	0.01
e.vegitation	-	-	-	-	-0.01*	0.21	-0.00	0.02
e.air	0.01*	0.18	0.01*	0.24	-	-	-0.02	0.08
Substrate niche size	0.001’	0.14	0.001*	0.19	0.002	0.01	0.00**	0.41
Foraging habitat								
f.wet.grslnd.tundra	-	-	-	-	0.01’	0.14	-	-
f.dry.grassland	-0.02*	0.14	-0.02*	0.15	-	-	0.03	0.07
f.rocky.slope	0.03	0.08	0.03’	0.11	-	-	**0.11****	**0.51**
f.fast.lotic	-	-	-	-	0.2*	0.21	0.10**	0.35
f.still.slow.lotic	0.02**	0.28	0.02**	0.27	**0.12****	**0.49**	0.02	0.07
f.saltmarsh	-	-	-	-	-	-	0.07**	0.37
f.mud.silt.flat	-0.06**	0.32	-0.06**	0.37	-0.22*	0.22	-	-
f.sandy.gravel.beach	-	-	-0.01	0.02	-	-	-	-
f.reed.marsh	0.02*	0.16	0.02*	0.16	**0.15****	**0.76**	-	-
f.conifer	-	-	-	-	-0.03**	0.36	-0.01	0.07
f.mixed	-0.02**	0.35	-0.01**	0.31	**-0.1****	**0.63**	-0.02	0.07
f.deciduous	-0.02	0.2	-0.01*	0.25	-0.07*	0.26	-0.02*	0.15
f.mediterranean.oak	-0.02**	0.28	-0.02**	0.29	-0.04	0.01	-0.04*	0.26
f.open.or.low.forest	-0.01	0.02	-0.01	0.01	-0.07*	0.26	**-0.04****	**0.63**
f.forest.habitat.edge	-0.02	0.06	-0.02	0.07	-0.13*	0.21	-0.06**	0.32

f.shrub.bush	0.01	0.02	0.01	0.02	-	-	-0.06**	0.43
f.urban	-	-	-	-	-0.13**	0.41	0.02	0.01
f.garden	-0.03**	0.34	-0.03**	0.36	**-0.18****	**0.78**	-	-
Foraging niche size	-0.0002*	0.21	-0.0002*	0.25	-0.001’	0.13	-	-
Breeding habitat								
b.wet.grslnd.tundra	-	-	-	-	0.04	0.01	-	-
b.dry.grassland	-	-	-	-	**0.17****	**0.55**	0.02	0.02
b.banks.sand.mud	-	-	-	-	-0.11**	0.37	0.03’	0.10
b.rockfaces.outcrops	-	-	-	-	-0.03’	0.12	0.01	0.03
b.nr.water.lkshr.island	0.02’	0.14	0.02*	0.15	0.11**	0.32	0.05**	0.37
b.sand.gravel.beach	0.03*	0.17	0.03’	0.11	**0.26****	**0.56**	0.04	0.04
b.reed.marsh	0.01	0.09	0.01	0.06	**0.16****	**0.82**	-	-
b.conifer	-0.003	0.02	-0.004	0.06	-0.03**	0.34	-0.01’	0.11
b.mixed	**-0.02****	**0.45**	-0.01**	0.41	**-0.07***	**0.43**	-0.02*	0.20
b.deciduous	-0.02*	0.2	-0.01*	0.21	-0.06’	0.1	-0.03*	0.18
b.mediterranean.oak.	-0.02*	0.24	-0.02*	0.25	-	-	-0.04**	0.34
b.open.low.forest	-0.02	0.06	-0.02	0.08	-	-	-0.06*	0.17
b.shrub.bush	-	-	-	-	0.05	0.08	-0.02	0.04
b.urban	-0.01	0.02	-0.01	0.01	-0.09*	0.24	0.03*	0.18
b.garden	-0.04**	0.38	-0.03**	0.41	**-0.21****	**0.65**	0.03	0.04
Breeding niche size	**-0.002****	**0.55**	**-0.002****	**0.59**	**-0.01****	**0.65**	0.00	0.09
Nest position								
nest.cavity	-	-	-	-	-0.003	0.04	0.00*	0.23
nest.elevated	-0.001	0.02	-0.001	0.04	-0.004’	0.13	**-0.00****	**0.50**
nest.ground	0.001*	0.16	0.001’	0.12	**0.01***	**0.54**	0.00	0.03
Migratory status								
mig.long	-	-	0.001	0	0.05’	0.11	**-0.00****	**0.58**
mig.sed	-0.001’	0.06	-0.001’	0.12	-	-	0.00*	0.15
mig.short	0.001’	0.09	0.001’	0.12	-0.01*	0.16	-	-
Range								

Prevalence	-	-	-	-	-0.12**	0.42	-0.02	0.00

Figures

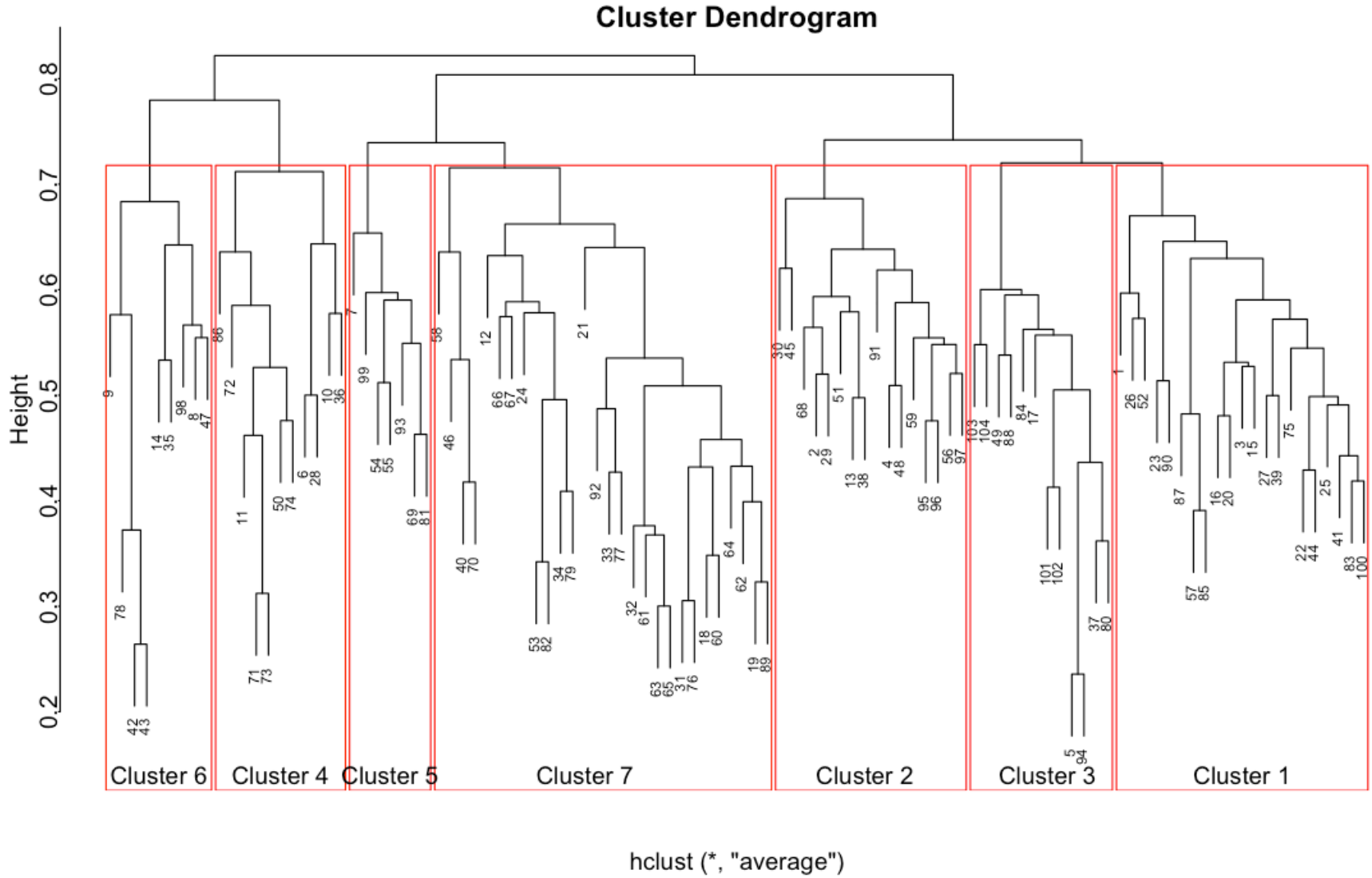

Figure S1. Dendrogram of functional dissimilarity and resulting bird functional groups (cf. Table S3).

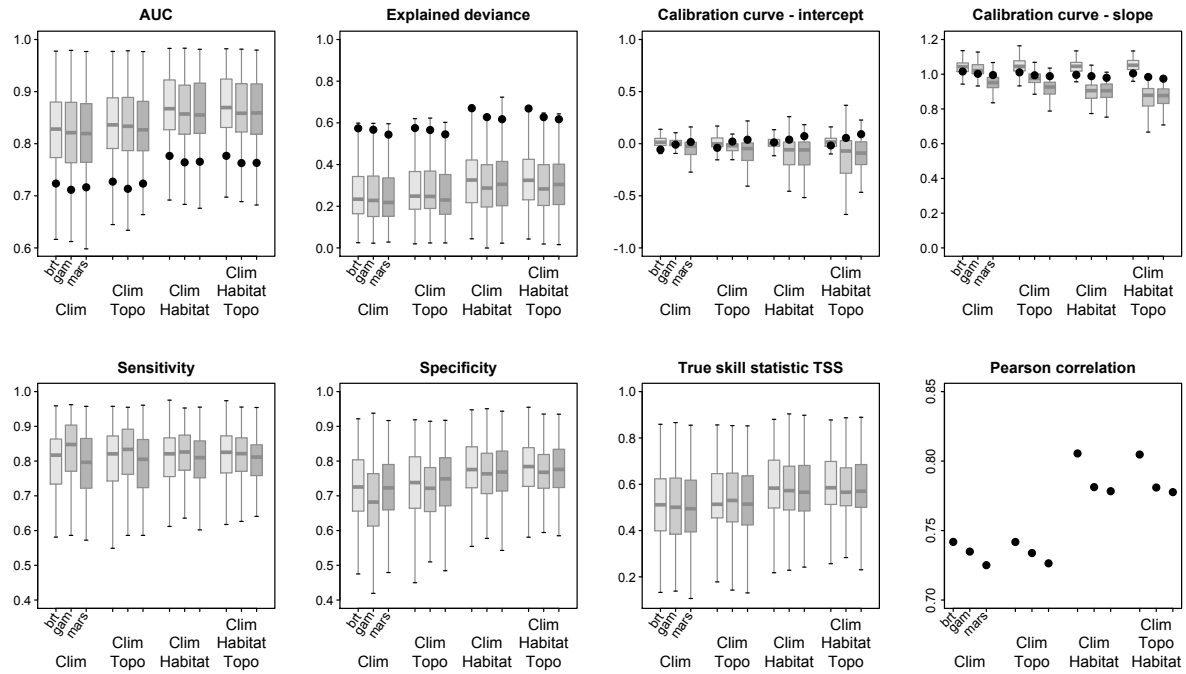

Figure S2. Model performance of single SDMs (boxplots) and MEMs (black dots) for different predictor sets and algorithms. For SDMs, we calculated the area under the ROC curve (AUC), the true skill statistic (TSS), sensitivity (true presences) and specificity (true absences), the explained deviance as well as slope and intercept of the calibration curve, which describe spread and bias in predictions. For MEMs, we calculated (rank-based) AUC, explained deviance, slope and intercept of calibration curve, and the Pearson correlation coefficient.

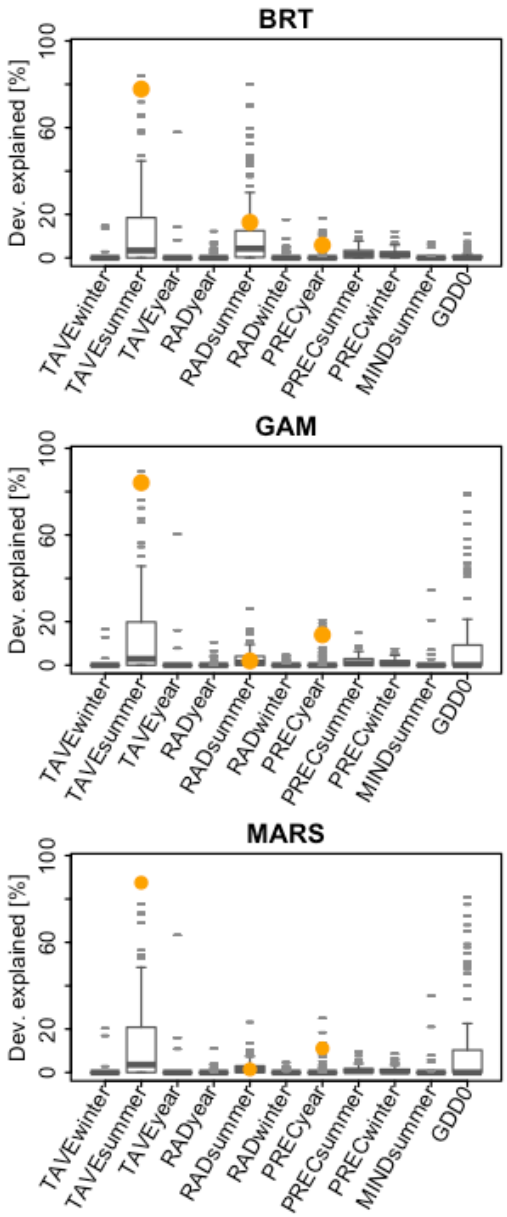

Figure S3. Variable importance (% deviance explained) in climate only models for different algorithms. Boxplots show the distribution of variable importance in single SDMs, orange dots show variable importance in MEM.

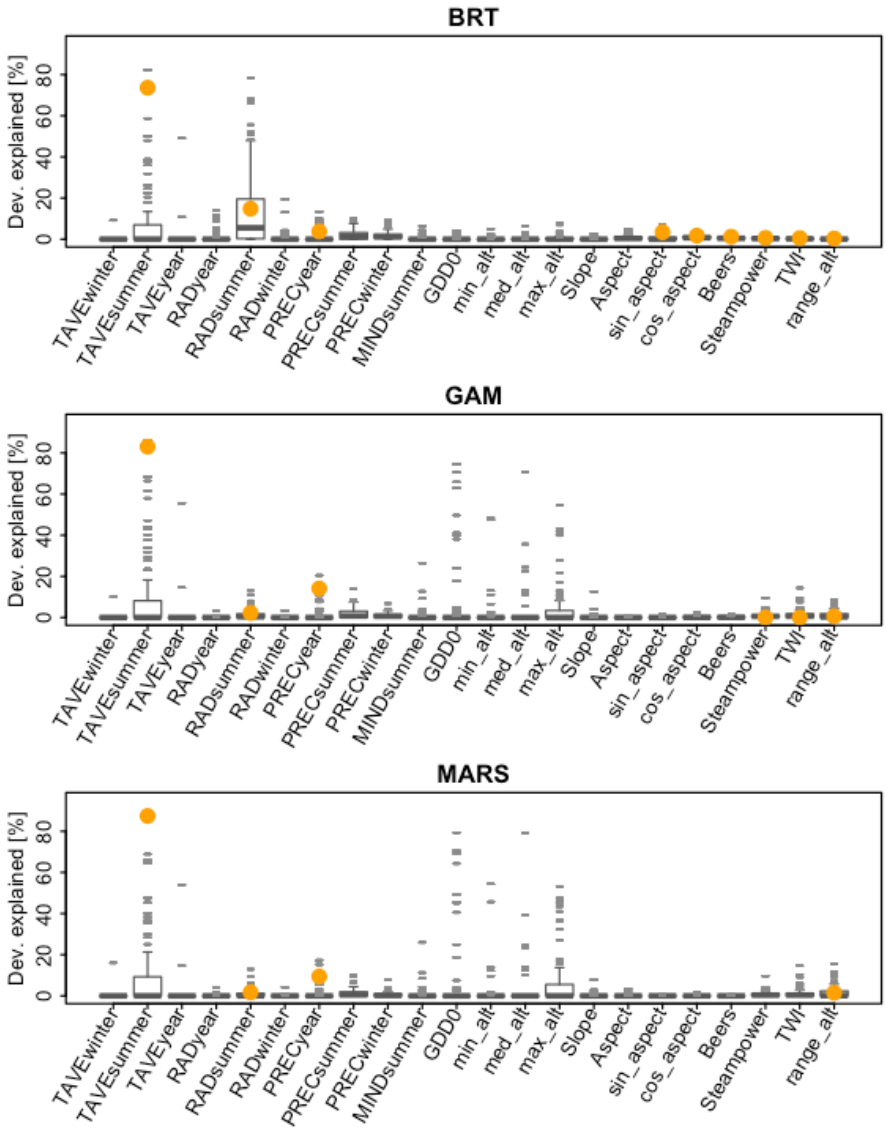

Figure S4. Variable importance (% deviance explained) in topoclimatic models for different algorithms. Boxplots show the distribution of variable importance in single SDMs, orange dots show variable importance in MEM.

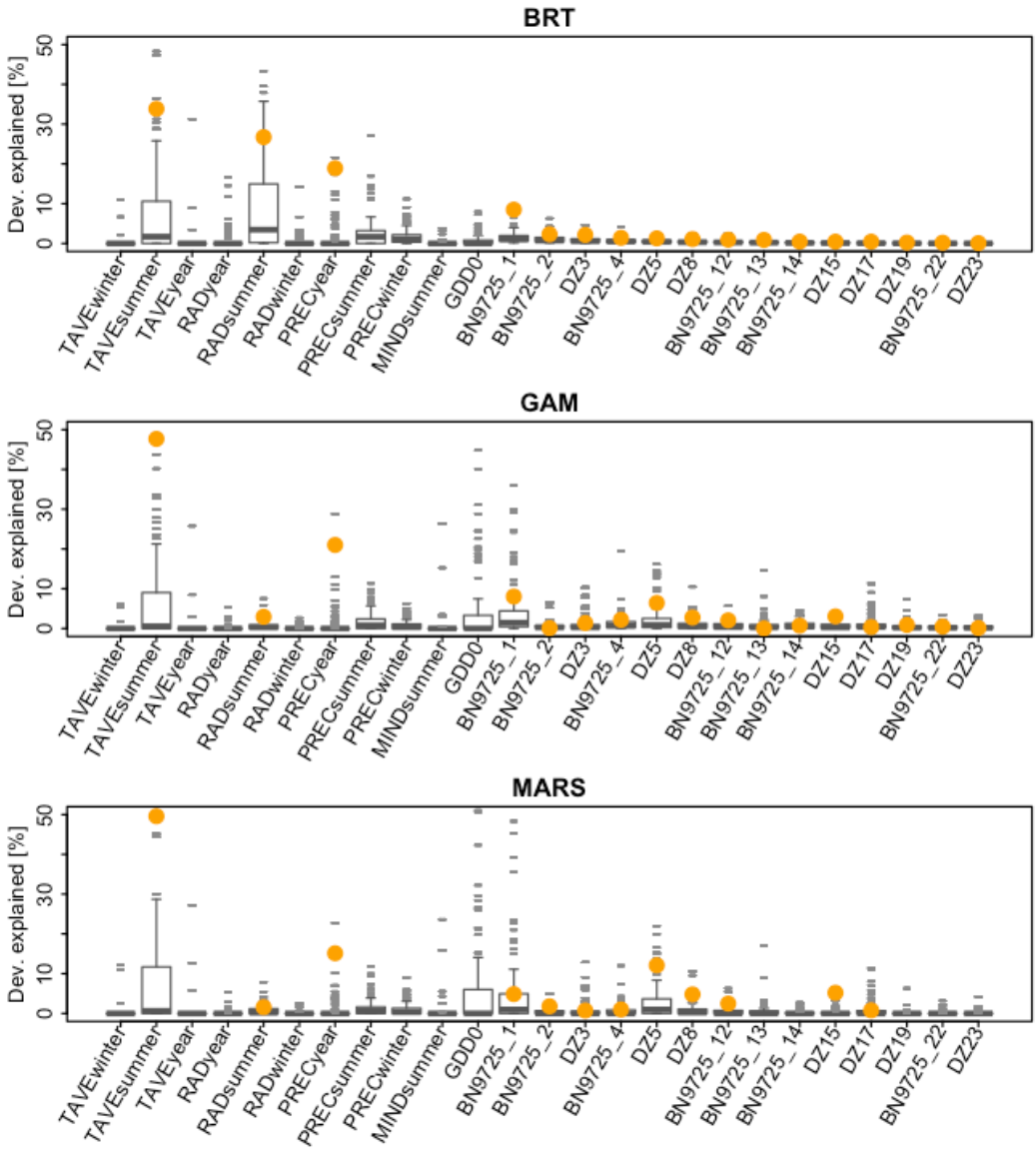

Figure S5. Variable importance (% deviance explained) in models including climatic and habitat predictors for different algorithms. Boxplots show the distribution of variable importance in single SDMs, orange dots show variable importance in MEM.

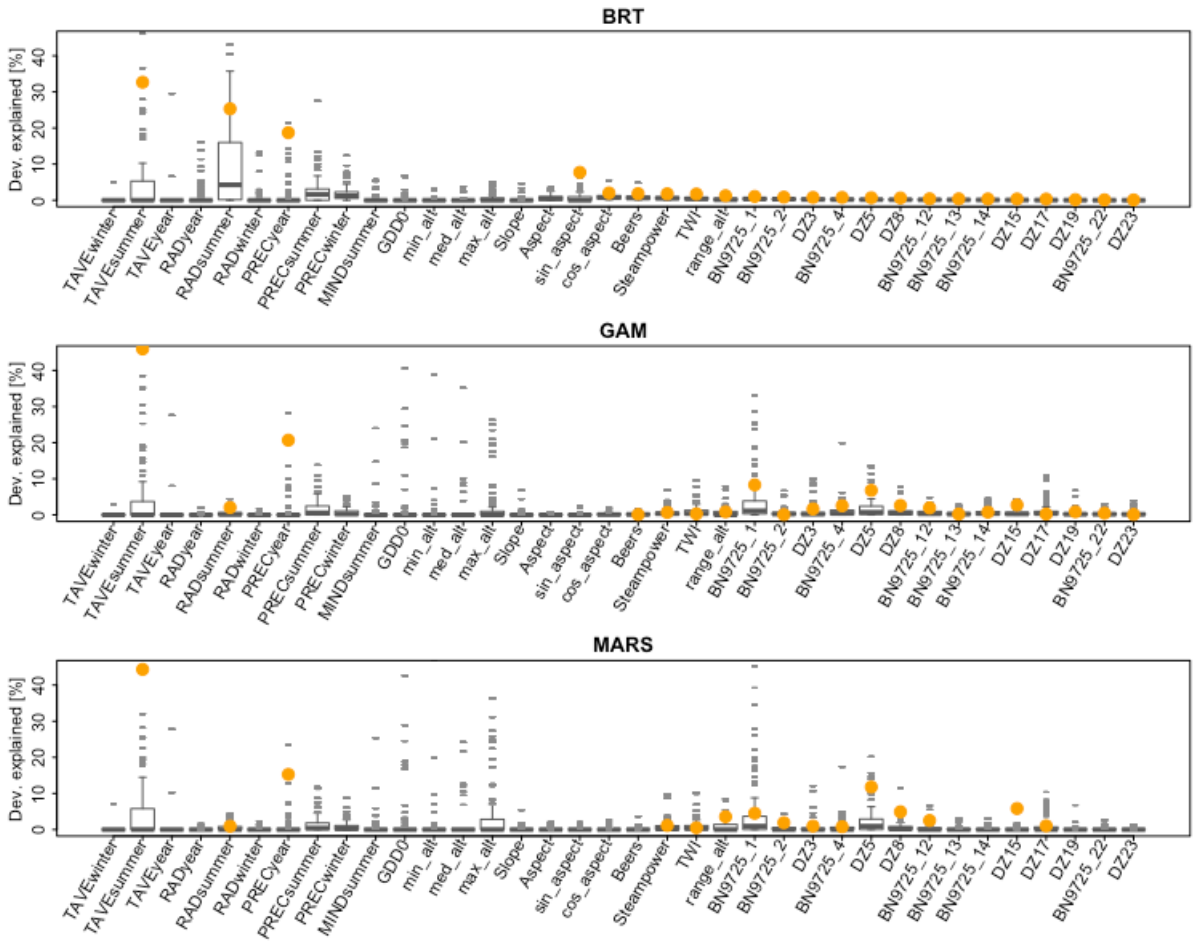

Figure S6. Variable importance (% deviance explained) in models including topoclimatic and habitat predictors for different algorithms. Boxplots show the distribution of variable importance in single SDMs, orange dots show variable importance in MEM.

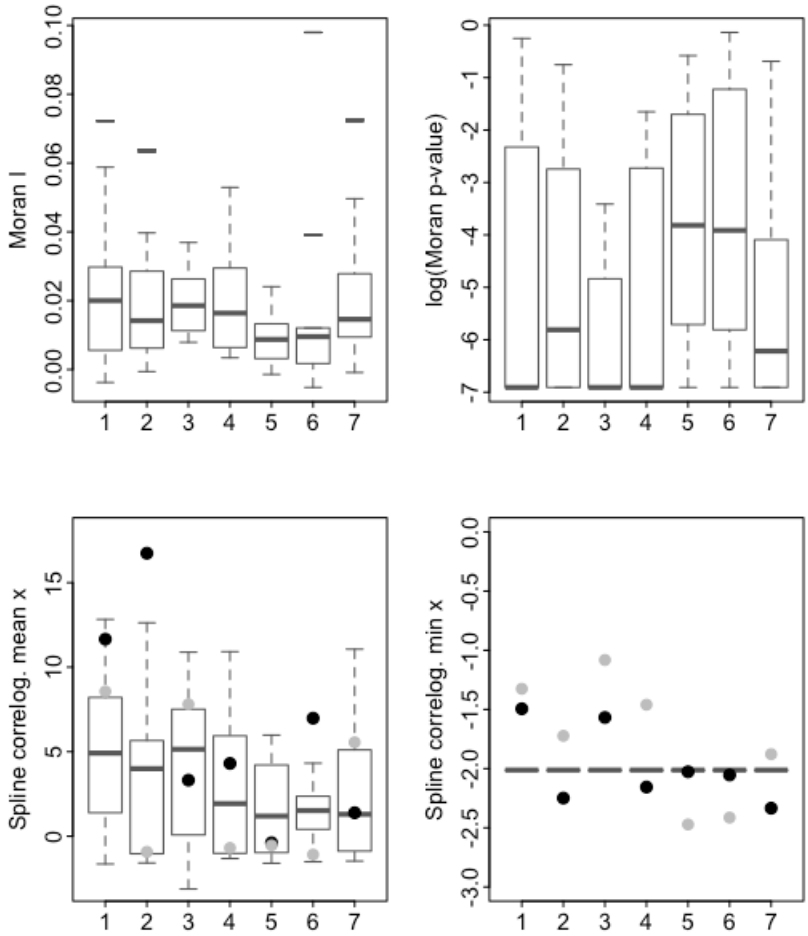

Figure S7. Spatial autocorrelation of single species SDMs and S-SDMs within bird functional groups. Top panels: Boxplots depict Moran's I statistics (left) and *p* value obtained from 1000 permutations (right) for single SDMs. Bottom panels: Spatial autocorrelation scores for bS-SDM predictions are shown as black dots, for pS-SDM predictions in grey. Only results for models estimated using BRTs on the CTH predictor set are shown.

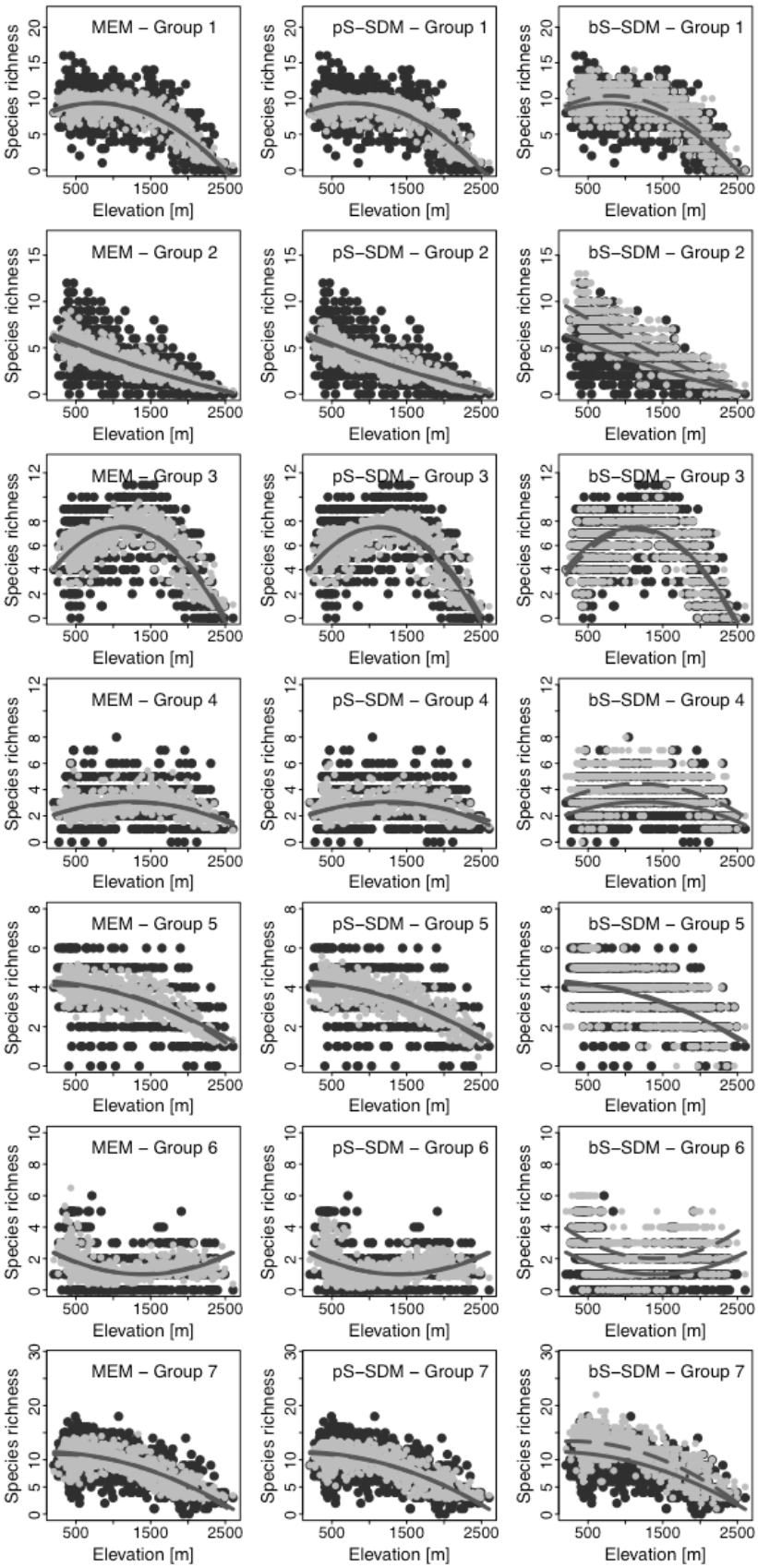

Figure S8. Predicted and observed species richness along elevation for different bird functional groups. Observed species richness values are shown in black and their mean as solid lines. Predicted species richness for the different model types are shown in grey and their mean as dashed lines. Predictions are made by a simple average consensus from BRTs, GAM and MARS that are based on CTH predictor set.

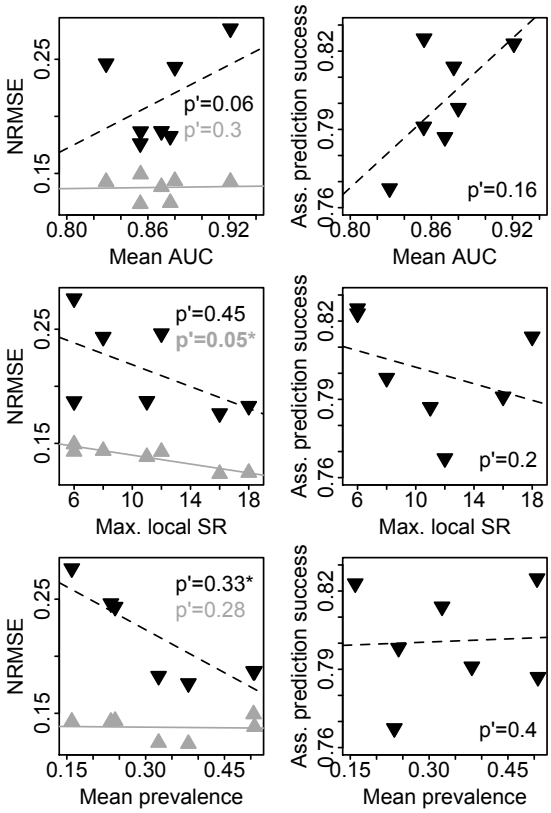

Figure S9. Effects of mean SDM accuracy (AUC), maximum local species richness and prevalence within functional groups on bS-SDM and pS-SDM performance in terms of NRMSE and assemblage prediction success (for bS-SDMs only). Performance of bS-SDM is depicted by black triangles pointing down, performance of pS-SDM by grey triangles pointing up. Lines indicate the fit of a linear model. Significance p' was tested by comparing the t-value of the slope of the linear model against a null distribution of 5000 t-values obtained by randomly permutating the group memberships of the species while keeping the number of species per group constant (null distributions are shown in Figs. S10). Significance of the linear model of original data is indicated by * (p<=0.05); significant p-values of the permutation test are shown in bold. Predictions were made on hold-out data using simple average consensus.

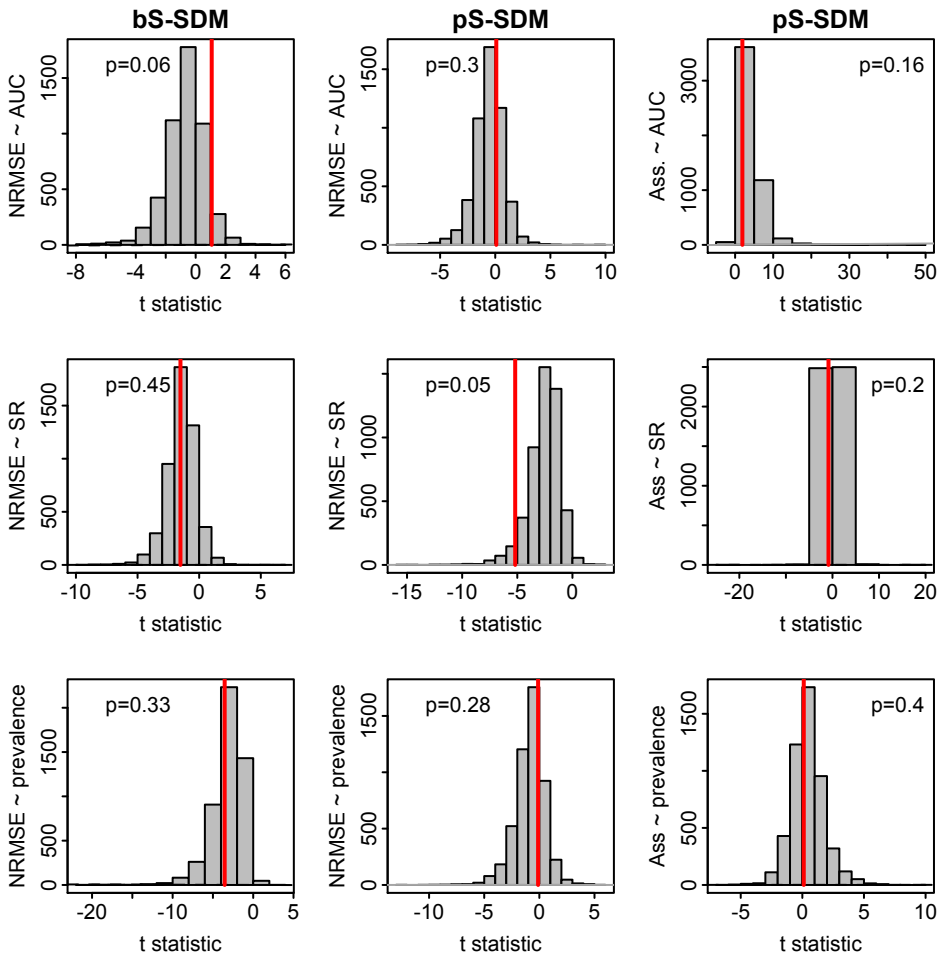

Figure S10. Null distributions of t-values obtained from correlating bS-SDM and pS-SDM performance (NRMSE, and Assemblage prediction success) within bird functional groups against mean AUC, mean prevalence and maximum local species richness. Group memberships of the species were randomly permuted (*n*=5000) while keeping the number of species per group constant. The red lines indicate the respective t-values obtained for the original data and the p-values the respective quantiles of the null distribution.

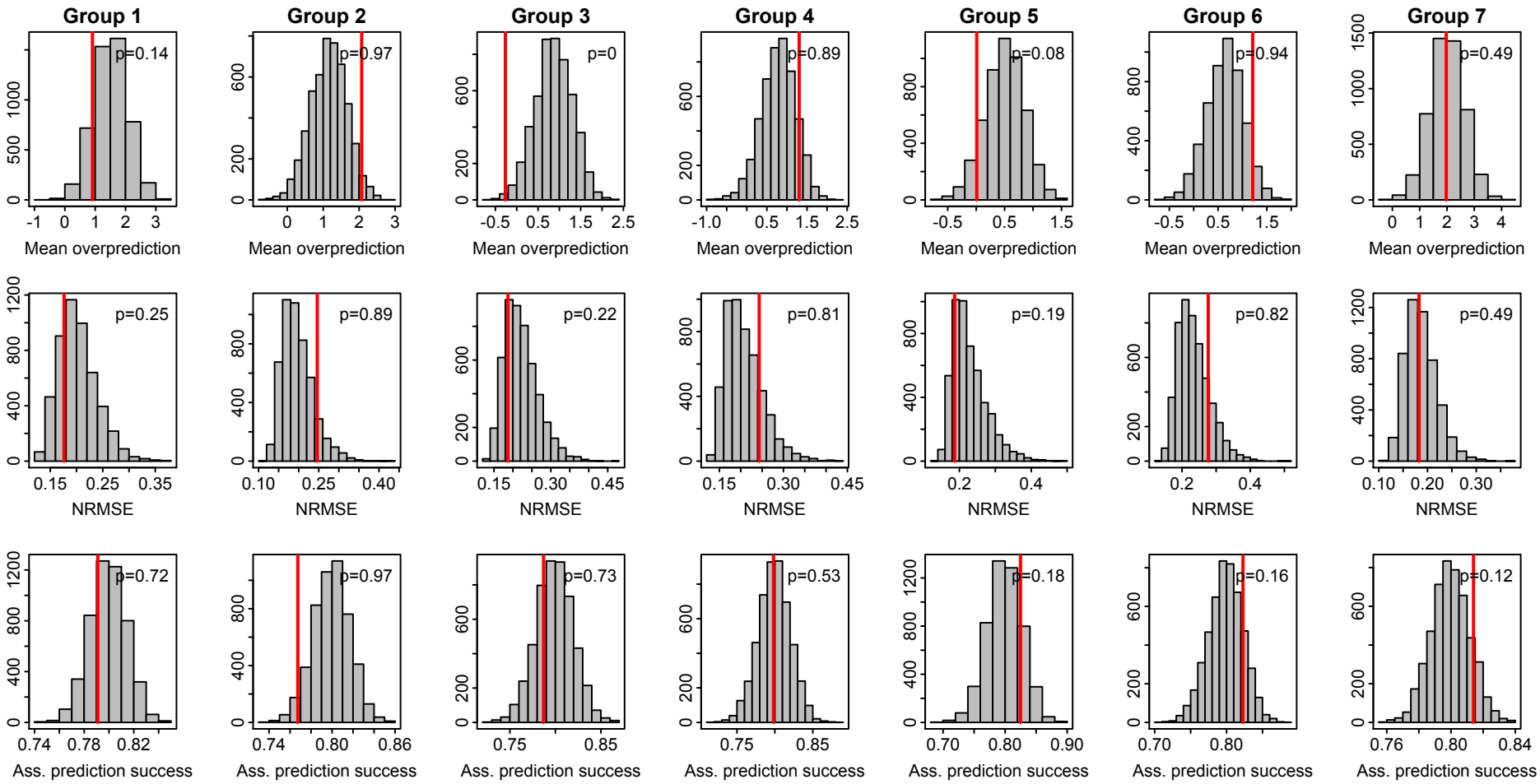

Figure S11. Null distributions of bS-SDM performance (mean overprediction, NRMSE, and Assemblage prediction success) for bird functional groups. Group memberships of the species were randomly permuted (*n*=5000) while keeping the number of species per group constant. The red lines indicate the performance obtained for the original data and the respective p-values.