SUPPLEMENTARY MATERIAL FOR:

Assessing risk for butterflies in the context of climate change, demographic uncertainty, and heterogenous data sources

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Contents included here:

Other supplementary materials:

https://elizagrames.shinyapps.io/butterflyRisk/

Interactive tool for exploring the impact of different weighting schemes (among contributing variables) on the risk index; also available are species-specific plots and maps similar to main Figures 4 - 6, as well as a subspecific table (like Table 1 in the main text) that can be filtered by state or taxonomic family.

Table S1. Sources and references searched for years of subspecies last occurrence.

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———. 2021c. "Nymphalidae Records for United States." Symbiota Collections of Arthropods Network.

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———. 2021e. "Pieridae Records for United States." Symbiota Collections of Arthropods Network.

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Table S2. Coefficients and other results from a Bayesian linear model predicting the composite risk index among A group species using seven predictor variables including climate, land use and natural history. Values shown in the table below are the standardized beta coefficients, upper and lower 95% credible intervals (CI), and probabilities of effect (the fraction of the posterior probability distributions above or below zero, depending on the sign of the coefficient). The variance explained (as the square of the correlation between observed and predicted values) for the whole model was 0.092.

Variable	Probability	Coefficient	Lower 95% CI	Upper 95% CI
Geographic range	0.81	0.0098	-0.012	0.032
Development	0.51	-0.00016	-0.014	0.014
Climate departure	0.54	-0.0014	-0.029	0.026
Precipitation	0.86	-0.012	-0.035	0.010
Voltinism	0.57	0.0015	-0.015	0.018
Wingspan	0.99	-0.020	-0.033	-0.0072
Host breadth	0.65	0.0029	-0.012	0.017

Table S3. Taxonomic key for differences between the North American Butterfly Association names (NABA, 2018, Checklist of North American Butterflies Occurring North of Mexico, Edition 2.4) and names used in Pelham (Pelham, 2022, A Catalogue of the Butterflies of the United States and Canada). Species names flagged with an asterisk in Figure 3 and Figures S6 - S8 are shown here in the NABA columns, with the corresponding names in the Pelham columns.

NABA checklist	Pelham 2022	NABA checklist	Pelham 2022
Achalarus casica	*Thorybes casica*	*Nymphalis vaualbum*	*Nymphalis l-album*
Adelpha bredowii	*Adelpha californica*	*Oarisma edwardsii*	*Copaeodes edwardsii*
Agraulis vanillae	*Dione incarnata*	*Oeneis taygete*	*Oeneis bore taygete*
Amblyscirtes elissa	*Amblyscirtes arizonae*	*Papilio canadensis*	*Pterourus canadensis*
Atrytonopsis edwardsii	*Atrytonopsis edwardsi*	*Papilio cresphontes*	*Heraclides cresphontes*
Autochton cellus	*Telegonus cellus*	*Papilio eurymedon*	*Pterourus eurymedon*
Boloria montinus	*Boloria chariclea*	*Papilio glaucus*	*Pterourus canadensis*
Boloria napaea	*Boloria alaskensis*	*Papilio multicaudata*	*Pterourus multicaudata*
Brephidium exile	*Brephidium exilis*	*Papilio rutulus*	*Pterourus rutulus*
Carterocephalus palaemon	*Carterocephalus skada*	*Phaeostrymon alcestis*	*Satyrium alcestis*
Chioides catillus	*Chioides albofasciatus*	*Pholisora mejicana*	*Pholisora mejicanus*
Chiomara asychis	*Chiomara georgina*	*Phyciodes campestris*	*Phyciodes pulchella*
Colias cesonia	*Zerene cesonia*	*Phyciodes selenis*	*Phyciodes cocyta selenis*
Colias eurydice	*Zerene eurydice*	*Phyciodes texana*	*Anthanassa texana*
Copaeodes aurantiacus	*Copaeodes aurantiaca*	*Phyciodes vesta*	*Phyciodes graphica*
Copaeodes minimus	*Copaeodes minima*	*Pieris napi*	*Pieris oleracea*
Dymasia dymas	*Microtia dymas*	*Piruna cingo*	*Piruna aea*
Emesis ares	*Apodemia ares*	*Plebejus acmon*	*Icaricia acmon*
Emesis zela	*Apodemia zela*	*Plebejus emigdionis*	*Plebulina emigdionis*
Erebia theano	*Erebia pawloskii*	*Plebejus icarioides*	*Icaricia icarioides*
Eurema boisduvaliana	*Abaeis boisduvaliana*	*Plebejus lupini*	*Icaricia lupini*
Eurema dina	*Pyrisitia dina*	*Plebejus neurona*	*Icaricia neurona*
Eurema lisa	*Pyrisitia lisa*	*Plebejus saepiolus*	*Icaricia saepiolus*
Eurema mexicana	*Abaeis mexicana*	*Plebejus shasta*	*Icaricia shasta*
Eurema nicippe	*Abaeis nicippe*	*Poanes hobomok*	*Lon hobomok*
Eurema nise	*Pyrisitia nise*	*Poanes melane*	*Lon melane*
Eurema proterpia	*Pyrisitia proterpia*	*Poanes taxiles*	*Lon taxiles*
Everes amyntula	*Cupido amyntula*	*Pontia beckerii*	*Pontieuchloia beckerii*
Everes comyntas	*Cupido comyntas*	*Pontia sisymbrii*	*Sisymbria sisymbrii*
Ganyra howarthii	*Ganyra howarthi*	*Pyrgus albescens*	*Burnsius albescens*
Hemiargus isola	*Echinargus isola*	*Pyrgus communis*	*Burnsius communis*
Junonia genoveva	*Junonia neildi*	*Pyrgus oileus*	*Burnsius oileus (Lin*

Lycaeides idas	*Plebejus idas*	*Pyrgus philetas*	*Burnsius philetas*
Lycaeides melissa	*Plebejus melissa*	*Pyrrhopyge araxes*	*Apyrrothrix araxes*
Lycaena arota	*Tharsalea arota*	*Satyrodes eurydice*	*Lethe eurydice*
Lycaena dione	*Tharsalea dione*	*Speyeria adiaste*	*Argynnis adiaste*
Lycaena editha	*Tharsalea editha*	*Speyeria aphrodite*	*Argynnis aphrodite*
Lycaena gorgon	*Tharsalea gorgon*	*Speyeria atlantis*	*Argynnis atlantis*
Lycaena helloides	*Tharsalea helloides*	*Speyeria callippe*	*Argynnis callippe*
Lycaena hermes	*Tharsalea hermes*	*Speyeria coronis*	*Argynnis coronis*
Lycaena heteronea	*Tharsalea heteronea*	*Speyeria cybele*	*Argynnis cybele*
Lycaena hyllus	*Tharsalea hyllus*	*Speyeria edwardsii*	*Argynnis edwardsii*
Lycaena mariposa	*Tharsalea mariposa*	*Speyeria egleis*	*Argynnis egleis*
Lycaena nivalis	*Tharsalea nivalis*	*Speyeria hydaspe*	*Argynnis hydaspe*
Lycaena rubidus	*Tharsalea rubidus*	*Speyeria idalia*	*Argynnis idalia*
Lycaena xanthoides	*Tharsalea xanthoides*	*Speyeria mormonia*	*Argynnis mormonia*
Megisto rubricata	*Cissia rubricata*	*Speyeria nokomis*	*Argynnis nokomis*
Neominois ridingsii	*Oeneis ridingsii*	*Speyeria zerene*	*Argynnis zerene*
Neophasia terlootii	*Neophasia terlooii*	*Texola elada*	*Microtia elada*
Nymphalis milberti	*Aglais milberti*	*Thorybes mexicanus*	*Thorybes nevada*

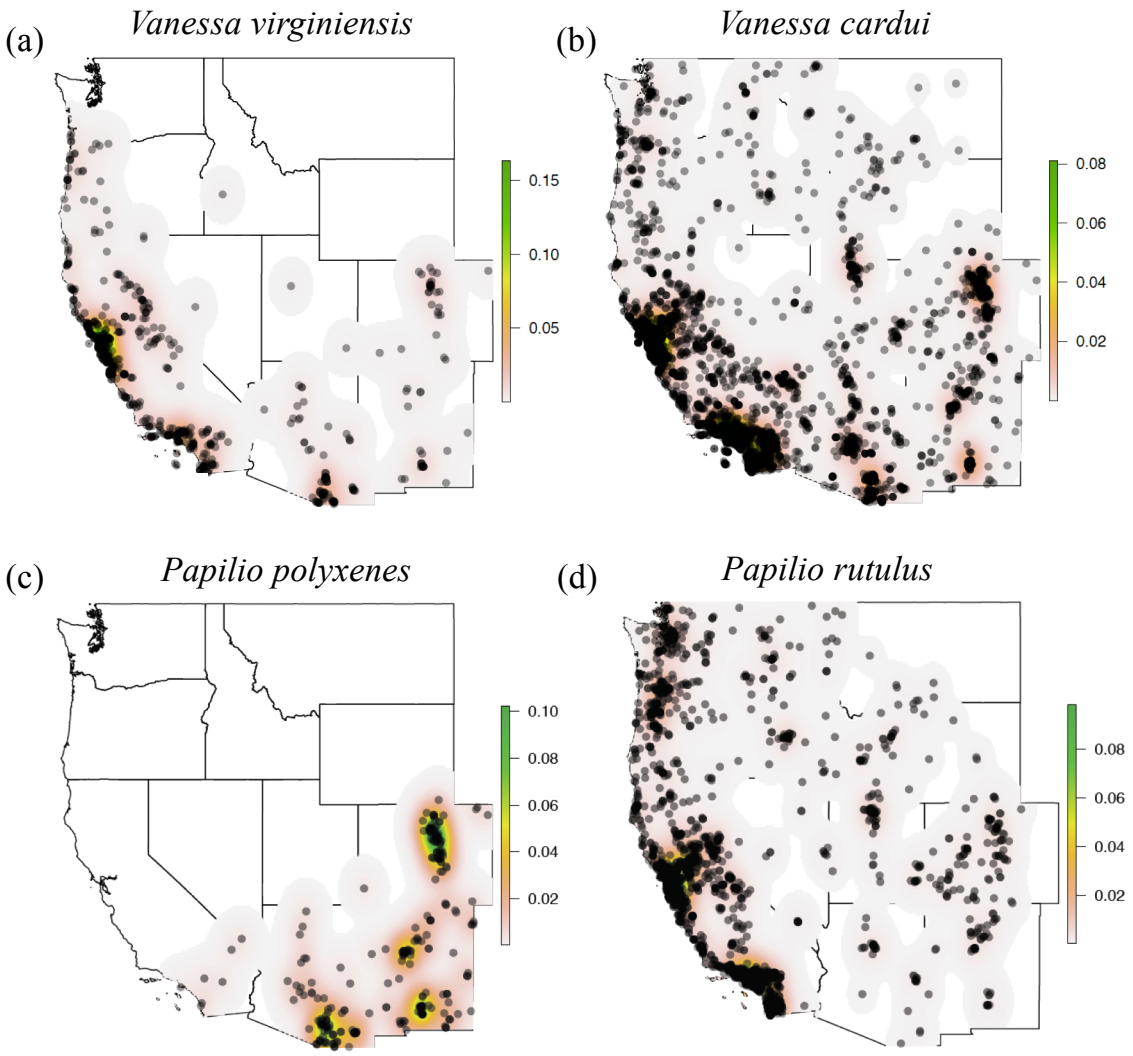

Figure S1. Examples of kernel density estimation based on iNaturalist records for two pairs of congeneric species (colors indicates relative density of observations). Among these four species, the first (*Vanessa virginiensis*, panel a) has been reported in iNaturalist records over a small area relative to the expectation for areal extent based on expert range size; thus, *V. virginiensis* has a large risk circle associated with iNaturalist records in Figure 3. The other species have smaller risk circles (in Figures S6 – S8) for the iNaturalist variable because they have been reported in Naturalist over spatial extents that were close to expected or greater than expected based on the size of their expert ranges (see Materials and Methods in main text for details on analyses).

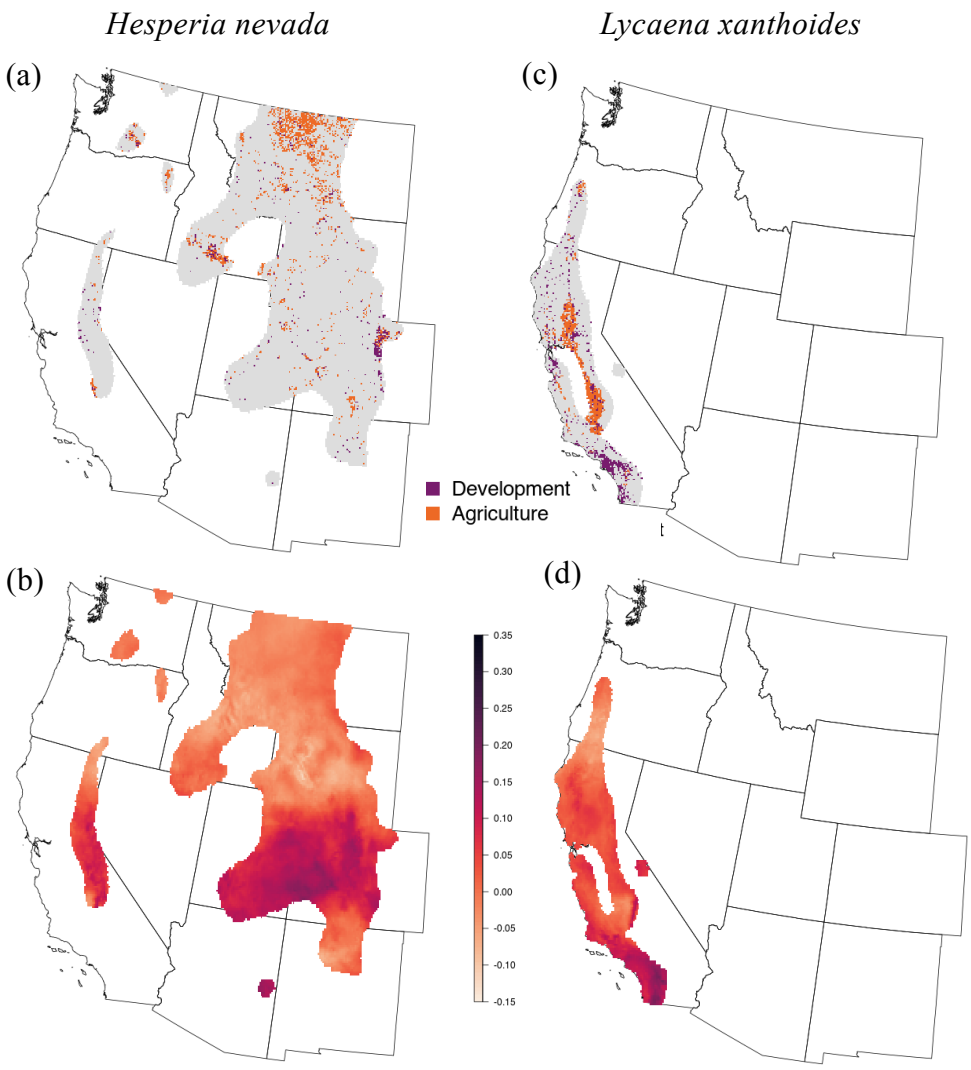

Figure S2. Examples of expert range outlines for two species: *Hesperia nevada* in panels (a) and (b), and *Lycaena xanthoides* in panels (c) and (d). In the top two panels, the range is colored by exposure to developed and agricultural lands; in the bottom two panels, the range is colored by multivariate departure from baseline climate conditions. *Lycaena xanthoides*, for example, has a smaller range concentrated in developed parts of California (c), which gives it a higher risk (relative to *H. nevada*) with respect to exposure to land use: this is summarized with a larger risk circle for development in Figure 3. In contrast, the two species have comparable range-wide exposure to climate change (and similar risk circles for that variable in Figure 3).

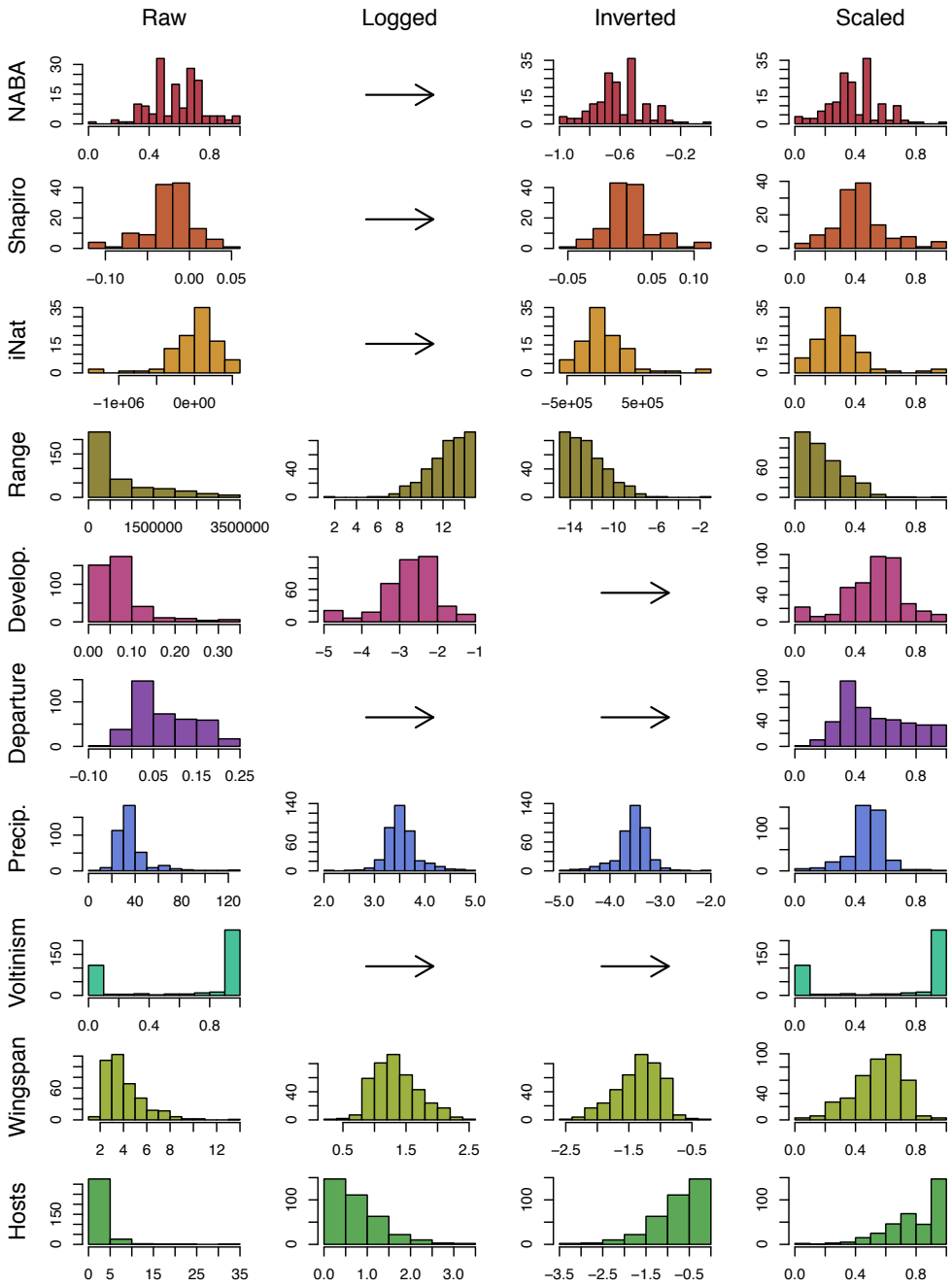

Figure S3. Illustration of the process (going from left to right) by which variables were transformed from raw scales into variables bounded between zero and 1, in which higher values correspond to greater risk. For example, NABA values (top row) are probability of population persistence (in 50-year simulations), and are inverted so that lower probabilities of persistence are closer to 1; in contrast, development values (5th row) are not inverted because higher values naturally correspond to higher risk (but development values are logged because of high skew). An arrow indicates a transformation not applied to a given variable. Colors here match colors in Figure 3 and Figures S6 – S8.

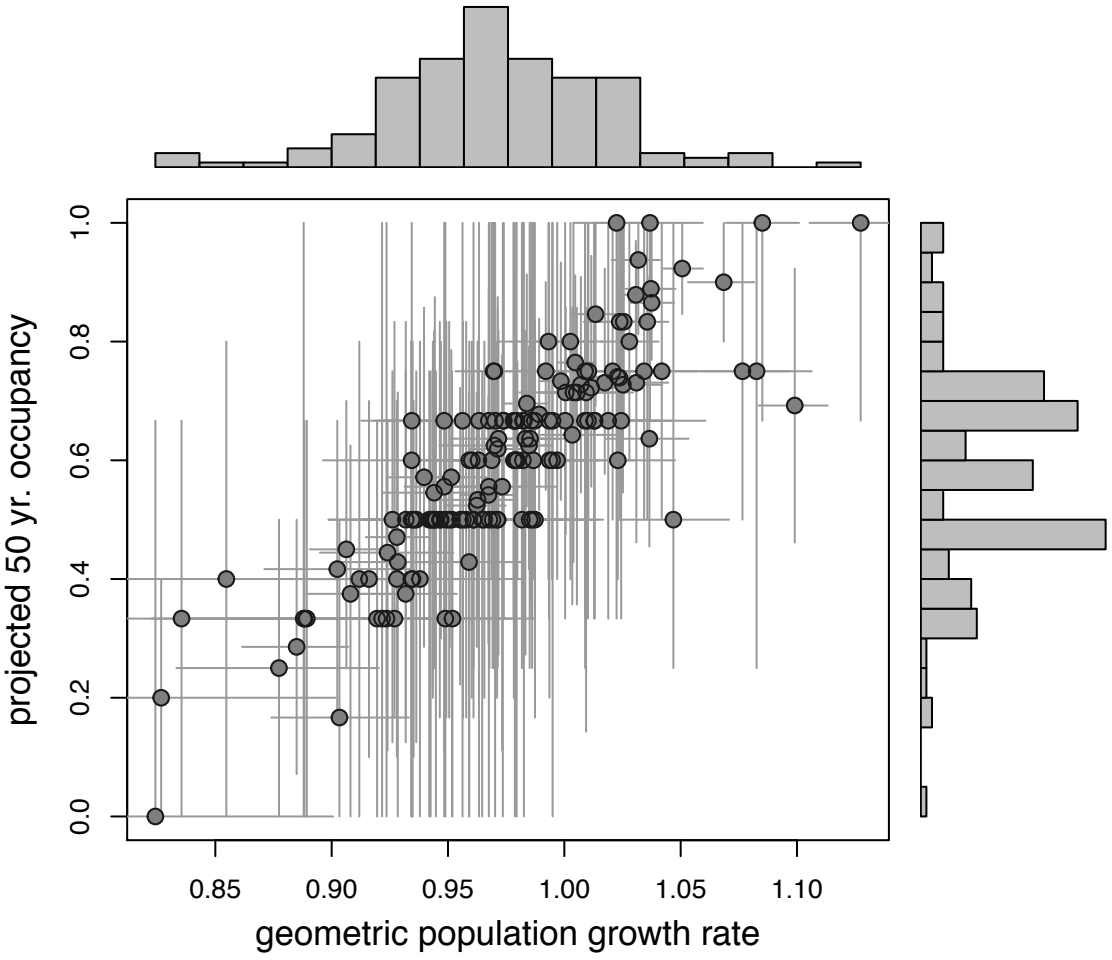

Figure S4. Relationship between two variables derived from the NABA community model, in which detection information is shared among species. Points are individual species, with 85% highest density intervals for both axes. The y axis is the projected 50 year occupancy across populations for each species (also referred to in the main text as the probability of population persistence); the x axis is the geometric population growth rate. The latter (growth rate) influences the former (occupancy) in simulations, therefore a positive relationship between these variables is expected (and observed), but we present it here as an illustration of the variation in the two aspects of our model. Marginal histograms show the distribution of among-species variation for values along both axes.

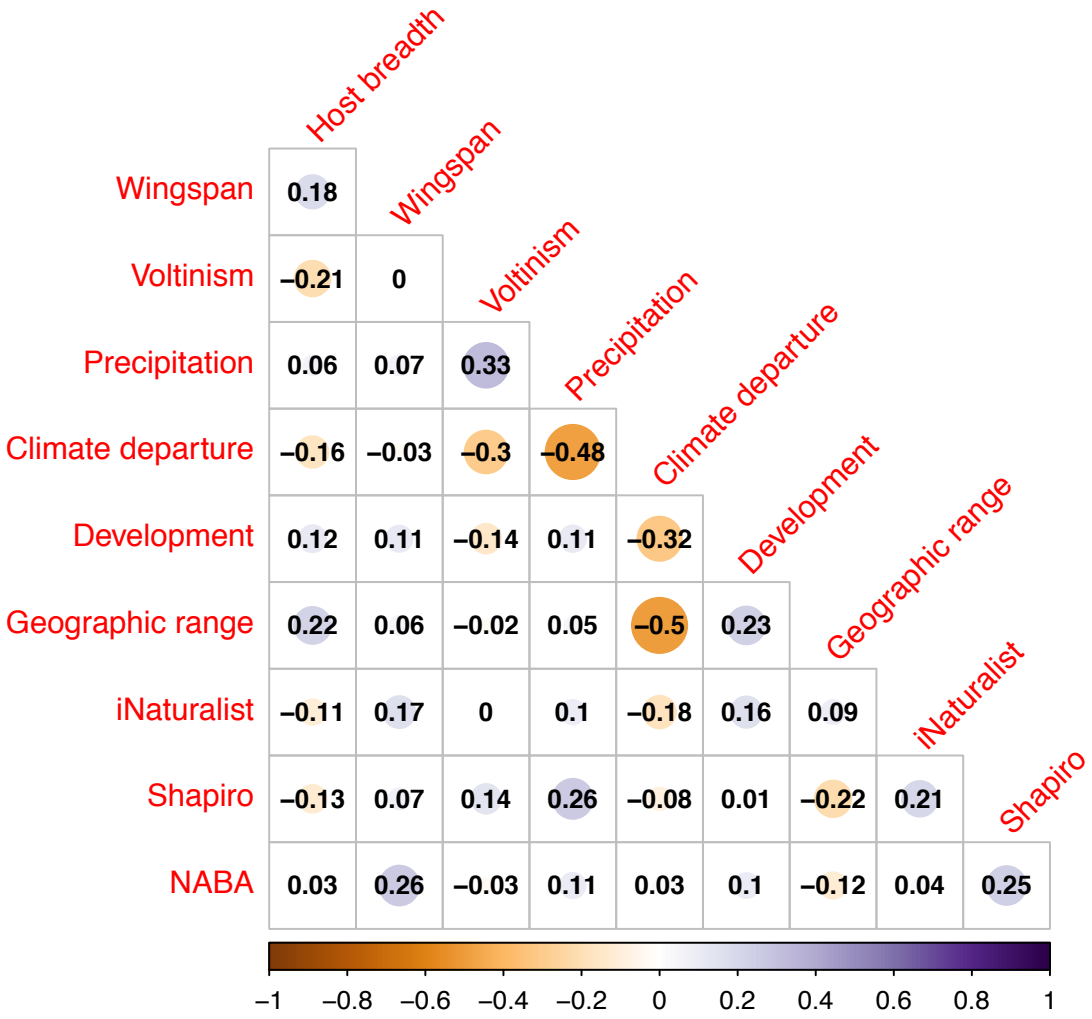

Figure S5. Pearson correlation coefficients among all variables shown in main risk plots (Figure 1 and Figures S6 – S8). Underlying circles and colors are shown for ease of visualizing relative magnitude of values.

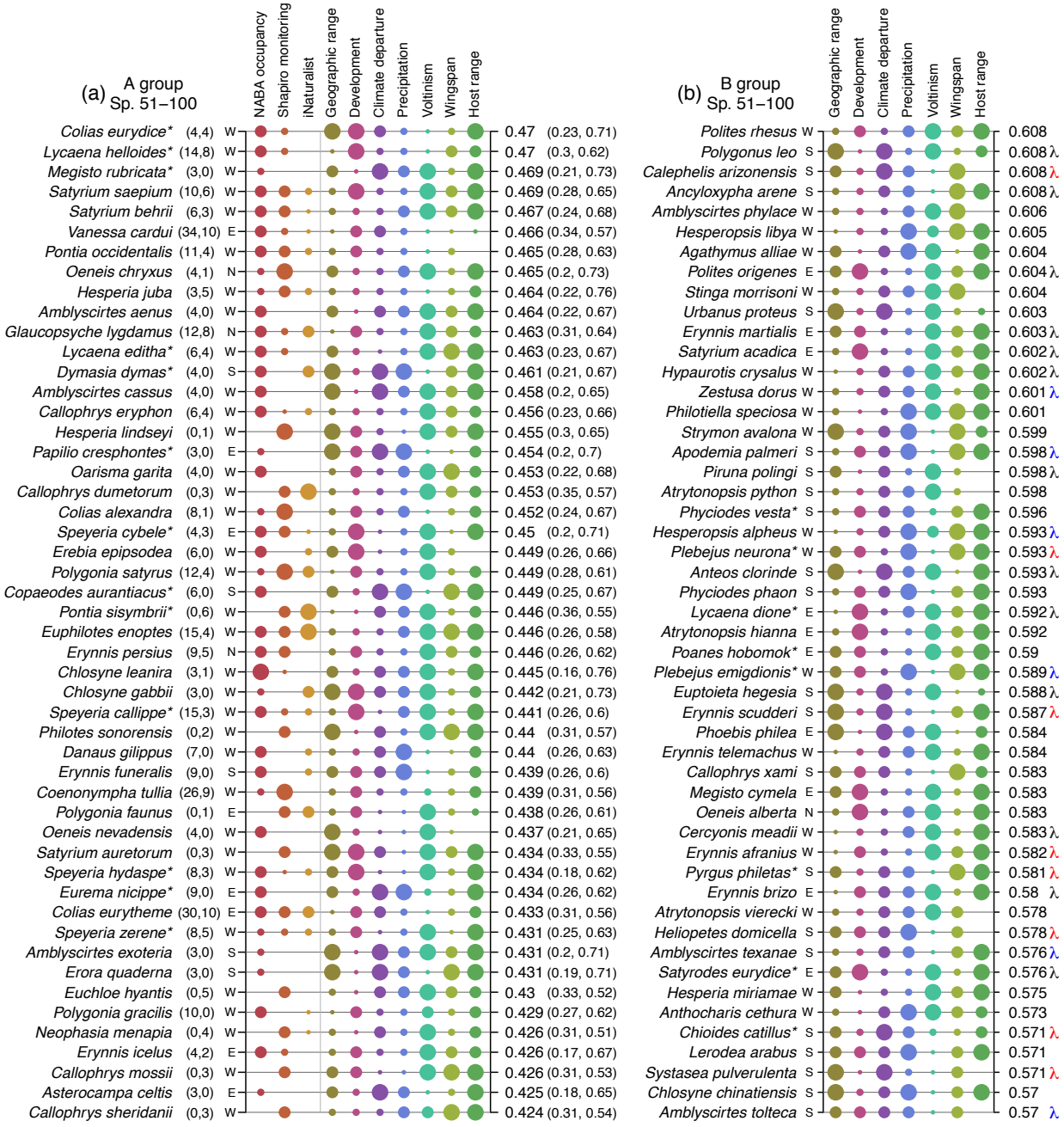

Figure S6. The second set of species (51 – 100 for both A and B groups) ranked by risk index values. See Figure 3 for the first set (species 1 – 50), and also see the Figure 3 legend for a full description of the features of the plot shown here.

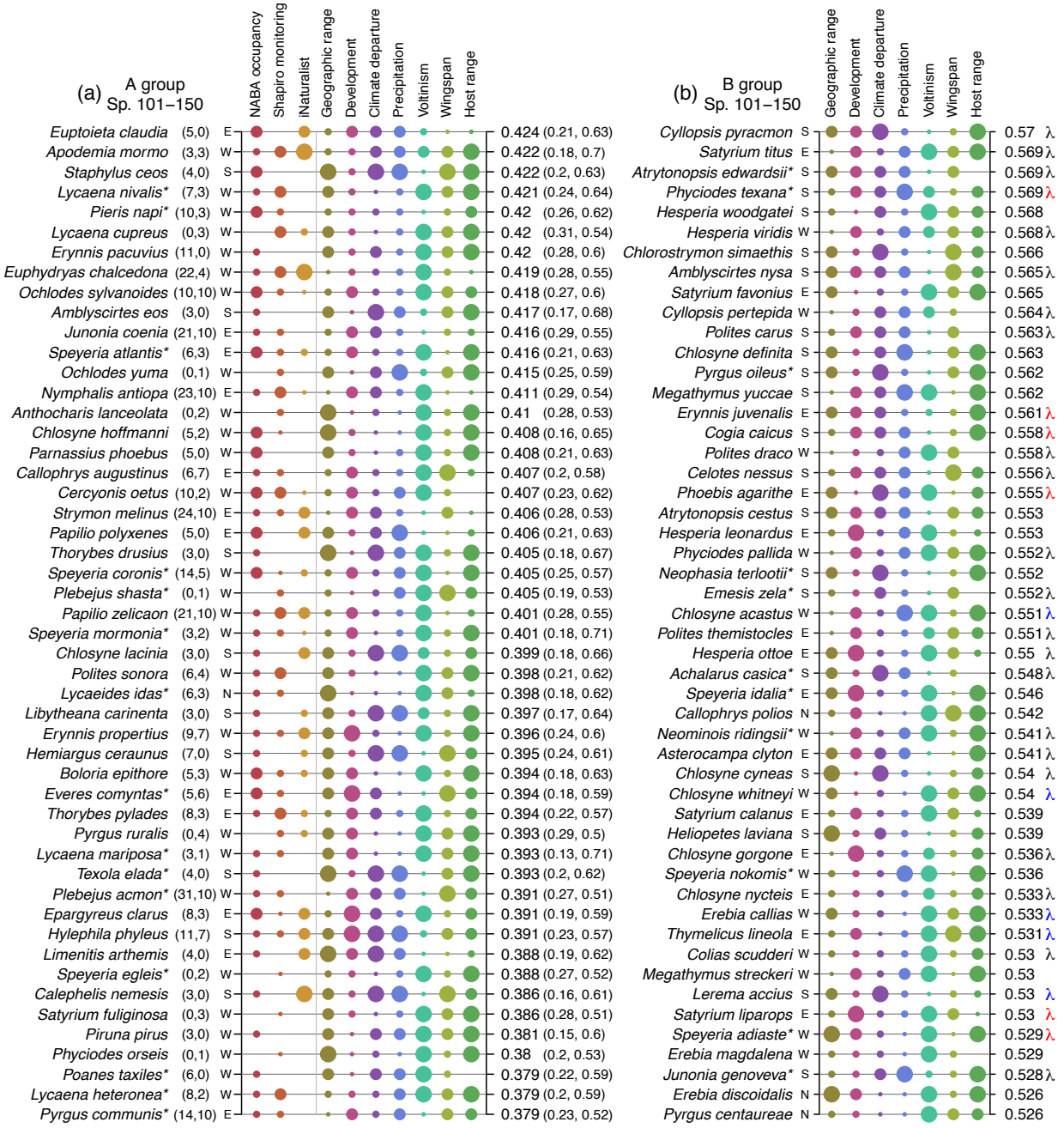

Figure S7. The third set of species (101 – 150 for both A and B groups) ranked by risk index values. See Figure 3 legend for a description of all features of the plot.

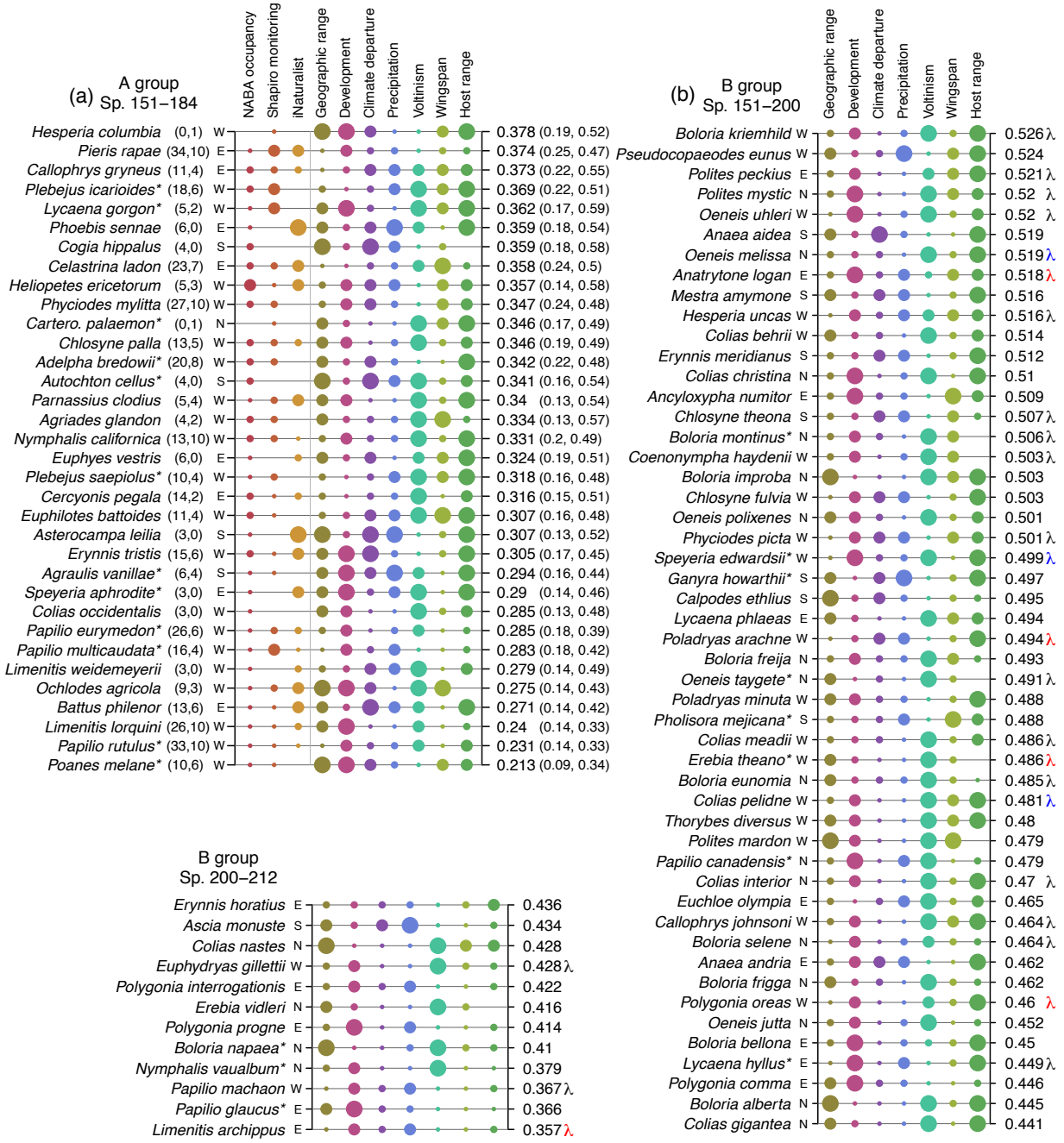

Figure S8. The fourth set of species (101 – 151 for the A group, and 151 – 212 for the B group) ranked by risk index values. See Figure 3 legend for a description of all features of the plot, and note here that the last species in the B group (200 – 212) are shown in the lower left of the plot.