Ecography

ECOG-03149
El-Gabbas, A. and Dormann, C. F. 2017. Improved species-occurrence predictions in data-poor regions: using large-scale data and bias correction with down-weighted Poisson regression and Maxent. – Ecography doi: 10.1111/ecog.03149

Supplementary material

Appendix 1: Supplementary figures and tables

Table A1: The estimated optimum combination of Maxent's feature classes (FC) and Regularization Multiplier (RM) for each species and bias model type.

Combinations with highest mean testing-AUC on 5-folds spatial-block cross-validation were selected. All the analyses were performed using modified code from the ENMeval package in R (Muscarella *et al.*, 2014). See main text for more information.

	Species	***Environment-only***		***Accessibility***		***Effort***	
		FC [a]	**RM** [b]	**FC**	**RM**	**FC**	**RM**
1	*Asellia tridens*	LQ	0.5	LQ	3	LQHPT	3
2	*Barbastella leucomelas*	LQ	0.5	LQ	0.5	LQHPT	3.5
3	*Eptesicus bottae*	LQ	0.5	LQHP	2	LQHP	4
4	*Hypsugo ariel*	LQHPT	2	LQHP	2	L	1
5	*Nycteris thebaica*	LQ	4	LQ	3.5	LQ	4
6	*Nycticeinops schlieffeni*	LQ	1	LQ	0.5	LQ	1.5
7	*Otonycteris hemprichii*	LQ	0.5	LQ	1	LQHPT	0.5
8	*Pipistrellus deserti*	L	2.5	LQ	0.5	L	3
9	*Pipistrellus kuhlii*	LQ	0.5	LQ	0.5	LQ	0.5
10	*Pipistrellus rueppellii*	LQ	4	LQ	0.5	LQ	4
11	*Plecotus christii*	LQ	0.5	LQHPT	0.5	LQHPT	0.5
12	*Rhinolophus clivosus*	LQHP	2.5	LQHPT	2	LQHPT	2.5
13	*Rhinolophus hipposideros*	LQ	0.5	LQ	0.5	LQ	0.5
14	*Rhinolophus mehelyi*	LQ	0.5	LQ	0.5	LQ	2.5
15	*Rhinopoma cystops*	LQ	1	LQ	1.5	LQHPT	1
16	*Rhinopoma microphyllum*	LQ	1.5	LQ	2	LQHPT	4
17	*Rousettus aegyptiacus*	LQHPT	2.5	LQ	3	LQ	4
18	*Tadarida aegyptiaca*	LQ	3	LQ	4	LQ	3
19	*Tadarida teniotis*	LQ	0.5	LQ	0.5	LQ	0.5
20	*Taphozous nudiventris*	LQ	1	L	2	LQHPT	2.5
21	*Taphozous perforatus*	LQ	1.5	LQ	1	LQ	1.5

[a] Feature classes (FC): **L** linear; **Q** quadratic; **H** hinge; **P** product; and **T** threshold. For more details see Elith *et al.* 2011.

[b] RM is a global multiplier to all individual regularization values; for more details see the main text and Muscarella *et al.* (2014).

Table A2: Estimated best α-values to run the elastic-net models (DWPR approach) for different species and bias models. For details, see main text.

Species		*Environment-only*	*Accessibility*	*Efforts*
1	*Asellia tridens*	1 (LASSO)	1 (LASSO)	0 (RIDGE)
2	*Barbastella leucomelas*	1 (LASSO)	0.9	0.7
3	*Eptesicus bottae*	0.3	0.8	0.1
4	*Hypsugo ariel*	1 (LASSO)	1 (LASSO)	0.2
5	*Nycteris thebaica*	1 (LASSO)	0.1	0.5
6	*Nycticeinops schlieffeni*	1 (LASSO)	1 (LASSO)	0.6
7	*Otonycteris hemprichii*	1 (LASSO)	1 (LASSO)	0.2
8	*Pipistrellus deserti*	0 (RIDGE)	0.8	0 (RIDGE)
9	*Pipistrellus kuhlii*	0.8	0.2	0.9
10	*Pipistrellus rueppellii*	0 (RIDGE)	0 (RIDGE)	0 (RIDGE)
11	*Plecotus christii*	0.6	0.1	0.5
12	*Rhinolophus clivosus*	0.1	0.1	0.2
13	*Rhinolophus hipposideros*	0.4	0.4	0.3
14	*Rhinolophus mehelyi*	1 (LASSO)	0.1	0.6
15	*Rhinopoma cystops*	1 (LASSO)	1 (LASSO)	0.6
16	*Rhinopoma microphyllum*	0.4	0.9	0.9
17	*Rousettus aegyptiacus*	0.7	1 (LASSO)	0.9
18	*Tadarida aegyptiaca*	1 (LASSO)	1 (LASSO)	0.9
19	*Tadarida teniotis*	0.5	0.4	0.7
20	*Taphozous nudiventris*	0.9	1 (LASSO)	0.8
21	*Taphozous perforatus*	0.1	1 (LASSO)	0.5

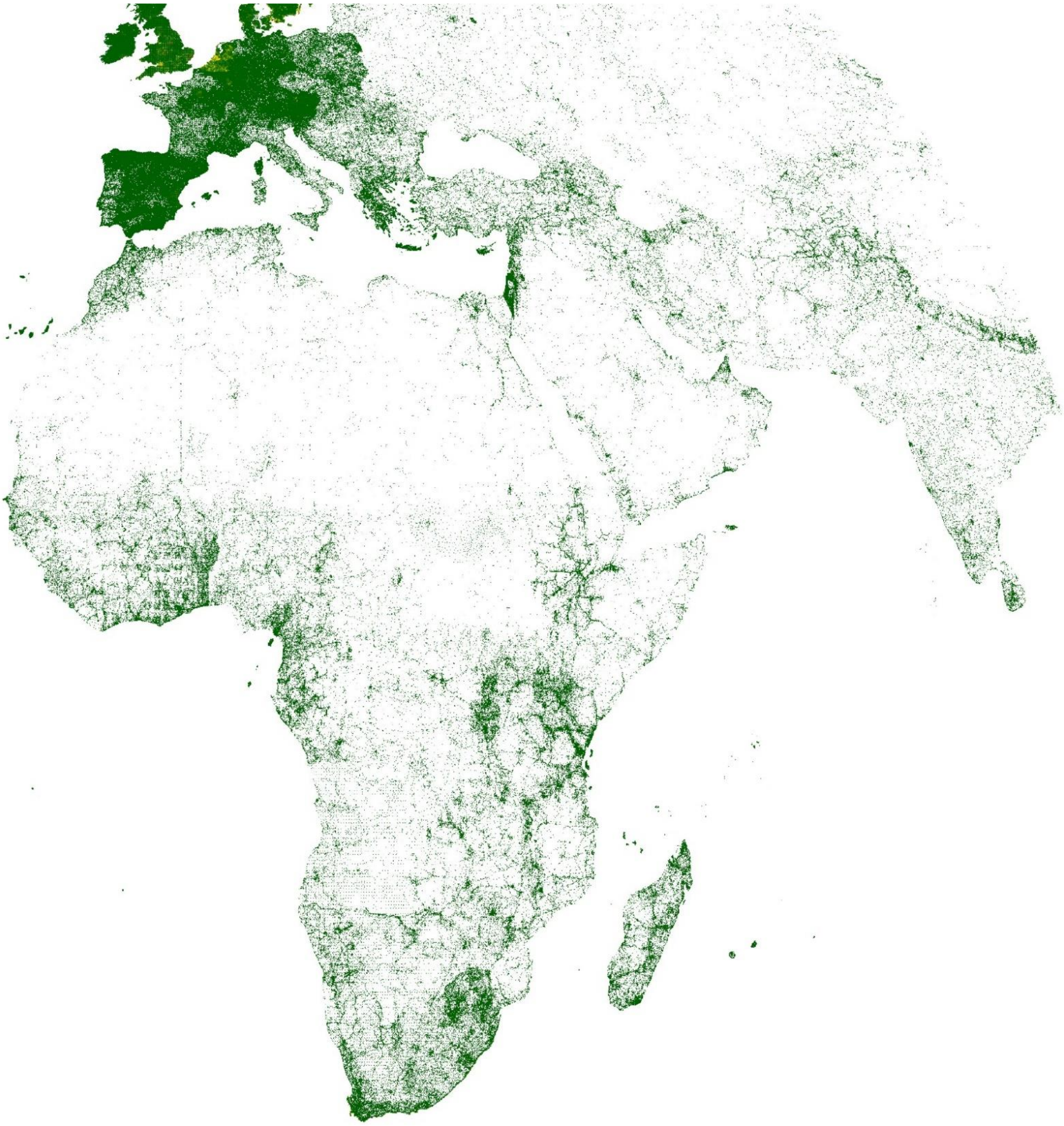


Fig. A1: Map of all non-marine GBIF-records. There are clear signs of sampling bias inherited in the GBIF database, disallowing the direct use of these records to run SDMs, unless action is taken to correct for sampling bias. GBIF-records are biased mainly towards Western Europe, with sparse locations across Africa, Asia, and Eastern Europe. Areas shown in white represent pixels without any records (the majority of North and central Africa, Arabia, and eastern Europe). Clearly errorneous records were excluded before plotting this map.

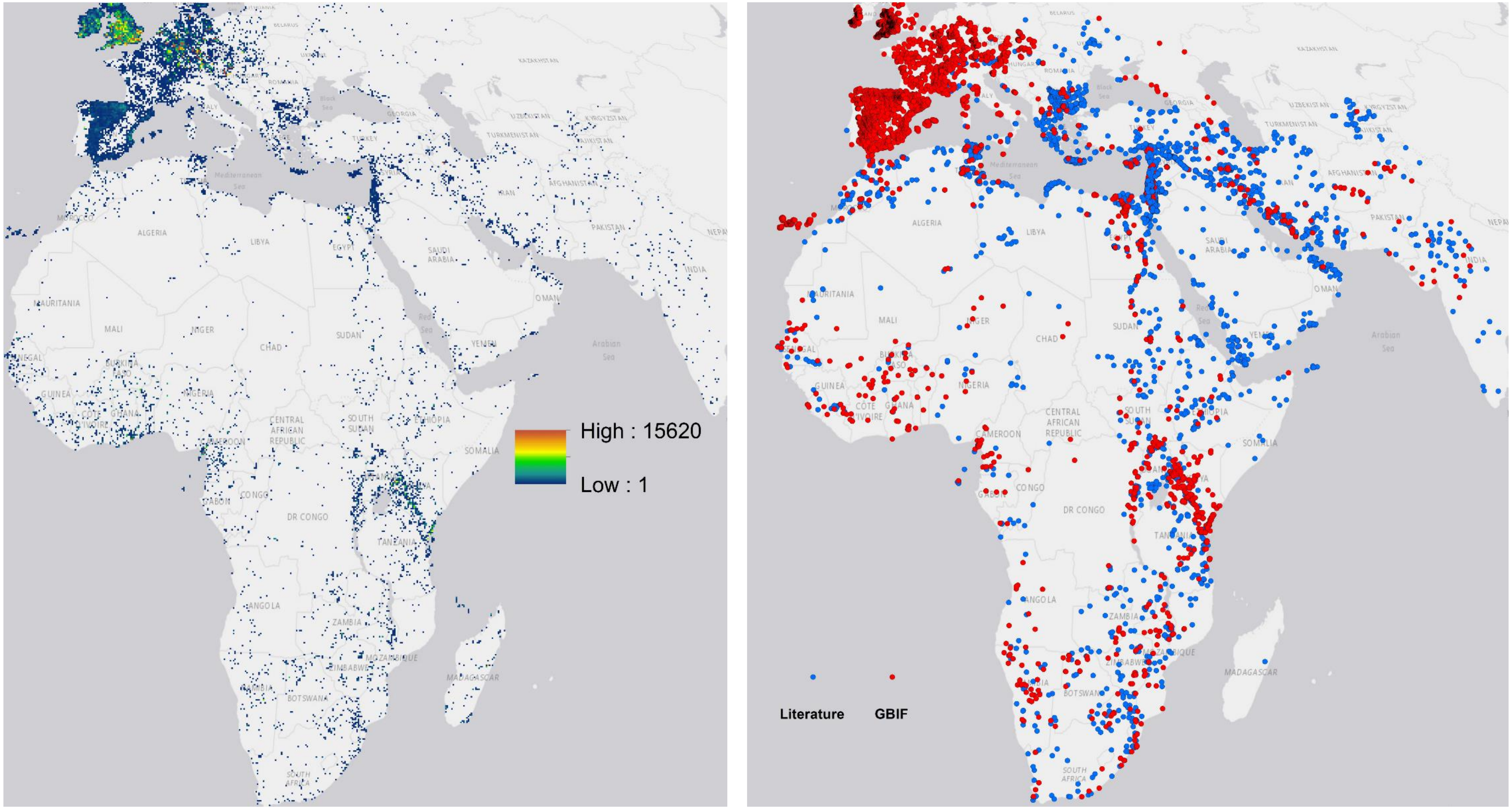


Fig. A2: Left: Map of all GBIF bat records (accessed date: April 2015) per a grid of 20 × 20 km^2.

Right: All records available of the study species, collected either from the literature (blue points) or GBIF (red points).

Both maps show large collection gaps.

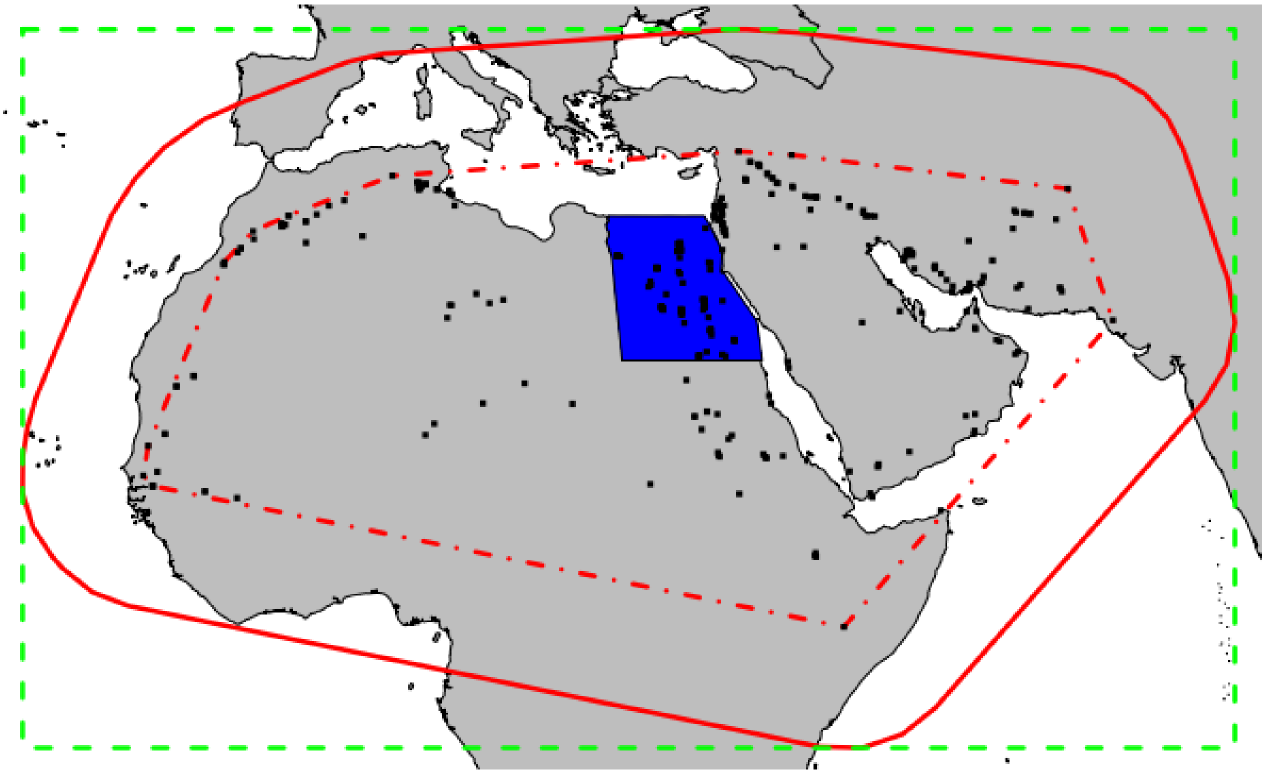


Fig. A3: Per-species study area: An example of how the 'per-species' study area was determined (here for *Asellia tridens*). The dashed red line indicates the species extent of occurrence (minimum convex polygon); the solid red line shows the buffer used (1000 km), and the dashed green line indicates the study area used.

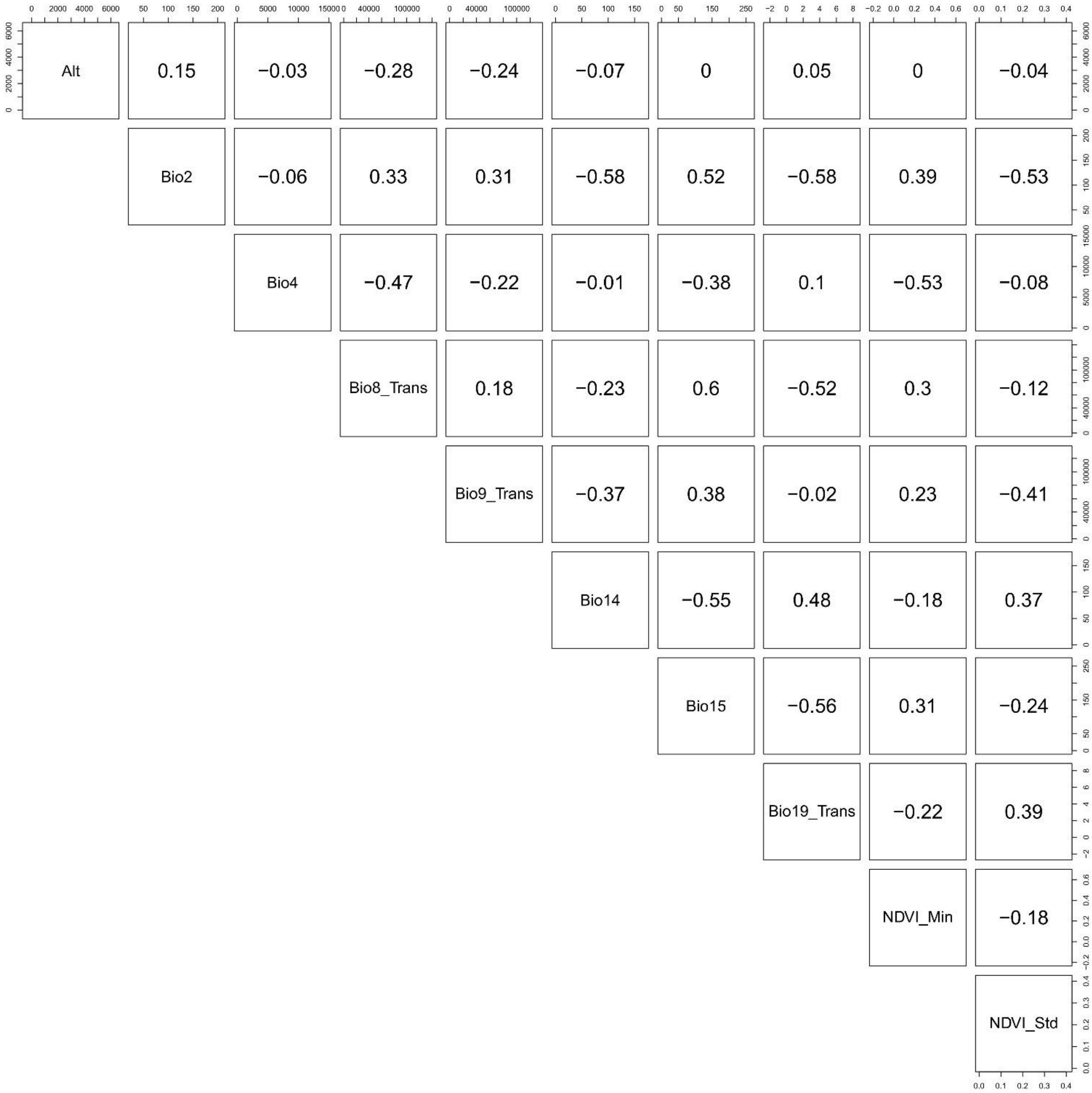


Fig. A4: Variables selection: Pearson correlation coefficient between each pair of the final covariates; see Appendix 3 for more information.

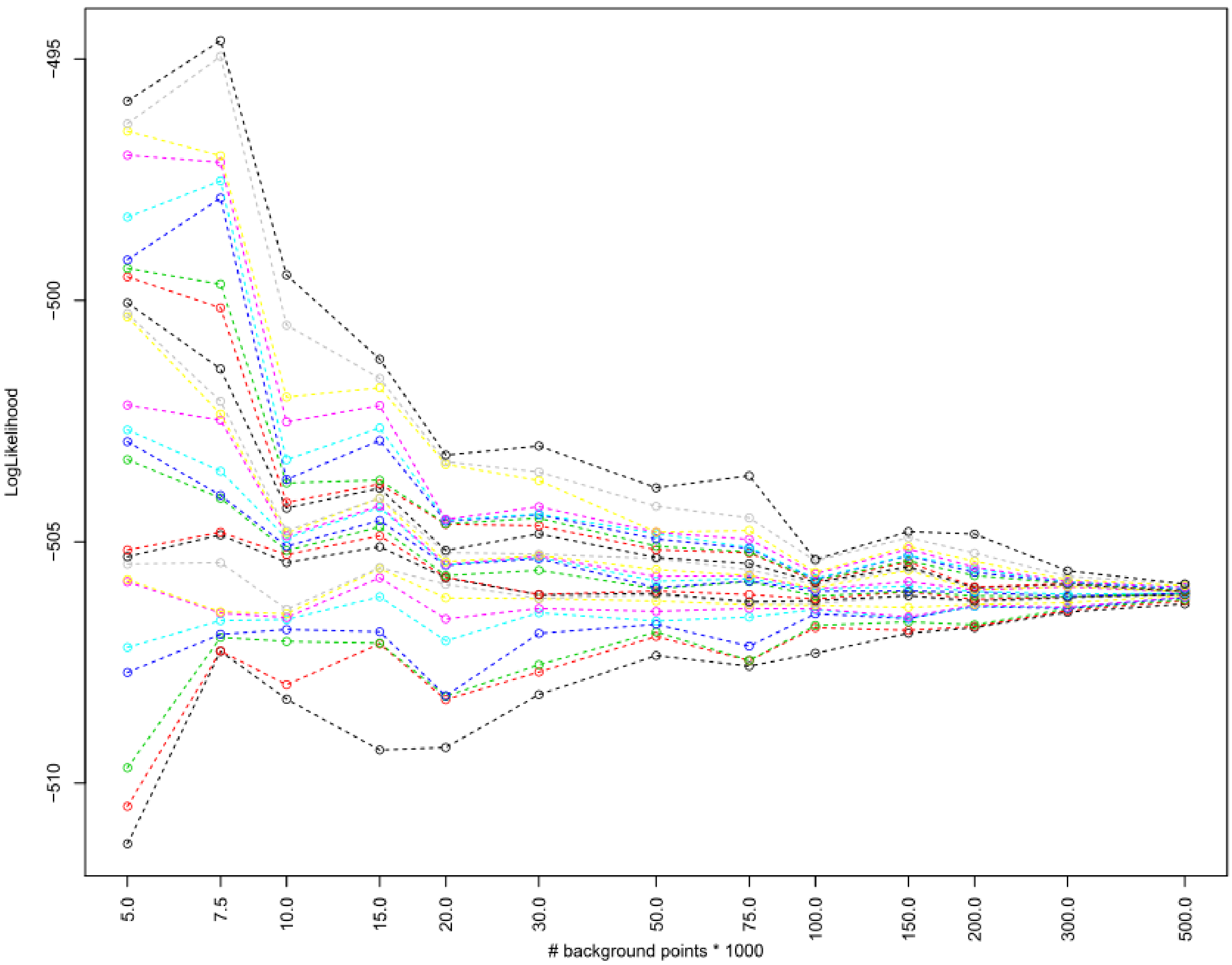


Fig A5: Per-species number of backgrounds: Objectively determining the adequate number of background ‘quadrature’ points to be used in GLM and elastic-net models (see main text and Renner *et al*., 2015). DWPR-GLM models (for each species, here: *Asellia tridens*) were repeated 25 times (each time, with a different random sample from the background) with progressively increase the number of background points (from 5000 to 500,000); and for each model, the log-likelihood value is calculated and plotted. The number of backgrounds at which the likelihood converges (i.e. no much benefit of using a higher number of backgrounds) is, visually, selected to run the final models. Here, no much improvement in the log-likelihood beyond 300,000 background points (out of 557,800 total available background points) and so we used it for this species.

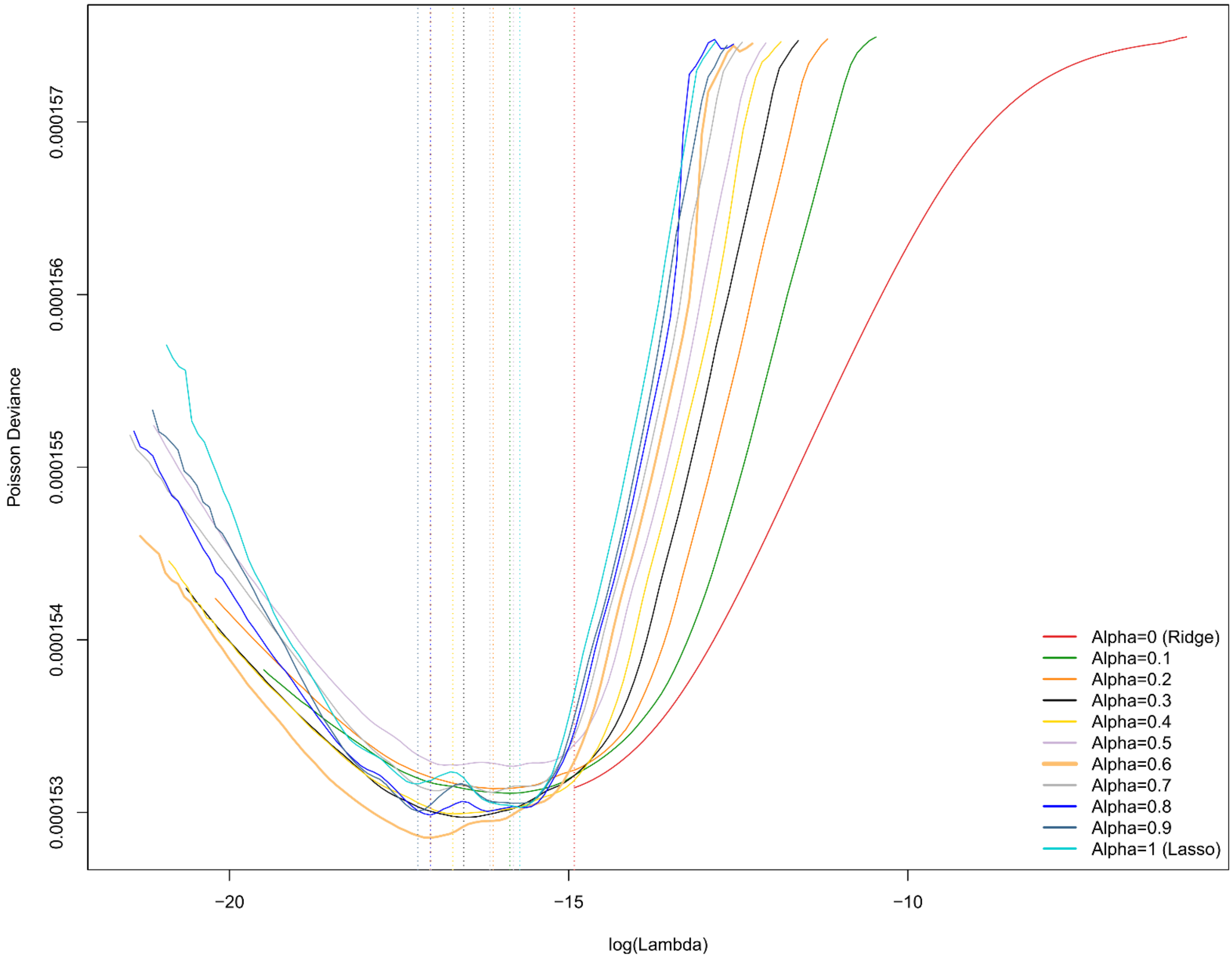


Fig. A6: Determining the best α-value to run the elastic-net model for *Nycticeinops schlieffeni* (effort model). Eleven α-values ranging from zero (ridge) to one (lasso), with an increment of 0.1, were used to run 11 models on cross-validation. For each value of α, glmnet ran many models on a range of λ-values (estimated from the data; x-axis) and measure the mean cross-validation error (cvm) (here: Poisson deviance; y-axis). The λvalue with the lowest cvm is used further while predicting (vertical dotted lines, with colours correspond to the α-value used). Here, an α-value of 0.6 is shown to have the lowest cvm and so used further. For more details, see Table A2 and the main text.

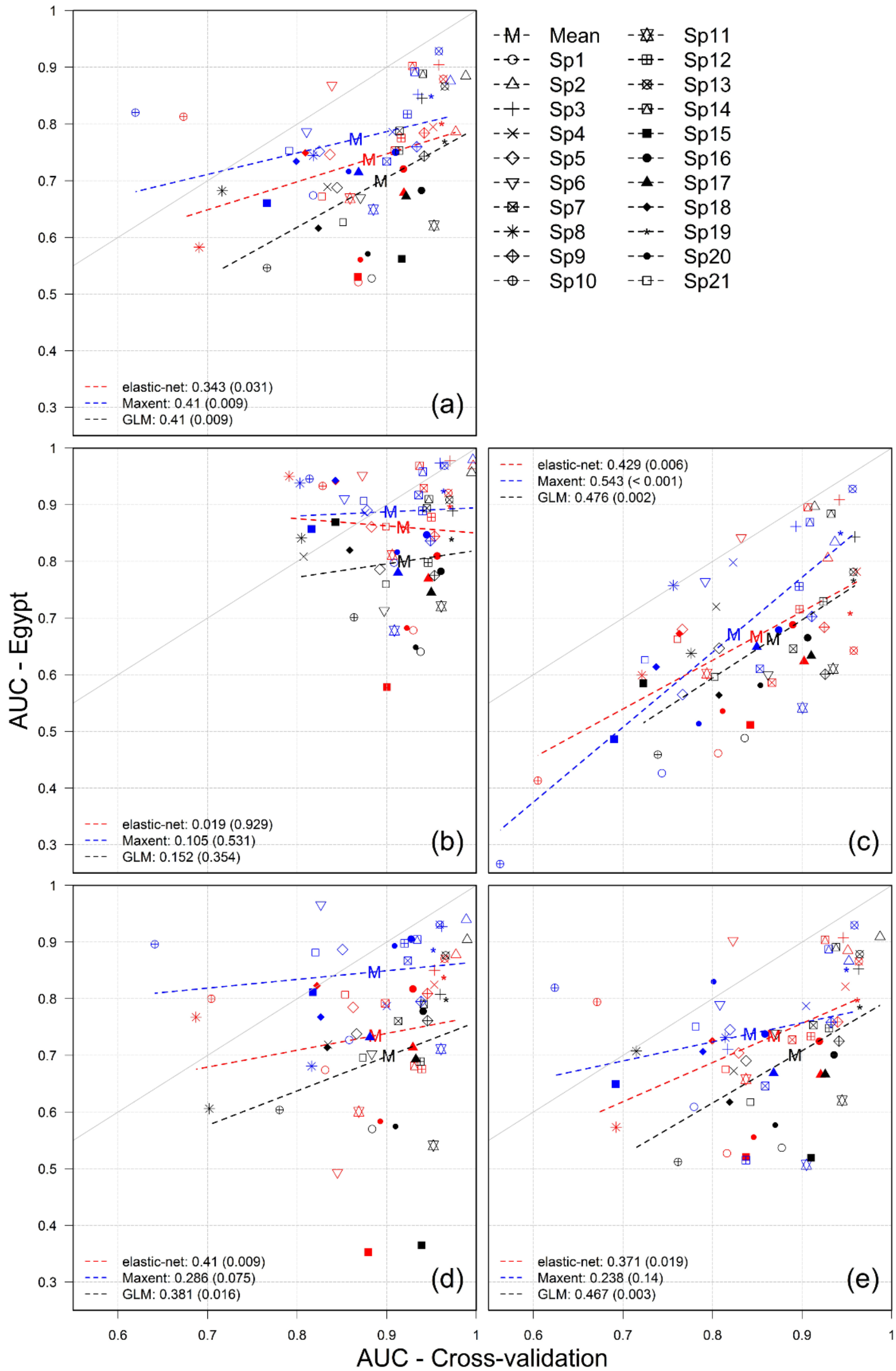


Fig. A7: Kendall's correlation between (per-species and modelling algorithm) mean AUC evaluated on spatial-block cross-validation and independent evaluation in Egypt. Each point represents the mean of 100 AUC values, with different symbols for each species. Colours represent different modelling algorithm used. 'M' indicates the overall mean for each modelling algorithm. Panel (a) shows the correlation for the environment-only models (no bias correction). Panels (b-c) represent the accessibility model, without and with correcting for sampling bias, respectively. Panels (d-e) represent the effort model, without and with correcting for sampling bias, respectively. Kendall's correlation coefficients (and their p-values) are reported in each block. Grey solid line represents the equality line. AUC performed on cross-validation were, on average, higher than AUC in Egypt. However, there is moderate correlation between bias-free evaluations on either scale.

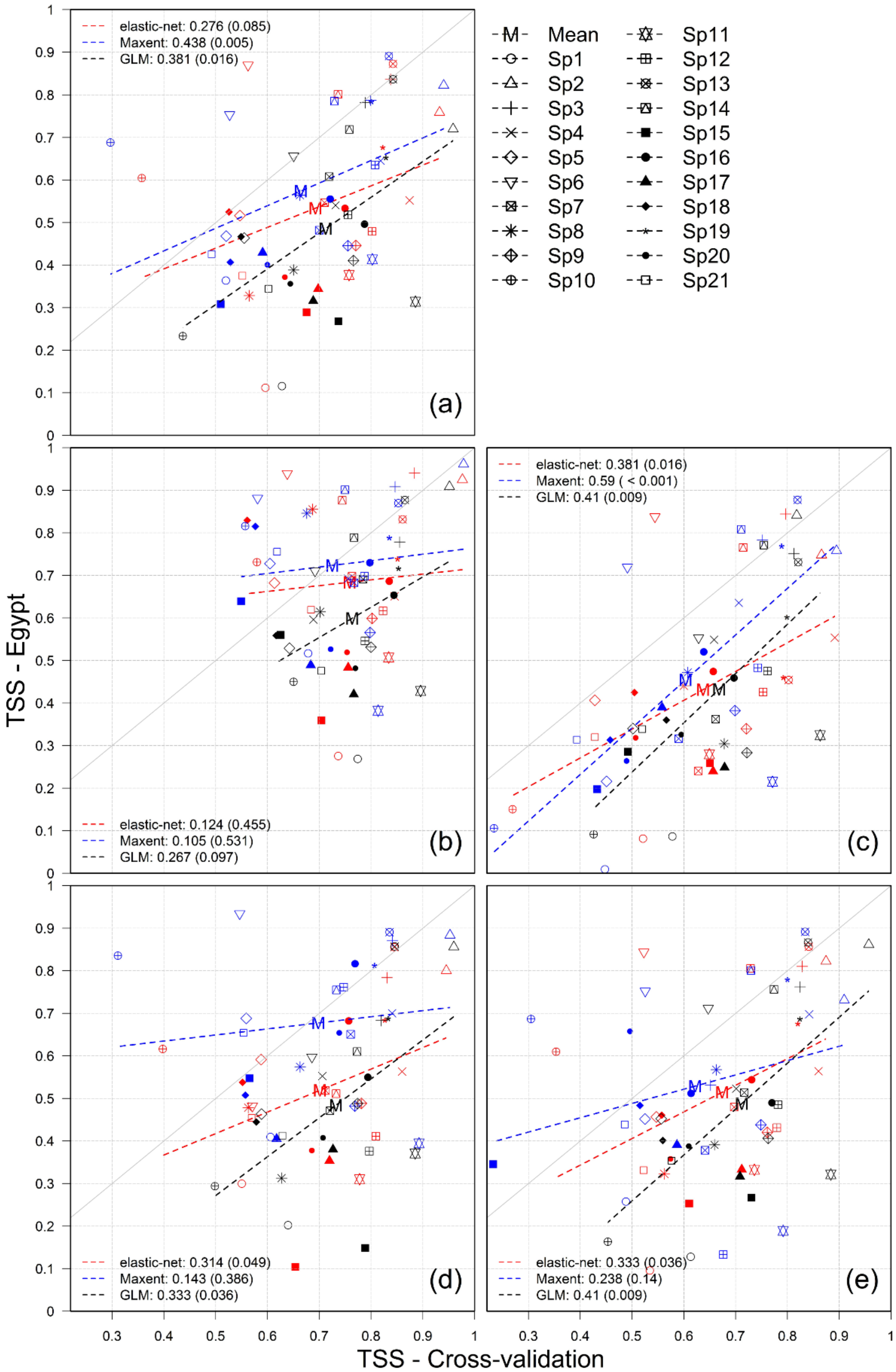


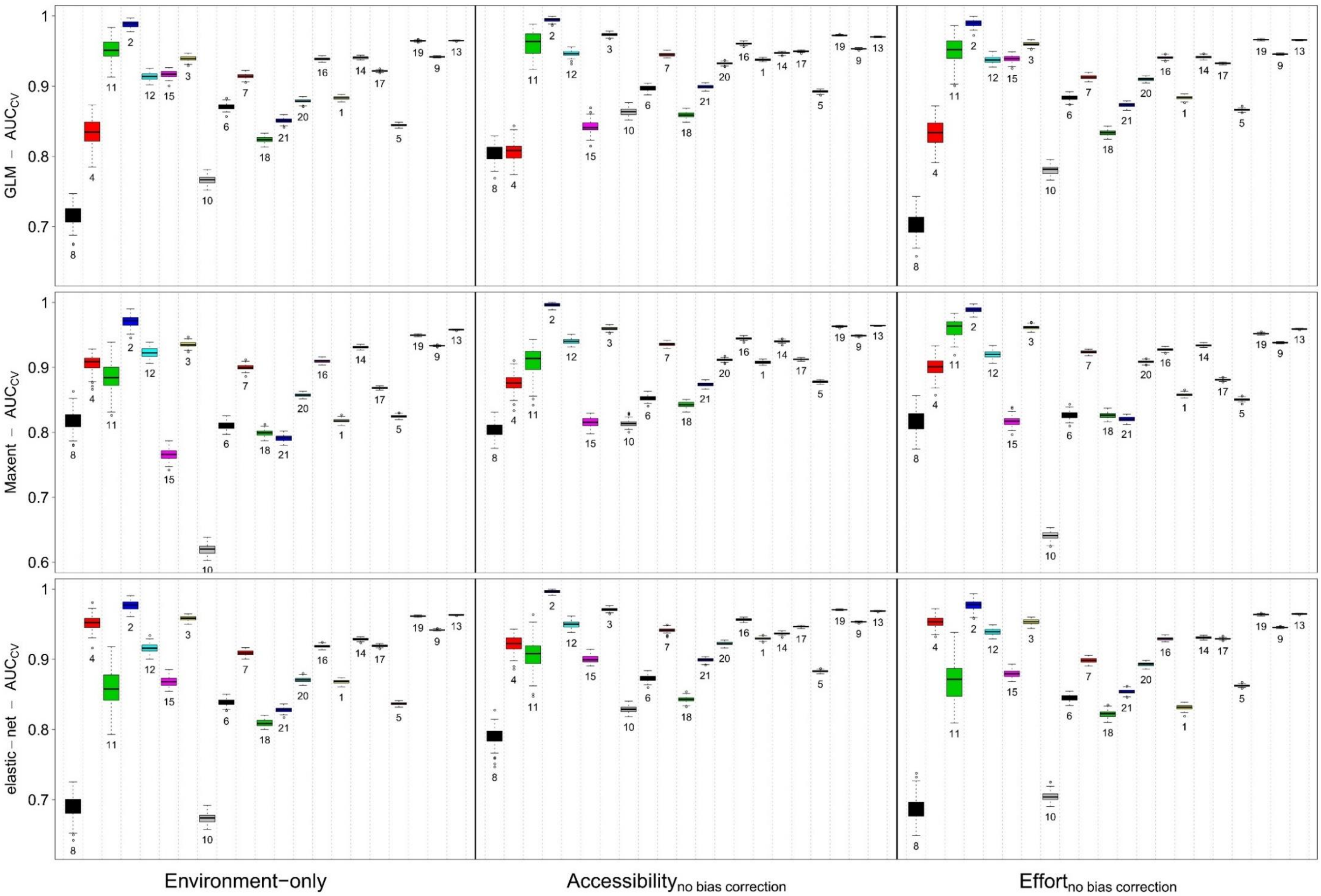
Fig. A8: Equivalent results to Fig. A7, for TSS evaluation.

Fig A9: Boxplots of the raw cross-validation evaluation (100 values) without (modelling evaluation; a and c) and with (bias-free evaluation; b and d) correction for sampling bias; either using AUC (a - b) or TSS (c - d); see Appendix 6 for more information. Horizontal panels show results for different modelling algorithm, while the vertical panels show different bias models.

Panels a & c show results for the environment-only model (without any bias manipulation) and bias-accounting models (accessibility and effort models) without correcting for sampling bias. However, panels b & d compare results for the environment-only model and bias-accounting models (accessibility and effort models) after correcting for sampling bias (see main text; for effort models, plots show evaluations either conditioning the predictions on a value of zero or the maximum relative sampling effort of training presences). Species are in ascending order according to their number of occupied pixels at cross-validation scale (with numbers represent the species; see Table 1 for full species names).

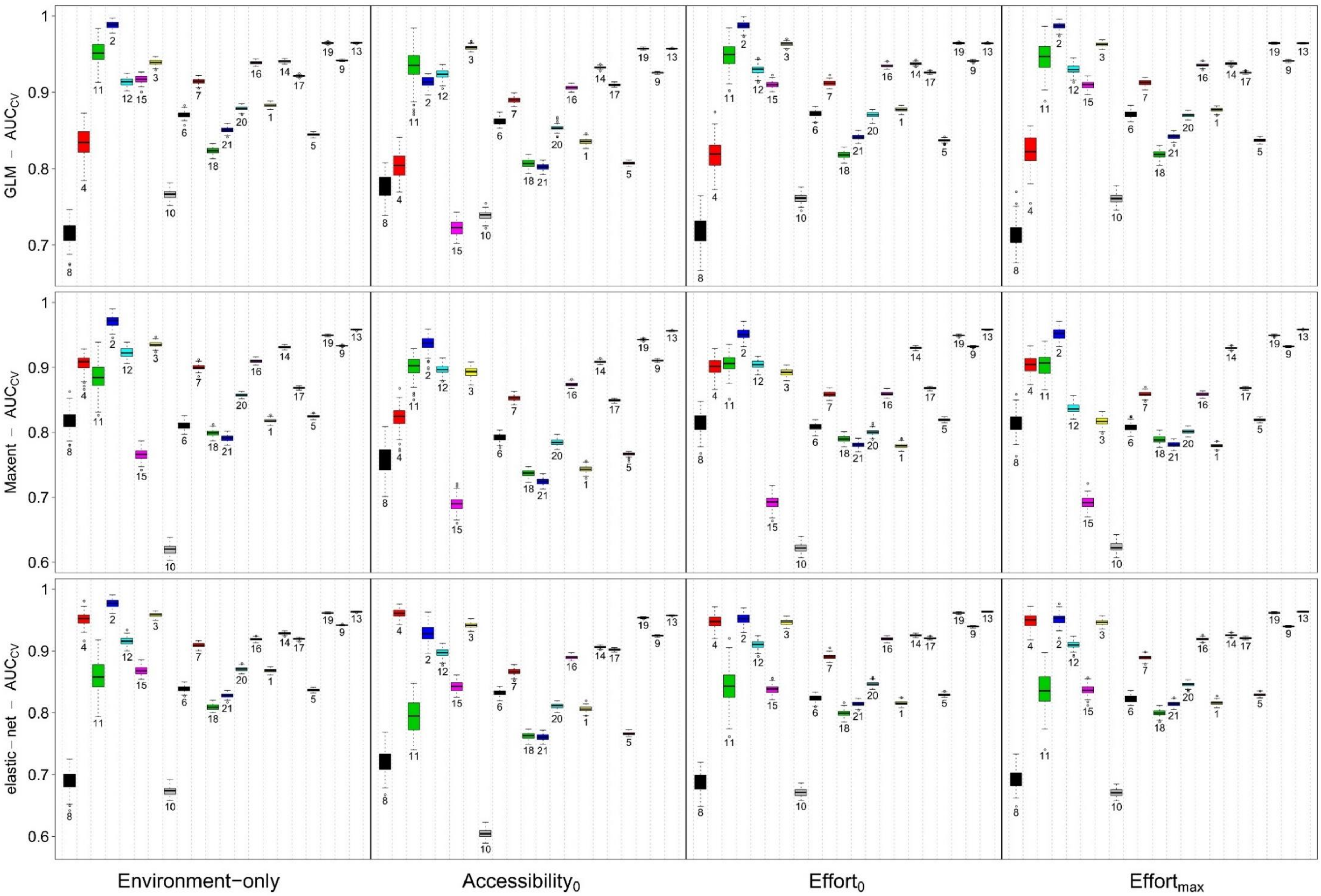
Fig. A10: Similar to Fig. A9, but showing results of independent evaluation in Egypt. Evaluation metrics are calculated in Egypt using mean predictions (of 5-folds cross-validation) in Egypt along with entirely independent species records from Egypt (not used to run any of the models). Species are in ascending order according to their number of occupied pixels in Egypt (with numbers represent the species; see Table 1 for full species names).

Fig. A11: Species mean TSS calculated either on cross-validation (a - b) or in Egypt (c - d), either without (modelling evaluation; a & c) or with (bias-free evaluation; b & d) sampling bias correction (for details, see Appendix 6). Each species is represented by different symbols (similar to those shown in Fig. A7; numbers represent species used, see Table 1). Red lines indicate the overall mean TSS at each modelling algorithm and bias models applied.



GLM − AUC_CV
Maxent − AUC_CV
elastic−net − AUC_CV
Environment−only
Accessibility no bias correction
Effort no bias correction

Fig. A9 (a)



GLM - AUC_CV
Maxent - AUC_CV
elastic-net - AUC_CV
Environment-only
Accessibility_0
Effort_0
Effort_max

Fig. A9 (b)

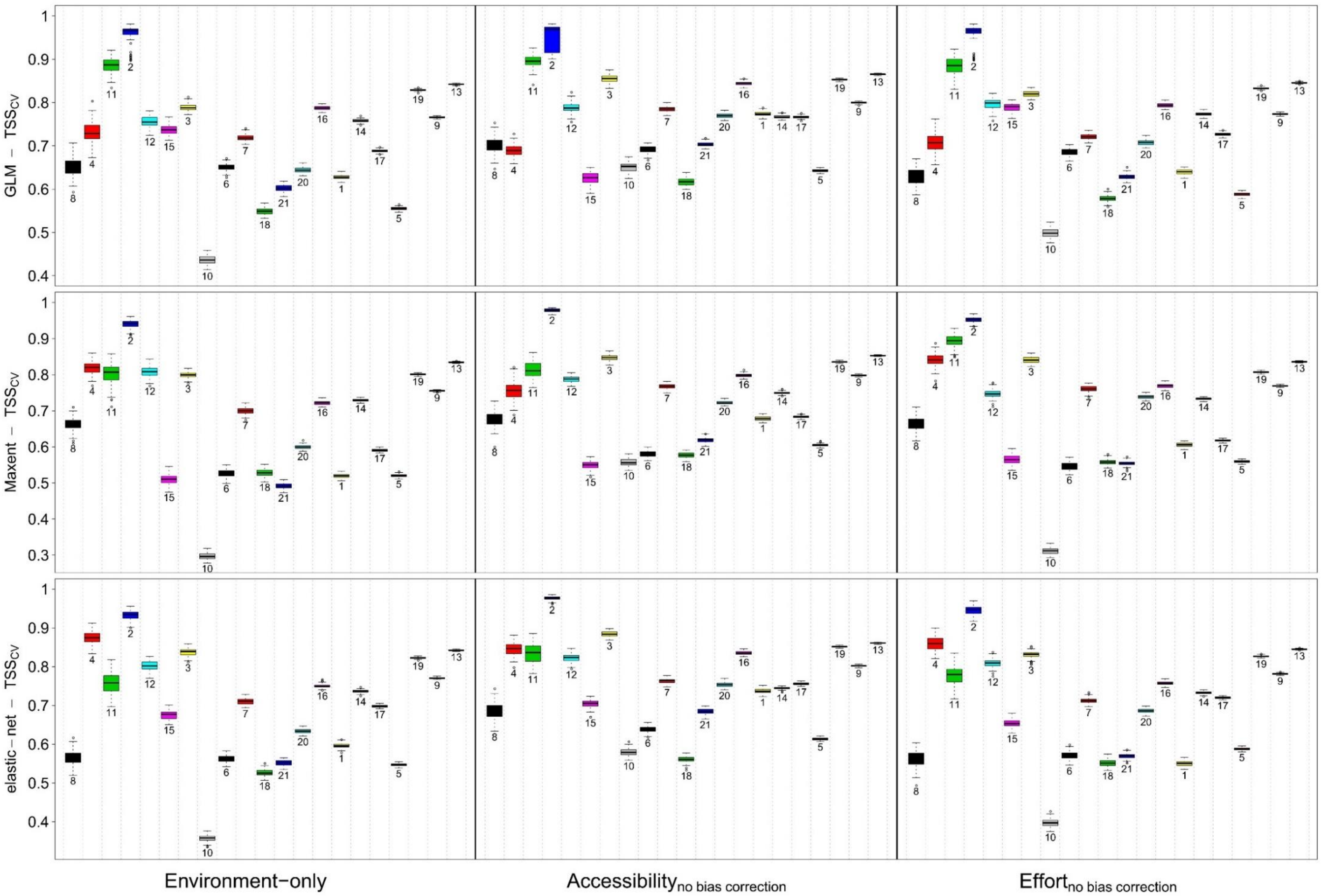

GLM − TSS$_{CV}$
Maxent − TSS$_{CV}$
elastic−net − TSS$_{CV}$
Environment−only
Accessibility$_{no\ bias\ correction}$
Effort$_{no\ bias\ correction}$

Fig. A9 (c)

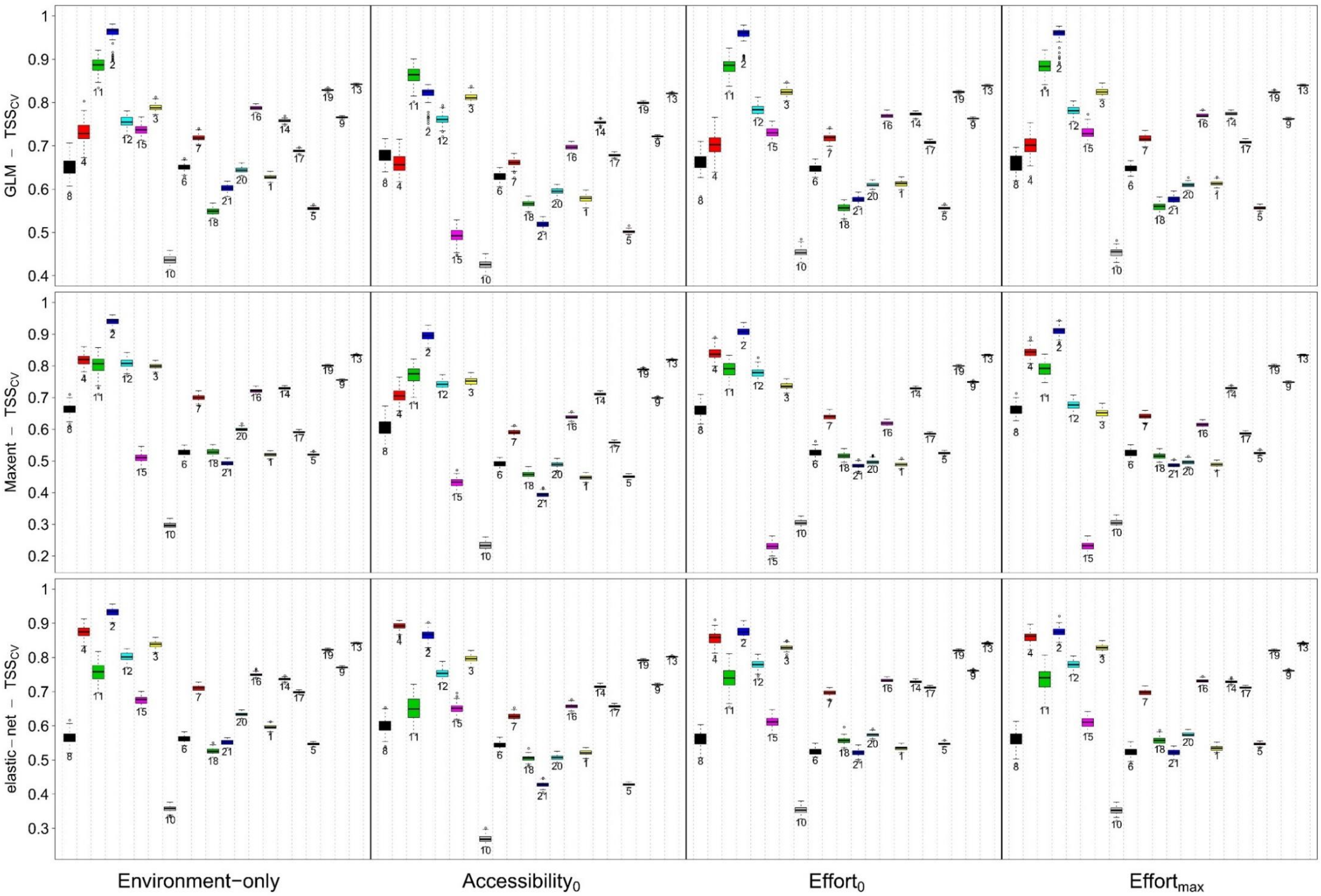

GLM − TSS$_{CV}$
Maxent − TSS$_{CV}$
elastic−net − TSS$_{CV}$
Environment−only
Accessibility$_0$
Effort$_0$
Effort$_{max}$

Fig. A9 (d)

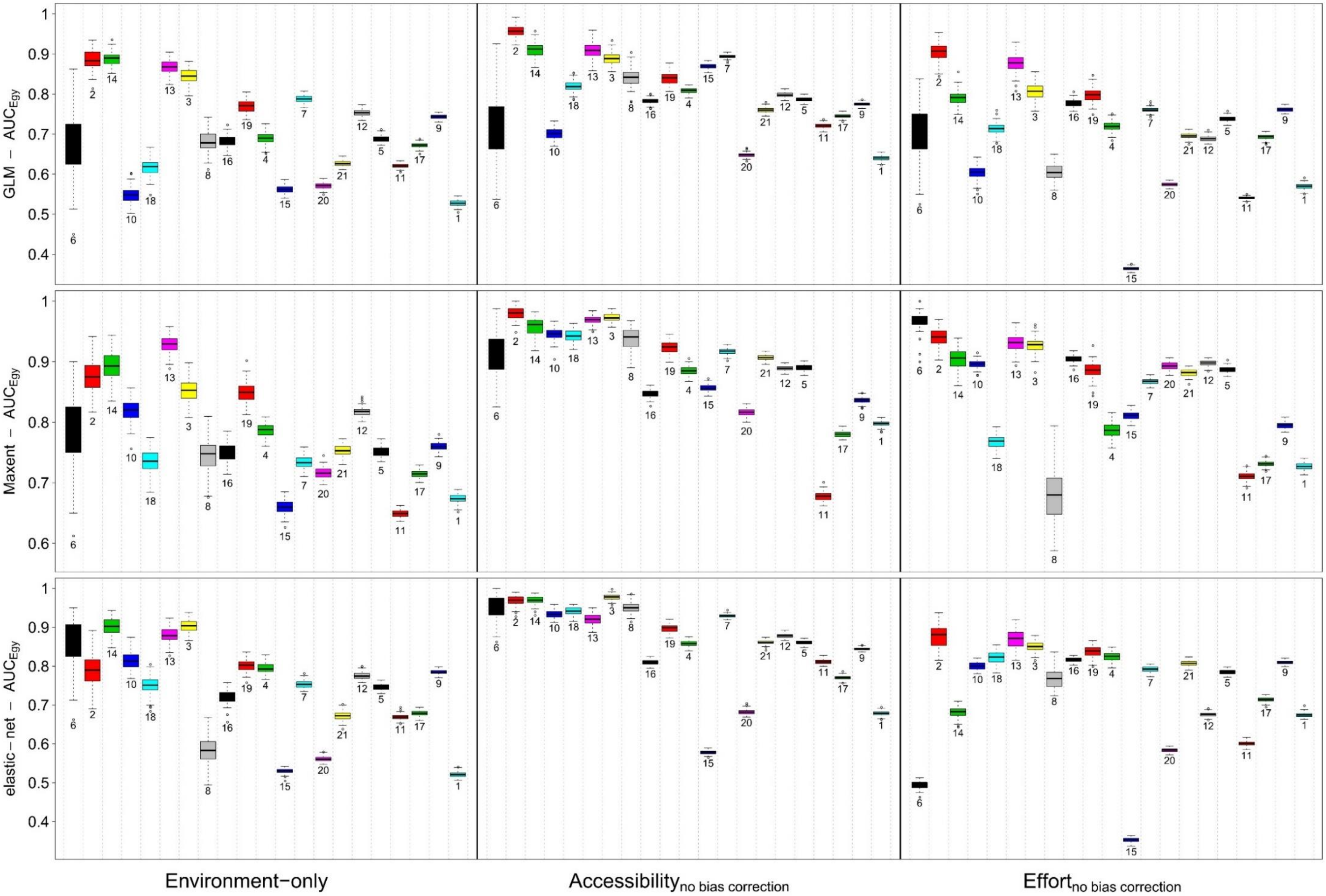

GLM - AUCEgy
Maxent - AUCEgy
elastic-net - AUCEgy
Environment-only
Accessibility no bias correction
Effort no bias correction

Fig. A10 (a)

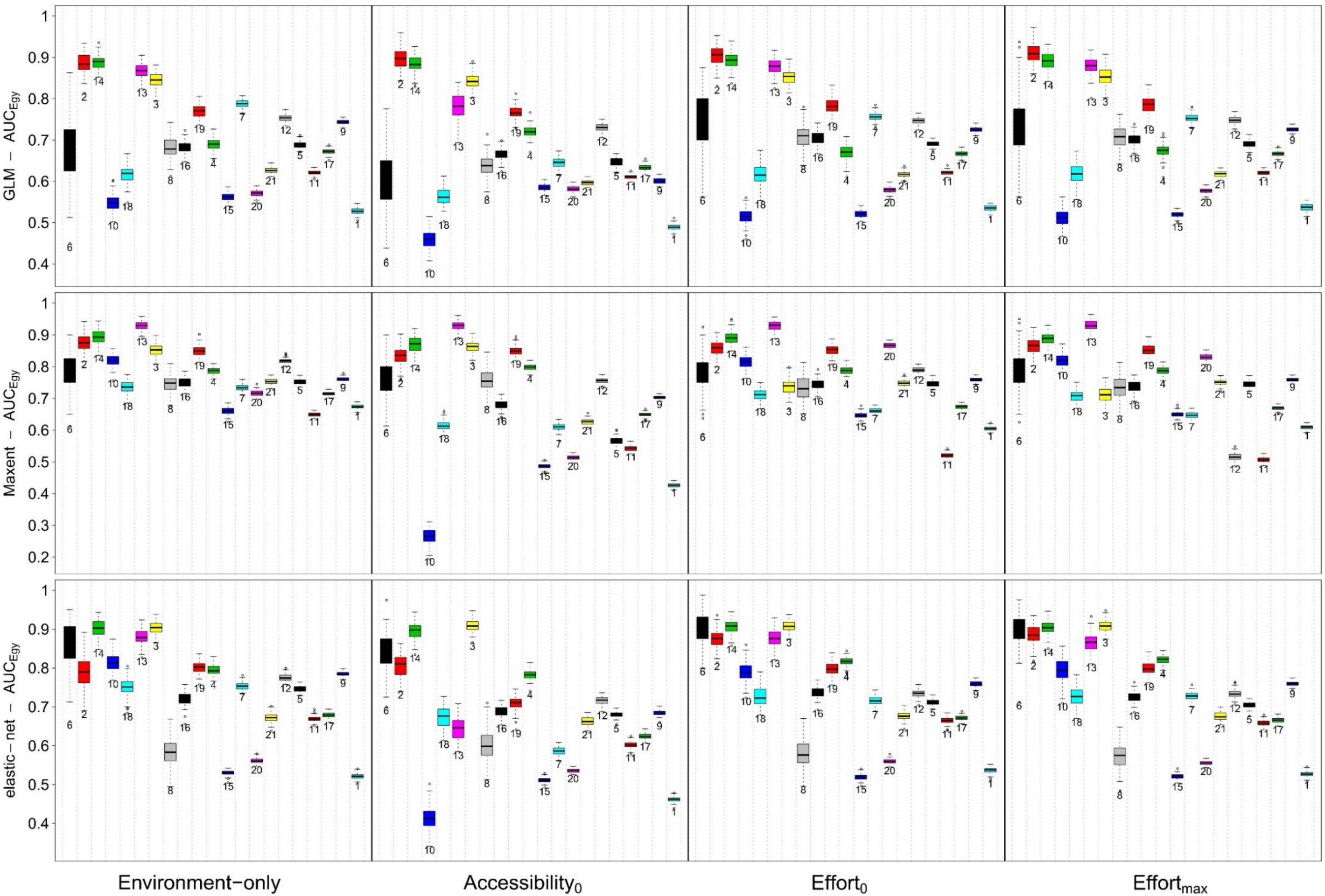
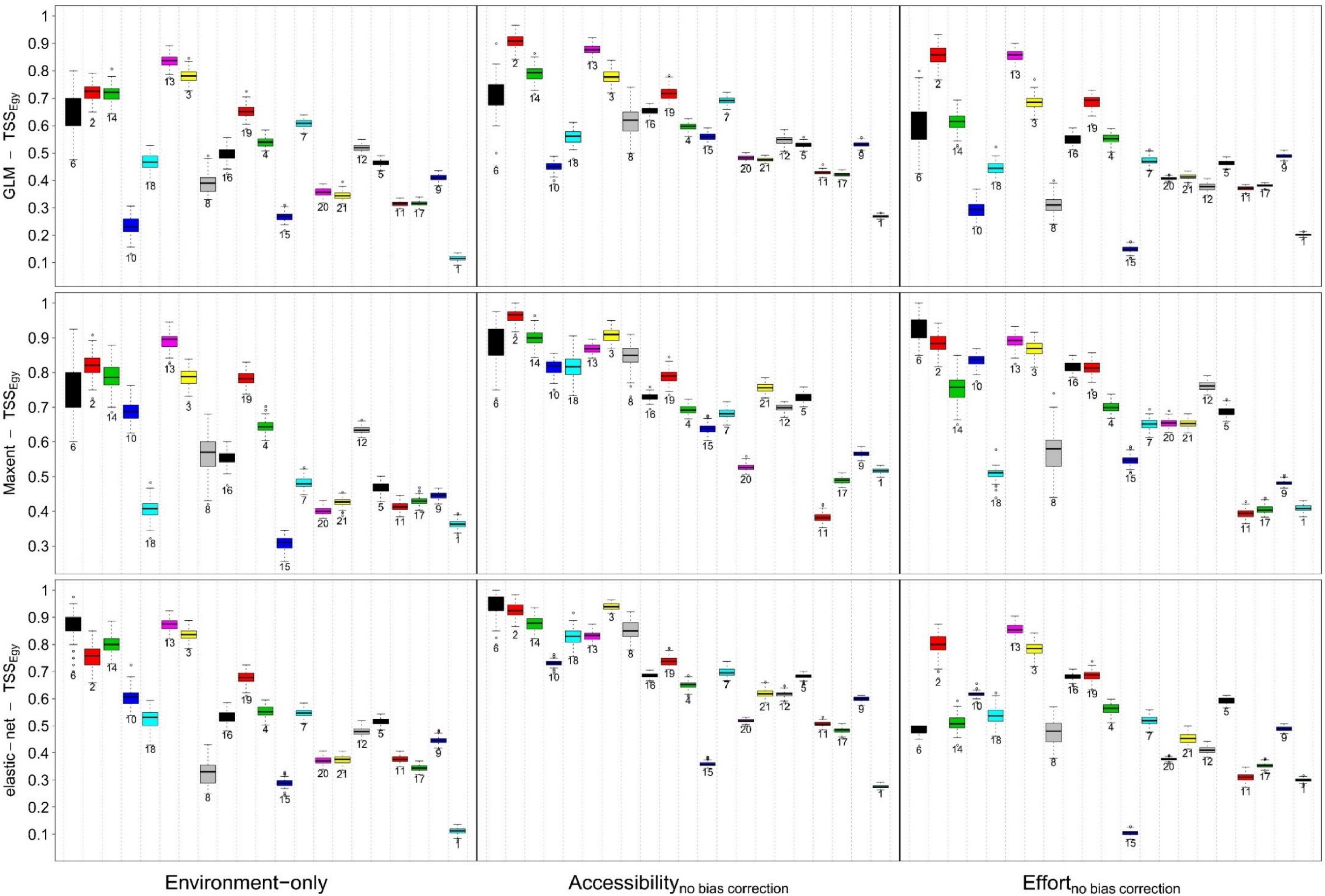

GLM - AUC$_{Egy}$
Maxent - AUC$_{Egy}$
elastic-net - AUC$_{Egy}$
Environment-only
Accessibility$_0$
Effort$_0$
Effort$_{max}$

Fig. A10 (b)



GLM – TSS_{Egy}
Maxent – TSS_{Egy}
elastic-net – TSS_{Egy}
Environment-only
Accessibility no bias correction
Effort no bias correction

Fig. A10 (c)

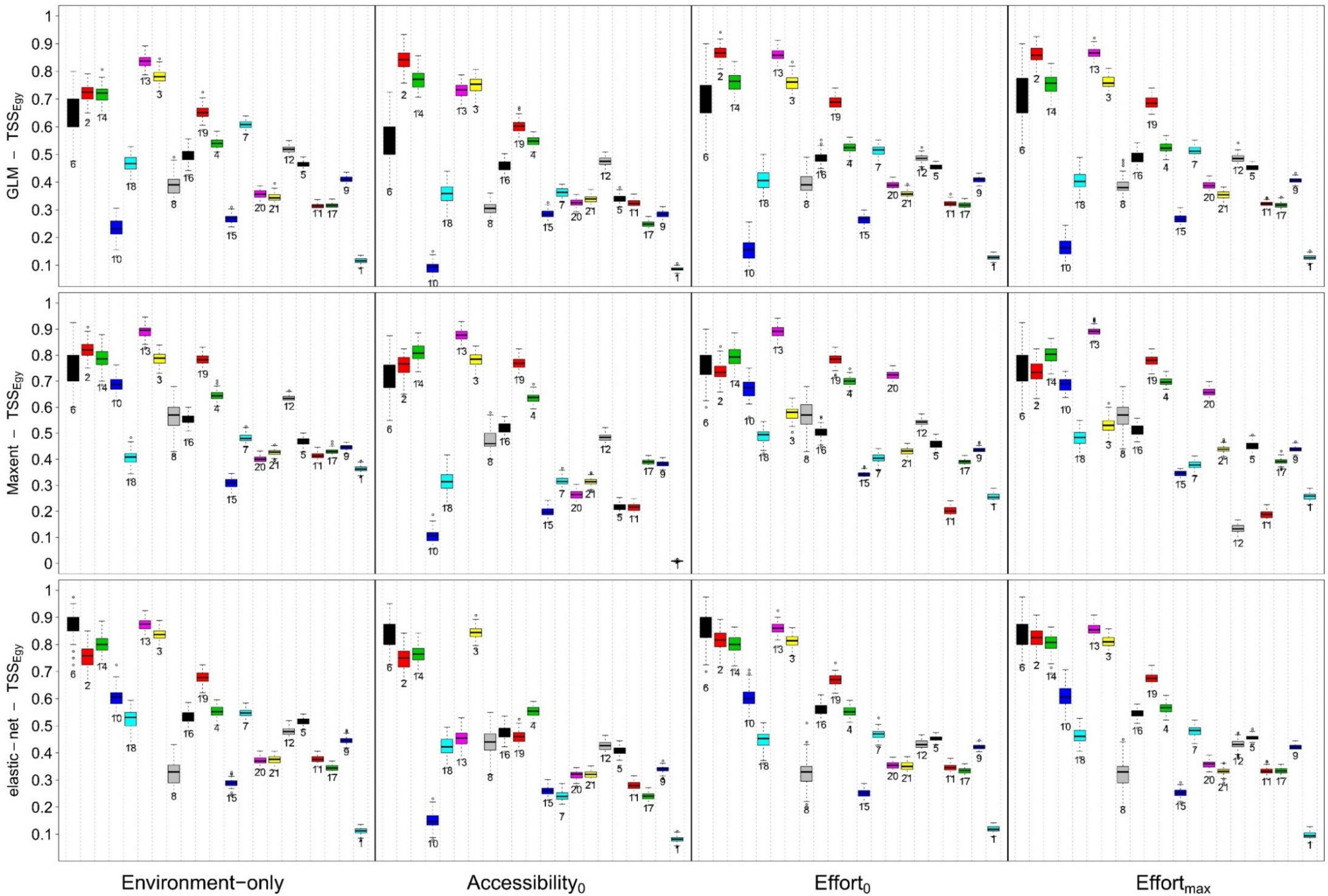

GLM - TSS_{Egy}
Maxent - TSS_{Egy}
elastic-net - TSS_{Egy}
Environment-only
$Accessibility_0$
$Effort_0$
$Effort_{max}$

Fig. A10 (d)

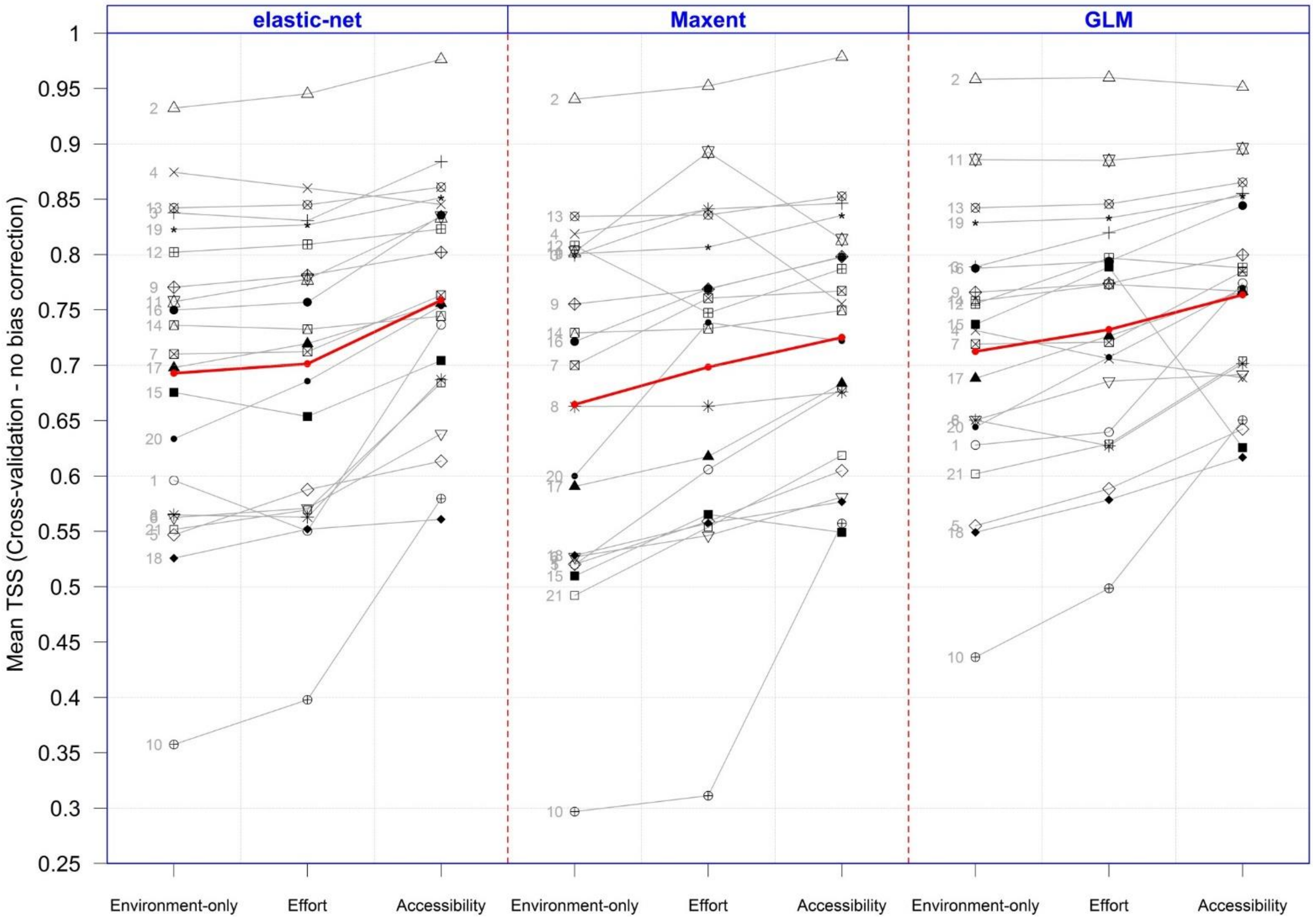


Fig. A11 (a)

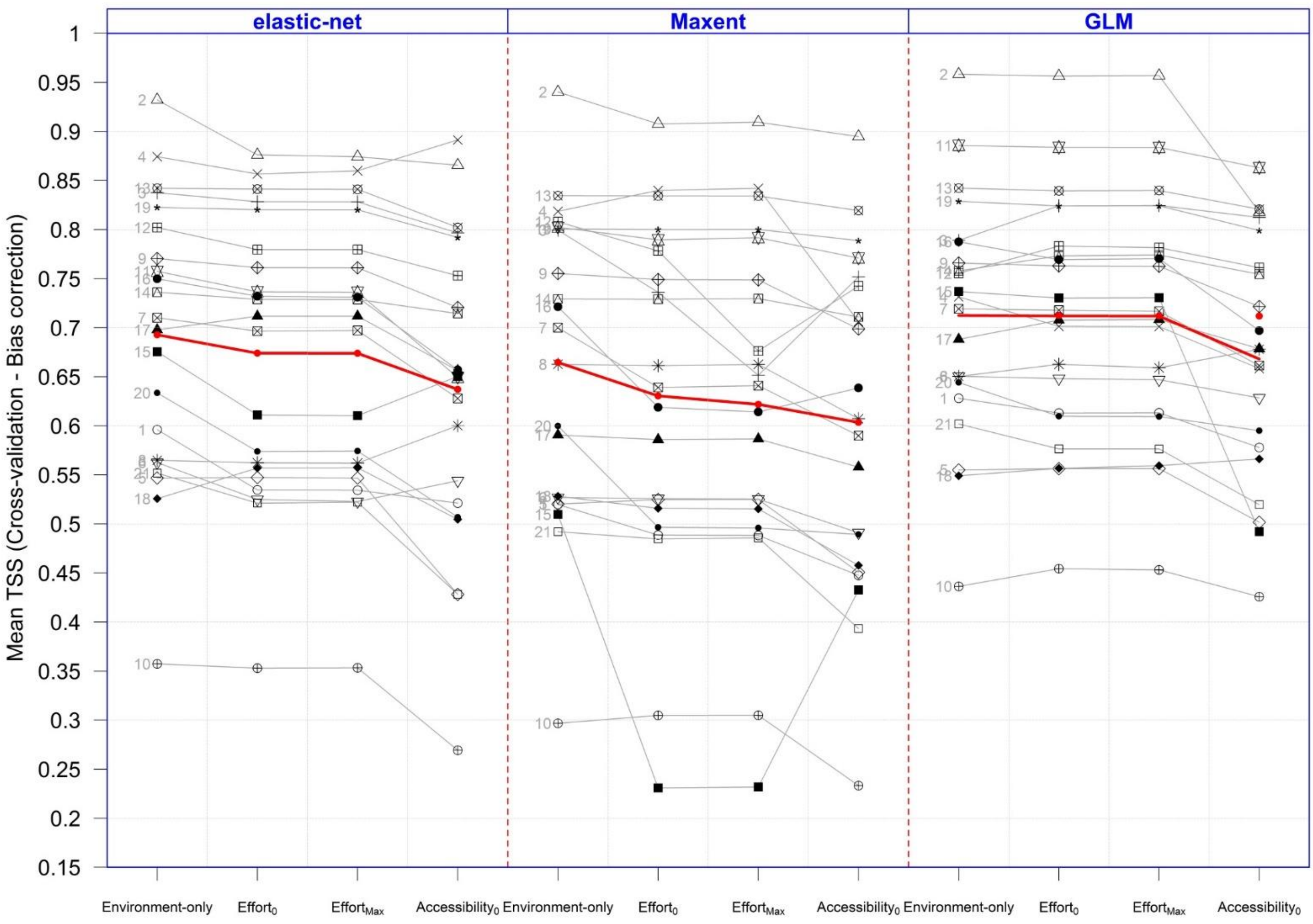


Fig. A11 (b)

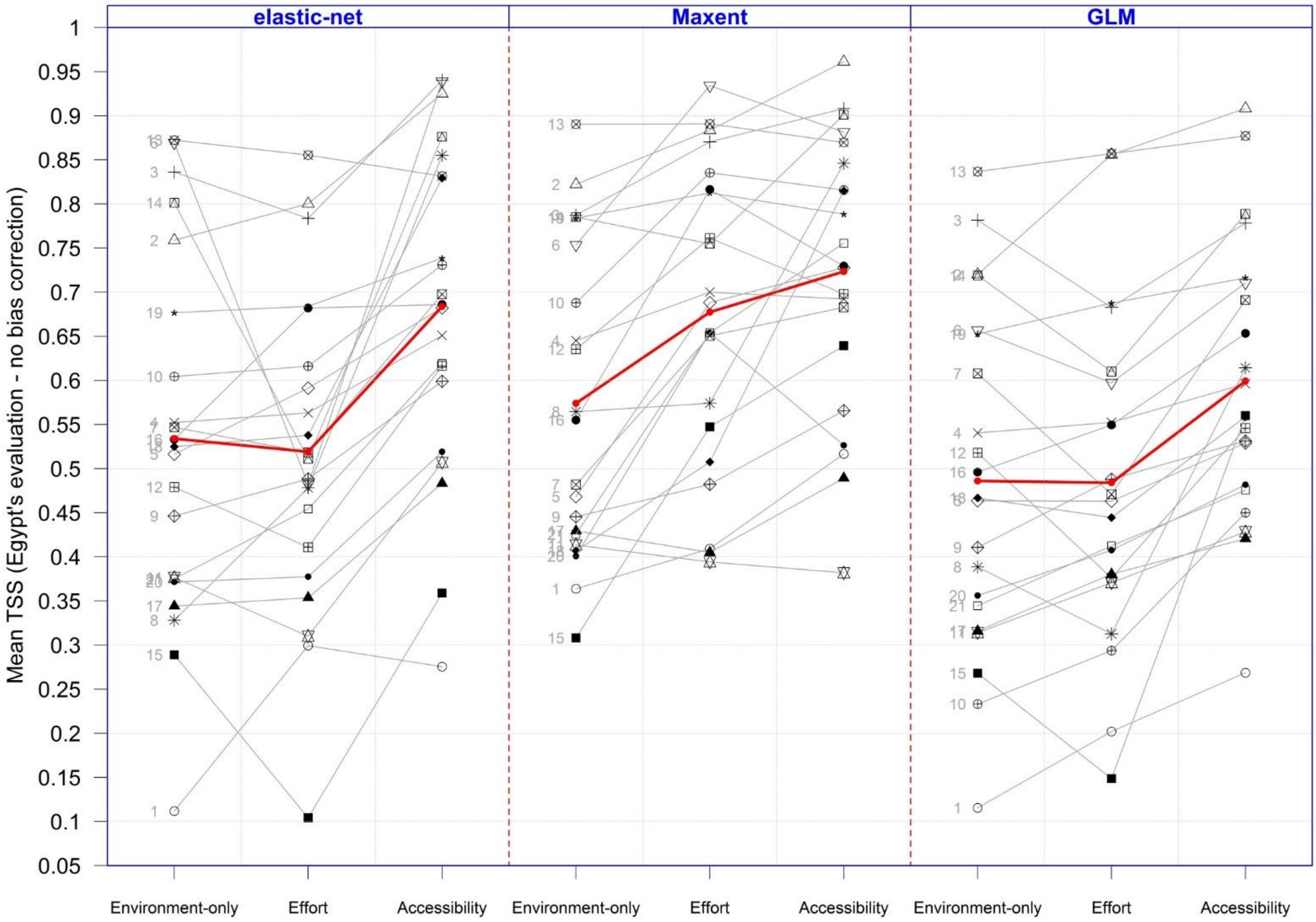


Fig. A11 (c)

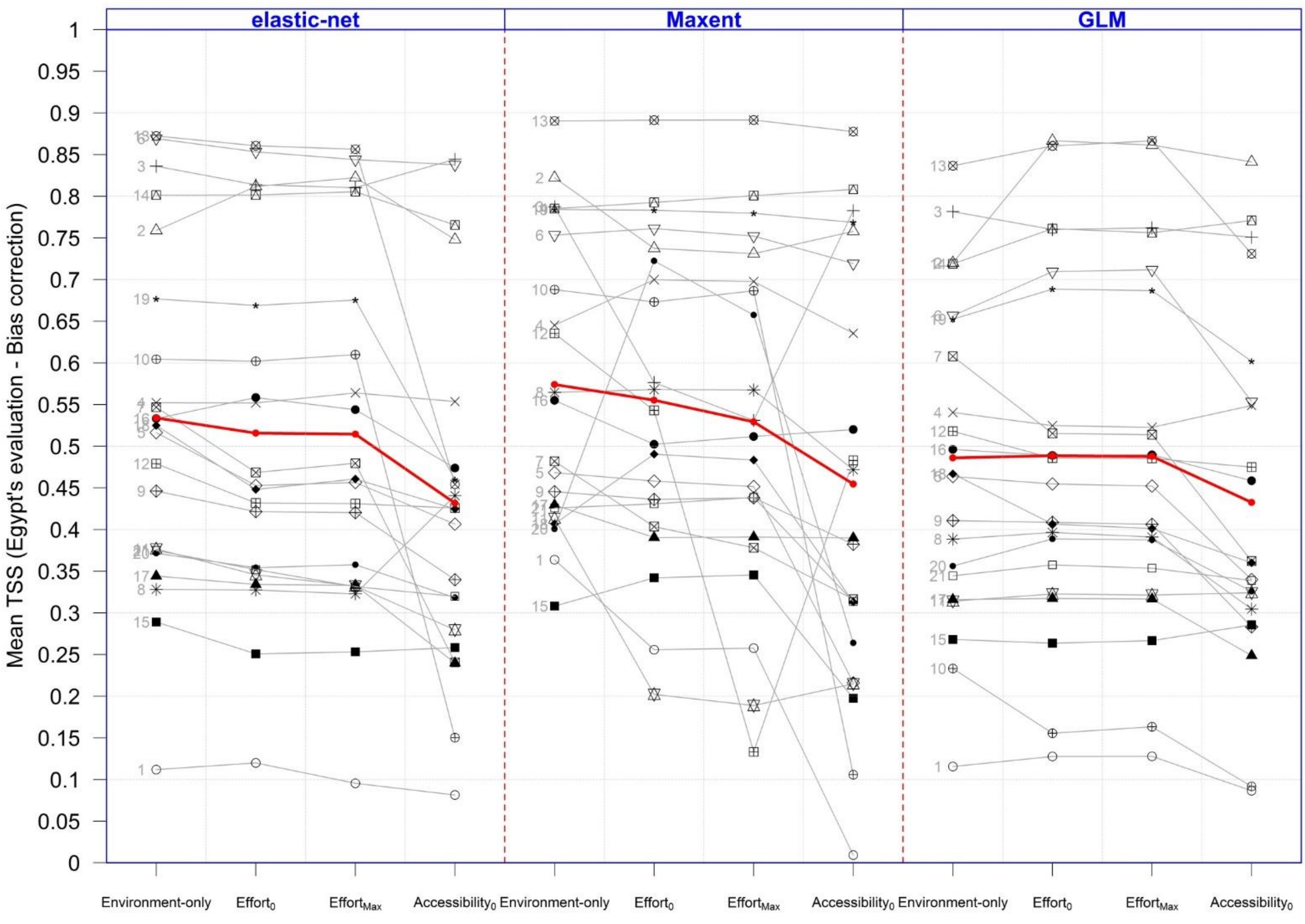


Fig. A11 (d)

Fig. A12: Kendall's correlation of the per-species mean TSS between different pairs of modelling algorithms (same as Fig. 2 in the main text, but for TSS). Each species is represented by different symbol (similar to those of Fig. A7) with different colours for different bias models applied (using predictions of environment-only model and bias-free prediction of accessibility and effort model). 'M' indicates the overall mean evaluation. First row represents mean spatial-block cross-validation evaluation, while the second is for independent evaluations in Egypt.

Fig. A13: Values of bias variables at presences and available locations (backgrounds), at the per-species study area (A) or at local scale 'Egypt' (B). Rows correspond to different species, with numbers indicates the species (see Table 1), and columns represent bias variables of the accessibility model (distances to roads, cities, and protected areas) and effort model (relative bats' sampling intensity). For each species, values at presence locations are indicated with black, and values at pixels unoccupied by the species are shown in grey. Most of the species are recorded from closer to roads and cities (and to some extent, the protected areas), and unexpectedly at low to moderate sampling efforts.

Fig. A14: AUC scores calculated the default way (using all available testing backgrounds – y-axis) versus using a fixed ratio between testing presences and backgrounds (test-data prevalence = 1:20 – x-axis).

(A) shows the raw outputs of 5-folds cross-validation.
(B) shows the per-species mean AUC on cross-validation.

Different colours represent the three bias models applied (environment-only, accessibility, and efforts).

Fig. A15: The predicted distribution of *Otonycteris hemprichii* (mean of 5-folds cross-validation), using different modelling algorithms (rows) and bias models (columns). Maps were scaled between zero and one, as different modelling algorithms do not have the same scale, with blue colour indicates higher predicted relative intensity.

(A) shows cropped predicted distribution of *Otonycteris hemprichii* (the same as Fig. 5) to Egypt. Grey points (in the top left panel) represents available records used for indepenent evaluation presences in Egypt.

In Fig. 5 of the main text, extreme values (> 0.9995 quantile of predicted values) were replaced with their next smaller value to improve map visualization, as GLM and elastic-net models sometimes yielded extreme values. Maps in (B) are equivalent to maps in Fig. 5, without any extreme values manipulation (using the linear scale), demonstrating the difficulty of visualizing the predicted patterns in the existence of extreme values; see main text for more details.

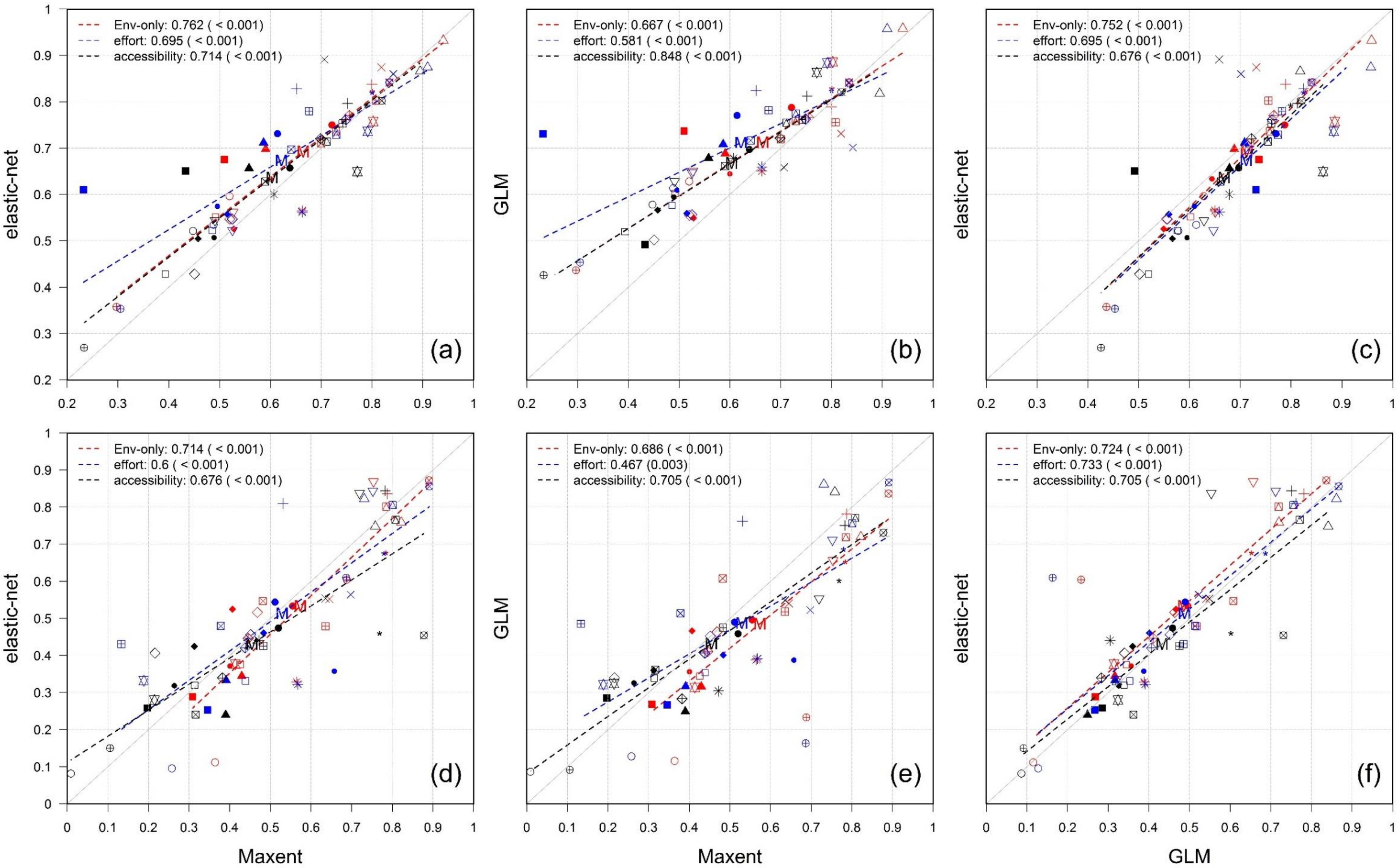

Env-only: 0.762 (< 0.001)
effort: 0.695 (< 0.001)
accessibility: 0.714 (< 0.001)
(a)
Env-only: 0.667 (< 0.001)
effort: 0.581 (< 0.001)
accessibility: 0.848 (< 0.001)
(b)
Env-only: 0.752 (< 0.001)
effort: 0.695 (< 0.001)
accessibility: 0.676 (< 0.001)
(c)
Env-only: 0.714 (< 0.001)
effort: 0.6 (< 0.001)
accessibility: 0.676 (< 0.001)
(d)
Env-only: 0.686 (< 0.001)
effort: 0.467 (0.003)
accessibility: 0.705 (< 0.001)
(e)
Env-only: 0.724 (< 0.001)
effort: 0.733 (< 0.001)
accessibility: 0.705 (< 0.001)
(f)
elastic-net
GLM
Maxent

Fig. A12

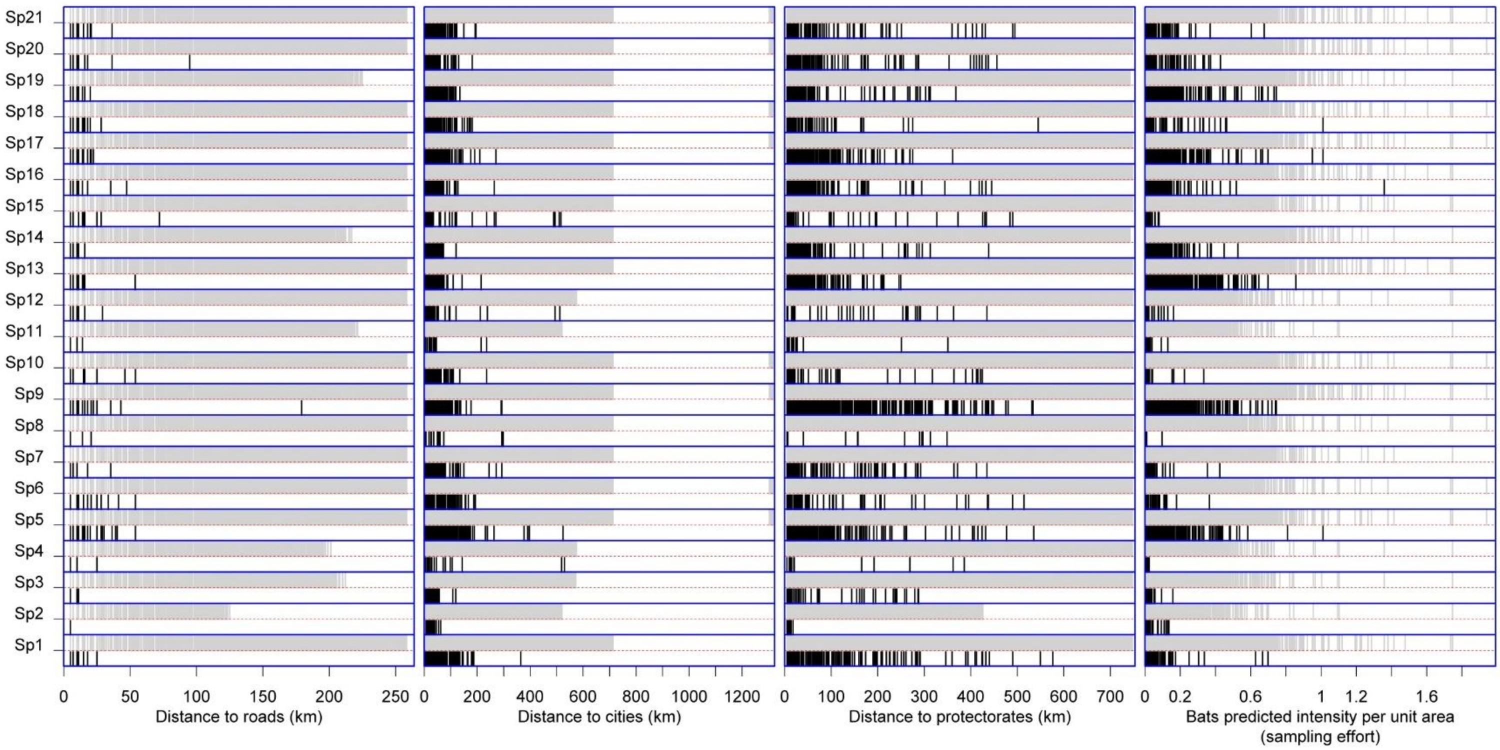


Fig. A13 (A)

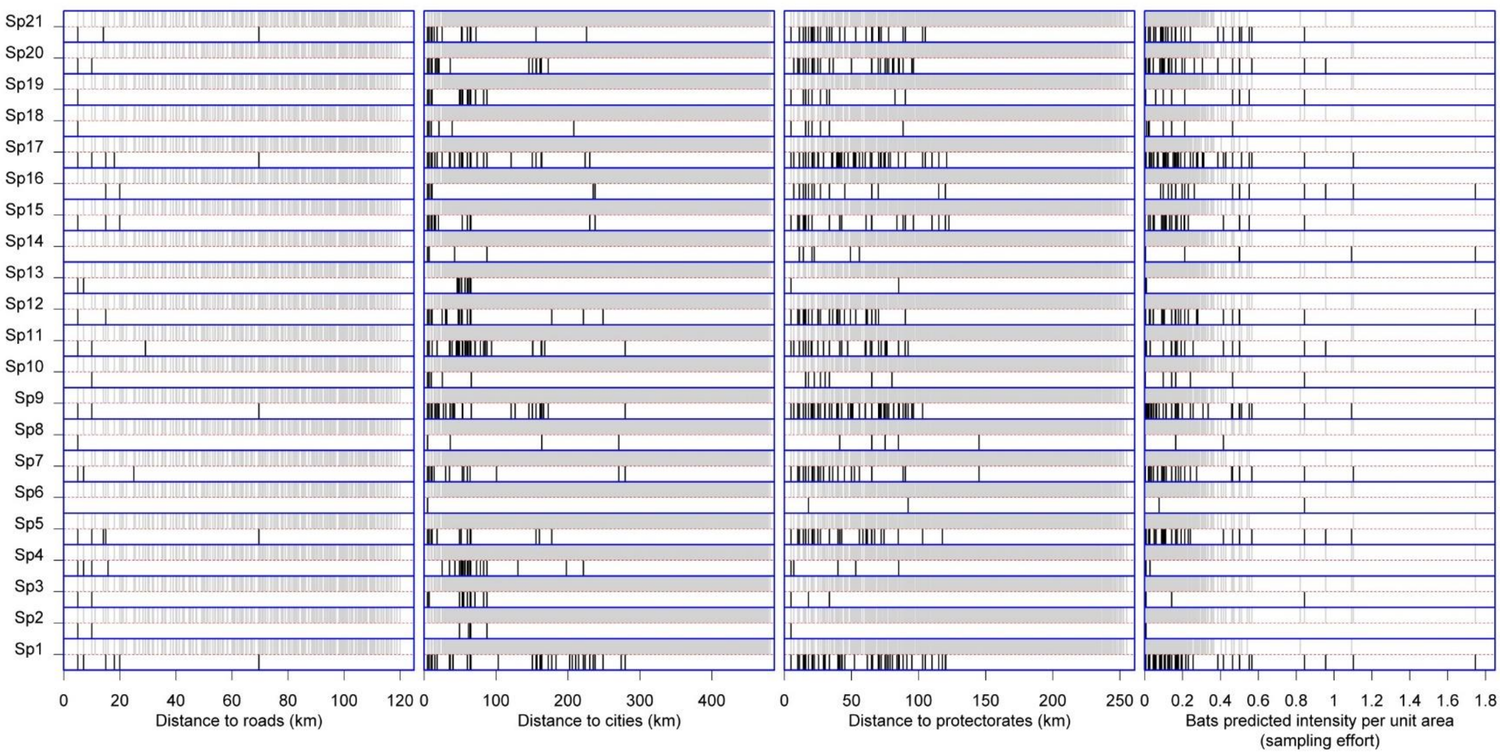


Fig. A13 (B)

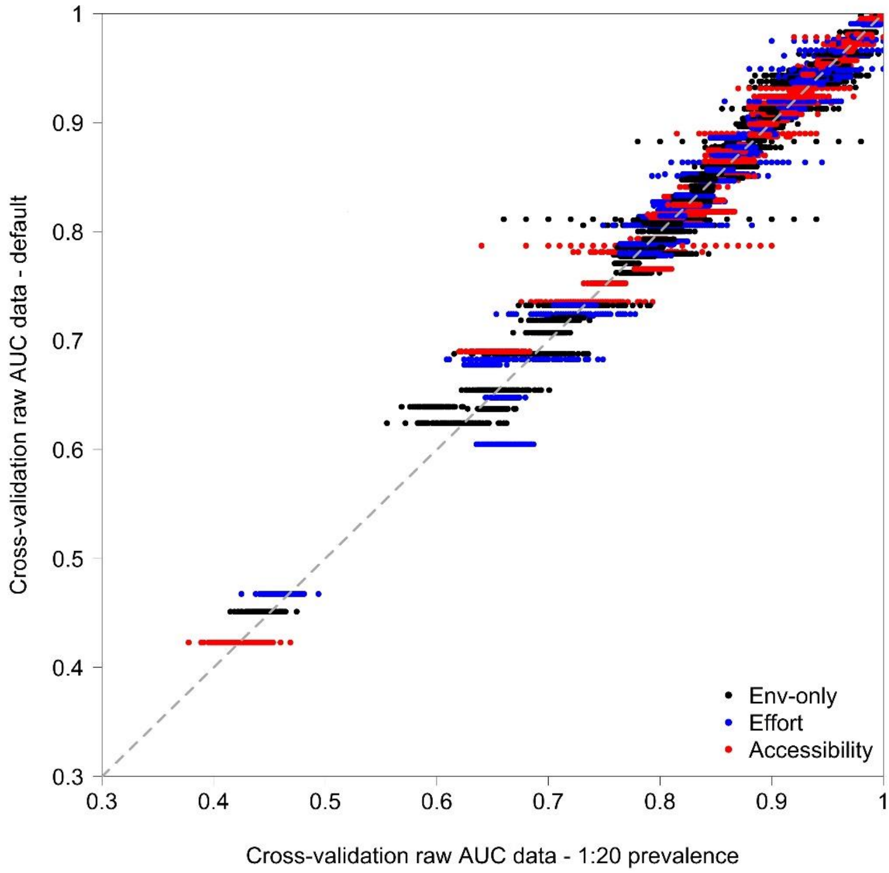


Fig. A14(A)

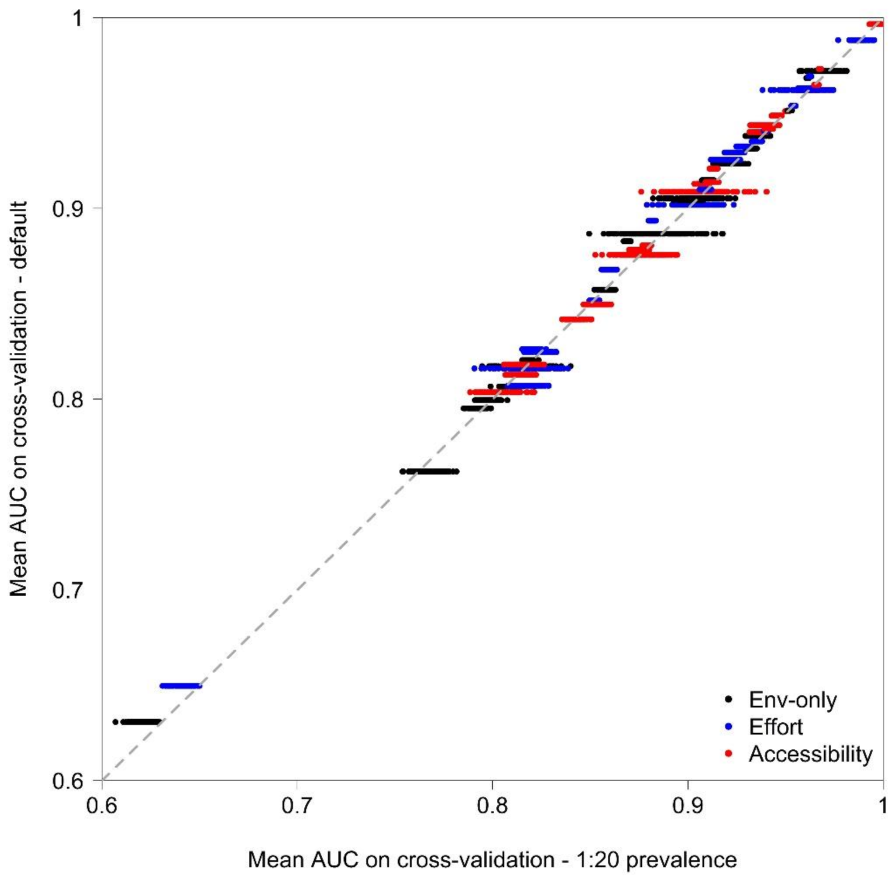


Fig. A14(B)

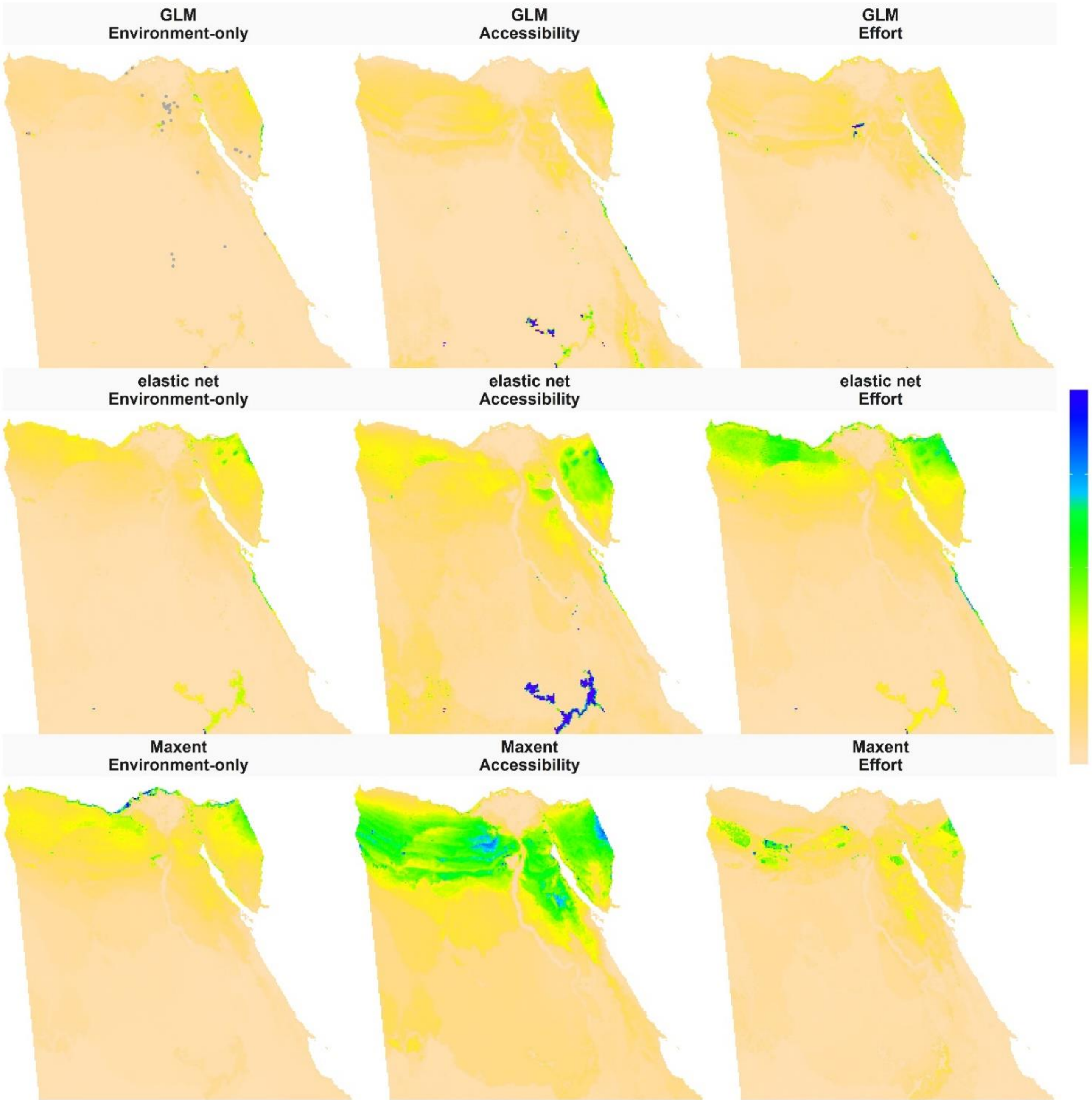

GLM
Environment-only
GLM
Accessibility
GLM
Effort
elastic net
Environment-only
elastic net
Accessibility
elastic net
Effort
Maxent
Environment-only
Maxent
Accessibility
Maxent
Effort

Fig. A15 (A)

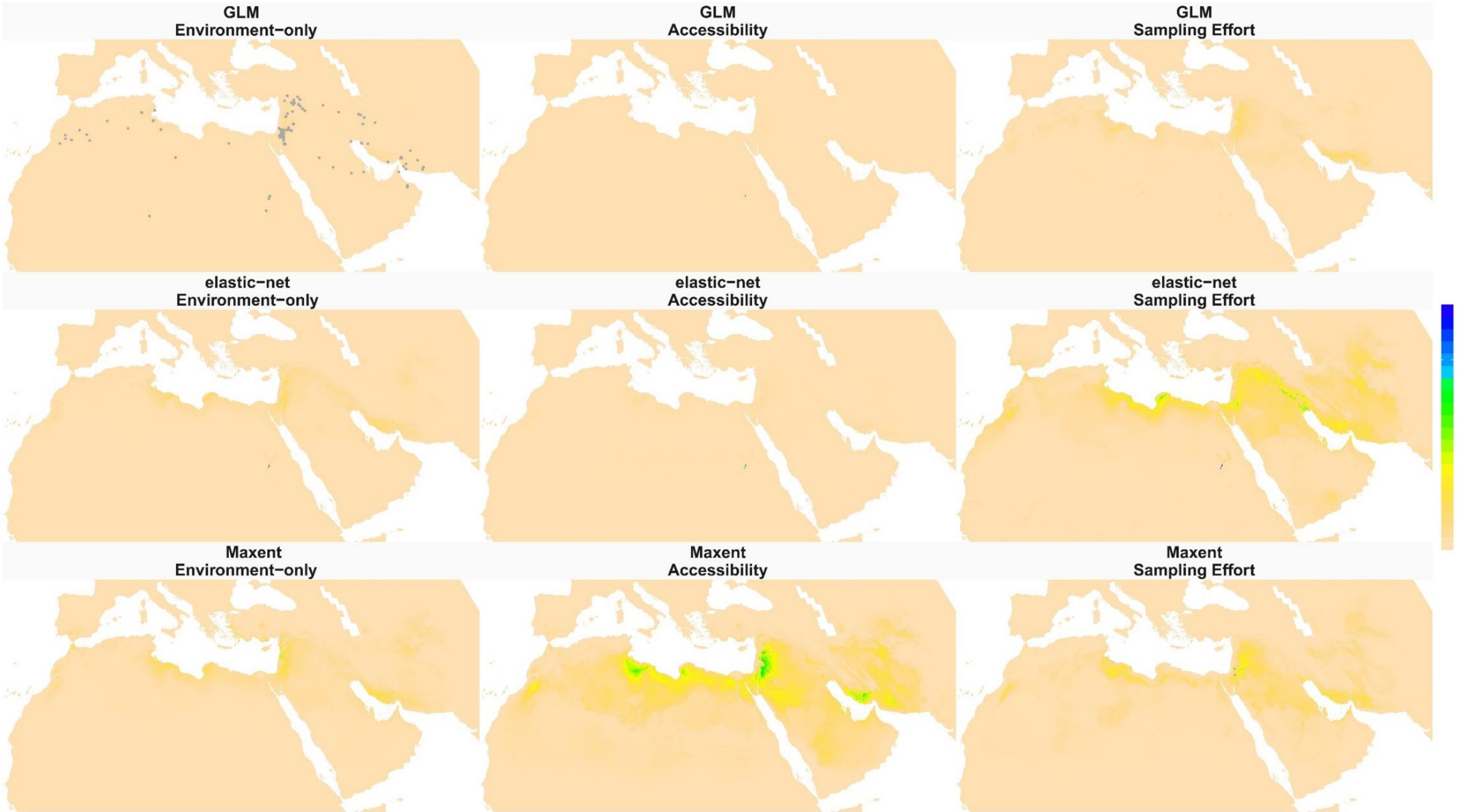

GLM
Environment−only
GLM
Accessibility
GLM
Sampling Effort
elastic−net
Environment−only
elastic−net
Accessibility
elastic−net
Sampling Effort
Maxent
Environment−only
Maxent
Accessibility
Maxent
Sampling Effort

Fig. A15 (B)

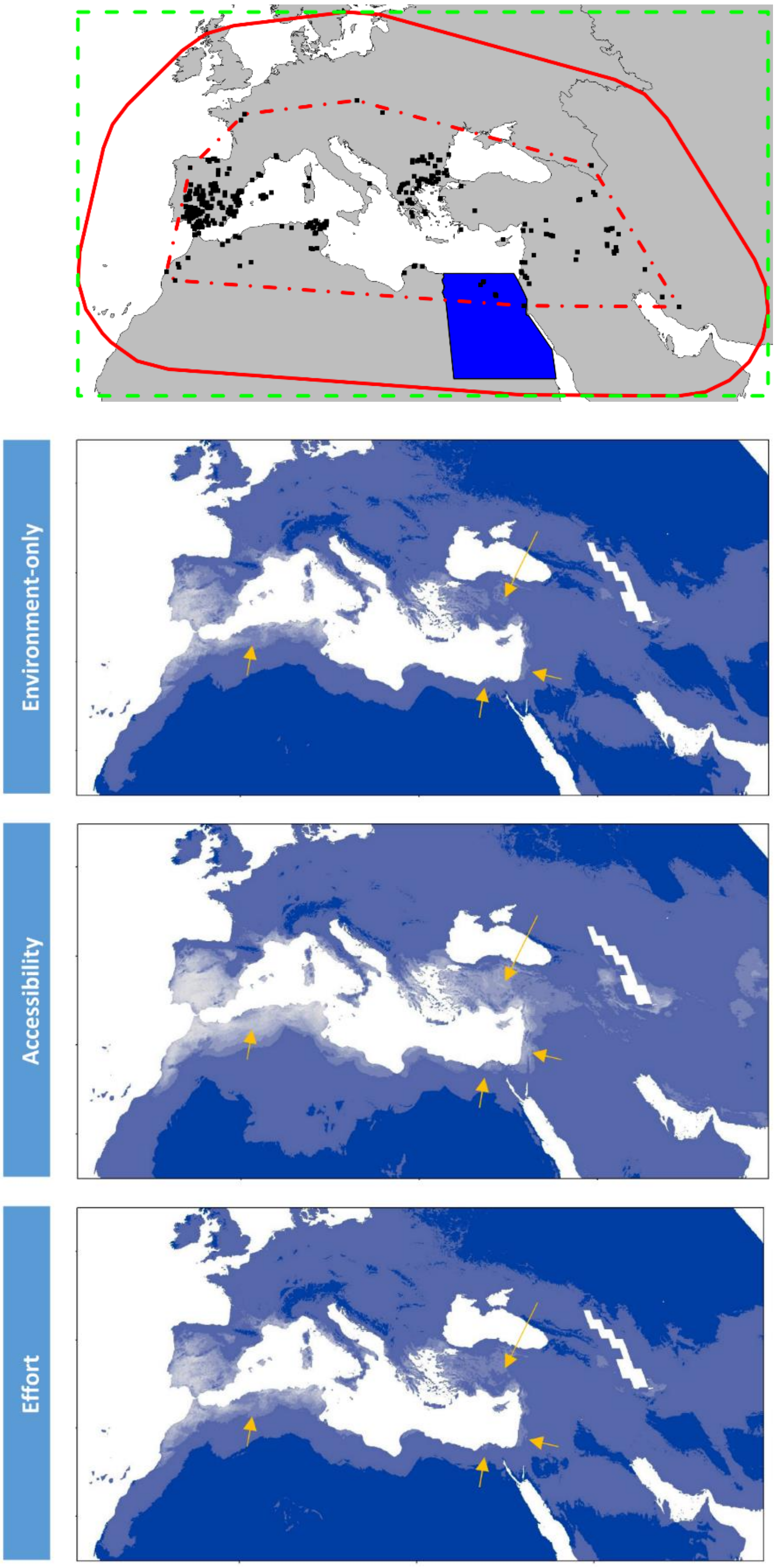


Fig. A16: The reported and predicted distribution of *Rhinolophus mehelyi* (Maxent). The 2nd to the 4th panels show predictions from environment-only model and bias-free prediction of accessibility and effort models, respectively. Arrows represent regions which gain higher predicted values after correcting for sampling bias (such as central Turkey or the Algerian Atlas). Predictions at these areas are of higher uncertainty (lower congurrence) and field validation is probably required to confirm the species existence. The lighter the colour, the more suitable the location.

Appendix 2: List of literature resources used for extracting bats records

Abd Rabou A.-F.N., Yassin M.M., Al Agha M.R., Hamad D.M., Ali A.-K.S. (2007) **Wild mammals in the Gaza Strip, with particular reference to Wadi Gaza**. The Islamic University Journal (Series of Natural Studies and Engineering) 15(1):87-109.

Albayrak I. (2003) **The bats of the eastern Black Sea region in Turkey (Mammalia: Chiroptera)**. Turkish Journal of Zoology 27(4):269-273.

Al-kuwari S.K. (1999) **On *Prosthodendrium parvouterus* (Trematoda: Lecithodendriidae) a parasite of the bat *Taohozous(sic) nudiventris***. Qatar University Science Journal, 18:155-158.

Allegrini B., Durand G., Durand E., Peyre O. (2011) **On some bats recorded in the Adrar region, Mauritania**. African Bat Conservation News, 26:2:4.

Al-Omari K.A., Abu Baker M.A., Amr Z.S. (2000) **First record of the Egyptian Slitfaced Bat, *Nycteris thebaica*, from Jordan**. Zoology in the Middle East 21:5–7.

Al-Shanti M.A., Pint J.J., Al-Juaid A.J., Al-Amoudi S.A. (2003) **Preliminary survey for caves in the Habakah region of the Kingdom of Saudi Arabia**. Saudi Geological Survey Open-File Report (SGS-OF-2003-3), 32 p.

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Appendix 3: Variables selection

List of initial covariates investigated for correlation/multi-collinearity and transformation applied. Final list used to run the model is marked in grey.

Variable		Transformation	VIF < 10	| cor | < 0.7	GVIF < 3
Alt [a]	Altitude		yes	yes	yes
Bio1 [a]	Annual mean temperature	^2			
Bio2 [a]	Mean diurnal range (mean of monthly (max temp - min temp))		yes	yes	yes
Bio3 [a]	Isothermality (Bio2/Bio7) (* 100)				
Bio4 [a]	Temperature seasonality (standard deviation *100)		yes	yes	yes
Bio5 [a]	Maximum temperature of warmest month				
Bio6 [a]	Minimum temperature of coldest month				
Bio7 [a]	Temperature annual range (Bio5-Bio6)				
Bio8 [a]	Mean temperature of wettest quarter	^2	yes	yes	yes
Bio9 [a]	Mean temperature of driest quarter	^2	yes	yes	yes
Bio10 [a]	Mean temperature of warmest quarter	^2			
Bio11 [a]	Mean temperature of coldest quarter		yes	yes	
Bio12 [a]	Annual precipitation	sqrt			
Bio13 [a]	Precipitation of wettest month		yes		
Bio14 [a]	Precipitation of driest month		yes	yes	yes
Bio15 [a]	Precipitation seasonality (coefficient of variation)		yes	yes	yes
Bio16 [a]	Precipitation of wettest quarter	sqrt			
Bio17 [a]	Precipitation of driest quarter				
Bio18 [a]	Precipitation of warmest quarter		yes	yes	
Bio19 [a]	Precipitation of coldest quarter	log	yes	yes	yes
PET [b]	Potential evapotranspiration				
AI [b]	Aridity index	sqrt			
AET [c]	Actual evapotranspiration	sqrt			
SWB [c]	Soil-water balance	sqrt			
NDVI_Max [d]	Maximum NDVI (Normalized Difference Vegetation Index)				
NDVI_Min [d]	Minimum NDVI		yes	yes	yes
NDVI_Mean [d]	Mean NDVI				

Variable		**Transfo-rmation**	**VIF < 10**	**| cor | < 0.7**	**GVIF < 3**
NDVI_Range [d]	Range NDVI (maximum – minimum)				
NDVI_SD [d]	Standard deviation of NDVI		yes	yes	yes
EVI_Max [d]	Maximum EVI (Enhanced Vegetation Index)				
EVI_Min [d]	Minimum EVI		yes		
EVI_Mean [d]	Mean EVI		yes		
EVI_Range [d]	Range EVI (maximum - minimum)		yes		
EVI_SD [d]	Standard deviation of EVI				

[a] WorldClim [1] : WorldClim provides a global dataset for the elevation and 19 bio-climatic variables interpolated from global monthly temperature and precipitation recordings from weather stations (Hijmans *et al.* 2005). Tiles for the overall study area were downloaded at 30 arc-seconds resolution (~1 km near the equator; using the *raster* R_package), then projected to Mollweide equal-area projection at 5 × 5 km^2 resolution. The high resolution of 30 arc-seconds was preferred over the 2.5 arc minutes (~5 km near the equator) in order not to lose much information while re-projecting. Instead of interpolation (assigning a value for the new pixel equals to the mean of the nearest three points at the original projection), a different approach was employed. First, a template grid covering the study area at the equal-area projection (5 × 5 km^2) was prepared. Then, pixels of the original variables (at 30 arc-seconds resolution) were converted into centroid points (at the original projection: WGS-1984), then projected into Mollweide projection, then these points were rasterized using the mean value (or other relevant function for some variables; e.g. maximum for Bio5) of the points that spatially fall within each cell of the template grid. The same approach was used to prepare all other covariates used in this study.

[b] Global Potential Evapotranspiration (Global-PET) & Global Aridity (Zomer *et al.* 2007, 2008) [2] : available at the global scale at a resolution of 1 km, and were prepared based on models that use data from WorldClim as inputs.

[c] Global Actual Evapotranspiration (Global-AET) & Global Soil-Water-Balance (Global-SWB) (Trabucco & Zomer 2010) [3] : available at the global scale at a resolution of 1 km, and are prepared based on WorldClim and Global-PET database as primary input.

[1] www.worldclim.org/bioclim/
[2] www.cgiar-csi.org/data/global-aridity-and-pet-database
[3] www.cgiar-csi.org/data/global-high-resolution-soil-water-balance

[d] NDVI (Normalized Difference Vegetation Index) & EVI (Enhanced Vegetation Index) (Didan, 2015) [4] : map tiles for the whole study area were downloaded (and merged) for the period from 18/2/2000 to 22/3/2015 each 16 days (MODIS product: MOD13A2 – resolution: 1 km) using the MODIS R package (Mattiuzzi, 2014). Summary maps (maximum, minimum, mean, range, and standard deviation) across the whole period (for NDVI & EVI) were produced at the original MODIS scale/projection using a python code in 'ArcGIS' as this was memory intensive to perform in raster package of R. Each of the summary layers were then projected into the equal-area projection at 5 × 5 km^2 resolution.

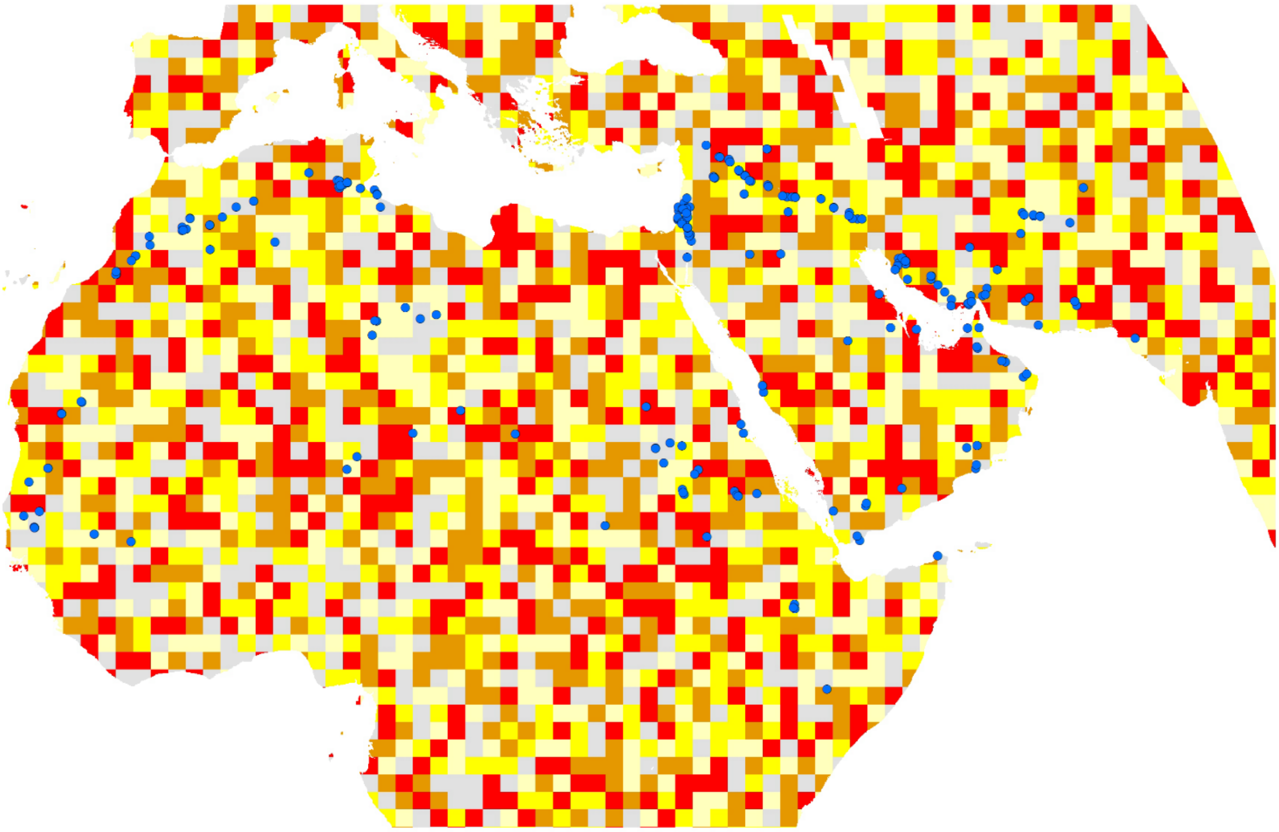
- Possible covariate transformations were investigated, trying to keep some degree of uniform distributions across the range of each covariate (following: Dormann 2011). For some covariates, no transformation was effective, and they were kept untransformed.
- Variable selection: Multicollinearity amongst the potential covariates (covering the total study area) was assessed, maintaining highest GVIF (Generalized Variance Inflation Factor) < 3 (Zuur et al. 2009) [which is equivalent, in our case, to maintaining a highest absolute correlation coefficient between each pair of covariates < 0.6 and highest VIF (Variance Inflation Factor) < 10]. This was also checked for each species' study area.
- Aridity-related covariates (actual/potential evapotranspiration, aridity-index, and soil-water-balance) were all excluded as they show high collinearity with other WorldClim covariates; unsurprisingly as they were derived from models that use WorldClim data as input.
- Out of tensummary vegetation-related covariates, two NDVI covariates were used further: the cumulative minimum and the standard deviation NDVI. They reflect indices of minimum biomass and variability of vegetation-cover across the study area, respectively.

[4] https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/ mod13a2_v006

Appendix 4: Per-species spatial-block cross-validation

For each species, a different spatial-block cross-validation structure was used to run SDMs. Pixels across the study area were aggregated into larger blocks (each of 20 × 20 cells = 100 × 100 km^2), and blocks were distributed into cross-validation folds. Presences and backgrounds in each block were used together either as training or testing (Fithian *et al.* 2015). The blocks were not distributed into cross-validation folds randomly, as this would have yielded highly unbalanced numbers of presence-locations across spatial folds. Instead, we balanced the number of presence locations at different folds by calculating their numbers at each block; the top 5 blocks were then, sequentially, randomly assigned to five folds (to avoid that the first fold always has the highest number of presences).

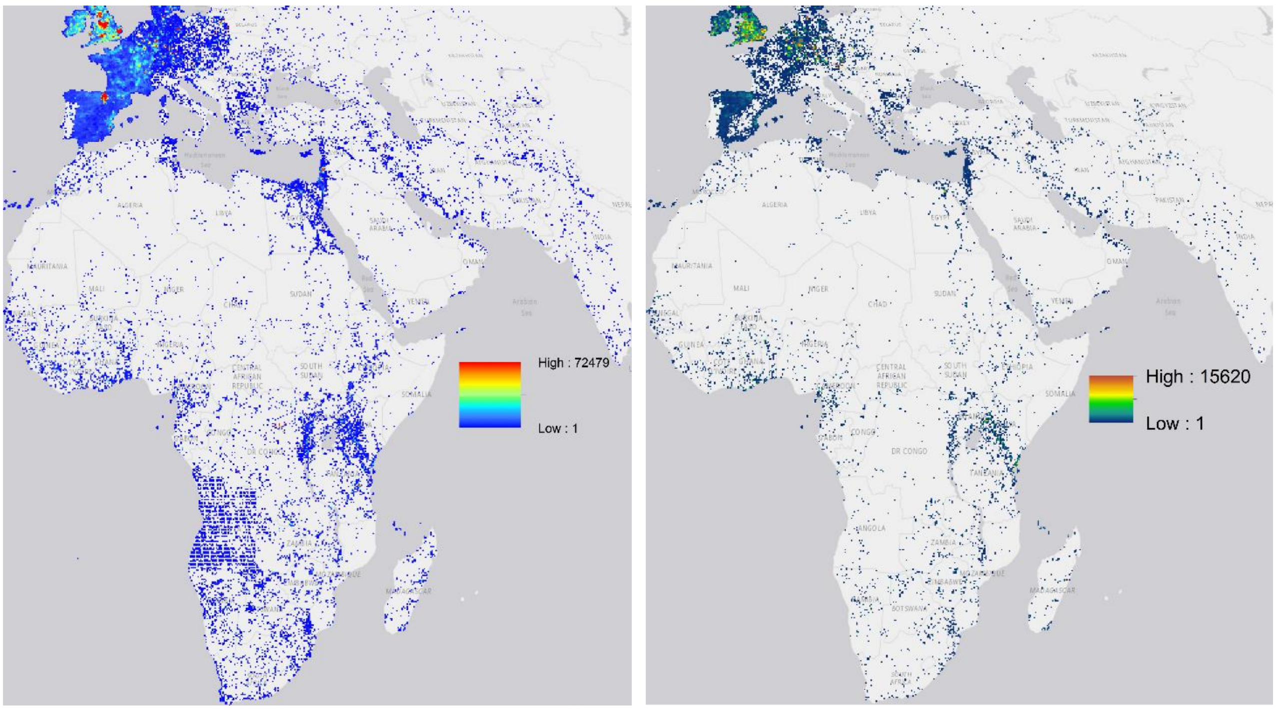
To avoid high variability in the environmental space between folds and minimise much extrapolation while predicting to the left-out-fold, blocks without any species records were distributed into folds depending on a mean index of their similarity to the overall study area: using the Multivariate Environmental Similarity Surfaces 'MESS'. MESS was proposed by Elith *et al.* (2010) to identify areas of novel climates by comparing future (or past) climate to those used to run the models, as the interpretation of future projections at these locations should be considered with caution. We calculated the MESS-score for each pixel (and a mean value for each block) quite differently from how it was proposed in the first place: we measured the environmental similarity of each pixel to all available pixels in the study area (using the 'dismo' package). The original application of MESS gives most dissimilar locations more negative values (Elith *et al.* 2010); however here we expect no negative values as there is no climates novelty. Blocks without any presence locations are sorted in descending order (depending on their average MESS value), and then the highest five blocks were distributed randomly into different folds. This was repeated for all blocks until all blocks were distributed to different folds.



An example of how spatial-block cross-validation applied for *Asellia tridens*. Different colours represent how different blocks are distributed into cross-validation folds. Blue points represent the species known distribution from outside Egypt. For each per species' study area, a different blocking structure was prepared, to balance the number of presence locations and environmental variability at different cross-validation model runs.

Appendix 5: Sampling-effort model

Data for closely related species (bats/non-marine mammals) were downloaded from GBIF (The Global Biodiversity Information Facility [5] – April 2015) and used (along with available focal species records: Tables 1 & A1) to model the relative sampling intensity (surveying effort) of bats/mammals. The prediction map of this model was used as bias covariate in the 'Effort models' (see main text, Fig. 1, bottom right). Records were assessed before usage (records with missing coordinates or with clear errors were excluded: e.g. missed latitude or longitude / equal latitude and longitude / records in the sea or the ocean / potentially swapped latitude and longitude), resulting in a total of 435,458 bat records / 2,039,158 non-marine mammal records (maps below). GBIF records (for both bats and mammals) show high bias towards the Western Europe compared to any other area in the study area, followed by scattered locations elsewhere (mostly close to the main cities, water bodies, populated areas, or seemingly a result of a mammals atlas mapping activity in southwest Africa). The majority of Africa and eastern Europe to western Asia is extremely under-represented in GBIF, with huge gaps in North Africa and Arabia.



Maps show the number of GBIF records of non-marine mammals (left) and bats (right) per a grid of 20 × 20 km^2 (accessed date: April 2015).

Initial trials for modelling the sampling effort were done using DWPR-GLM (Down-Weighted Poisson Regression) and Maxent (both using PPM-like approach; see main text); without much difference in the resulted prediction pattern (although Maxent model 'using default feature classes and regularization multiplier' shows, visually, an over-fitted spatial pattern). DWPR-GLM model was chosen to run at 5×5 km^2 equal-area projection: all the bats/mammals presence locations as the response (without duplicates removal) and using different covariate set than the environmental variables used to run the species SDMs (Merow et al. 2016):

→ *Terrain roughness* (represented here as a per-pixel standard deviation of altitude): Altitude maps from WorldClim [6] was downloaded at of 30 arc-seconds resolution [~1 km near the equator], then projected as points in Mollwide equal-area projection. The points were then converted to a raster (rasterized), representing the standard deviation of the elevation values located at any target pixel at the resolution of 5×5 km^2;

→ *Distance to main cities* [7] : the Euclidean distance between the centroid of each pixel and the nearest human settlement;

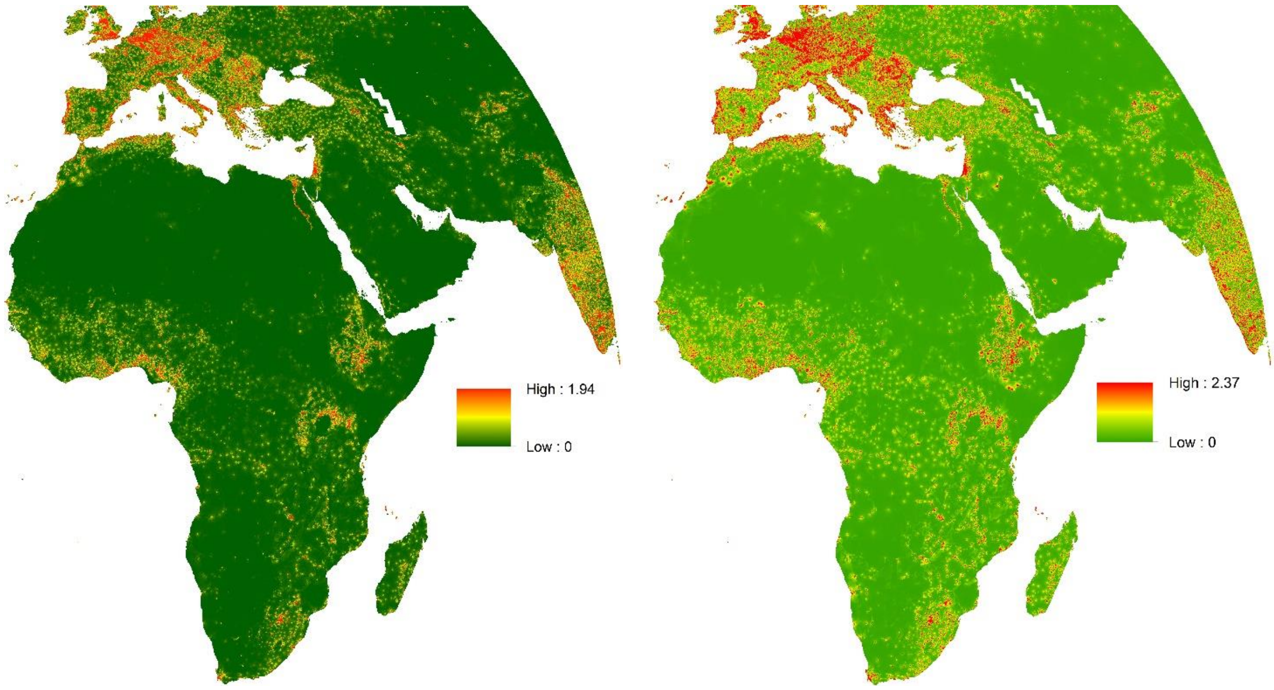
→ *Distance to main roads* [8] : the Euclidean distance between the centroid of each pixel and the nearest road (Source: Global Roads Open Access Data Set 'gROADS');

→ *Population count* [9] : global population count in 2000;

→ Protection status [10] : a binary variable indicating the protection status of each pixel [source: The world Database of Protected Areas:].

The overall pattern of the predicted sampling effort for both bats and mammals were roughly similar (maps below), so the prediction from the bats sampling effort model was used further (as bias covariate in the effort model). It represents the overall relative abundance of bat species sightings per unit area (based only on non-climatic covariates).

[5] http://www.gbif.org/
[6] http://www.worldclim.org/
[7] http://sedac.ciesin.columbia.edu/data/set/grump-v1-settlement-points/data-download; year: 2000
[8] http://sedac.ciesin. columbia.edu/data/set/groads-global-roads-open-access-v1
[9] http://sedac.ciesin.columbia.edu/ data/set/gpw-v3-population-count;
[10] http://protectedplanet.net



The predicted sampling intensity of sightings (sampling effort) for all bats (left) and non-marine mammals (right) using the DWPR-GLM (Down-Weighted Poisson Regression) model.

Appendix 6: Mixed effect model analysis of evaluation

Mixed Models formula:

Evaluation metric ~ Modelling algorithms * Bias models + total number of training presences (training data) + number of pixels in the study area (total area) + (1 | species)

- *Evaluation metric*
  - continuous variable for either AUC or TSS
  - either using mean cross-validation evaluation (AUC_{cv}/TSS_{cv}) or independent evaluation in Egypt (using mean prediction of 5-folds cross-validation to Egypt and independent testing data from Egypt)

- Modelling algorithms: categorical variable indicating the modelling algorithm used (elastic net / GLM / Maxent)

- Bias models:
  1. *Modelling evaluation:* evaluation of environment-only model (base line; no bias manipulation) is compared with those of bias-accounting models (accessibility and effort), without correction for sampling bias [without fixing bias variables at any values].

  2. *Bias correction evaluation:* evaluation of environment-only model (base line; no bias manipulation) is compared with those of bias accounting models (accessibility and effort), after correction for sampling bias [accessibility bias variables are set to zero, while the effort bias variable is set to either zero or the maximum estimated effort of the target species' presence records; see below].

- Species: random factor; categorical variable for the species.

1. Modelling Evaluation – Without Bias correction

Variance explained (sum of squares)

	AUC		TSS	
	Mean cross-validation	Egypt evaluation	Mean cross-validation	Egypt evaluation
Bias models	3.8	44.3	11.4	66.3
Model techniques	1.2	33.7	5.1	58.2
Bias models * Model techniques	0.2	5.5	0.7	11.5
Total number of training presences	0.005	0.03	0.02	0.043
Study area	0.004	0.02	0.05	0.039

Parameter estimates (Mixed models summary)

	AUC		TSS	
	Mean cross-validation	Egypt evaluation	Mean cross-validation	Egypt evaluation
(Intercept) [env-only/elastic net]	0.88036	0.7377	0.6928	0.5340
Effort.elastic net	0.00684	− 0.0026	0.0086	− 0.0149
Accessibility.elastic net	0.03815	0.1227	0.0660	0.1499
Env-only.Maxent	− 0.01480	0.0361	− 0.0281	0.0400
Effort.Maxent	0.00596	0.1096	0.0057	0.1434
Accessibility.Maxent	0.02399	0.1500	0.0325	0.1894
Env-only.GLM	0.01329	− 0.0380	0.0198	− 0.0480
Effort.GLM	0.02205	− 0.0383	0.0395	− 0.0500
Accessibility.GLM	0.03916	0.0626	0.0709	0.0652
Total number of training presences	0.03274	0.0418	0.0664	0.0842
Study area	− 0.02970	− 0.0347	− 0.0933	− 0.0797

Estimated differences in the least square means

		AUC		TSS	
		Mean cross-validation	Egypt evaluation	Mean cross-validation	Egypt evaluation
Modelling techniques	elastic net – Maxent	0.010	− 0.0585	0.0215	− 0.0793
	elastic net – GLM	− 0.010	0.0446	− 0.0185	0.0559
	Maxent – GLM	− 0.020	0.1031	− 0.0401	0.1352
Bias models	Env-only – Effort	− 0.012	− 0.0235	− 0.0207	− 0.0288
	Env-only – Accessibility	− 0.034	− 0.1124	− 0.0592	− 0.1375
	Effort – Accessibility	− 0.022	− 0.0889	− 0.0385	− 0.1087

Estimated differences in the least square means (interactions)

			AUC		TSS	
			Mean cross-validation	**Egypt evaluation**	**Mean cross-validation**	**Egypt evaluation**
Bias models	**elastic net**	Env-only – Effort	− 0.0068	0.0026	− 0.0086	0.0149
		Env-only – Accessibility	− 0.0381	− 0.1227	− 0.0660	− 0.1499
		Effort – Accessibility	− 0.0313	− 0.1254	− 0.0574	− 0.1647
	GLM	Env-only – Effort	− 0.0088	0.0003	− 0.0198	0.0020
		Env-only – Accessibility	− 0.0259	− 0.1006	− 0.0511	− 0.1133
		Effort – Accessibility	− 0.0171	− 0.1009	− 0.0314	− 0.1153
	Maxent	Env-only – Effort	− 0.0207	− 0.0735	− 0.0338	− 0.1034
		Env-only – Accessibility	− 0.0388	− 0.1139	− 0.0606	− 0.1494
		Effort – Effort	− 0.0180	− 0.0404	− 0.0268	− 0.0460
Modelling techniques	**Effort**	elastic net – Maxent	0.0009	− 0.1123	0.0029	− 0.1583
		elastic net – GLM	− 0.0152	0.0356	− 0.0309	0.0352
		Maxent – GLM	− 0.0161	0.1479	− 0.0339	0.1934
	Accessibility	elastic net – Maxent	0.0142	− 0.0273	0.0336	− 0.0396
		elastic net – GLM	− 0.0010	0.0602	− 0.0049	0.0846
		Maxent – GLM	− 0.0152	0.0874	− 0.0384	0.1242
	Env-only	elastic net – Maxent	0.0148	− 0.0361	0.0281	− 0.0400
		elastic net – GLM	− 0.0133	0.0380	− 0.0198	0.0480
		Maxent – GLM	− 0.0281	0.0741	− 0.0479	0.0880

2. Bias correction evaluation – using bias-free predictions

After correcting for sampling bias, initial trials show that using either value for fixing the effort bias covariate produce very similar evaluations (however, Maxent models show quite lower AUCs using the maximum effort value of training presences than for fixing at zero; Fig. 3), so we limited further analyses to $\text{effort}_{\text{Max}}$.

When predicting with fixed values for the bias-covariates, modelling algorithms were most important for explaining variability of cross-validations, followed by sampling-bias models and then their interaction (for evaluation in Egypt highest variability was explained by the sampling-bias models, followed by the modelling algorithm, and then their interaction). Again, the number of training presences and study area were much less important (and the sign of their effects resembles those of modelling evaluation). The accessibility model had lower AUC compared to the two other sampling-bias models in all comparisons (Fig. 3). On cross-validation, bias-accounting models had lower AUC-values compared to the environment-only model (very little difference between environment-only and effort model for GLM; Fig. 3a). For evaluations in Egypt, environment-only and effort model were hardly different (effort model had lower AUC for Maxent-; Fig. 3b).

Variance explained (sum of squares)

	AUC		TSS	
	Mean cross-validation	**Egypt evaluation**	**Mean cross-validation**	**Egypt evaluation**
Bias models	3.5	17.3	9.20	29.2
Model techniques	5.2	5.1	14.40	8.0
Bias models * Model techniques	0.3	2.5	0.96	2.7
Total number of training presences	0.010	0.04	0.04	0.06
Study area	0.007	0.03	0.07	0.06

Parameter estimates (Mixed models summary)

	AUC		TSS	
	Mean cross-validation	**Egypt evaluation**	**Mean cross-validation**	**Egypt evaluation**
(Intercept) [env-only/ elastic net]	0.8804	0.7377	0.6928	0.5340
Effort.elastic net	− 0.0118	− 0.0030	− 0.0188	− 0.0195
Accessibility.elastic net	− 0.0313	− 0.0701	− 0.0556	− 0.1025
Env-only.Maxent	− 0.0148	0.0361	− 0.0281	0.0400
Effort.Maxent	− 0.0385	0.0002	− 0.0708	− 0.0048
Accessibility.Maxent	− 0.0565	− 0.0664	− 0.0892	− 0.0794
Env-only.GLM	0.0133	− 0.0380	0.0198	− 0.0480
Effort.GLM	0.0117	− 0.0368	0.0191	− 0.0462
Accessibility.GLM	− 0.0127	− 0.0742	− 0.0246	− 0.1015
Total number of training presences	0.0439	0.0557	0.0821	0.1028
Study area	− 0.0385	− 0.0546	− 0.1095	− 0.1045

Estimated differences in the least square means

		AUC		TSS	
		Mean cross-validation	**Egypt evaluation**	**Mean cross-validation**	**Egypt evaluation**
Modelling techniques	elastic net − Maxent	0.0222	− 0.0143	0.0379	− 0.0259
	elastic net − GLM	− 0.0184	0.0253	− 0.0296	0.0246
	Maxent − GLM	− 0.0407	0.0396	− 0.0675	0.0505
Bias models	Env-only − Effort	0.0124	0.0125	0.0207	0.0208
	Env-only − Accessibility	0.0330	0.0696	0.0537	0.0918
	Effort − Accessibility	0.0207	0.0570	0.0330	0.0709

Estimated differences in the least square means (interactions)

			AUC		TSS	
			Mean cross-validation	**Egypt evaluation**	**Mean cross-validation**	**Egypt evaluation**
Bias models	**elastic net**	Env-only – Effort	0.0118	0.0030	0.0188	0.0195
		Env-only − Accessibility	0.0313	0.0701	0.0556	0.1025
		Effort − Accessibility	0.0196	0.0671	0.0368	0.0830
	GLM	Env-only – Effort	0.0016	− 0.0012	0.0006	− 0.0018
		Env-only − Accessibility	0.0260	0.0362	0.0444	0.0535
		Effort − Accessibility	0.0244	0.0374	0.0437	0.0553
	Maxent	Env-only – Effort	0.0237	0.0359	0.0427	0.0448
		Env-only − Accessibility	0.0417	0.1025	0.0611	0.1194
		Effort − Accessibility	0.0180	0.0666	0.0184	0.0746
Modelling techniques	**Effort**	elastic net − Maxent	0.0267	− 0.0032	0.0520	− 0.0146
		elastic net – GLM	− 0.0235	0.0338	− 0.0379	0.0267
		Maxent – GLM	− 0.0502	0.0370	− 0.0899	0.0414
	Accessibility	elastic net − Maxent	0.0252	− 0.0037	0.0336	− 0.0230
		elastic net – GLM	− 0.0186	0.0041	− 0.0310	− 0.0009
		Maxent – GLM	− 0.0437	0.0078	− 0.0646	0.0221
	Env-only	elastic net − Maxent	0.0148	− 0.0361	0.0281	− 0.0400
		elastic net – GLM	− 0.0133	0.0380	− 0.0198	0.0480
		Maxent – GLM	− 0.0281	0.0741	− 0.0479	0.0880

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