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SUPPLEMENTARY INFORMATION

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Long-distance migratory birds threatened by multiple independent risks from global change

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Supplementary Information

Long-distance migratory birds threatened by multiple independent risks from global change

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This Supplementary Information contains the following information:

- Supplementary Figure S1. Projected changes in seasonal species richness of long-distance migratory birds for 2050.
- Supplementary Figure S2. Relationship between projected change in migration distance and current-day migration distance.
- Supplementary Figure S3. Projected changes in seasonal range sizes and migration distance for different global change scenarios and dispersal buffers.
- Supplementary Figure S4. Species richness in breeding areas for different projected risks and risk combinations.
- Supplementary Figure S5. Projected change in summer and winter range size and in migratory distance for different IUCN risk categories.
- Supplementary Figure S6. Maps of multiple global change risks for different emission scenarios.
- Supplementary Figure S7. Sensitivity analyses for multiple and single global change risks for different IUCN categories.

- Supplementary Figure S8. Prediction accuracy of SDMs calibrated in summer and winter ranges.
- Supplementary Figure S9. Effect of different resolutions and thinning approaches on residual spatial autocorrelation and on estimates of global change impacts.
- Supplementary Figure S10. Goodness-of-fit between observed and predicted range properties for different dispersal buffer distances.

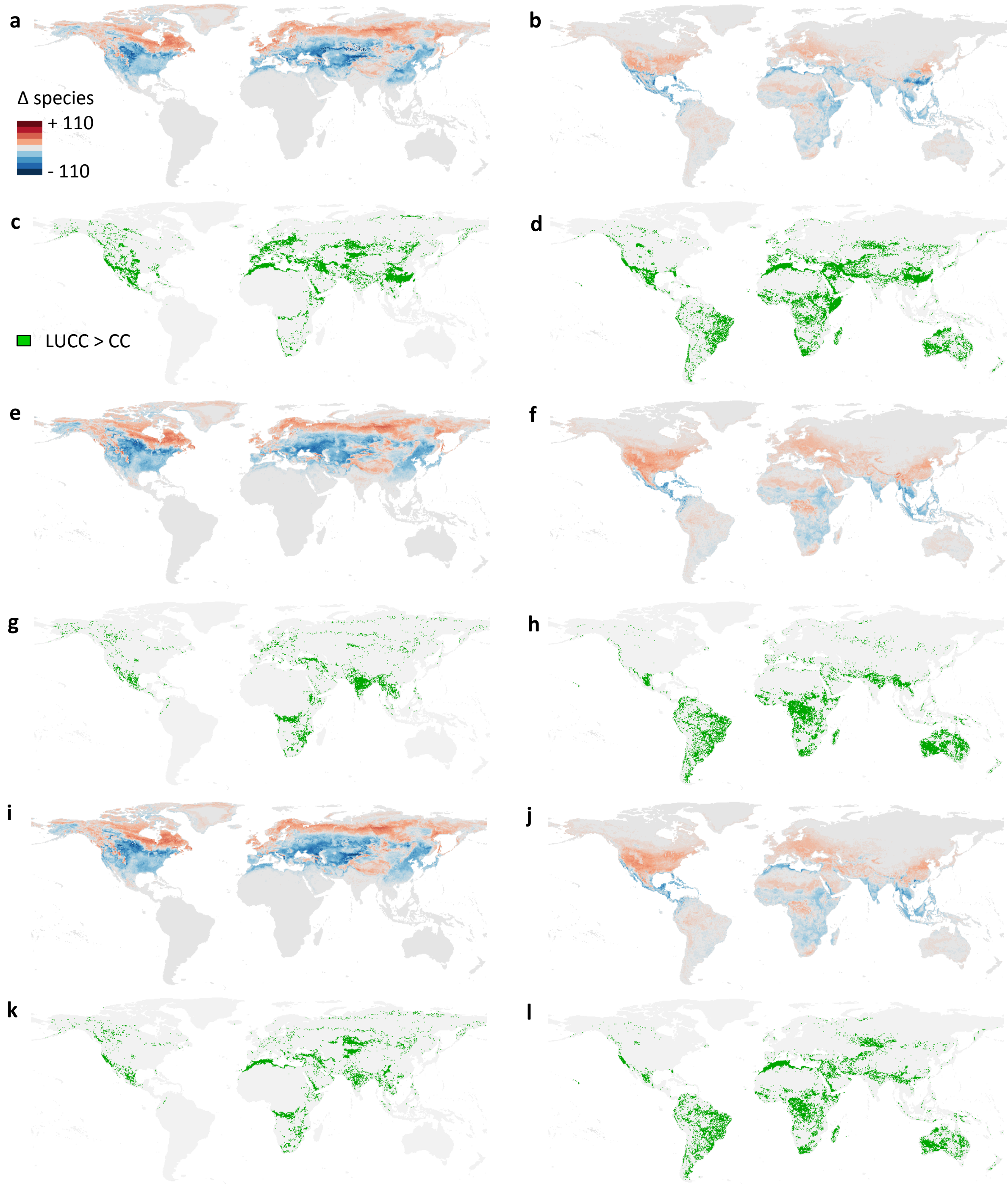

Figure S1. Projected changes in seasonal species richness of long-distance migratory birds for 2050. We present projected changes in summer (**a,e,i**) and winter (**b,f,j**) richness for the climate and land cover change scenarios RCP4.5-SSP1(**a-d**), RCP8.5-SSP3 (**e-h**) and RCP8.5-SSP5 (**i-l**). Additionally, we highlight areas where the projected effects from land cover change were stronger than from climate change for the different scenarios (**c,d,g,h,k,l**). The projected changes were derived from the ensemble means for each scenario, with a maximum dispersal distance of 1000 km.

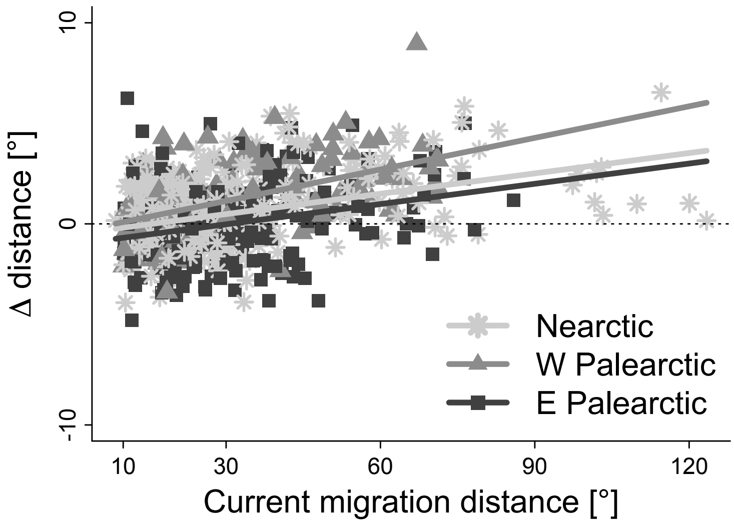

Figure S2. Relationship between projected change in migration distance and current-day migration distance. Lines show the trends as estimated from phylogenetic regression. Projections correspond to the ensemble means for the scenario RCP4.5-SSP1, with a maximum dispersal distance of 1000 km.

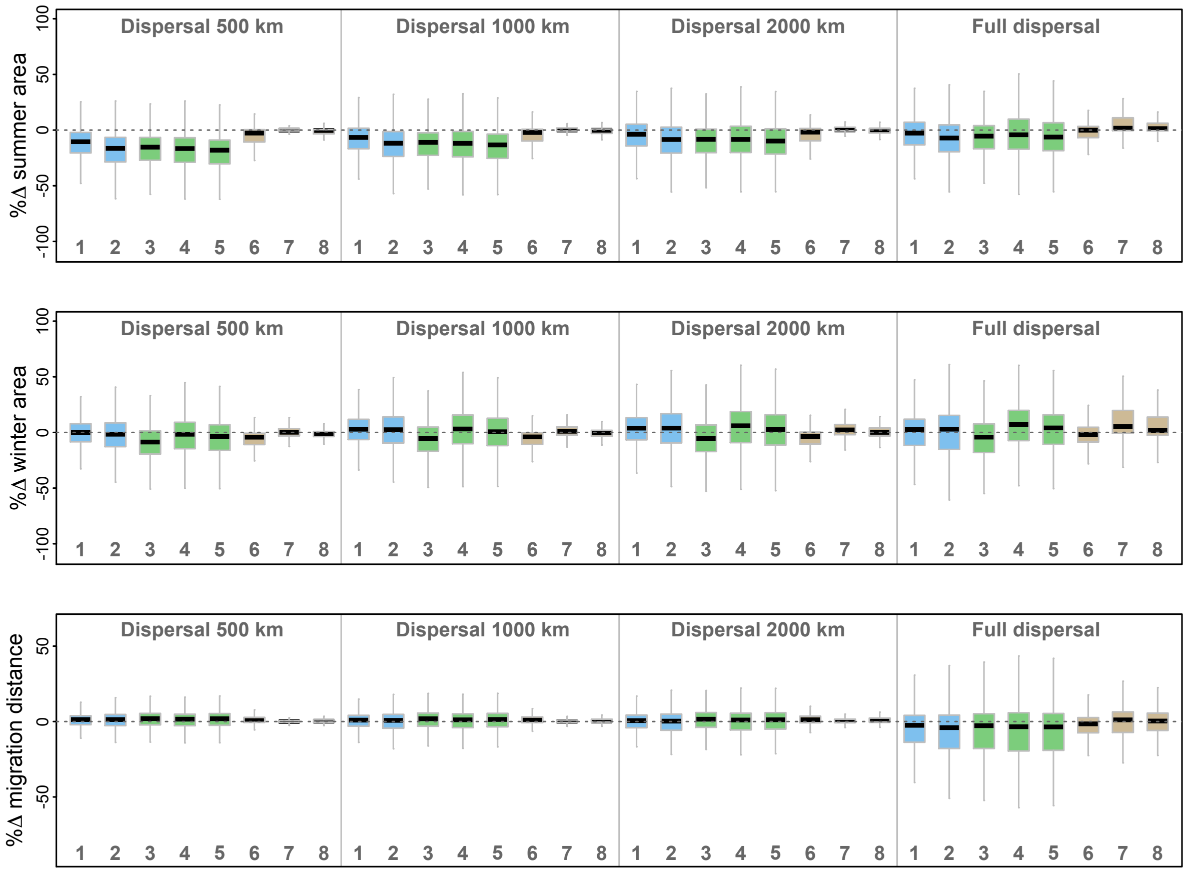

Figure S3. Projected changes in seasonal range sizes and migration distance for different global change scenarios and dispersal buffers. Climate and land cover scenarios are coded as numbers 1-8 (1: RCP4.5, 2: RCP8.5, 3: RCP4.5 + SSP1, 4: RCP8.5 + SSP3, 5: RCP8.5 + SSP5, 6: SSP1, 7: SSP3, 8: SSP5).

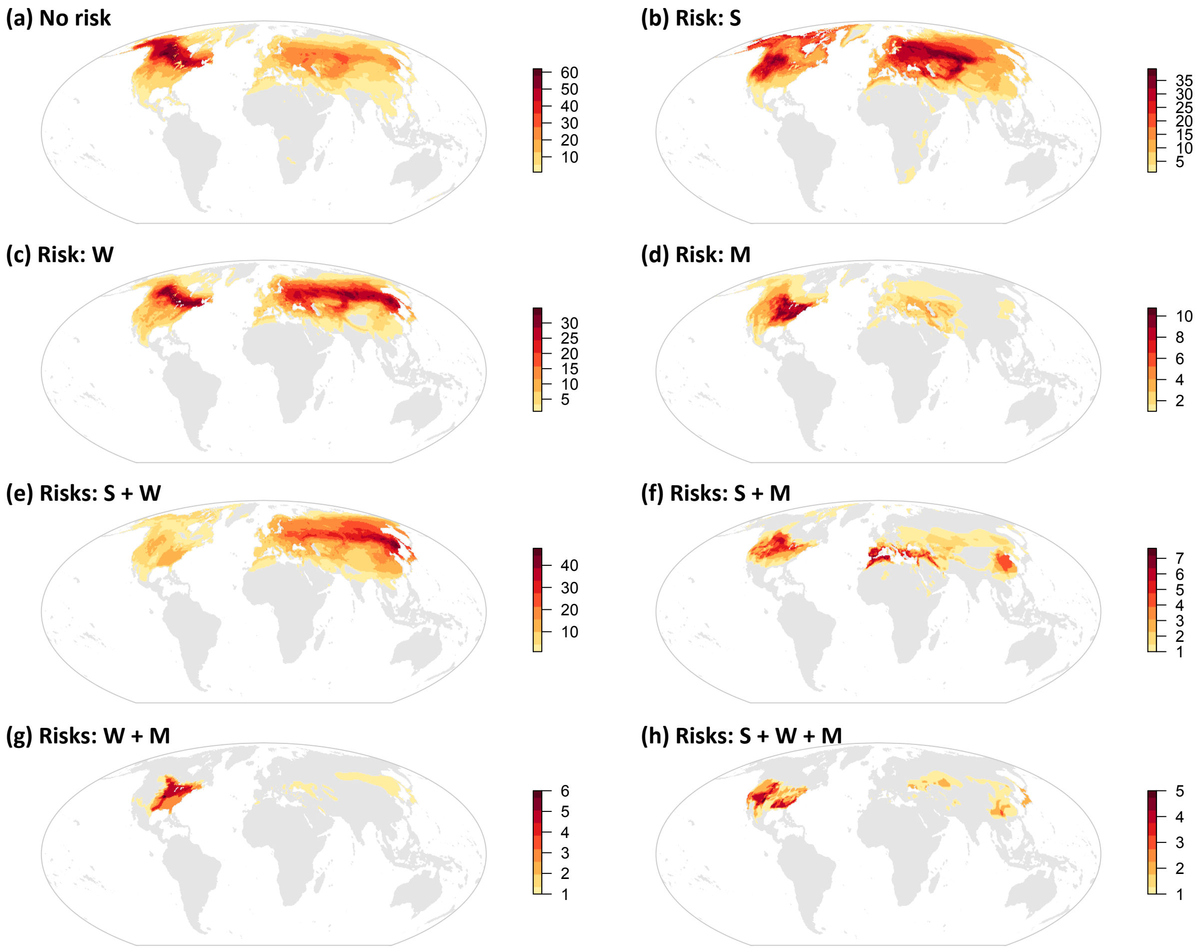

Figure S4. Species richness in breeding areas for different projected risks and risk combinations. We distinguish **s**pecies projected to be at no risk (**a**), at risk from single threats (**b-d**; S = summer population reduction > 10%, W = winter population reduction >10%, M = migration distance increase >10%) and at risk from multiple threats (**e-h**). Projections correspond to the ensemble means for the RCP4.5-SSP1 scenario, with a maximum dispersal distance of 1000 km.

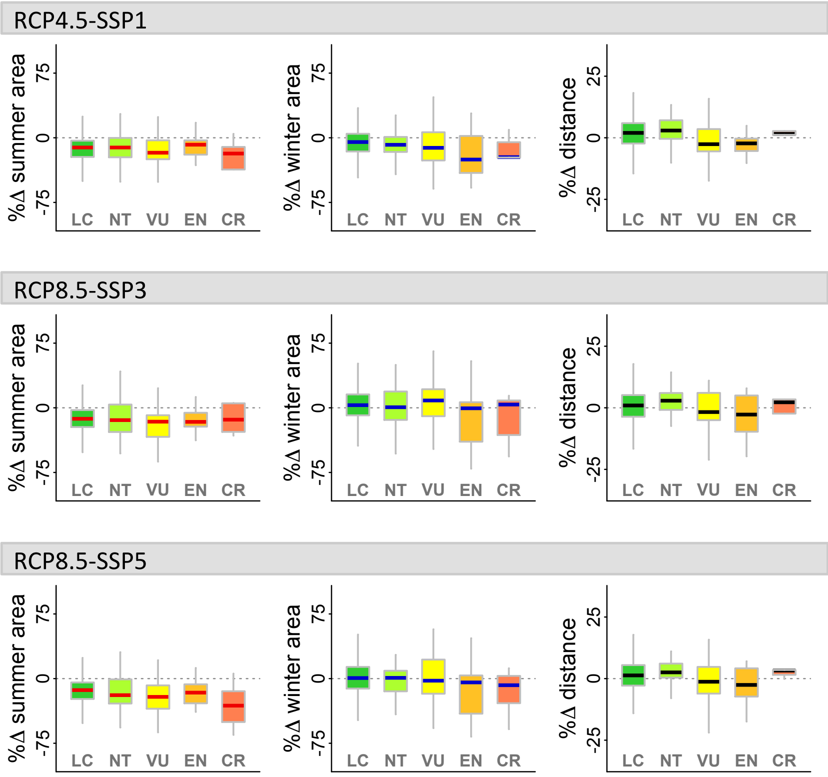

Figure S5. Projected change in summer and winter range size and in migratory distance for different IUCN risk categories. IUCN risks are: LC least concern, NT near threatened, VU vulnerable, EN endangered, CR critically endangered. Outliers are not shown. Projections correspond to the ensemble means for the different emission scenarios, with a maximum dispersal distance of 1000 km.

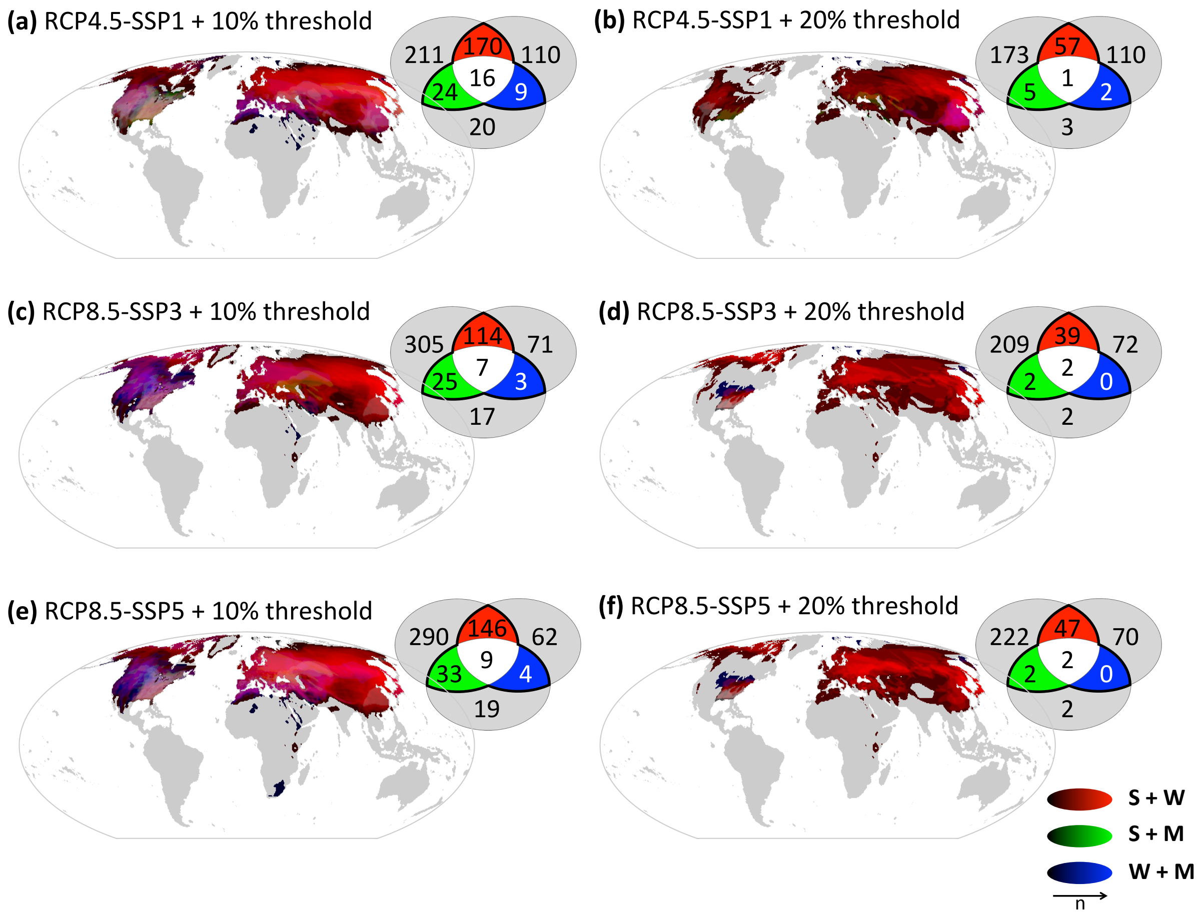

Figure S6. Maps of multiple global change risks for different emission scenarios. Venn diagrams illustrate number of species projected to experience single and multiple risks (for legend please see Fig. 4 and Fig. S7). We classified species as at risk if population reduction or migration distance increase exceeded 10% (**a,c,e**) or 20% (**b,d,f**). RGB maps illustrate the relative number of species facing multiple risks (the coloured areas of the Venn diagrams). Dark to light colours indicate increasing species numbers. Colour bands represent specific risk combinations; mixed colours indicate that species with different risk combinations are present. Projections correspond to the ensemble means and a maximum dispersal distance of 1000 km.

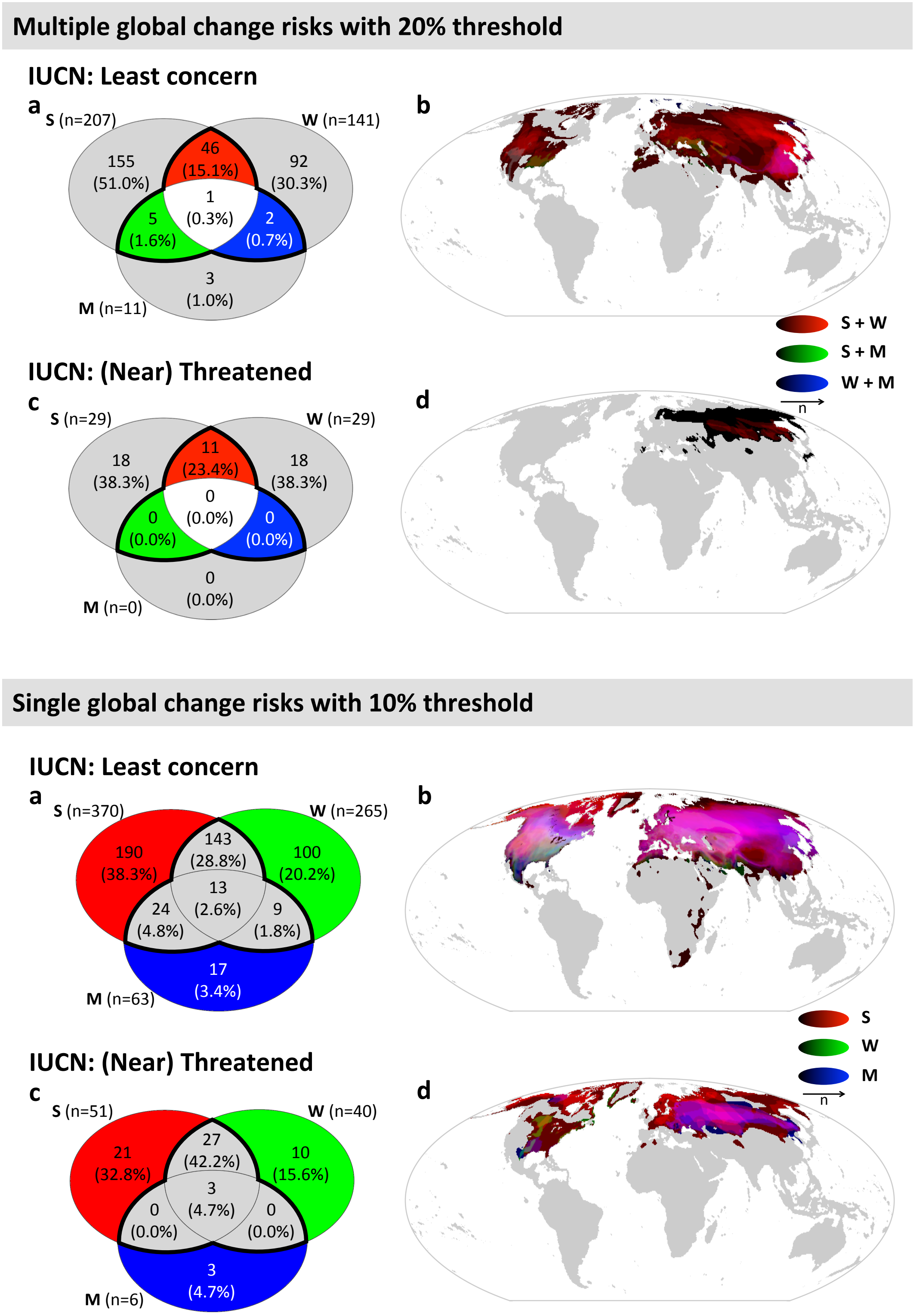

Figure S7. Sensitivity analyses for multiple and single global change risks for different IUCN categories. a-d Number of species projected to experience multiple risks from global change when a 20% threshold is used for classifying species as at risk. **e-h** Number of species projected to experience single (but not multiple) risks, thus concentrating on those areas of the Venn diagrams where risks do not overlap (outside black border). Here, a 10% threshold was used for classifying species as at risk. Projections correspond to the ensemble means for the RCP4.5-SSP1 scenario and a maximum dispersal distance of 1000 km. For further explanation please see Fig. 4 in main text.

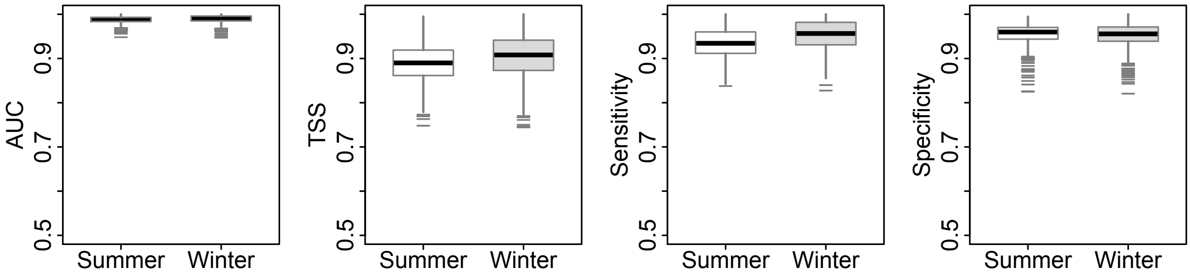

Figure S8. Prediction accuracy of SDMs calibrated in summer and winter ranges. Models were internally validated using a 70-30 split sample approach with 3 repetitions. AUC is the area under the receiver operating characteristic curve; TSS is the true skill statistic calculated as TSS = sensitivity + specificity – 1; sensitivity is the true positive rate and specificity the true negative rate.

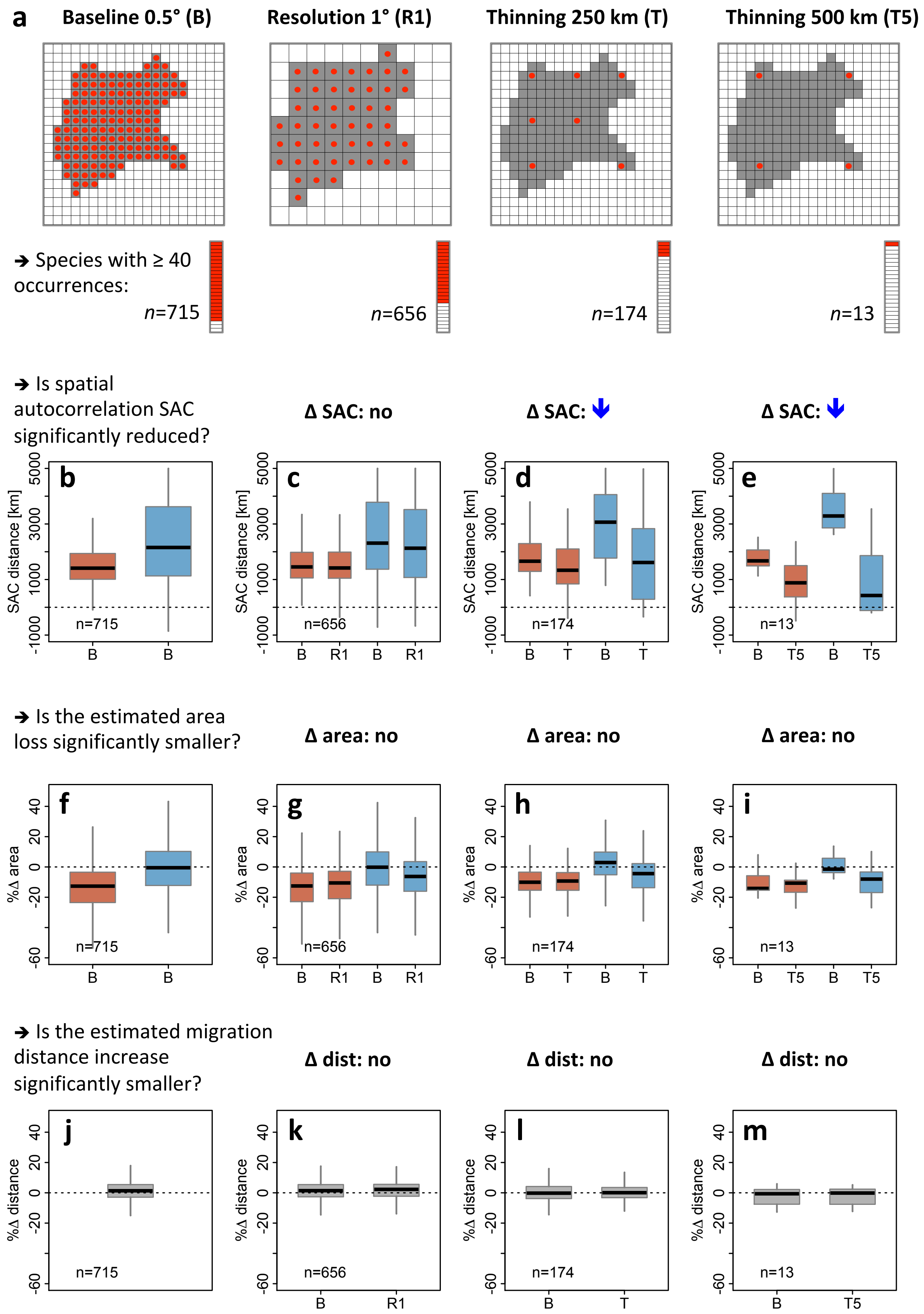

Figure S9. Effect of different resolutions and thinning approaches on residual spatial autocorrelation and on estimates of global change impacts. a In the baseline SDMs, species range maps and environmental data were gridded at 0.5° resolution. We compared these to SDMs estimated at coarser resolution of 1° and to SDMs estimated for spatially thinned data with minimum distance of 250km and 500km between presence points (at 0.5° resolution). Because the number of species with at least 40 presences in summer and winter range changes across resolution and thinning choices (i.e. species numbers are decreasing from left to right panels), the results of the 2nd, 3rd, and 4th columns show only the respective species sub-sets. **b-e** show the distance classes at which spatial autocorrelation in model residuals becomes insignificant for species distribution models (SDMs) calibrated in summer (red) and winter ranges (blue). **f-i** show the projected change in summer (red) and winter area (blue). **j-k** show the projected change in migration distances. Significant differences were tested using two-sample Wilcoxon tests with a significance level of 0.05. Projections correspond to the ensemble means for the RCP4.5-SSP1 scenario, with a maximum dispersal distance of 1000 km.

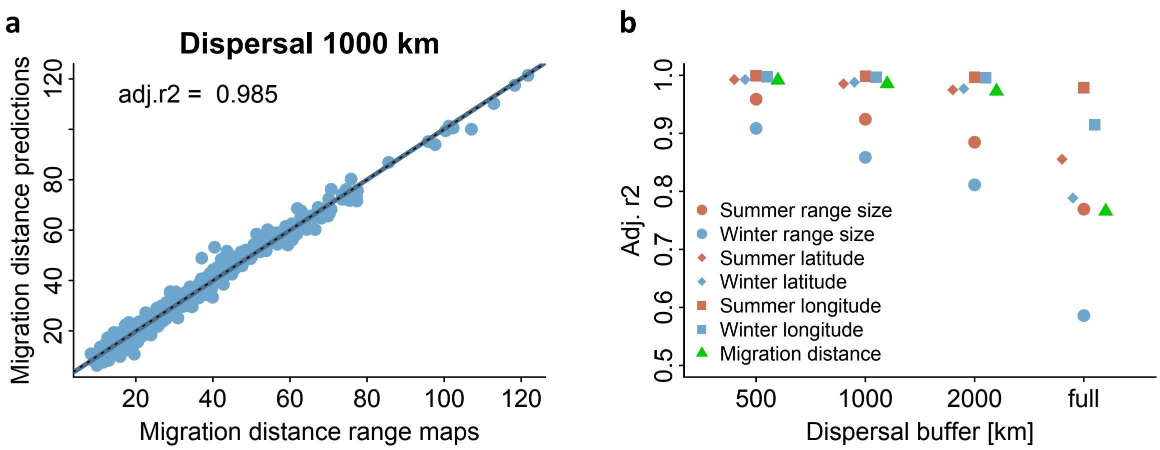

Figure S10. Goodness-of-fit between observed and predicted range properties for different dispersal buffer distances. a exemplifies how migration distance between predicted summer and winter range centroids (with 1000km dispersal buffer) corresponds to migration distance obtained from range maps. The predictions from the linear model explain 99% of the observed variation in migration distance (as indicated by the adjusted r^2). **b** summarises the explained variances (adjusted r^2) for different range properties.