

Supporting Information

Testing species assemblage predictions from stacked and joint species distribution models

Damaris Zurell, Niklaus E. Zimmermann, Helge Gross, Andri Baltensweiler, Thomas Sattler, Rafael O. Wüest

This supporting information contains the following items:

- Table S1. Forest bird species included in analyses.
- Table S2. Tree and shrub species included in the analyses.
- Fig. S1. Distribution of bird and tree prevalence levels.
- Fig. S2. Spatial blocks used in 5-fold spatial block cross-validation.
- Fig. S3. Predictor variables for forest bird and tree species analyses.
- Fig. S4. Single species model performance.
- Fig. S5. Spatial autocorrelation in model residuals.
- Fig. S6. Prevalence of species with higher JSDM or SDM performance.
- Fig. S7. Assemblage sensitivity and specificity.

Supplementary Tables

Table S1. Forest bird species included in the analyses. For each species, we list the predictive performance achieved in the single-species ensemble SDMs and JSMDs (cf. Fig. S3).

Latin Name	English Name	JSMD				SDM			
		AUC	Sens	Spec	TSS	AUC	Sens	Spec	TSS
Accipiter gentilis	Northern Goshawk	0.61	0.83	0.34	0.17	0.85	0.81	0.75	0.56
Accipiter nisus	Eurasian Sparrowhawk	0.56	0.79	0.32	0.10	0.85	0.85	0.75	0.59
Aegithalos caudatus	Long-tailed Bushtit	0.67	0.89	0.37	0.27	0.83	0.80	0.72	0.52
Anthus trivialis	Tree Pipit	0.83	0.79	0.77	0.56	0.90	0.88	0.78	0.66
Asio otus	Long-eared Owl	0.54	0.46	0.71	0.17	0.94	0.91	0.90	0.80
Bonasa bonasia	Hazel Grouse	0.60	0.12	0.95	0.07	0.94	1.00	0.79	0.79
Buteo buteo	Common Buzzard	0.85	0.77	0.77	0.54	0.90	0.78	0.84	0.62
Carduelis spinus	Eurasian Siskin	0.83	0.89	0.67	0.56	0.89	0.94	0.70	0.64
Certhia brachydactyla	Short-toed Treecreeper	0.88	0.85	0.77	0.62	0.92	0.88	0.81	0.68
Certhia familiaris	Eurasian Treecreeper	0.74	0.61	0.73	0.34	0.83	0.74	0.75	0.48
Coccothraustes coccothraustes	Hawfinch	0.76	0.87	0.54	0.41	0.86	0.77	0.78	0.54
Columba oenas	Stock Dove	0.75	0.93	0.53	0.46	0.88	0.93	0.71	0.64
Columba palumbus	Common Wood Pigeon	0.89	0.83	0.80	0.63	0.92	0.87	0.81	0.68
Corvus corax	Northern Raven	0.58	0.60	0.52	0.12	0.79	0.82	0.62	0.44
Corvus corone	Carrion Crow	0.82	0.68	0.83	0.51	0.89	0.79	0.86	0.65
Cuculus canorus	Common Cuckoo	0.63	0.49	0.74	0.24	0.78	0.77	0.65	0.41
Dendrocopos major	Great Spotted Woodpecker	0.81	0.73	0.75	0.48	0.87	0.74	0.84	0.58
Dendrocopos minor	Lesser Spotted Woodpecker	0.83	0.85	0.64	0.49	0.90	0.95	0.71	0.67
Dryocopus martius	Black Woodpecker	0.72	0.91	0.43	0.34	0.83	0.88	0.62	0.50
Emberiza citrinella	Yellowhammer	0.82	0.75	0.75	0.50	0.89	0.85	0.76	0.61
Falco subbuteo	Eurasian Hobby	0.78	0.92	0.54	0.46	0.90	0.91	0.74	0.65
Ficedula hypoleuca	European Pied Flycatcher	0.75	0.90	0.55	0.45	0.85	0.88	0.67	0.55
Garrulus glandarius	Eurasian Jay	0.81	0.80	0.67	0.48	0.90	0.76	0.85	0.60
Hippolais icterina	Icterine warbler	0.75	0.50	0.88	0.38	0.95	0.98	0.85	0.83
Lanius collurio	Red-backed Shrike	0.66	0.91	0.34	0.25	0.84	0.73	0.79	0.52
Loxia curvirostra	Red Crossbill	0.79	0.74	0.73	0.47	0.86	0.87	0.70	0.57

1	Luscinia megarhynchos	Common Nightingale	0.91	0.78	0.85	0.63	0.95	0.98	0.83	0.82
2	Milvus migrans	Black Kite	0.79	0.81	0.64	0.45	0.86	0.92	0.64	0.56
3	Muscicapa striata	Spotted Flycatcher	0.79	0.86	0.63	0.49	0.86	0.89	0.65	0.55
4	Nucifraga caryocatactes	Spotted Nutcracker	0.88	0.91	0.74	0.65	0.92	0.90	0.80	0.70
5	Oriolus oriolus	Eurasian Golden Oriole	0.90	0.88	0.79	0.67	0.93	0.97	0.79	0.76
6	Parus caeruleus	Blue Tit	0.92	0.90	0.83	0.73	0.96	0.91	0.85	0.75
7	Parus cristatus	European Crested Tit	0.81	0.81	0.65	0.46	0.88	0.79	0.79	0.58
8	Parus montanus	Willow Tit	0.86	0.83	0.82	0.65	0.91	0.85	0.83	0.69
9	Parus palustris	Marsh Tit	0.82	0.80	0.74	0.54	0.89	0.84	0.75	0.59
10	Pernis apivorus	European Honey Buzzard	0.58	0.90	0.25	0.15	0.87	0.95	0.69	0.64
11	Phoenicurus phoenicurus	Common Redstart	0.61	0.77	0.43	0.20	0.81	0.76	0.72	0.49
12	Phylloscopus bonelli	Western Bonellis Warbler	0.68	0.55	0.75	0.30	0.86	0.85	0.70	0.55
13	Phylloscopus sibilatrix	Wood Warbler	0.74	0.79	0.63	0.41	0.85	0.80	0.74	0.54
14	Phylloscopus trochilus	Willow Warbler	0.69	0.87	0.49	0.36	0.84	0.81	0.72	0.53
15	Picus canus	Grey-headed Woodpecker	0.80	0.79	0.70	0.49	0.90	0.92	0.79	0.71
16	Picus viridis	European Green Woodpecker	0.67	0.71	0.54	0.26	0.81	0.72	0.74	0.46
17	Prunella modularis	Dunnock	0.77	0.64	0.77	0.41	0.86	0.75	0.80	0.55
18	Pyrrhula pyrrhula	Eurasian Bullfinch	0.79	0.74	0.69	0.43	0.87	0.72	0.83	0.55
19	Regulus ignicapillus	Firecrest	0.83	0.76	0.78	0.54	0.89	0.82	0.79	0.62
20	Regulus regulus	Goldcrest	0.80	0.85	0.64	0.49	0.88	0.78	0.80	0.58
21	Serinus citrinella	Citril Finch	0.88	0.90	0.80	0.70	0.92	0.99	0.73	0.73
22	Sitta europaea	Eurasian Nuthatch	0.84	0.77	0.78	0.55	0.90	0.80	0.81	0.61
23	Streptopelia turtur	European Turtle Dove	0.85	0.80	0.78	0.57	0.93	0.99	0.80	0.79
24	Strix aluco	Tawny Owl	0.60	0.71	0.46	0.16	0.86	0.89	0.70	0.59
25	Sylvia borin	Garden Warbler	0.69	0.56	0.73	0.29	0.81	0.72	0.76	0.48
26	Sylvia curruca	Lesser Whitethroat	0.84	0.80	0.80	0.60	0.91	0.89	0.78	0.67
27	Tetrao tetrix	Black Grouse	0.94	0.97	0.80	0.78	0.96	0.96	0.88	0.83
28	Turdus pilaris	Fieldfare	0.65	0.81	0.45	0.26	0.81	0.65	0.82	0.47
29	Turdus torquatus	Ring Ouzel	0.94	0.98	0.84	0.82	0.96	0.99	0.85	0.84
30	Turdus viscivorus	Mistle Thrush	0.79	0.77	0.70	0.47	0.87	0.79	0.77	0.56

Table S2. Tree and shrub species included in the analyses. For each species, we list the predictive performance achieved in the single-species ensemble SDMs and JSMDs (cf. Fig. S3).

Latin Name	English Name	JSMD				SDM			
		AUC	Sens	Spec	TSS	AUC	Sens	Spec	TSS
<i>Abies alba</i>	Silver Fir	0.82	0.79	0.71	0.50	0.88	0.86	0.72	0.58
<i>Acer campestris</i>	Hedge Maple	0.82	0.76	0.74	0.50	0.92	0.99	0.74	0.73
<i>Acer opalus</i>	Italian Maple	0.67	0.00	1.00	0.00	0.97	1.00	0.93	0.93
<i>Acer platanoides</i>	Norway Maple	0.74	0.88	0.55	0.43	0.93	0.95	0.82	0.77
<i>Acer pseudoplatanus</i>	Sycamore Maple	0.75	0.80	0.60	0.39	0.85	0.72	0.79	0.51
<i>Alnus glutinosa</i>	Black Alder	0.82	0.84	0.68	0.53	0.97	1.00	0.92	0.92
<i>Alnus incana</i>	European Alder	0.68	0.76	0.51	0.27	0.90	0.93	0.70	0.64
<i>Alnus viridis</i>	Green Alder	0.90	0.80	0.83	0.63	0.94	0.98	0.78	0.76
<i>Berberis vulgaris</i>	Barberry	0.81	0.64	0.87	0.51	0.97	0.99	0.90	0.89
<i>Betula pendula</i>	Weeping Birch	0.74	0.79	0.57	0.36	0.87	0.89	0.68	0.57
<i>Carpinus betulus</i>	Hornbeam	0.89	0.94	0.76	0.70	0.95	0.96	0.86	0.83
<i>Castanea sativa</i>	Sweet Chestnut	0.89	0.71	0.92	0.63	0.99	0.99	0.94	0.93
<i>Clematis vitalba</i>	Old Mans Beard	0.82	0.79	0.73	0.52	0.93	0.98	0.81	0.78
<i>Cornus sanguinea</i>	Red Dogwood	0.82	0.61	0.80	0.40	0.92	0.96	0.74	0.70
<i>Corylus avellana</i>	Hazel	0.74	0.82	0.57	0.39	0.84	0.78	0.73	0.51
<i>Crataegus monogyna</i>	Common Hawthorn	0.76	0.75	0.66	0.41	0.92	0.90	0.79	0.68
<i>Crataegus oxyacantha</i>	English Hawthorn	0.81	0.85	0.65	0.50	0.94	0.98	0.77	0.75
<i>Daphne mezereum</i>	Paradise Plant	0.54	0.47	0.60	0.07	0.97	0.92	0.92	0.84
<i>Euonymus europaeus</i>	European Spindle Tree	0.86	0.65	0.84	0.48	0.95	0.98	0.82	0.80
<i>Fagus sylvatica</i>	Beech	0.92	0.87	0.83	0.70	0.95	0.87	0.87	0.74
<i>Fraxinus excelsior</i>	Ash	0.82	0.82	0.72	0.54	0.89	0.88	0.71	0.59
<i>Hedera helix</i>	English Ivy	0.85	0.91	0.67	0.58	0.91	0.89	0.80	0.69
<i>Ilex aquifolium</i>	English Holly	0.82	0.91	0.61	0.53	0.95	0.94	0.85	0.79
<i>Juglans regia</i>	Walnut	0.81	0.92	0.63	0.55	0.95	0.97	0.88	0.85
<i>Juniperus communis</i>	Common Juniper	0.82	0.68	0.76	0.44	0.95	0.96	0.86	0.82
<i>Juniperus communis</i> ssp <i>alpina</i>	Common Juniper (Ssp Alpina)	0.87	0.75	0.85	0.59	0.96	0.97	0.88	0.86
<i>Larix decidua</i>	European Larch	0.79	0.67	0.78	0.45	0.88	0.77	0.81	0.58
<i>Ligustrum vulgare</i>	Common Privet	0.82	0.37	0.88	0.25	0.92	0.96	0.76	0.72
<i>Lonicera alpigena</i>	Alpine Honeysuckle	0.67	0.74	0.50	0.24	0.94	0.95	0.82	0.77
<i>Lonicera caerulea</i>	Blue Honeysuckle	0.60	0.18	0.87	0.05	0.99	0.98	0.97	0.95
<i>Lonicera nigra</i>	Black Honeysuckle	0.66	0.74	0.52	0.26	0.94	0.94	0.84	0.78

1	Lonicera	European Fly								
2	<i>xylosteum</i>	Honeysuckle	0.71	0.84	0.51	0.35	0.85	0.74	0.77	0.51
3	Picea abies	Norway Spruce	0.75	0.74	0.64	0.38	0.88	0.73	0.88	0.61
4	Pinus cembra	Swiss Stone								
5		Pine	0.95	0.89	0.90	0.79	0.98	0.99	0.91	0.90
6	Pinus mugo	Mountain Pine								
7	<i>arborea</i>	(Var Arborea)	0.86	0.04	0.99	0.03	0.98	0.98	0.92	0.91
8	Pinus mugo	Mountain Pine								
9	<i>prostrata</i>	(Var Prostrata)	0.91	0.68	0.89	0.57	0.98	1.00	0.94	0.94
10	Pinus sylvestris	Scots Pine	0.73	0.83	0.54	0.36	0.88	0.86	0.75	0.62
11	Populus tremula	Aspen	0.70	0.52	0.75	0.28	0.94	0.94	0.86	0.80
12	Prunus avium	Sweet Cherry	0.80	0.84	0.64	0.48	0.88	0.88	0.71	0.59
13	Prunus padus	European Bird								
14		Cherry	0.79	0.62	0.85	0.46	0.97	0.98	0.91	0.88
15	Prunus spinosa	Blackthorn	0.78	0.25	0.91	0.16	0.95	0.97	0.84	0.81
16	Pseudotsuga	Douglas Fir								
17	<i>menziesii</i>		0.85	0.81	0.77	0.58	0.98	0.99	0.93	0.92
18	Quercus petraea	Eych	0.85	0.92	0.65	0.57	0.92	0.97	0.77	0.74
19	Quercus	Downy Oak								
20	<i>pubescens</i>		0.84	0.45	0.96	0.41	0.99	1.00	0.96	0.96
21	Quercus robur	Common Oak	0.88	0.88	0.74	0.62	0.93	0.97	0.75	0.72
22	Rhamnus frangula	Alder								
23		Buckthorn	0.78	0.60	0.79	0.39	0.97	1.00	0.90	0.90
24	Rhododendron	Rusty Leaved								
25	<i>ferrugineum</i>	Alpenrose	0.89	0.58	0.93	0.51	0.95	0.98	0.82	0.79
26	Ribes alpinum	Mountain								
27		Currant	0.54	0.00	1.00	0.00	1.00	0.97	0.97	0.94
28	Robinia	Black Locust								
29	<i>pseudoacacia</i>		0.92	0.70	0.92	0.61	0.99	1.00	0.97	0.97
30	Rubus fruticosus	Blackberry								
31	<i>spec</i>		0.75	0.15	0.96	0.10	0.92	0.92	0.77	0.69
32	Rubus idaeus	American Red								
33		Raspberry	0.64	0.07	0.97	0.03	0.95	0.94	0.85	0.79
34	Salix caprea	Goat Willow	0.61	0.74	0.45	0.18	0.83	0.75	0.74	0.50
35	Sambucus nigra	Common Elder	0.81	0.75	0.74	0.49	0.89	0.86	0.75	0.61
36	Sambucus	Red Elderberry								
37	<i>racemosa</i>		0.61	0.71	0.46	0.17	0.91	0.90	0.78	0.68
38	Sorbus aria	Whitebeam	0.69	0.62	0.65	0.27	0.85	0.78	0.75	0.53
39	Sorbus aucuparia	Rowan	0.72	0.72	0.62	0.34	0.84	0.77	0.74	0.51
40	Taxus baccata	Yew	0.67	0.00	1.00	0.00	0.99	0.98	0.97	0.95
41	Tilia cordata	Small-Leaved								
42		Lime	0.83	0.88	0.66	0.53	0.94	0.96	0.87	0.82
43	Tilia platyphyllos	Large-Leaved								
44		Lime	0.75	0.92	0.51	0.42	0.94	0.95	0.85	0.80
45	Ulmus glabra	Scots Elm	0.71	0.92	0.46	0.38	0.87	0.84	0.74	0.58
46	Vaccinium	Black								
47	<i>myrtillus</i>	Whortleberry	0.69	0.00	1.00	0.00	0.98	0.97	0.91	0.87
48	Viburnum lantana	Wayfaring-								
49		Tree	0.76	0.53	0.79	0.31	0.90	0.95	0.70	0.65
50	Viburnum opulus	Guelder Rose	0.78	0.75	0.69	0.44	0.93	0.97	0.75	0.73

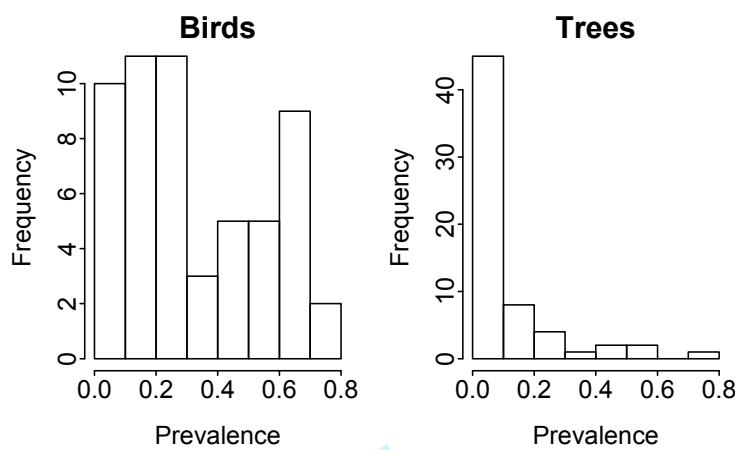
Supplementary Figures

Figure S1. Distribution of bird and tree prevalence levels.



Figure S2. Spatial blocks used in 5-fold spatial block cross-validation.

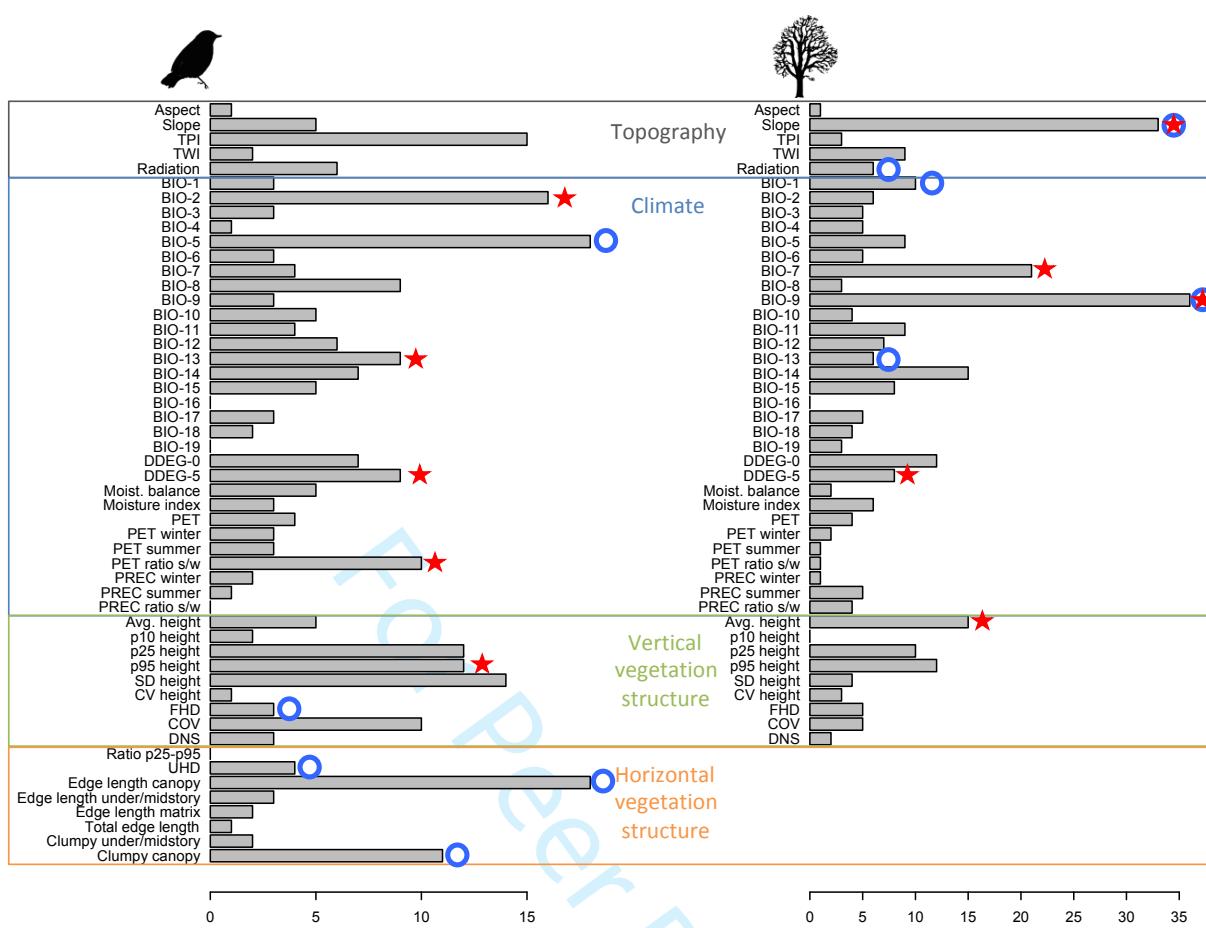


Figure S3. Predictor variables for forest bird and tree species analyses. The barplots indicate the number of times each predictor variable was selected in the individual SDMs. Red stars indicate the five globally selected predictor variables that were used for the JSMDs and global SDMs. Blue circles indicate the five predictor variables selected for (individual) MEMs. Please refer to main text for description of the predictor variables and variable selection.

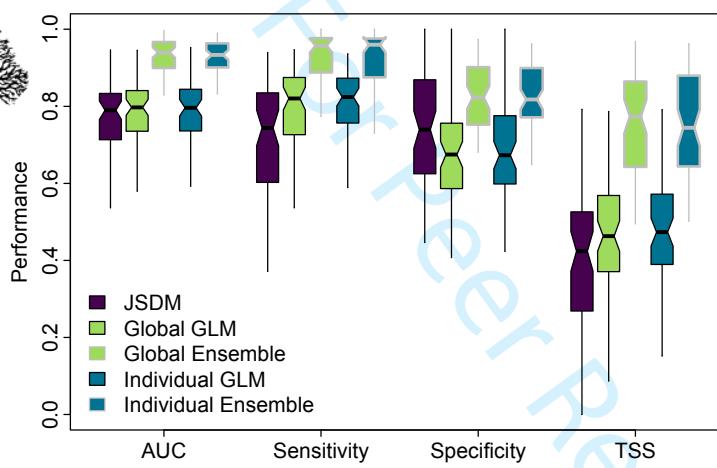
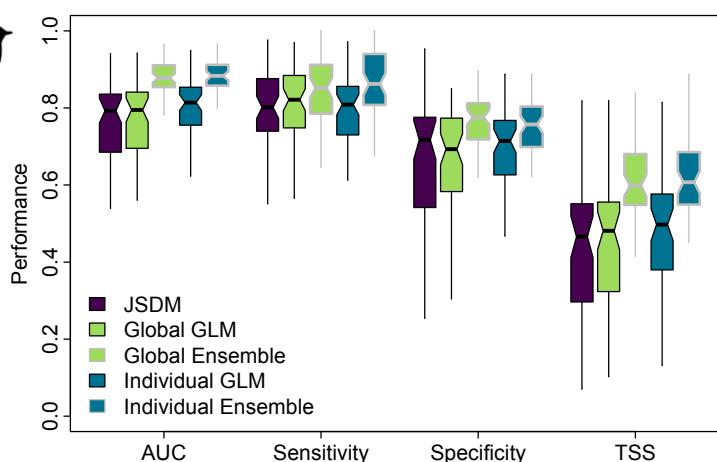


Figure S4. Single species performance for forest birds (top) and tree species (bottom). Global GLM and Global Ensemble refer to SDMs estimated using the same globally selected predictor set as in JSDMs. Individual GLM and Individual Ensemble refer to SDMs estimated using species-specific predictor sets. Outliers are not shown.

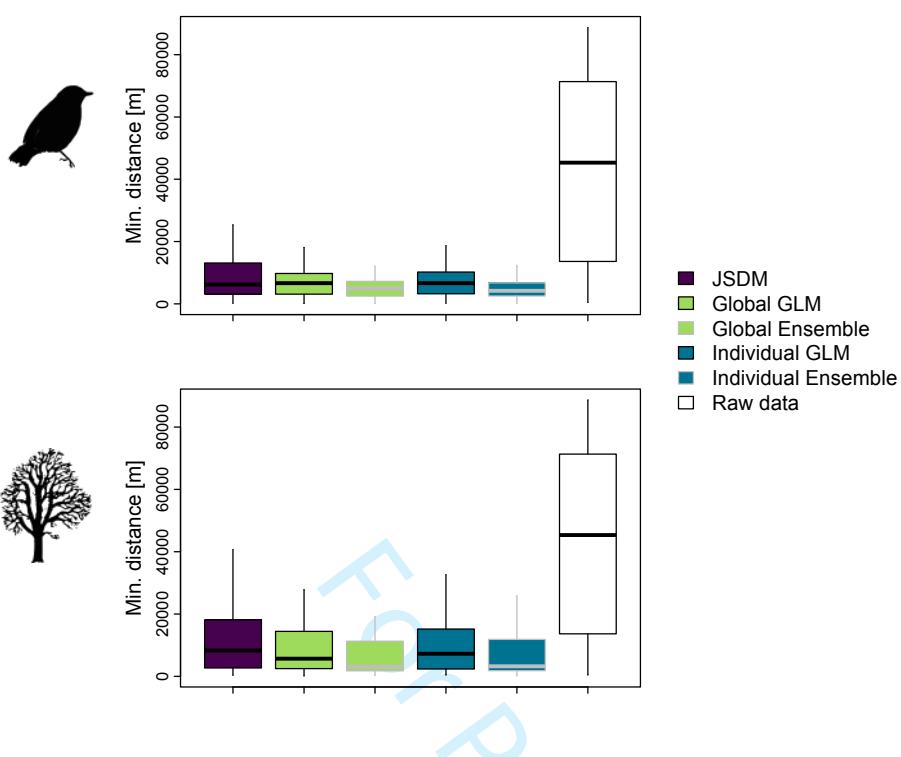


Figure S5. Spatial autocorrelation in single species model residuals. Presented are the distances up to which spatial autocorrelation in SDM and JSDM residuals was significant. Residual autocorrelation is low in all models compared to autocorrelation in raw data.

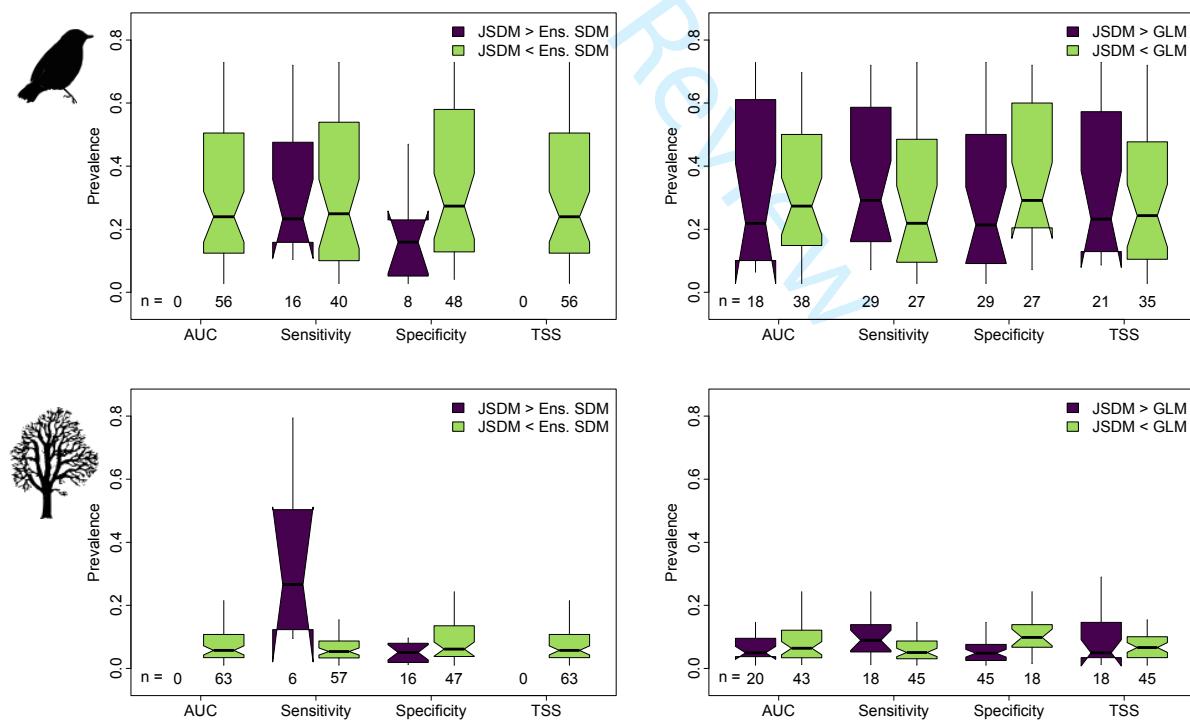


Figure S6. Prevalence for species with higher JSDM performance and with higher SDM performance in terms of AUC, sensitivity, specificity and TSS. Left panels show comparison of JSDMs against ensemble SDM, right panels JSDMs against GLMs. Numbers below the boxplots indicate the number of species exhibiting higher JSDM performance and higher SDM performance, respectively. Outliers are not shown.

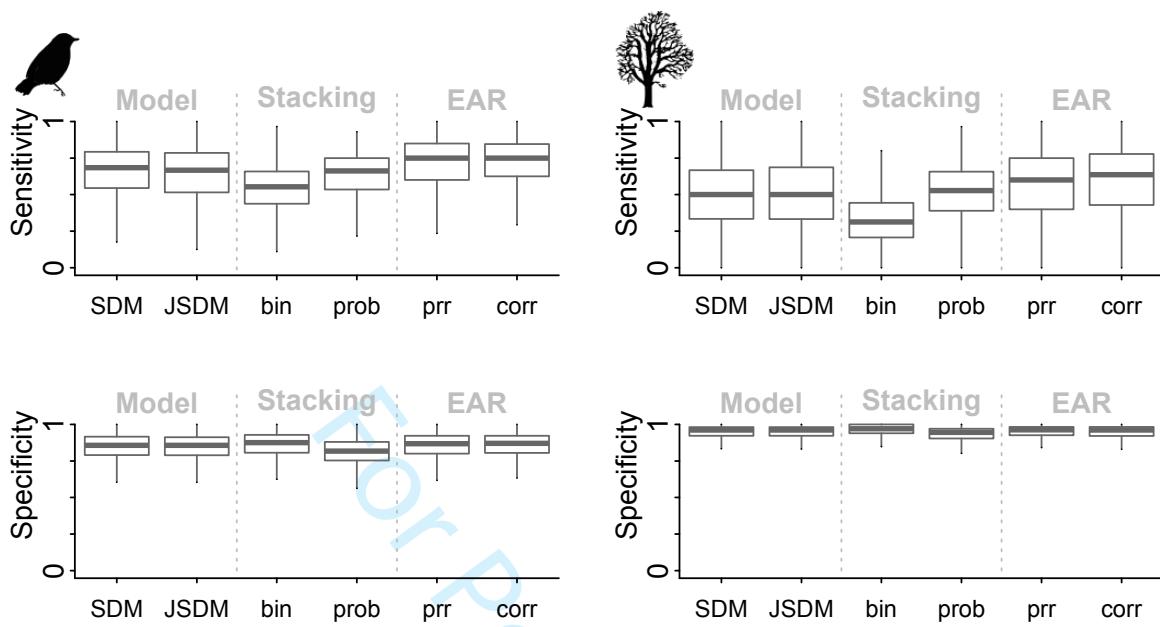


Figure S7. Assemblage specificity and sensitivity. Results are separated for different underlying model types (SDMs vs. JSDMs), different stacking procedures (binary vs. probabilistic), and for the application of ecological assembly rules without and with bias correction of the macroecological constraints. Assemblage sensitivity represents the proportion of species correctly predicted as present. Assemblage specificity represents the proportion of species correctly predicted as absent.