

Supporting information for

Geographical range area, habitat breadth and specialisation on natural habitats are associated with land-use responses and climate-change sensitivity more consistently than life-history and dietary traits in terrestrial vertebrates

May 14, 2022

S1 Compiling diet information

For mammals and birds, diet information was obtained from the EltonTraits database (Wilman et al., 2014). Before processing the data, the taxonomy was aligned to that of the trait datasets from Etard et al. (2020) (Chapter 2). Primary diet – that is, the diet inferred from the combination of food items that represent more than 50% of species consumption – was directly available for birds, but not for mammals. For both classes, diet was described as the percent use of different food items (namely: invertebrates, vertebrates – either ectotherms, endotherms, fish or unknown –, carrion, fruit, nectar, seed or other plant material). In order to have a consistent classification scheme across mammals and birds, we chose not to use the provided primary diet for birds, and instead we applied our own procedure to infer primary diet from recorded food items across birds and mammals. We first grouped the different vertebrate food items together with carrion to create a single ‘vertebrate’ food item category. We then used the percent uses of the food items to infer primary diet, classifying species’ primary diet into the following categories: vertebrate eaters; invertebrate eaters; plant/seed eaters; fruit/nectar eaters; and omnivores [these categories are similar to those employed for birds’ primary diet in EltonTraits]. When all food items had a percent use below (or equal to) 50% percent, species were classified as omnivores. For each species, we calculated diet breadth as the number of consumed food items (regardless of the percent use of those items).

For amphibians, diet information was partly extracted from the AmphiBIO database (Oliveira et al., 2017), and partly compiled from the literature (see next section). In AmphiBIO, diet information was recorded as the consumption of six food items (leaves, flowers, seeds, fruit, arthropods and vertebrates), but the percent use of these items was not recorded (only whether they were consumed or not). From AmphiBIO, we classified amphibians into the different diet categories, depending on the combinations of consumed food items.

To increase diet data coverage for amphibians, we compiled data from published papers and from the grey literature, targeting species occurring in the PREDICTS database (which we used for inferring land-use responses). We were able to collect diet information for an additional 108 amphibians from 26 published sources (all found to be invertebrate eaters; see below for the list of sources). For reptiles, there was no readily available diet information (except for trophic level information, see Etard et al. (2020)). Thus, we collected diet data from the literature, again specifically targeting reptiles occurring in the PREDICTS database. From the literature, we added diet information for 239 reptiles. Finally, diet breadth was calculated across amphibians and reptiles from the recorded food items. The compiled diet data are available at: https://figshare.com/articles/Reptile_Diet_csv/12024309 (DOI: 10.6084/m9.figshare.12024309.v1) and https://figshare.com/articles/Untitled_Item/12024312 (DOI: 10.6084/m9.figshare.12024312.v4).

Complementary data sources for amphibians

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- Yap, C.H. & Jafaar, I. (2012). Feeding analysis of *Hylarana cf. labialis*, *Leptobrchiun hendricksoni*, and *Occidozyga laevis* (Amphibia: Anura) from a lowland dipterocarp forest in Kedah, Malaysia. *Herpetological Review*, 43(1).
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- Yap, C.H. & Jaafar, I. (2011). Stomach Content Analysis of Tropical Forest Toads *Ingerophrynus parvus* and *Phrynooides aspera* (ANURA : BUFONIDAE) from Kedah, Malaysia. Taxonomist and Ecologist Conference 2011.

Complementary data sources for reptiles

The 148 sources are listed in the dataset available from https://figshare.com/articles/Reptile_Diet_csv/12024309 (DOI: 10.6084/m9.figshare.12024309.v1).

S2 Imputing missing trait values

S2.1 Trait data coverage

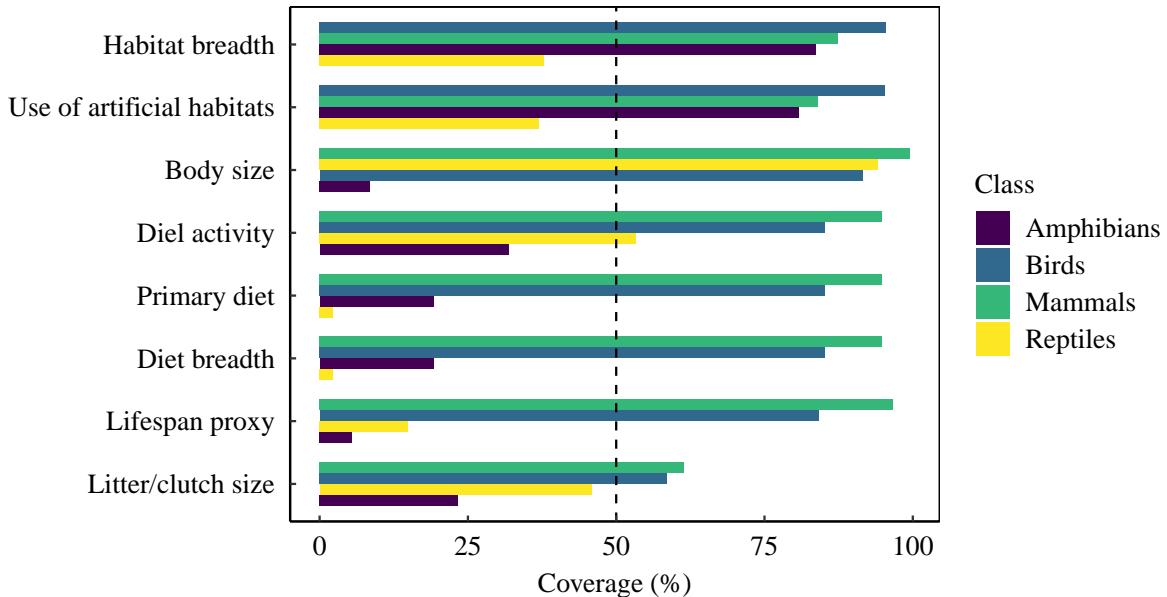


Figure S1: Trait coverage, including coverage for diet information, calculated as the proportion of species for which trait values are not missing. The dashed line represents 50% coverage.

S2.2 Phylogenetic signal in traits

We measured the phylogenetic signal in traits using Pagel's λ (for continuous traits) and Borges' δ (for categorical traits). We found evidence of phylogenetic conservatism in all traits.

Table S1: Phylogenetic signal in continuous and categorical traits. BM: body mass; BL: body length; GL: generation length; MA: age at sexual maturity; ML: maximum longevity; L: longevity; LCS: litter/clutch size; HB: habitat breadth; DA: diel activity; UA: use of artificial habitats. Continuous traits were log-10 transformed to improve normality before estimating Pagel's λ – except for habitat breadth which was square-rooted. A star indicates a significant signal ($P<0.05$ for the log-likelihood ratio test in the case of λ ; and a significant difference from the simulated null distribution of δ for categorical traits). 'NA' indicates traits that were not considered for a given class.

Class	Pagel's λ								Borges' δ		
	BM	BL	GL	MA	ML	L	LCS	HB	Diet	DA	UA
Amphibians	0.98*	0.94*	NA	0.85*	0.82*	NA	0.93*	0.99*	3.4*	3.4*	4.5*
Birds	0.99*	NA	0.97*	NA	NA	NA	0.95*	0.60*	6.4*	32e3*	1.8*
Mammals	0.99*	NA	0.97	NA	NA	NA	0.99	0.71	26*	52*	1.3*
Reptiles	1.0*	NA	NA	NA	0.94*	0.98*	1.0*	0.52*	2.2*	6.4*	1.4*

S2.3 Implementation of missing value imputations

We imputed missing trait values using random forest algorithms, as implemented in R with missForest (Stekhoven, 2016; Stekhoven and Bühlmann, 2012). Phylogenetic relationships were included as additional

predictors in the form of phylogenetic eigenvectors (Diniz-Filho et al., 2012), extracted from the phylogenies using the PVR package (Santos, 2018). We used class-specific phylogenetic trees from <https://zenodo.org/record/3690867#.Xyc5wyhKhPZ> for mammals (Phylacine 1.2; Faurby et al. (2018, 2020)); and from <https://data.vertlife.org/> for amphibians (Jetz & Pyron 2018), birds (Jetz et al. 2012) and squamates (Tonini et al. 2016). For each class, we used a consensus tree obtained with the TreeAnnotator programme of the BEAST software (Bouckaert et al. 2014), from an available distribution of 1000 trees.

Following Penone et al. (2014), we included the first ten phylogenetic eigenvectors as additional predictors of missing trait values in each class. As not all species were represented in the phylogenies, we also added taxonomic order as a predictor for all species. All traits in Table S1 were included in the imputations, as well as diet breadth. Habitat & diet breadth were considered as categorical variables for the imputations (and so, discretised). Tuning parameters of missForest were set to ten maximum iterations and to one hundred trees grown in each forest.

S2.4 Imputation error

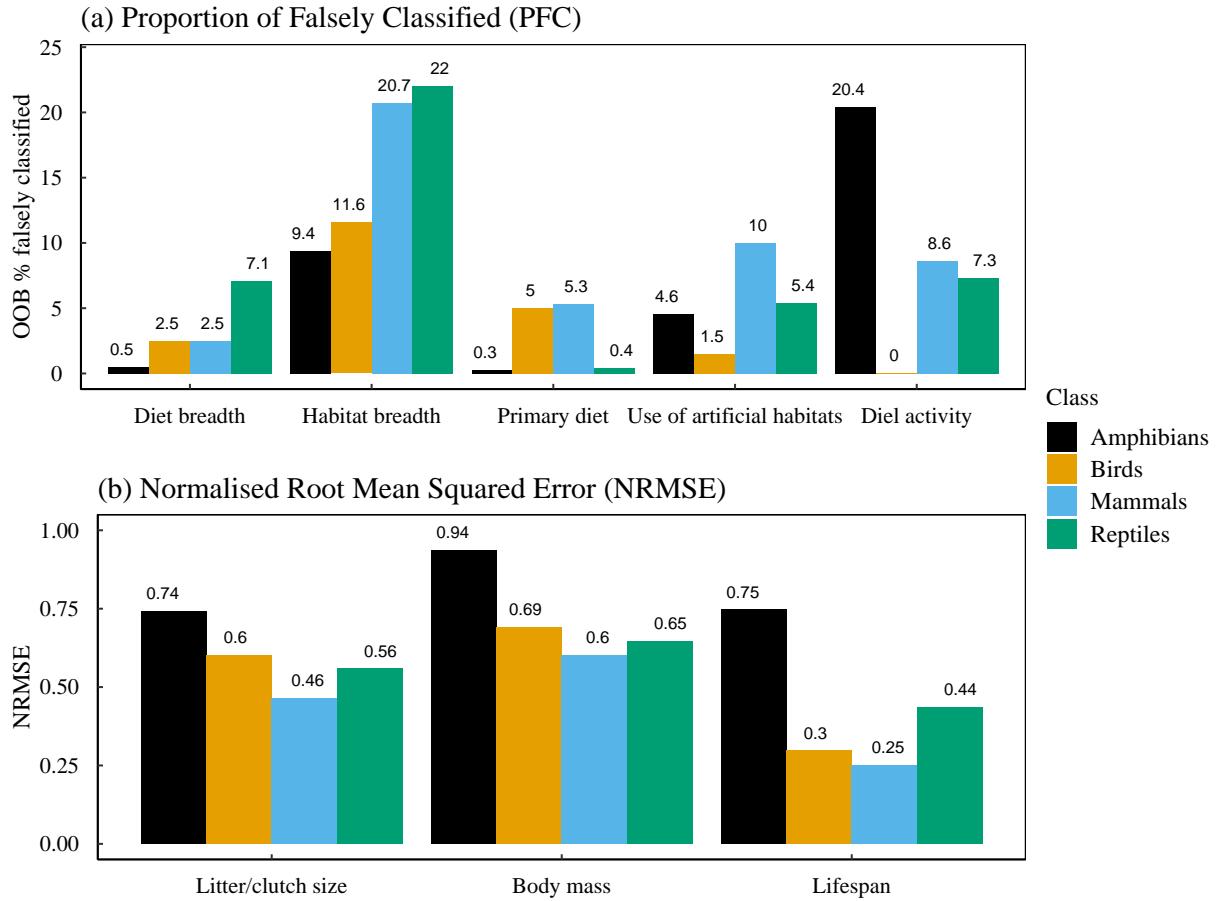


Figure S2: Estimation of imputation errors for the traits included in the analyses. (a) For the categorical traits, we show the proportion of falsely classified traits ('PFC', out-of-bag estimates); (b) For the continuous traits, we calculate the normalised root-mean-squared error from the mean square error (that we divide by the standard deviation of the known trait distribution).

S3 Land-use types in PREDICTS and sample sizes (number of sampled sites across classes)

Table S2: Land-use categories in the PREDICTS database. See Hudson et al. (2014, 2017) for more details.

Land-use category	Definition
Primary vegetation	Native vegetation, undisturbed since its establishment under current climatic conditions. No known alterations due to human activities or to extreme natural events.
Mature secondary vegetation	Vegetation recovering after complete destruction of primary vegetation & where succession is near complete – the structure approaches that of primary vegetation.
Intermediate secondary vegetation	Vegetation recovering after complete destruction of primary vegetation at a mid-successional stage.
Young secondary vegetation	Vegetation recovering after complete destruction of primary vegetation at an early successional stage.
Plantation forest	Previously cleared areas planted with crop trees or shrubs grown and harvested for human consumption or for commercial purposes (includes wood, fruit, oil, biofuel, rubber, etc).
Pasture	Areas grazed by livestock, permanently or regularly. Can be improved through cultivation techniques.
Cropland	Previously cleared areas planted with herbaceous crops and harvested for human or animal consumption (including animal feed and crops used in the food industry), or for commercial purposes (e.g., crops grown for the textile industry).
Urban	Previously cleared areas built up by humans. Vegetation is managed for civic or personal purposes.

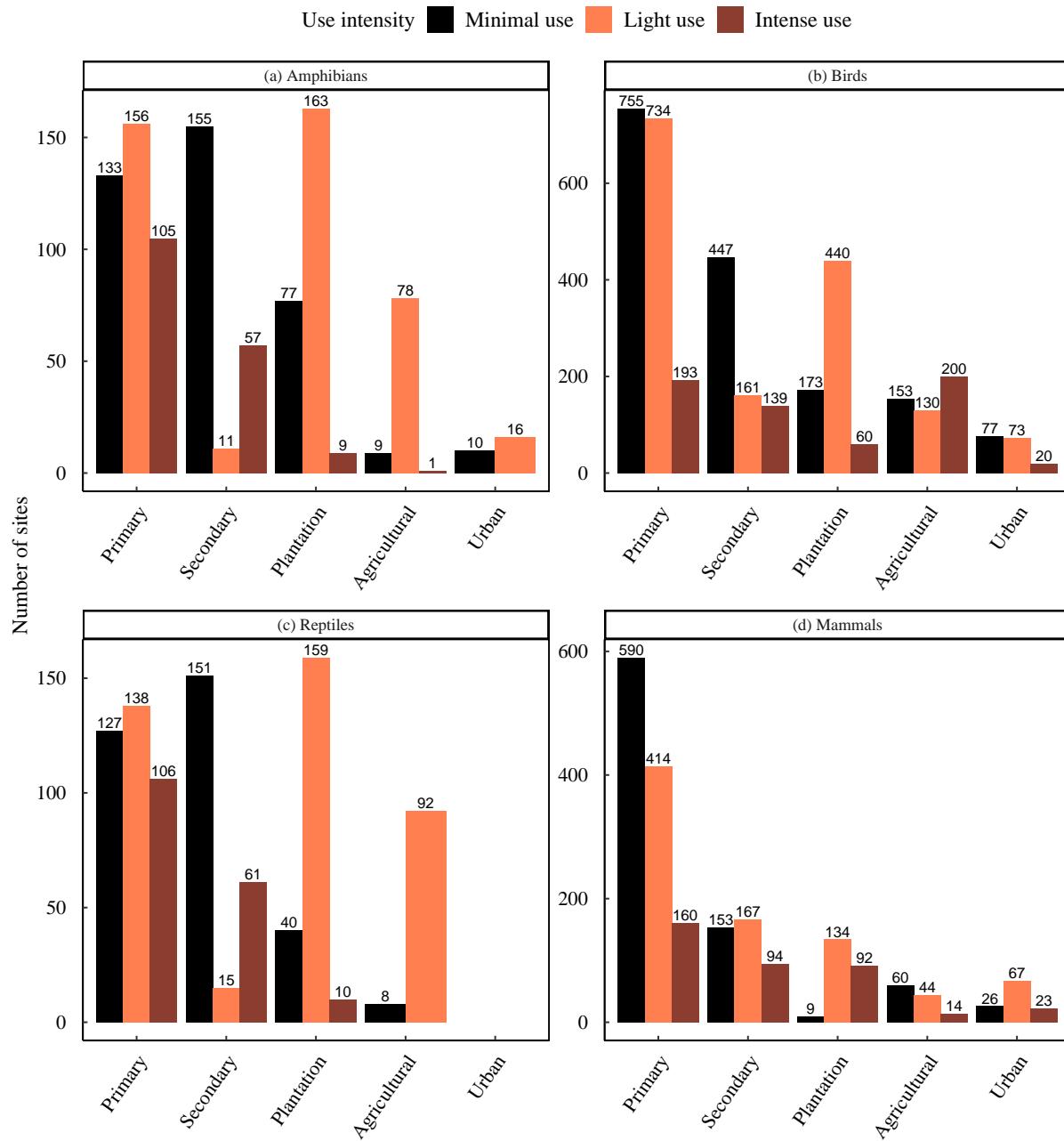


Figure S3: Sample sizes (number of PREDICTS sites) for the different land-use types, in each class.

S4 Land-use responses: multicollinearity checks among the models' explanatory variables

Table S3: Generalised Variance Inflation Factors among the candidate explanatory variables for the mixed-effects model fitted across amphibians, prior to the exclusion of diet. The model aimed at investigating the effects of land use, land-use intensity and the species-level ecological characteristics on species occurrence probability.

Predictor	GVIF
Diel activity	1.7
Lifespan proxy (\log_{10})	1.8
Specialisation	1.8
Range area (\log_{10})	2.0
Body mass (\log_{10})	2.0
Land use	2.0
Litter/clutch size (\log_{10})	2.5
Land-use intensity	2.6
Habitat breadth (square-root)	3.2
Diet breadth (square-root)	22.8
Primary diet	23.6

Table S4: Generalised Variance Inflation Factors among the explanatory variables for the mixed-effects model fitted across amphibians (after the exclusion of diet), looking at the effects of land use, land-use intensity and the species-level ecological characteristics on species occurrence probability.

Predictor	GVIF
Diel activity	1.6
Diet breadth (sqrt)	1.7
Lifespan proxy (\log_{10})	1.8
Specialisation	1.8
Range area (\log_{10})	1.9
Land use	2.0
Body mass (\log_{10})	2.0
Litter/clutch size (\log_{10})	2.4
Land-use intensity	2.6
Habitat breadth (square-root)	3.1

Table S5: Generalised Variance Inflation Factors among the explanatory variables for the mixed-effects model fitted across birds, looking at the effects of land use, land-use intensity and the species-level ecological characteristics on species occurrence probability.

Predictor	GVIF
Diel activity	1.1
Land use	1.2
Land-use intensity	1.2
Litter/clutch size (\log_{10})	1.3
Range area (\log_{10})	1.4
Diet breadth (square-root)	1.5
Specialisation	1.6
Lifespan proxy (\log_{10})	1.7
Habitat breadth (square-root)	1.8
Body mass (\log_{10})	1.9
Primary diet	2.3

Table S6: Generalised Variance Inflation Factors among the explanatory variables for the mixed-effects model fitted across mammals, looking at the effects of land use, land-use intensity and the species-level ecological characteristics on species occurrence probability.

Predictor	GVIF
Diel activity	1.2
Range area (\log_{10})	1.2
Specialisation	1.4
Land-use intensity	1.4
Diet breadth (square-root)	1.7
Land use	1.8
Habitat breadth (square-root)	1.8
Litter/clutch size (\log_{10})	2.7
Body mass (\log_{10})	3.0
Lifespan proxy (\log_{10})	3.4
Primary diet	4.4

Table S7: Generalised Variance Inflation Factors among the candidate explanatory variables for the mixed-effects model fitted across reptiles, prior to the exclusion of diet. The model aimed at investigating the effects of land use, land-use intensity and the species-level ecological characteristics on species occurrence probability.

Predictor	GVIF
Diel activity	1.1
Specialisation	1.3
Range area (\log_{10})	1.3
Habitat breadth (square-root)	1.6
Lifespan proxy (\log_{10})	1.9
Litter/clutch size (\log_{10})	2.8
Land use	3.2
land-use intensity	3.5
Body mass (\log_{10})	3.9
Diet breadth (square-root)	5.8
Primary diet	9.9

Table S8: Generalised Variance Inflation Factors among the explanatory variables for the mixed-effects model fitted across reptiles (*after the exclusion of diet*), looking at the effects of land use, land-use intensity and the species-level ecological characteristics on species occurrence probability.

Predictor	GVIF
Diel activity	1.1
Diet breadth (square-root)	1.2
Specialisation	1.2
Range area (\log_{10})	1.3
Habitat breadth (square-root)	1.6
Lifespan proxy (\log_{10})	1.9
Litter/clutch size (\log_{10})	2.7
Land use	3.2
Body mass (\log_{10})	3.2
Land-use intensity	3.4

S5 Implementing Climate-niche Factor Analysis across terrestrial vertebrates

S5.1 Historical climate data: groups of intercorrelated variables

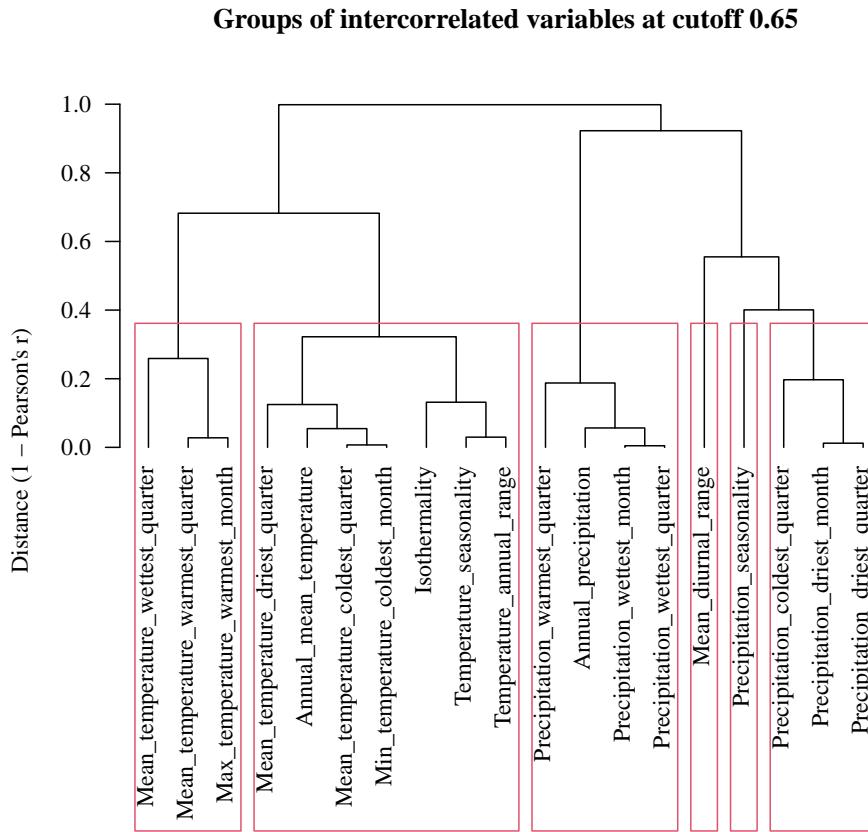


Figure S4: Groups of intercorrelated climatic variables at cutoff 0.65, obtained using the ‘removeCollinearity’ R function (‘virtualspecies’ package, Leroy et al. (2015)).

S5.2 CENFA estimation and resolution

We estimated climate change sensitivity across terrestrial vertebrates with the CENFA framework using three different resolutions for the species distribution files and the climatic variables: 50 km², 10 km² and 5 km². Indeed, the finer the resolution, the better species distribution is likely to be captured, particularly for narrow-ranging species (Figure S5). When working with coarser resolutions, the actual geographical distribution of a narrow-ranging species might be overestimated (Figure S5), such that the climatic niche breadth of the species, and consequently its climate-change sensitivity, might also be overestimated. However, finer resolutions are more computationally demanding, which can be limiting when working across several thousand species.

Thus, we looked for a resolution that provided the best estimations of climate-change sensitivity for the narrow-ranging species while requiring acceptable computational load. With a resolution of 50 km², climate-change sensitivity tended to be overestimated for more narrow-ranging species than at 10 km² (Figure S6); and at 10 km², climate-change sensitivity tended to be overestimated for more narrow-ranging species than

at 5 km^2 (Figure S6). Below 5 km^2 , we deemed the computational load not acceptable for a global estimation of climate-change sensitivity across terrestrial vertebrates.

Hence, we chose to work with a resolution of 5 km^2 . At this resolution, there were still some-narrow ranging species for which sensitivity was likely overestimated (Figure S6). To prevent any impact of these species on the analyses, we removed species with the smallest geographical range areas, using a conservative threshold of 100 km^2 for geographical range area (Figure S6).

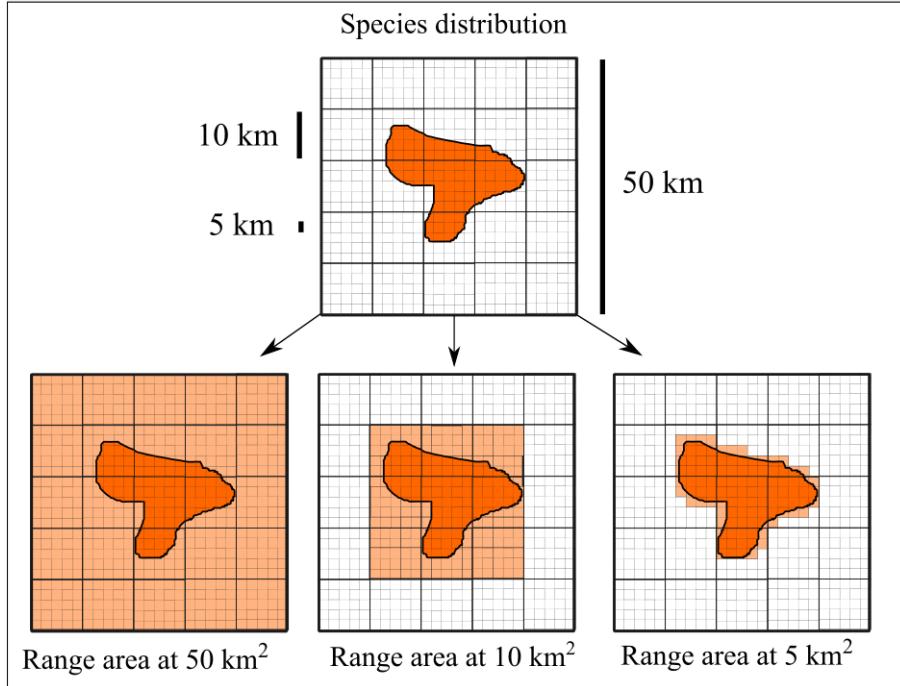


Figure S5: Possible impact of resolution on estimated geographical range area. We represent a virtual distribution for a species (orange shape). The species distribution is more accurately captured at finer resolutions (e.g., 5 km^2) than at coarser resolutions (e.g., 10 km^2 or 50 km^2). A possible consequence is that coarser resolutions can tend to disproportionately overestimate the geographical range area of narrow-ranging species, because the aggregation of grid cells where the species is found to be present can artificially augment the amount of occupied area at coarser resolutions, and relatively more so if the species is narrow-ranged.

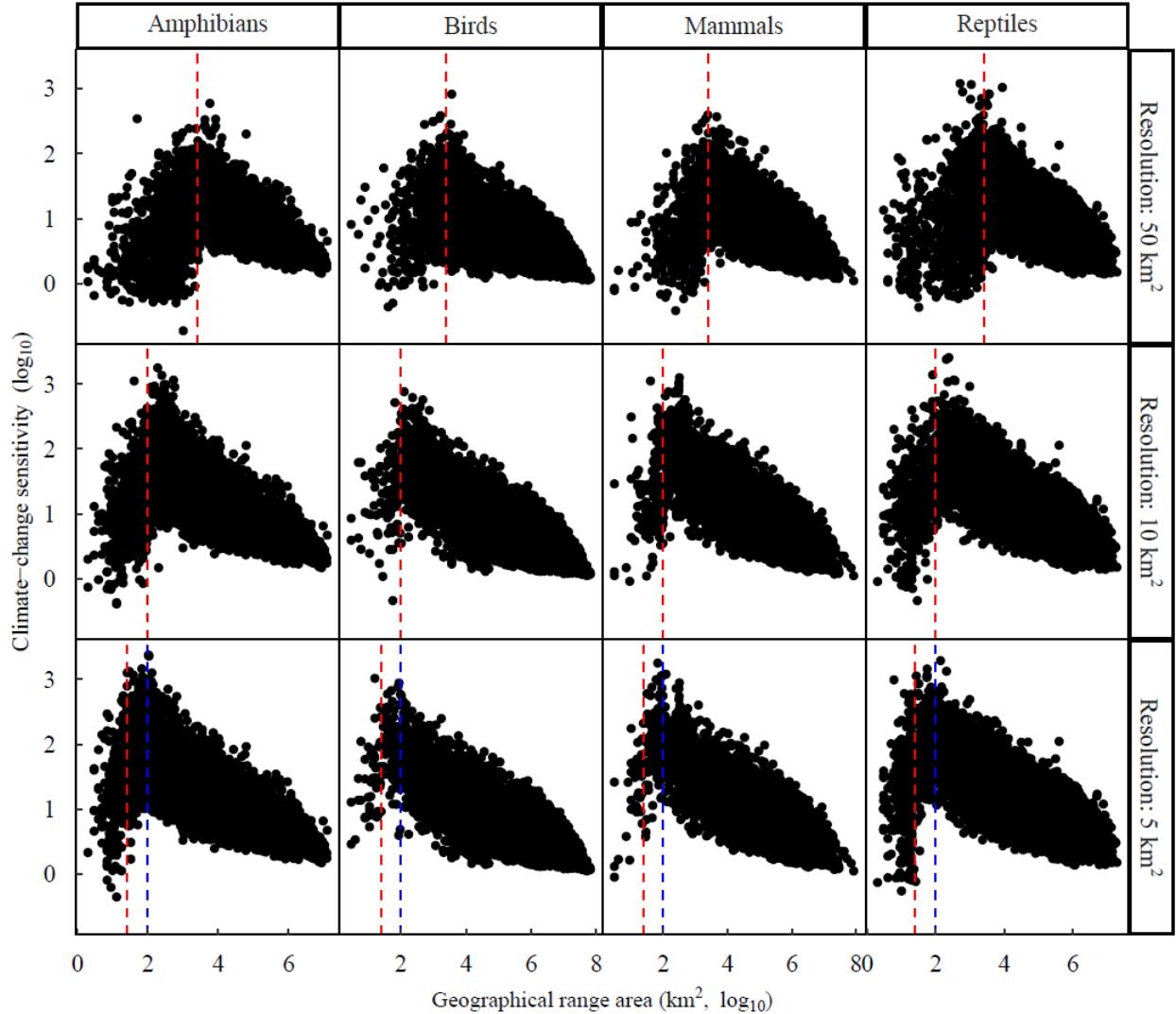


Figure S6: Estimated climate-change sensitivity estimations at three different resolutions (50 km^2 , 10 km^2 and 5 km^2) against geographical range area (estimated at 1 km^2). With the red dashed lines, we highlight the range areas that correspond to the surface area of one grid cell (*i.e.*, $2,500 \text{ km}^2$, 100 km^2 and 25 km^2 respectively). Climate-change sensitivity was estimated using the CENFA framework (Rinnan and Lawler, 2019). We chose to work at a resolution of 5 km^2 and we excluded species whose range area was $\leq 100 \text{ km}^2$ (blue dashed line), that is, species whose distribution could intersect up to four grid cells at a resolution of 5 km^2 .

S6 Climate-change sensitivity models: multicollinearity checks among models' explanatory variables

Table S9: Generalised Variance Inflation Factors among the candidate explanatory variables for the phylogenetic least-square regression fitted across amphibians, prior to the exclusion of diet breadth. The model aimed at investigating the association between the species-level ecological characteristics and species climate-change sensitivity.

Predictor	GVIF
Diel activity	1.1
Lifespan proxy (\log_{10})	1.2
Range area (\log_{10})	1.3
Body mass (\log_{10})	1.4
Litter/clutch size (\log_{10})	1.5
Specialisation	1.6
Habitat breadth (square-root)	1.9
Primary diet	17.1
Diet breadth (square-root)	17.1

Table S10: Generalised Variance Inflation Factors among the explanatory variables for the phylogenetic least-square regression fitted across amphibians, after excluding diet breadth. The model aimed at investigating the association between the species-level ecological characteristics and species climate-change sensitivity.

Predictor	GVIF
Diel activity	1.1
Primary diet	1.1
Lifespan proxy (\log_{10})	1.2
Range area (\log_{10})	1.3
Body mass (\log_{10})	1.4
Litter/clutch size (\log_{10})	1.5
Specialisation	1.6
Habitat breadth (square-root)	1.9

Table S11: Generalised Variance Inflation Factors among the explanatory variables for the phylogenetic least-square regression fitted across birds. The model aimed at investigating the association between the species-level ecological characteristics and species climate-change sensitivity.

Predictor	GVIF
Diel activity	1.1
Range area (\log_{10})	1.2
Litter/clutch size (\log_{10})	1.3
Diet breadth (square-root)	1.5
Specialisation	1.6
Habitat breadth (square-root)	1.8
Lifespan proxy (\log_{10})	1.9
Body mass (\log_{10})	2.0
Primary diet	2.1

Table S12: Generalised Variance Inflation Factors among the explanatory variables for the phylogenetic least-square regression fitted across mammals. The model aimed at investigating the association between the species-level ecological characteristics and species climate-change sensitivity.

Predictor	GVIF
Range area (\log_{10})	1.2
Diel activity	1.3
Specialisation	1.3
Habitat breadth (square-root)	1.5
Diet breadth (square-root)	1.6
Body mass(\log_{10})	2.3
Litter/clutch size (\log_{10})	2.4
Primary diet	2.7
Lifespan proxy (\log_{10})	3.0

Table S13: Generalised Variance Inflation Factors among the explanatory variables for the phylogenetic least-square regression fitted across reptiles. The model aimed at investigating the association between the species-level ecological characteristics and species climate-change sensitivity.

Predictor	GVIF
Diel activity	1.1
Range area(\log_{10})	1.2
Specialisation	1.4
Habitat breadth (square-root)	1.5
Lifespan proxy (\log_{10})	1.6
Litter/clutch size (\log_{10})	2.0
Body mass (\log_{10})	2.9
Diet breadth (square-root)	2.9
Primary diet	3.6

S7 Land-use responses: occurrence probability predictions from the partial models for artificial habitat use and diel activity

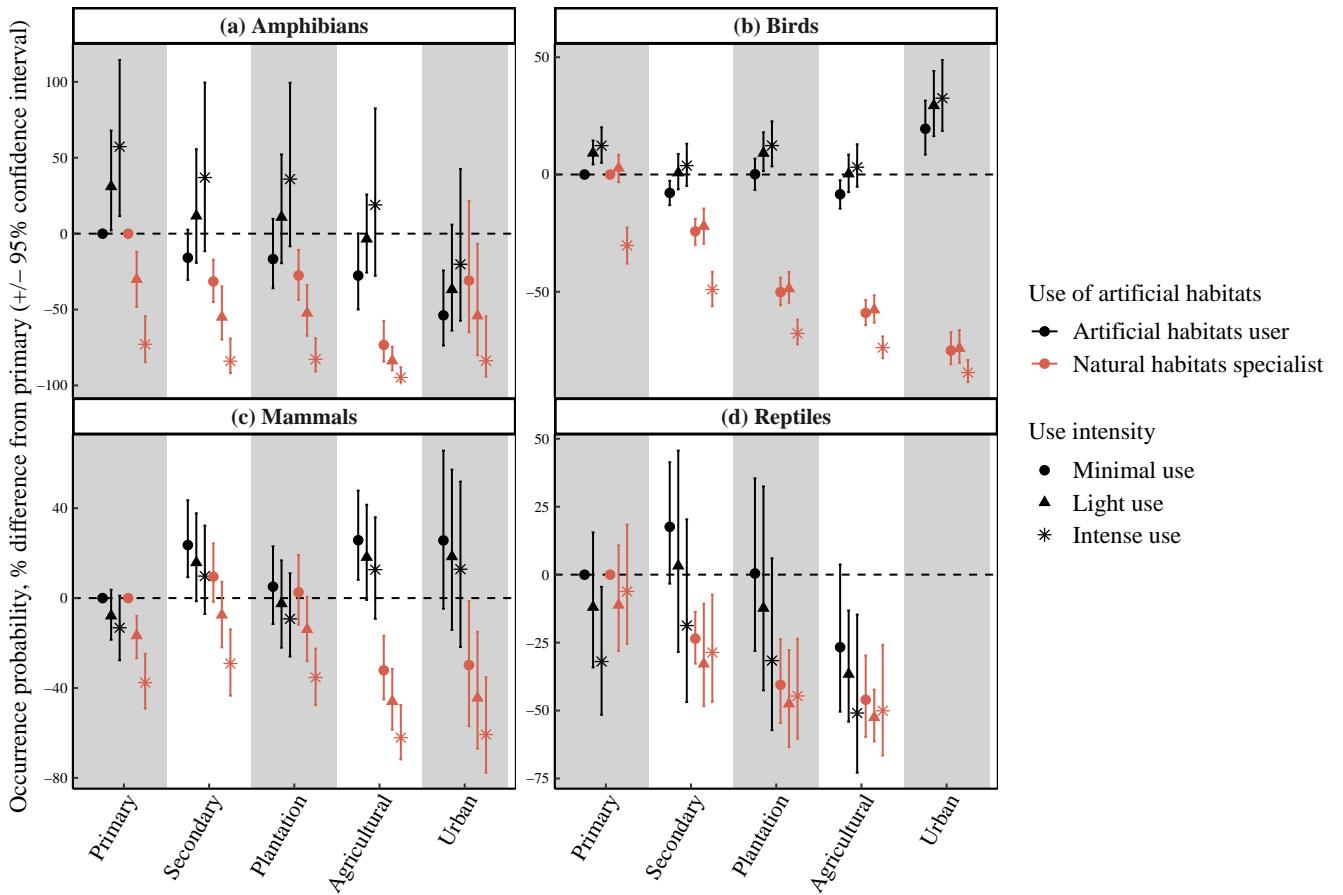


Figure S7: Predicted occurrence probability as a function of land use, land-use intensity, artificial habitat use and their interactions in each class. The predictions were obtained from the partial models fitted in each class for artificial habitat use. Effects could not be estimated for urban reptiles, as there weren't any sampled sites. The predictions are rescaled with reference to minimally-used primary vegetation. Primary: primary vegetation; Secondary: secondary vegetation; plantation: plantation forest; agricultural: cropland and pasture.

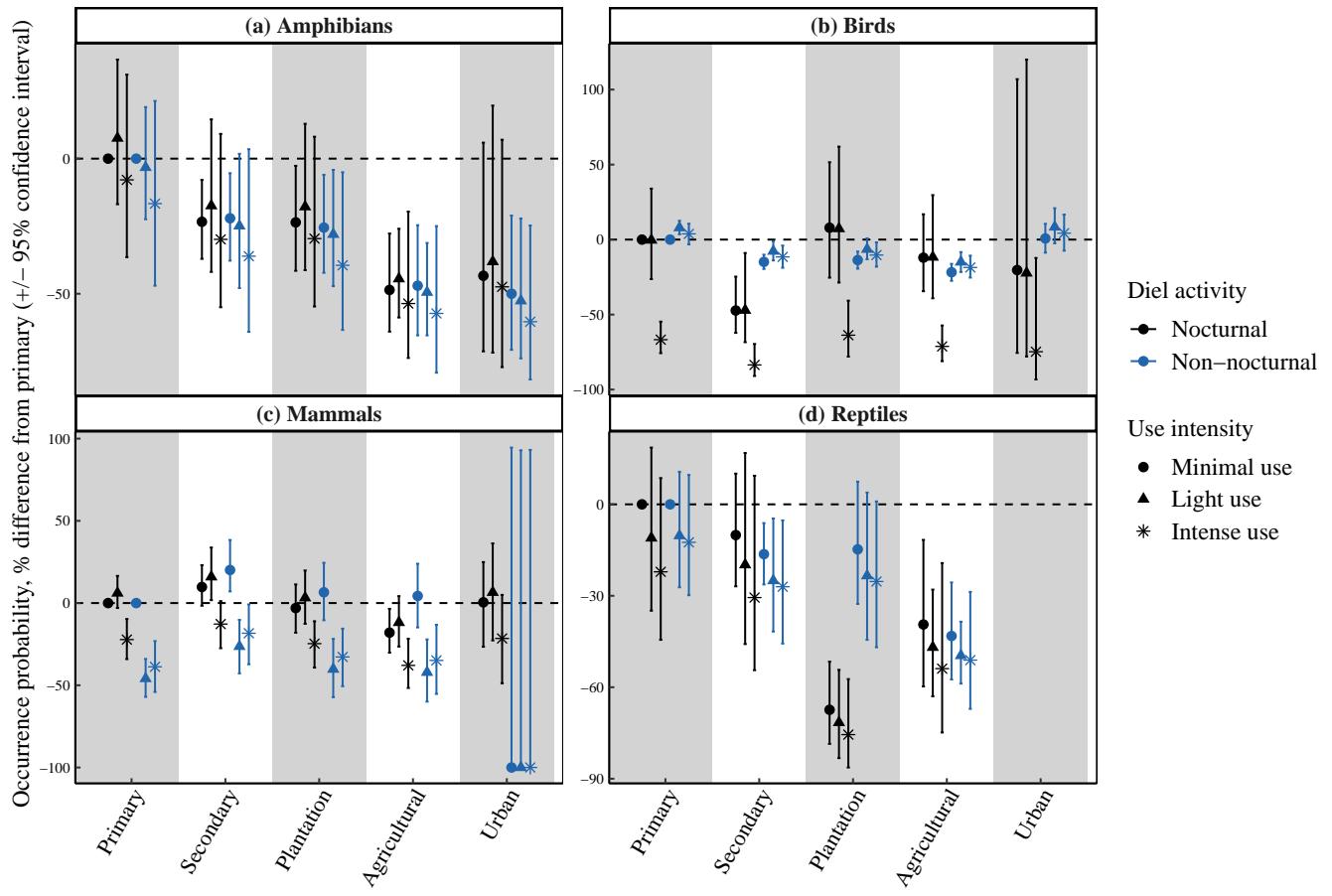


Figure S8: Predicted occurrence probability as a function of land use, land-use intensity, diel activity and their interactions in each class. The predictions were obtained from the partial models fitted in each class for diel activity. Effects could not be estimated for urban reptiles, as there weren't any sampled sites. Error bars are large for non-nocturnal urban mammals because there were very few sampled species (only five). The predictions are rescaled with reference to minimally-used primary vegetation. Primary: primary vegetation; Secondary: secondary vegetation; plantation: plantation forest; agricultural: cropland and pasture.

S8 Land-use responses: diagnostic plots for the full (all-predictor) models

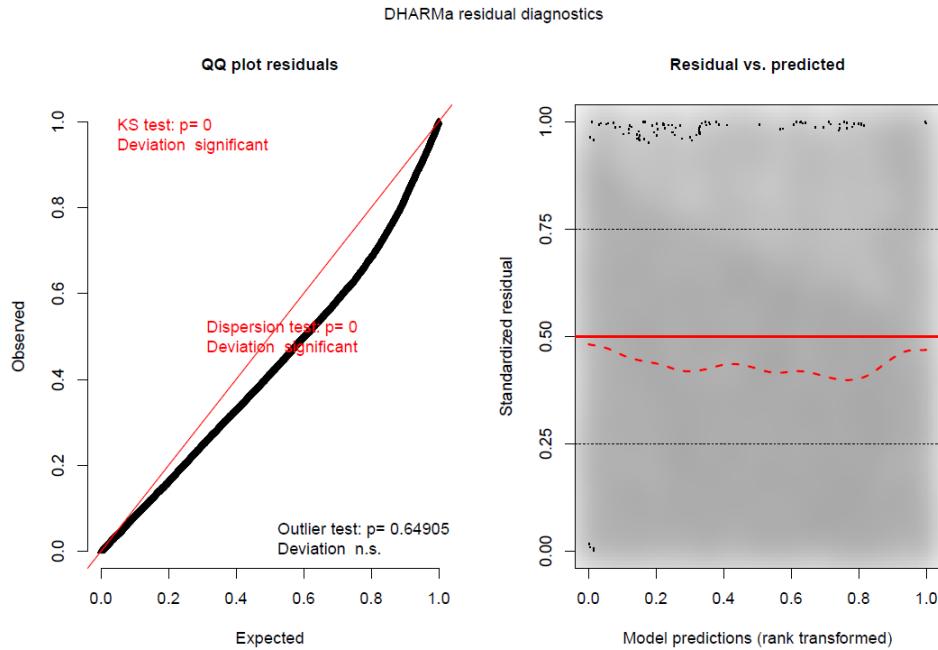


Figure S9: Diagnostic plots for the mixed-effects model fitted on amphibians, looking at the effects of land use, land-use intensity and the species-level ecological characteristics on species occurrence probability (all-predictor model). The diagnostic plots were obtained from the ‘DHARMA’ R package (Hartig, 2021).

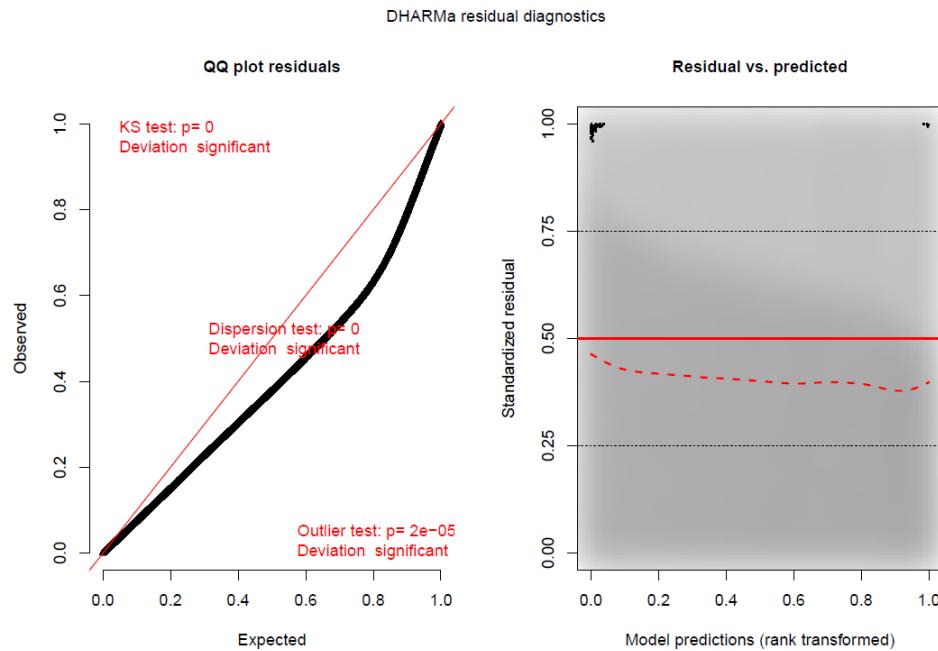


Figure S10: Diagnostic plots for the mixed-effects model fitted on birds, looking at the effects of land use, land-use intensity and the species-level ecological characteristics on species occurrence probability (all-predictor model). The diagnostic plots were obtained from the ‘DHARMA’ R package (Hartig, 2021).

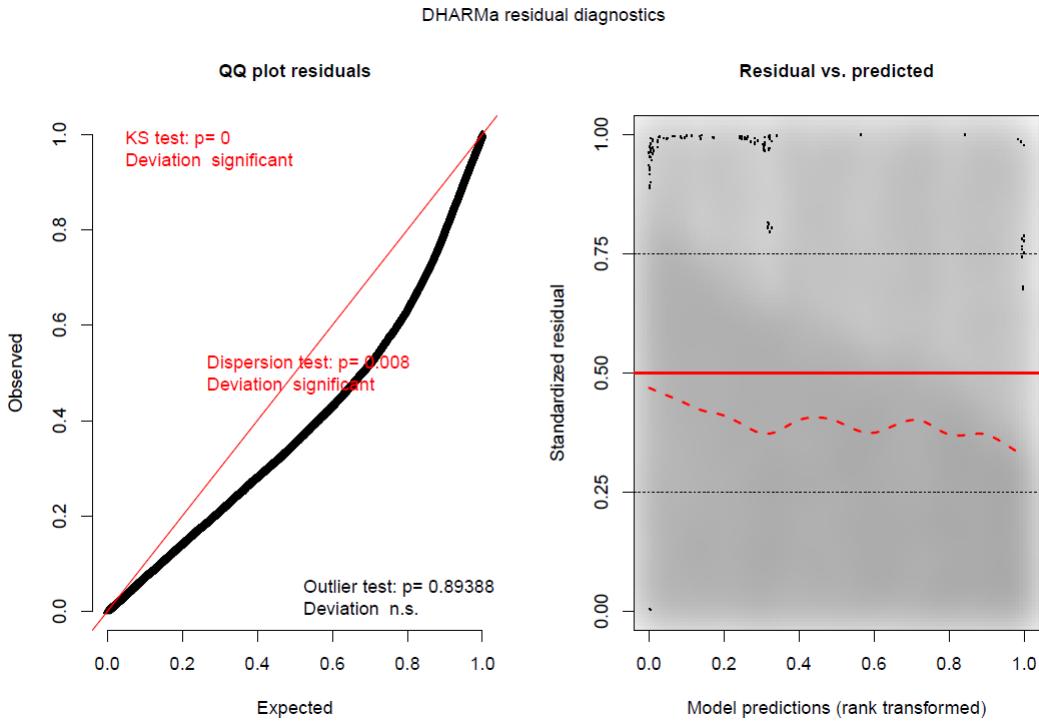


Figure S11: Diagnostic plots for the mixed-effects model fitted on mammals, looking at the effects of land use, land-use intensity and the species-level ecological characteristics on species occurrence probability (all-predictor model). The diagnostic plots were obtained from the ‘DHARMA’ R package (Hartig, 2021).

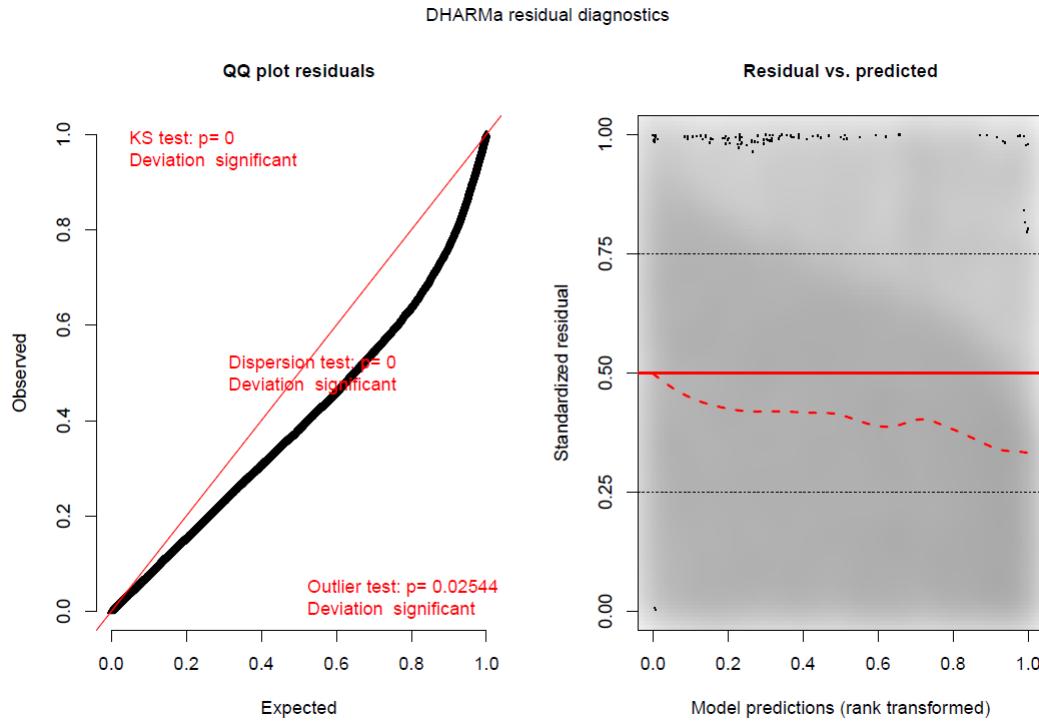


Figure S12: Diagnostic plots for the mixed-effects model fitted on reptiles, looking at the effects of land use, land-use intensity and the species-level ecological characteristics on species occurrence probability (all-predictor model). The diagnostic plots were obtained from the ‘DHARMA’ R package (Hartig, 2021).

S9 Climate-change sensitivity: model summaries and diagnostic plots

S9.1 Summaries & diagnostic plots for models fitted on species with range area $>100 \text{ km}^2$

Table S14: Summary for the PGLS model fitted on amphibians, investigating associations between species-level ecological characteristics and climate-change sensitivity. We excluded species whose range area was $\leq 100 \text{ km}^2$ (the sample size was n=4,537).

	Estimate	Std. Error	t value	Pr(> t)
Intercept	1.15	0.21	5.49	< 0.001
$\log_{10}(\text{Body mass})$	-1.97	0.61	-3.22	0.001
$\log_{10}(\text{Body mass})^2$	-0.26	0.42	-0.60	0.55
$\log_{10}(\text{Body mass})^3$	0.46	0.37	1.24	0.22
$\log_{10}(\text{Lifespan proxy})$	-0.21	0.59	-0.36	0.72
$\log_{10}(\text{Lifespan proxy})^2$	-0.14	0.43	-0.32	0.75
$\log_{10}(\text{Lifespan proxy})^3$	0.58	0.35	1.66	0.10
$\log_{10}(\text{Litter/clutch size})$	1.59	0.54	2.96	0.003
$\log_{10}(\text{Litter/clutch size})^2$	-0.06	0.38	-0.16	0.87
$\log_{10}(\text{Litter/clutch size})^3$	-0.74	0.31	-2.37	0.02
$\log_{10}(\text{Range area})$	-26.60	0.34	-77.15	< 0.001
$\log_{10}(\text{Range area})^2$	4.27	0.29	14.57	< 0.001
$\log_{10}(\text{Range area})^3$	-1.65	0.28	-5.96	< 0.001
square-root(Habitat breadth)	-2.26	0.43	-5.32	< 0.001
square-root(Habitat breadth) ²	0.81	0.30	2.67	0.01
square-root(Habitat breadth) ³	-0.59	0.28	-2.10	0.04
Specialisation: Natural habitat specialist	0.02	0.01	1.85	0.06
Diel activity: Non-nocturnal	0.04	0.01	3.28	0.001
Primary diet: Omnivore	0.01	0.03	0.29	0.77
Primary diet: Plants/seeds	0.04	0.13	0.31	0.76
Primary diet: Vertebrates	0.13	0.15	0.87	0.39

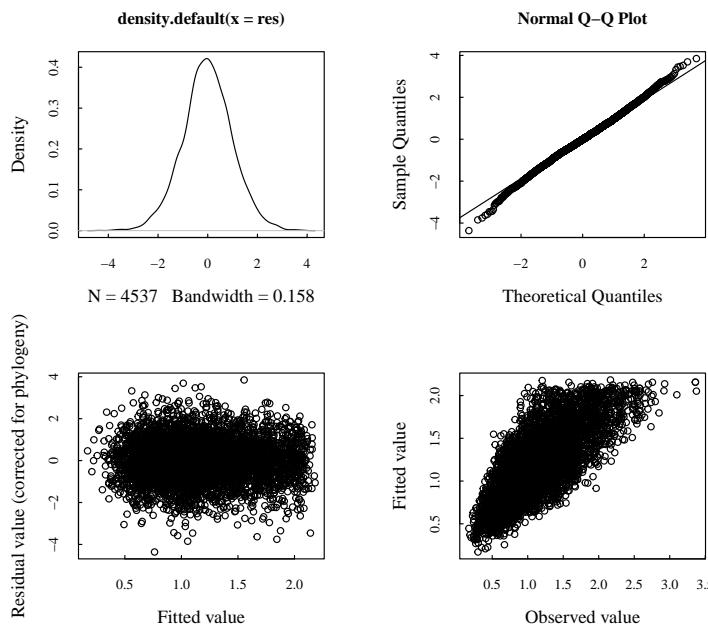


Figure S13: Diagnostic plots for the PGLS model fitted on amphibians, investigating associations between species-level ecological characteristics and climate-change sensitivity. We excluded species whose range area was $\leq 100 \text{ km}^2$ (the sample size was n=4,537).

Table S15: Summary for the PGLS model fitted on birds, investigating associations between species-level ecological characteristics and climate-change sensitivity. We excluded species whose range area was $\leq 100 \text{ km}^2$ (the sample size was n=10,198).

	Estimate	Std. Error	t value	Pr(> t)
Intercept	0.64	0.08	7.91	< 0.001
$\log_{10}(\text{Body mass})$	2.24	0.67	3.36	0.001
$\log_{10}(\text{Body mass})^2$	0.16	0.42	0.37	0.71
$\log_{10}(\text{Body mass})^3$	-0.22	0.37	-0.60	0.55
$\log_{10}(\text{Lifespan proxy})$	-0.23	0.59	-0.38	0.70
$\log_{10}(\text{Lifespan proxy})^2$	-0.84	0.39	-2.16	0.03
$\log_{10}(\text{Lifespan proxy})^3$	-0.10	0.28	-0.36	0.72
$\log_{10}(\text{Litter/clutch size})$	3.72	0.39	9.46	< 0.001
$\log_{10}(\text{Litter/clutch size})^2$	-0.42	0.33	-1.26	0.21
$\log_{10}(\text{Litter/clutch size})^3$	-0.40	0.27	-1.47	0.14
$\log_{10}(\text{Range area})$	-30.69	0.27	-113.09	< 0.001
$\log_{10}(\text{Range area})^2$	7.22	0.24	29.92	< 0.001
$\log_{10}(\text{Range area})^3$	-2.73	0.23	-11.74	< 0.001
square-root(Habitat breadth)	0.86	0.33	2.59	0.01
square-root(Habitat breadth) ²	-0.89	0.24	-3.63	< 0.001
square-root(Habitat breadth) ³	-0.22	0.23	-0.95	0.34
square-root(Diet breadth)	-0.50	0.31	-1.64	0.10
square-root(Diet breadth) ²	-0.11	0.25	-0.44	0.66
square-root(Diet breadth) ³	0.32	0.24	1.36	0.18
Specialisation: Natural habitat specialist	0.06	0.01	10.13	< 0.001
Diel activity: Non-nocturnal	-0.02	0.04	-0.66	0.51
Primary diet: Invertebrates	0.06	0.01	5.53	< 0.001
Primary diet: Omnivores	0.02	0.01	2.09	0.04
Primary diet: Plants/seeds	0.06	0.01	4.69	< 0.001
Primary diet: Vertebrates	0.01	0.02	0.83	0.41

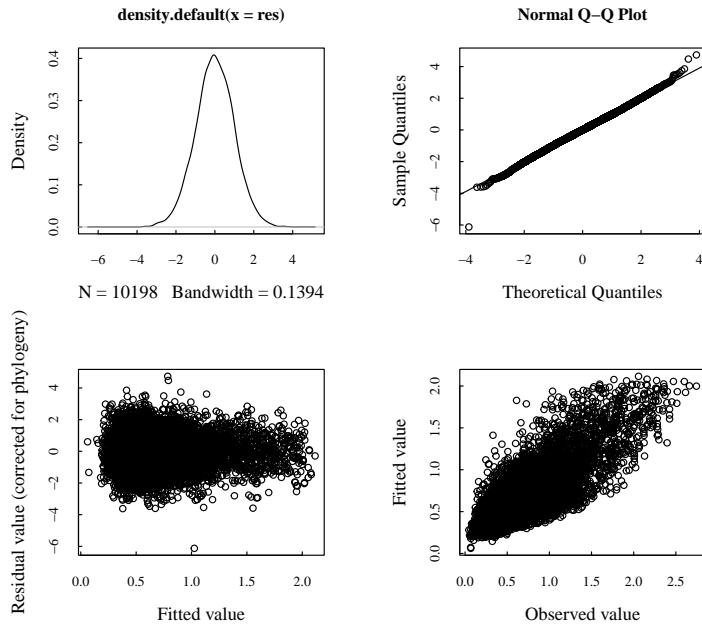


Figure S14: Diagnostic plots for the PGLS model fitted on birds, investigating associations between species-level ecological characteristics and climate-change sensitivity. We excluded species whose range area was $\leq 100 \text{ km}^2$ (the sample size was $n=10,198$).

Table S16: Summary for the PGLS model fitted on mammals, investigating associations between species-level ecological characteristics and climate-change sensitivity. We excluded species whose range area was $\leq 100 \text{ km}^2$ (the sample size was n=4,712).

	Estimate	Std. Error	t value	Pr(> t)
Intercept	0.84	0.16	5.37	< 0.001
$\log_{10}(\text{Body mass})$	-4.62	0.94	-4.93	< 0.001
$\log_{10}(\text{Body mass})^2$	0.40	0.56	0.72	0.47
$\log_{10}(\text{Body mass})^3$	0.59	0.44	1.33	0.18
$\log_{10}(\text{Lifespan proxy})$	1.60	1.03	1.55	0.12
$\log_{10}(\text{Lifespan proxy})^2$	-0.79	0.49	-1.60	0.11
$\log_{10}(\text{Lifespan proxy})^3$	-0.15	0.43	-0.35	0.73
$\log_{10}(\text{Litter/clutch size})$	3.29	0.71	4.63	< 0.001
$\log_{10}(\text{Litter/clutch size})^2$	0.06	0.42	0.14	0.89
$\log_{10}(\text{Litter/clutch size})^3$	-0.16	0.33	-0.47	0.64
$\log_{10}(\text{Range area})$	-24.17	0.31	-78.21	< 0.001
$\log_{10}(\text{Range area})^2$	4.15	0.28	15.09	< 0.001
$\log_{10}(\text{Range area})^3$	-0.90	0.26	-3.45	0.001
square-root(Habitat breadth)	-1.24	0.34	-3.60	< 0.001
square-root(Habitat breadth) ²	0.22	0.27	0.82	0.41
square-root(Habitat breadth) ³	-0.03	0.26	-0.10	0.92
square-root(Diet breadth)	-1.21	0.47	-2.55	0.01
square-root(Diet breadth) ²	0.33	0.36	0.91	0.36
square-root(Diet breadth) ³	0.11	0.34	0.33	0.74
Specialisation: Natural habitat specialist	0.04	0.01	3.22	0.001
Diel activity: Non-nocturnal	0.003	0.01	0.23	0.82
Primary diet: Invertebrates	-0.02	0.03	-0.62	0.54
Primary diet: Omnivores	-0.02	0.03	-0.77	0.44
Primary diet: Plants/seeds	0.03	0.02	1.32	0.19
Primary diet: Vertebrates	-0.04	0.04	-0.98	0.33

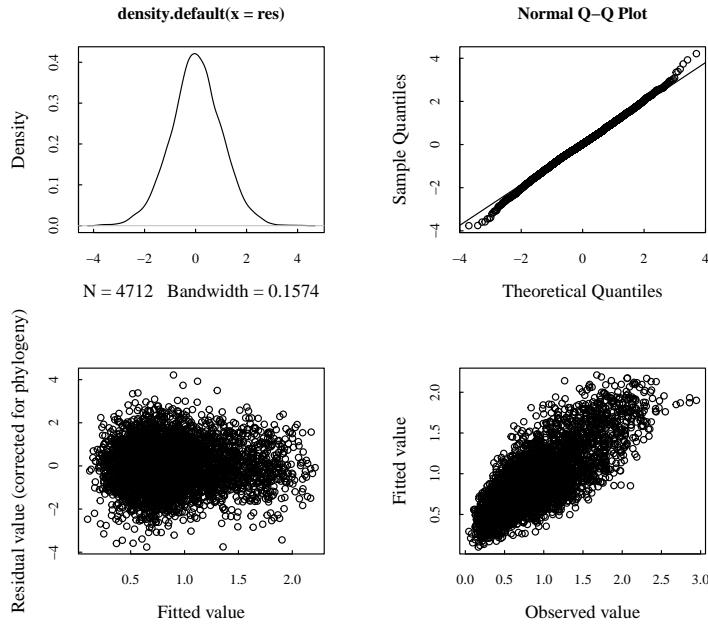


Figure S15: Diagnostic plots for the PGLS model fitted on mammals, investigating associations between species-level ecological characteristics and climate-change sensitivity. We excluded species whose range area was $\leq 100 \text{ km}^2$ (the sample size was $n=4,712$).

Table S17: Summary for the PGLS model fitted on reptiles, looking at the effects of species-level ecological characteristics on climate-change sensitivity. We excluded species whose range area was $\leq 100 \text{ km}^2$ (the sample size was $n=7,330$).

	Estimate	Std. Error	t value	Pr(> t)
Intercept	1.02	0.13	7.70	< 0.001
$\log_{10}(\text{Body mass})$	-4.62	0.62	-7.47	< 0.001
$\log_{10}(\text{Body mass})^2$	0.97	0.41	2.35	0.02
$\log_{10}(\text{Body mass})^3$	-0.96	0.33	-2.90	0.004
$\log_{10}(\text{Lifespan proxy})$	0.89	0.51	1.74	0.08
$\log_{10}(\text{Lifespan proxy})^2$	-1.27	0.39	-3.27	0.001
$\log_{10}(\text{Lifespan proxy})^3$	-0.29	0.33	-0.88	0.38
$\log_{10}(\text{Litter/clutch size})$	0.84	0.68	1.24	0.22
$\log_{10}(\text{Litter/clutch size})^2$	-0.34	0.45	-0.76	0.45
$\log_{10}(\text{Litter/clutch size})^3$	0.26	0.35	0.74	0.46
$\log_{10}(\text{Range area})$	-31.88	0.31	-101.48	< 0.001
$\log_{10}(\text{Range area})^2$	5.15	0.27	19.03	< 0.001
$\log_{10}(\text{Range area})^3$	-1.97	0.26	-7.53	< 0.001
square-root(Habitat breadth)	0.56	0.35	1.59	0.11
square-root(Habitat breadth) ²	-0.67	0.27	-2.49	0.01
square-root(Habitat breadth) ³	0.05	0.26	0.21	0.83
square-root(Diet breadth)	-0.33	0.37	-0.90	0.37
square-root(Diet breadth) ²	-0.02	0.27	-0.08	0.94
square-root(Diet breadth) ³	0.31	0.26	1.22	0.22
Specialisation: Natural habitat specialist	0.10	0.01	8.50	< 0.001
Diel activity: Non-nocturnal	-0.02	0.01	-1.88	0.06
Primary diet: Omnivore	-0.03	0.03	-0.92	0.36
Primary diet: Vertebrates	-0.02	0.02	-1.05	0.30

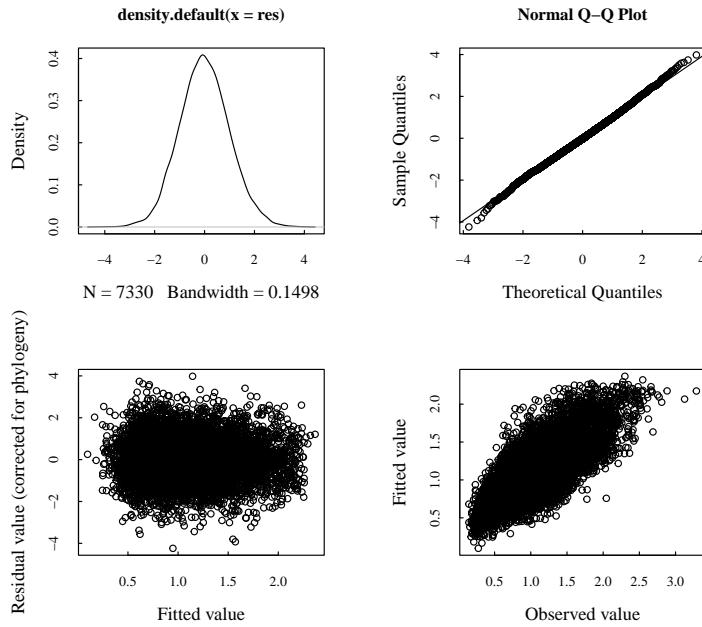


Figure S16: Diagnostic plots for the PGLS model fitted on reptiles, investigating associations between species-level ecological characteristics and climate-change sensitivity. We excluded species whose range area was $\leq 100 \text{ km}^2$ (the sample size was n=7,330).

S9.2 Summaries for the PGLS models fitted on all species (including those with range area $\leq 100 \text{ km}^2$)

Table S18: Summary for the PGLS model fitted on amphibians, investigating associations between species-level ecological characteristics and climate-change sensitivity. We included species whose range area was $\leq 100 \text{ km}^2$ (the sample size was n=5,197).

	Estimate	Std. Error	t value	Pr(> t)
Intercept	1.23	0.20	6.01	< 0.001
$\log_{10}(\text{Body mass})$	-1.70	0.74	-2.29	0.02
$\log_{10}(\text{Body mass})^2$	-0.56	0.52	-1.09	0.28
$\log_{10}(\text{Body mass})^3$	0.12	0.44	0.27	0.78
$\log_{10}(\text{Lifespan proxy})$	0.46	0.72	0.64	0.52
$\log_{10}(\text{Lifespan proxy})^2$	0.21	0.53	0.40	0.69
$\log_{10}(\text{Lifespan proxy})^3$	0.50	0.43	1.17	0.24
$\log_{10}(\text{Litter/clutch size})$	0.95	0.64	1.48	0.14
$\log_{10}(\text{Litter/clutch size})^2$	-0.34	0.45	-0.74	0.46
$\log_{10}(\text{Litter/clutch size})^3$	-1.07	0.38	-2.79	0.01
$\log_{10}(\text{Range area})$	-28.60	0.42	-67.90	< 0.001
$\log_{10}(\text{Range area})^2$	-3.57	0.37	-9.76	< 0.001
$\log_{10}(\text{Range area})^3$	8.78	0.34	25.56	< 0.001
square-root(Habitat breadth)	-2.55	0.52	-4.89	< 0.001
square-root(Habitat breadth) ²	0.46	0.38	1.21	0.23
square-root(Habitat breadth) ³	-1.26	0.35	-3.62	< 0.001
Specialisation: Natural habitat specialist	0.02	0.01	1.55	0.12
Diel activity: Non-nocturnal	0.03	0.01	2.46	0.01
Primary diet: Omnivore	0.001	0.04	0.02	0.99
Primary diet: Plants/seeds	-0.12	0.15	-0.80	0.42
Primary diet: Vertebrates	0.20	0.18	1.14	0.26

Table S19: Summary for the PGLS model fitted on birds, investigating associations between species-level ecological characteristics and climate-change sensitivity. We included species whose range area was $\leq 100 \text{ km}^2$ (the sample size was n=10,340).

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	0.64	0.08	7.62	< 0.001
$\log_{10}(\text{Body mass})$	2.07	0.70	2.94	0.003
$\log_{10}(\text{Body mass})^2$	0.26	0.45	0.57	0.57
$\log_{10}(\text{Body mass})^3$	-0.15	0.39	-0.39	0.70
$\log_{10}(\text{Lifespan proxy})$	-0.47	0.62	-0.76	0.45
$\log_{10}(\text{Lifespan proxy})^2$	-0.67	0.41	-1.64	0.10
$\log_{10}(\text{Lifespan proxy})^3$	-0.07	0.29	-0.24	0.81
$\log_{10}(\text{Litter/clutch size})$	3.25	0.41	7.84	< 0.001
$\log_{10}(\text{Litter/clutch size})^2$	-0.64	0.35	-1.82	0.07
$\log_{10}(\text{Litter/clutch size})^3$	-0.30	0.29	-1.04	0.30
$\log_{10}(\text{Range area})$	-33.48	0.29	-116.96	< 0.001
$\log_{10}(\text{Range area})^2$	6.56	0.25	25.72	< 0.001
$\log_{10}(\text{Range area})^3$	1.56	0.24	6.39	< 0.001
square-root(Habitat breadth)	1.01	0.35	2.88	0.004
square-root(Habitat breadth) ²	-1.22	0.26	-4.75	< 0.001
square-root(Habitat breadth) ³	-0.38	0.24	-1.59	0.11
square-root(Diet breadth)	-0.44	0.32	-1.38	0.17
square-root(Diet breadth) ²	-0.27	0.26	-1.04	0.30
square-root(Diet breadth) ³	0.43	0.25	1.73	0.08
Specialisation: Natural habitat specialist	0.06	0.01	9.75	< 0.001
Diel activity: Non-nocturnal	-0.01	0.04	-0.35	0.73
Primary diet: Invertebrates	0.06	0.01	6.03	< 0.001
Primary diet: Omnivore	0.03	0.01	2.61	0.01
Primary diet: Plants/seeds	0.07	0.01	5.13	< 0.001
Primary diet: Vertebrates	0.02	0.02	0.85	0.39

Table S20: Summary for the PGLS model fitted on mammals, investigating associations between species-level ecological characteristics and climate-change sensitivity. We included species whose range area was $\leq 100 \text{ km}^2$ (the sample size was n=4,841).

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	0.86	0.15	5.68	< 0.001
$\log_{10}(\text{Body mass})$	-4.57	0.97	-4.69	< 0.001
$\log_{10}(\text{Body mass})^2$	0.37	0.59	0.62	0.53
$\log_{10}(\text{Body mass})^3$	0.67	0.47	1.44	0.15
$\log_{10}(\text{Lifespan proxy})$	1.50	1.09	1.38	0.17
$\log_{10}(\text{Lifespan proxy})^2$	-0.93	0.52	-1.79	0.07
$\log_{10}(\text{Lifespan proxy})^3$	-0.05	0.46	-0.11	0.91
$\log_{10}(\text{Litter/clutch size})$	3.28	0.75	4.35	< 0.001
$\log_{10}(\text{Litter/clutch size})^2$	0.19	0.44	0.43	0.67
$\log_{10}(\text{Litter/clutch size})^3$	-0.35	0.35	-0.99	0.32
$\log_{10}(\text{Range area})$	-26.32	0.34	-78.41	< 0.001
$\log_{10}(\text{Range area})^2$	2.16	0.30	7.26	< 0.001
$\log_{10}(\text{Range area})^3$	3.80	0.29	13.28	< 0.001
square-root(Habitat breadth)	-1.24	0.37	-3.31	0.001
square-root(Habitat breadth) ²	0.10	0.29	0.34	0.73
square-root(Habitat breadth) ³	-0.15	0.28	-0.55	0.58
square-root(Diet breadth)	-1.57	0.50	-3.12	0.002
square-root(Diet breadth) ²	0.34	0.38	0.88	0.38
square-root(Diet breadth) ³	-0.03	0.36	-0.09	0.93
Specialisation: Natural habitat specialist	0.04	0.01	3.55	< 0.001
Diel activity: Non-nocturnal	-0.001	0.02	-0.07	0.95
Primary diet: Invertebrates	-0.03	0.03	-0.97	0.33
Primary diet: Omnivore	-0.03	0.03	-0.96	0.34
Primary diet: Plants/seeds	0.02	0.03	0.83	0.41
Primary diet: Vertebrates	-0.06	0.04	-1.59	0.11

Table S21: Summary for the PGLS model fitted on reptiles, investigating associations between species-level ecological characteristics and climate-change sensitivity. We included species whose range area was $\leq 100 \text{ km}^2$ (the sample size was $n=7,945$).

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	1.08	0.14	7.79	< 0.001
$\log_{10}(\text{Body mass})$	-4.04	0.72	-5.64	< 0.001
$\log_{10}(\text{Body mass})^2$	0.22	0.48	0.46	0.64
$\log_{10}(\text{Body mass})^3$	-0.84	0.39	-2.19	0.03
$\log_{10}(\text{Lifespan proxy})$	0.72	0.61	1.18	0.24
$\log_{10}(\text{Lifespan proxy})^2$	-1.42	0.46	-3.07	0.002
$\log_{10}(\text{Lifespan proxy})^3$	-0.30	0.39	-0.77	0.44
$\log_{10}(\text{Litter/clutch size})$	1.23	0.80	1.54	0.12
$\log_{10}(\text{Litter/clutch size})^2$	-0.21	0.53	-0.40	0.69
$\log_{10}(\text{Litter/clutch size})^3$	-0.23	0.41	-0.56	0.58
$\log_{10}(\text{Range area})$	-32.18	0.37	-87.40	< 0.001
$\log_{10}(\text{Range area})^2$	-6.51	0.32	-20.05	< 0.001
$\log_{10}(\text{Range area})^3$	9.84	0.31	31.28	< 0.001
square-root(Habitat breadth)	1.05	0.42	2.53	0.01
square-root(Habitat breadth) ²	-0.91	0.32	-2.83	0.005
square-root(Habitat breadth) ³	-0.06	0.30	-0.20	0.84
square-root(Diet breadth)	-0.52	0.43	-1.20	0.23
square-root(Diet breadth) ²	0.02	0.32	0.07	0.95
square-root(Diet breadth) ³	0.24	0.31	0.77	0.44
Specialisation: Natural habitat specialist	0.10	0.01	7.07	< 0.001
Diel activity: Non-nocturnal	-0.02	0.01	-1.76	0.08
Primary diet: Omnivore	-0.01	0.04	-0.18	0.85
Primary diet: Vertebrates	-0.01	0.02	-0.64	0.52

S9.3 Models estimates for the PGLS models fitted on all species, against models estimates for the PGLS models fitted on species whose range area >100 km²

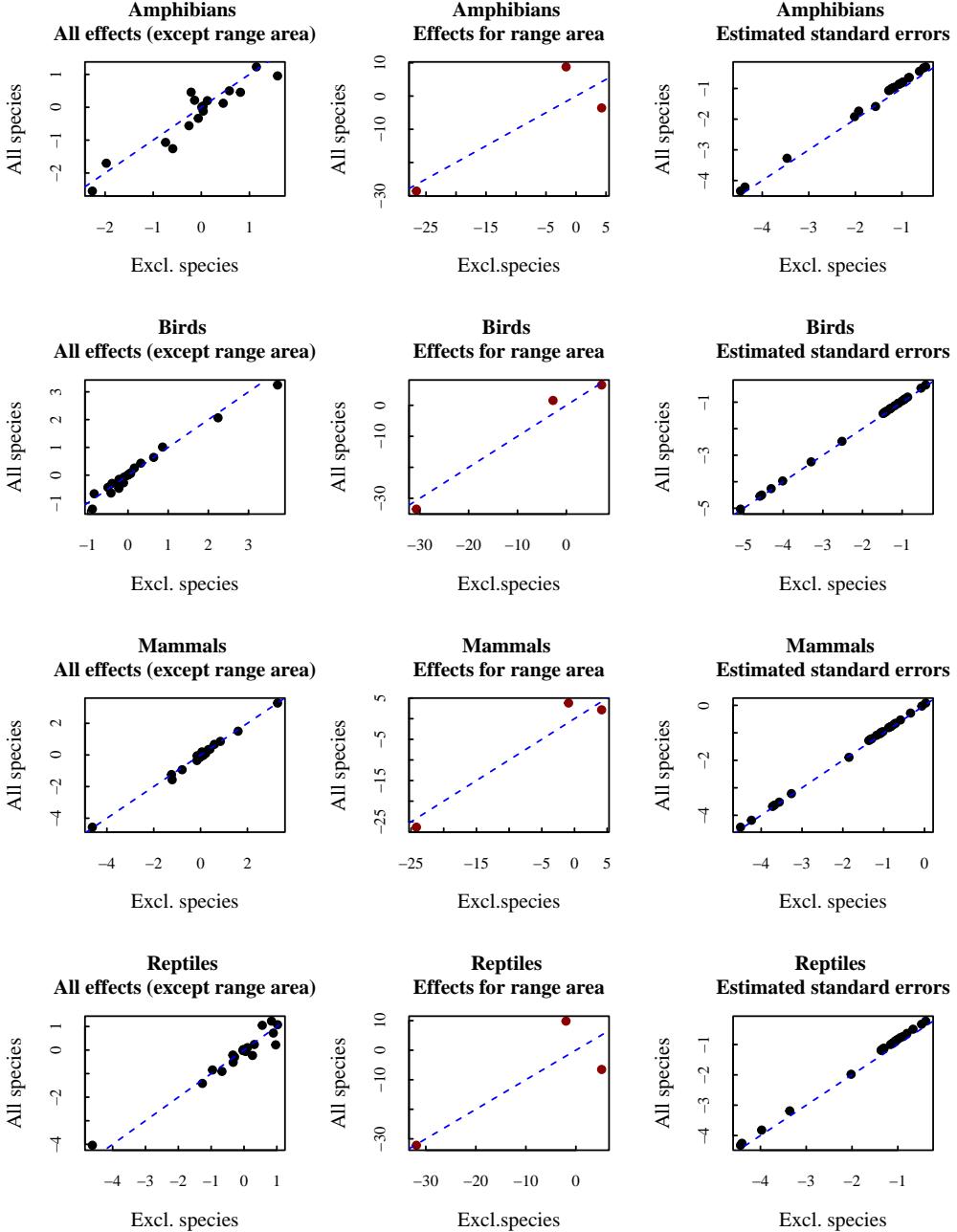


Figure S17: Estimates for the PGLS models looking at the effects of the species-level ecological characteristics on species climate-change sensitivity, either fitted on all species (y-axis), or fitted on the species whose range area was >100 km² (x-axis). Overall, the estimates from both sets of models were congruent, except for those estimated for geographical range area (we show the effects for range area separately from the effects of other predictors). Across all classes, the relationship between sensitivity and geographical range area was reversed between the two sets of models. We found that sensitivity was positively affected by geographical range area when including all species, likely because of the underestimation of climate-change sensitivity for the most narrow-ranging species when working with a resolution of 5 km² (see Figure S6). The dashed line is the identity line ($y=x$).

S10 Validations on complete trait data subsets

S10.1 Synthesis table

Table S22: Summary of the effects of the ecological characteristics (except for diet) on (a) species responses to disturbed land uses (within land-use type effects) and on (b) species climate-change sensitivity, for each class of terrestrial vertebrates, from the models fitted on empirical trait values (excluding all imputed values). The symbol - indicates where a characteristic has a significant negative effect on occurrence probability within a disturbed land use, or where the characteristic renders species significantly more sensitive to climate change. A + indicates a significantly positive effect of a characteristic on occurrence probability in a land-use type, or significantly lower sensitivity to climate change. For the land-use effects, we report "within land-use type effects" here, that is, within a disturbed land use whether there were significant differences in occurrence probability among species with different trait values. These effects were derived from the interactive terms of the full, all-predictor models.

(a) "Within land-use type" effects of the species-level characteristics on occurrence probability - <=> more sensitive; + <=> less sensitive																Predictors				(b) Climate-change sensitivity: - <=> more sensitive + <=> less sensitive				
0	-	0	0	0	-	0	0	0	-	-	+	+	-	0	NA	More narrowly-distributed				Habitat affinity	-	-	-	(-)
0	-	0	0	-	-	0	0	-	-	0	-	-	-	0	NA	Smaller habitat breadth				Specialisation	0	-	-	-
-	-	0	0	0	-	0	0	-	-	-	+	0	-	0	NA	Natural habitat specialist				Resource use	0	-	0	-
0	+	+	0	+	+	(+)	+	0	+	+	0	0	0	0	NA	Non-nocturnal				Life-history	0	0	0	0
-	0	(+)	0	(-)	0	+	0	-	0	(+)	+	-	-	0	NA	Narrower diet breadth				+	0	0	0	0
NA	(+)	+	NA	NA	+	+	NA	NA	-	0	NA	NA	+	0	NA	Smaller body mass				+	(+)	-	0	0
NA	0	0	-	NA	-	(-)	0	NA	-	(-)	0	NA	0	-	NA	Smaller litter/clutch size				+	+	+	0	0
NA	0	0	-	NA	(-)	0	0	NA	+	0	+	NA	-	0	NA	Shorter-lived				(+)	0	0	0	0

S10.2 Predicted occurrence probability as a function of land use, land-use intensity, diet and their interactions, in each class (validation on empirical trait data subsets (excluding imputed trait values) using partial models)

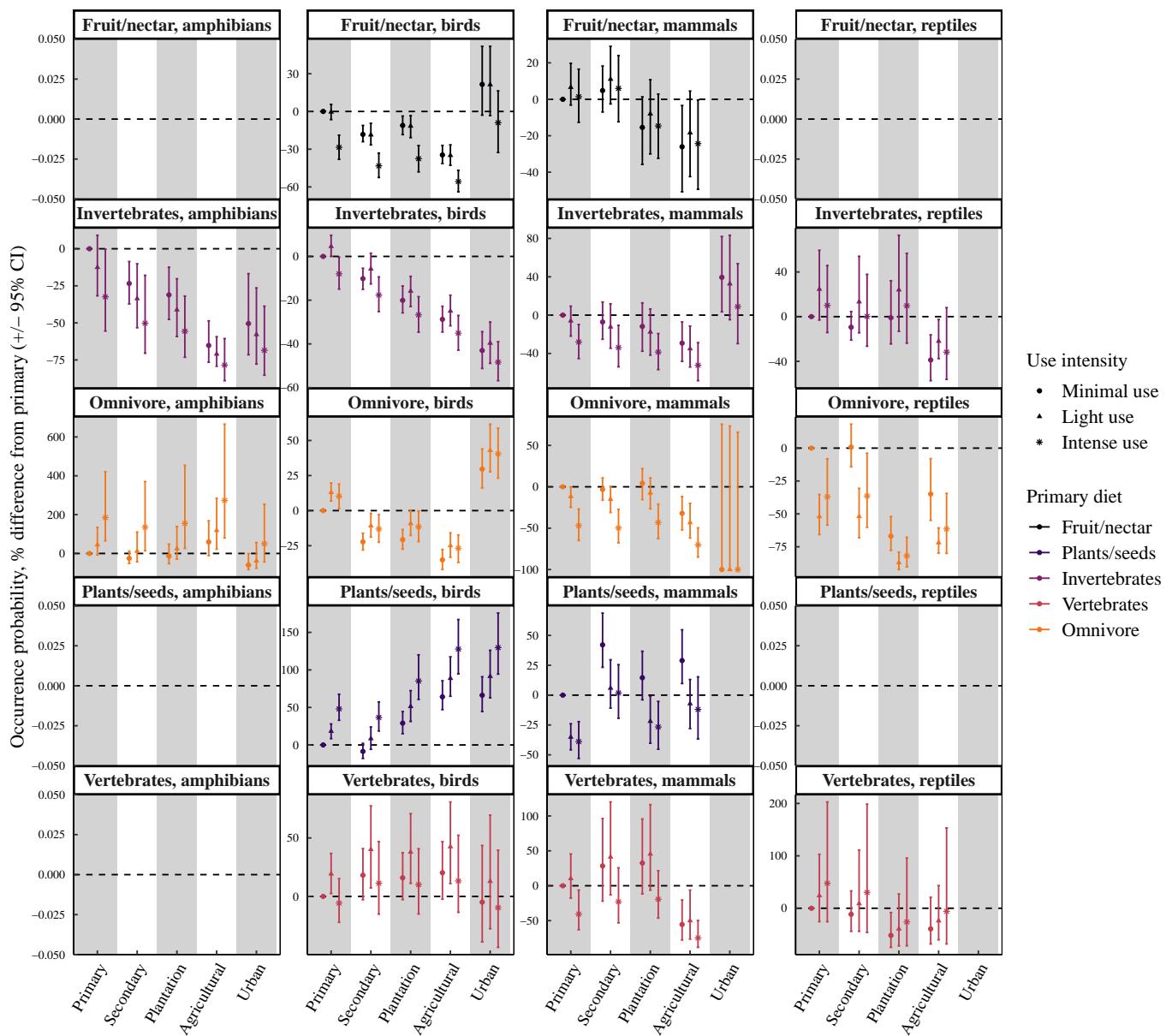


Figure S18: Predicted occurrence probability as a function of land use, land-use intensity, diet and their interactions in each class. The predictions were obtained from the partial models fitted in each class for diet, estimated using empirical trait data subsets (i.e., excluding imputed trait values). Empty plots are drawn where there were no data for a diet category in given class (e.g., amphibian fruit/nectar eaters). Effects could not be estimated for urban reptiles, as well as for urban vertebrate, fruit/nectar and plant/seed eaters for mammals because there were no sampled species. The predictions are rescaled with reference to minimally-used primary vegetation. Primary: primary vegetation; Secondary: secondary vegetation; plantation: plantation forest; agricultural: cropland and pasture.

S10.3 PGLS climate-change sensitivity models, validations on empirical trait data subsets: PGLS model summaries

Table S23: Summary for the PGLS model fitted on amphibians, *using the empirical trait data subset (i.e., excluding imputed trait values)*, looking at the effects of the species-level ecological characteristics on climate-change sensitivity.

	Estimate	Std. Error	t value	Pr(> t)
Intercept	1.825	0.342	5.344	< 0.001
$\log_{10}(\text{Body mass})$	-0.030	0.035	-0.875	0.385
$\log_{10}(\text{Lifespan proxy})$	0.180	0.103	1.742	0.086
$\log_{10}(\text{Litter/clutch size})$	0.052	0.032	1.639	0.106
$\log_{10}(\text{Range area})$	-0.261	0.024	-10.888	< 0.001
square-root(Habitat breadth)	-0.032	0.030	-1.078	0.285
square-root(Diet breadth)	-0.068	0.107	-0.635	0.527
Specialisation: Natural habitat specialist	-0.006	0.059	-0.095	0.925
Diel activity: Non-nocturnal	-0.009	0.044	-0.205	0.839

Table S24: Summary for the PGLS model fitted on birds, *using the empirical trait data subset (i.e., excluding imputed traits values)*, looking at the effects of the species-level ecological characteristics on climate-change sensitivity.

	Estimate	Std. Error	t value	Pr(> t)
Intercept	1.551	0.143	10.875	< 0.001
$\log_{10}(\text{Body mass})$	0.020	0.011	1.759	0.079
$\log_{10}(\text{Lifespan proxy})$	0.047	0.036	1.308	0.191
$\log_{10}(\text{Litter/clutch size})$	0.212	0.022	9.487	< 0.001
$\log_{10}(\text{Range area})$	-0.230	0.003	-73.130	< 0.001
square-root(Habitat breadth)	-0.011	0.005	-2.319	0.020
square-root(Diet breadth)	0.015	0.011	1.319	0.187
Specialisation: Natural habitat specialist	0.044	0.007	6.586	< 0.001
Diel activity: Non-nocturnal	0.001	0.058	0.019	0.984
Primary diet: Invertebrates	0.047	0.014	3.330	0.001
Primary diet: Omnivore	0.016	0.014	1.144	0.253
Primary diet: Plants/seeds	0.048	0.016	2.993	0.003
Primary diet: Vertebrates	-0.005	0.022	-0.247	0.805

Table S25: Summary for the PGLS model fitted on mammals, using the empirical trait data subset (i.e., excluding imputed trait values), looking at the effects of the species-level ecological characteristics on climate-change sensitivity.

	Estimate	Std. Error	t value	Pr(> t)
Intercept	2.194	0.187	11.705	< 0.001
$\log_{10}(\text{Body mass})$	-0.047	0.012	-3.865	< 0.001
$\log_{10}(\text{Lifespan proxy})$	0.065	0.046	1.416	0.157
$\log_{10}(\text{Litter/clutch size})$	0.147	0.034	4.293	< 0.001
$\log_{10}(\text{Range area})$	-0.269	0.005	-54.621	< 0.001
square-root(Habitat breadth)	-0.042	0.010	-4.320	< 0.001
square-root(Diet breadth)	-0.030	0.020	-1.487	0.137
Specialisation: Natural habitat specialist	0.016	0.013	1.235	0.217
Diel activity: Non-nocturnal	0.012	0.015	0.792	0.428
Primary diet: Invertebrates	-0.038	0.031	-1.220	0.223
Primary diet: Omnivores	-0.031	0.027	-1.148	0.251
Primary diet: Plants/seeds	0.034	0.027	1.298	0.195
Primary diet: Vertebrates	-0.039	0.040	-0.995	0.320

Table S26: Summary for the PGLS model fitted on reptiles, using the empirical trait data subset (i.e., excluding imputed trait values), looking at the effects of the species-level ecological characteristics on climate-change sensitivity.

	Estimate	Std. Error	t value	Pr(> t)
Intercept	1.269	0.522	2.433	0.018
$\log_{10}(\text{Body mass})$	-0.033	0.058	-0.570	0.571
$\log_{10}(\text{Lifespan proxy})$	0.015	0.130	0.119	0.905
$\log_{10}(\text{Litter/clutch size})$	0.095	0.128	0.739	0.463
$\log_{10}(\text{Range area})$	-0.093	0.049	-1.878	0.066
square-root(Habitat breadth)	-0.094	0.045	-2.097	0.041
square-root(Diet breadth)	0.067	0.112	0.595	0.554
Specialisation: Natural habitat specialist	0.221	0.075	2.936	0.005
Diel activity: Non-nocturnal	-0.118	0.080	-1.486	0.143

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