## Appendix S2. Waterbird distribution modelling

**Selection of pseudo-absence points**

Pseudo-absences selected from a small extent can produce spurious and poorly performing models, whereas large extents, such as the AEWA scale, can lead to artificially inflated test statistics, less informative response variables and simplified models dominated by only two variables (VanderWal et al., 2009).

In a pilot study using 34 African species, we tested the influence of including background from the AEWA range, from Africa and from the flyways of the species. We selected both widespread and restricted range species, e.g. Madagascar Heron, Blue-winged Goose.  We used evaluation strips, i.e. response plots (see Elith *et al.*, 2005), to identify those models with biologically non-meaningful response curves that might result from too large or small geographic extents for selecting the background (SM2 Figures 1 – 34). Additionally, we compared performance between models based on the three different backgrounds using test statistics (TSS, AUC, sensitivity and specificity). Especially, sensitivity is suited to compare these models because it informs about the ability of the models to predict the presences correctly. The other three indices include also the background and are therefore less suited for the comparison.

We found that the response curves were similar for most species, but the ecologically most realistic response curves were produced using the entire AEWA background. Models based on background from a smaller geographic extent often did not capture the full environmental gradient or showed ecologically not meaningful peaks in the evaluation strips. Moreover, model sensitivity was significantly different between different background extents (Kruskal-Wallis test: H(2) = 11.72, *p* < 0.01) and best with background from the AEWA range. There was marginal but non-significant difference between models based on the AEWA range and models including background from Africa. In contrast, models including background from the species’ flyway were inferior and significantly different compared to models based on background from the AEWA range (SM2 Fig. 35). For Specificity (Kruskal-Wallis test: H(2) = 23.38, *p* < 0.01), TSS (Kruskal-Wallis test: H(2) = 23.56, *p* < 0.01) and AUC (Kruskal-Wallis test: H(2) = 21.55, *p* < 0.01), models were significantly different between the different background extents as well. Pairwise comparisons of the mean ranks showed that the difference was significant between background from the flyway and the two other groups but not between background from the AEWA range and from Africa (SM2 Fig. 35).

**Resampling process to deal with sampling bias**

First, we created a map which identified oversampled and undersampled areas (SM2 Fig. 36) by binarizing the sampling bias grid (SM2 Fig. 37) using an appropriate threshold that leads to a small number of distinct, homogeneous polygons (1050 occupied cells). For each species, occurrences were resampled within the oversampled areas by removing repeatedly and randomly observations with a lower or equal minimum distance of 50 km to their nearest neighbouring observation until the minimum distance to the nearest neighbour was more than 50 km for all observations, or the number of observations within the oversampled area equalled the number of observations in the under-sampled area. Half of the observations in the under-sampled area and the same number of observations in the over-sampled area were randomly selected after the thinning-out process, and were used for model calibration. The remaining hold-out data was used for model evaluation. The whole process of thinning-out and resampling was repeated 10 times for observations classified as breeding, passage, wintering and resident. To avoid losing too many data for model calibration for species with a low number of observations (<100), we used a 10x repeated random 5-fold split-sampling procedure, where 75% of the data was used for calibration and 25% for evaluation.

**Model fit by season**

It is possible that our results were influenced by differences in model quality. For example, dispersive species apparently suffer more negative range changes because the model quality is poorer. To test this, we have compared the True Test Statistics (TSS) and Area Under the Curve (AUC) values of the different seasonal models.

The median TSS for dispersive species and for Palearctic migrants during passage and wintering was 0.84, but for Palearctic migrants in the breeding season was 0.90, and there were statistically significant differences between seasons, H(3) = 50.23, *p* < 0.01 using the Kruskal-Wallis test because the TSS values were not normally distributed. Pairwise comparison of mean ranks between seasons showed significant differences between the breeding season and all other seasons, but not amongst the other seasons.

Comparison of the AUC values revealed a very similar pattern but much smaller differences. The median AUC values were 0.976 for the dispersive species, 0.984 for the Palearctic migrants in the breeding, 0.973 in the passage and 0.974 in the wintering seasons, H(3) = 35,775, *p* < 0.01. Pairwise comparison of mean ranks between seasons revealed significant differences only between the breeding and the passage seasons and between the breeding and wintering seasons but not amongst the other seasons.

As both the AUC and TSS values were similar for all groups of models but ranges projected to decrease in case of the migrants in the breeding season and for dispersive species while the passage and wintering ranges of migrants were projected to increase, we can conclude that differences in model quality has not influenced our conclusions.

**Relationship between model fit and expert evaluation**

The median AUC values indicated excellent model fit using the scale Araújo *et al.* (2005). The median values for models the experts evaluated as ‘good’ or ‘fair’ were almost identical (0.976 and 0.977, respectively), but it was higher for the small number of models assessed by the experts as ‘poor’ (0.993). The Kruskal-Wallis test indicated a significant difference amongst models with different expert evaluations, H(2) = 6.5474, *p* < 0.05. Pairwise comparison of mean ranks of the models experts assessed differently revealed significant differences between the ‘poor’ models and the ‘good’ and the ‘fair’ ones, but not between the latter two groups. The pattern was the same in case of the TSS values. The median TSS value for models classified as ‘good’ representation of the range was slightly lower (0.852) than for the ones experts classified as ‘fair’ (0.860), but it was much higher for ‘poor’ models (0.940), H(2) = 7.9013, *p* < 0.05. These results highlight that (1) good model test statistics not necessarily indicate ecologically valid models. (2) The test statistics for models that experts assessed as ‘good’ or ‘fair’ did not differ significantly.

**References**

Araújo, M. B., Pearson, R. G., Thuiller, W., & Erhard, M. (2005). Validation of species–climate impact models under climate change. *Global change biology*, 11(9), 1504-1513.

Elith, J., Ferrier, S., Huettmann, F., & Leathwick, J. (2005). The evaluation strip: a new and robust method for plotting predicted responses from species distribution models. *Ecological modelling*, 186(3), 280-289.

VanDerWal, J., Shoo, L. P., Graham, C., & Williams, S. E. (2009). Selecting pseudo-absence data for presence-only distribution modeling: how far should you stray from what you know? *Ecological modelling*, 220(4), 589-594.

## **Appendix S2: Figures**

**Chart

Description automatically generated****App. S2 Figure 1. Response curves for White-faced Whistling-duck Dendrocygna viduata. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.**

**App. S2Chart, line chart

Description automatically generated Figure 2. Response curves for Maccoa Duck Oxyura maccoa. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.**

**Chart

Description automatically generated App. S2 Figure 3. Response curves for Egyyptian Goose Alopochen aegyptiaca. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.**

**Chart

Description automatically generated App. S2 Figure 4. Response curves for South African Shelduck Tadorna cana. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.**

**Chart

Description automatically generated App. S2 Figure 5. Response curves for Spur-winged Goose Plectopterus gambensis. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.**

Chart

Description automatically generatedApp. S2 Figure 6. Response curves for Blue-winged Goose *Cyanochen cyanoptera*. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

**Chart, line chart

Description automatically generated App. S2 Figure 7. Response curves for Southern Pochard Netta erythrophtalma. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.**

Chart

Description automatically generated **App. S2 Figure 8. Response curves for Hottentot Teal Spatula hottentota. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.**

**Chart

Description automatically generated App. S2 Figure 9. Response curves for Yellow-billed Duck Anas undulata. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.**

Chart, line chart

Description automatically generatedApp. S2 Figure 10. Response curves for Cape Teal *Anas capensis*. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

Chart, histogram

Description automatically generated App. S2 Figure 11. Response curves for Lesser Flamingo Phoeniconaias minor. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

Chart, line chart, histogram

Description automatically generatedApp. S2 Figure 12. Response curves for Allen’s Gallinule Porphyrio alleni. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

App. S2Chart

Description automatically generated Figure 13. Response curves for Red-knobbed Coot Fulica cristata. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

Chart, line chart

Description automatically generatedSM2 Figure 14. Response curves for Black Crowned Crane Balearica pavonia. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

**Chart, line chart

Description automatically generated** App. S2 Figure 15. Response curves for Wattled Crane Bugeranus carunculatus. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

Chart, line chart

Description automatically generatedSM2 Figure 16. Response curves for Wattled Ibis Bostrychia carunculata. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

Chart, line chart

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Chart, line chart

Description automatically generatedApp. S2 Figure 18. Response curves for Saddlebill *Ephippiorhynchus senegalensis*. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

Chart

Description automatically generatedApp. S2Figure 19. Response curves for African Spoonbill Platalea alba. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

Chart, histogram

Description automatically generatedApp. S2 Figure 20. Response curves for Cattle Egret Bubulcus ibis. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

Chart, line chart

Description automatically generatedApp. S2 Figure 21. Response curves for Madagascar Heron Ardea humbloti. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

**Chart, line chart

Description automatically generated**App. S2 Figure 22. Response curves for Yellow-billed Egret Ardea brachyrhyncha. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

Chart

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Chart

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Chart, line chart

Description automatically generated App. S2 Figure 25. Response curves for African Darter Anhinga rufa. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

Chart, line chart

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Chart, histogram

Description automatically generated App. S2 Figure 27. Response curves for White-fronted Plover Charadrius marginatus. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

Chart

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**Chart, line chart

Description automatically generated**App. S2 Figure 29. Response curves for Wattled Lapwing Vanellus senegallus. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

Chart

Description automatically generatedApp. S2 Figure 30. Response curves for Spot-breasted Lapwing Vanellus melanocephalus. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

Chart

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**Chart, line chart

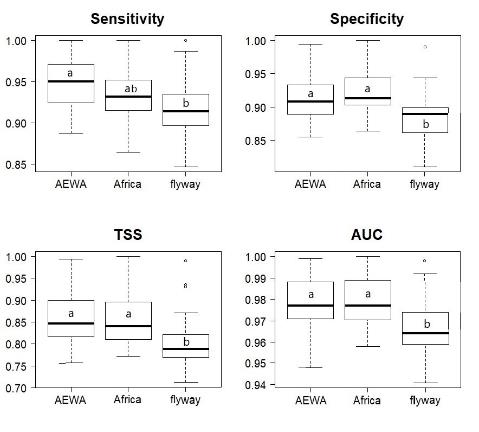
Description automatically generated**App. S2 Figure 32. Response curves for African Skimmer Rynchops flavirostris. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

**Chart

Description automatically generated**App. S2 Figure 33. Response curves for Grey-headed Gull Larus cirrocephalus. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.

**Chart, line chart

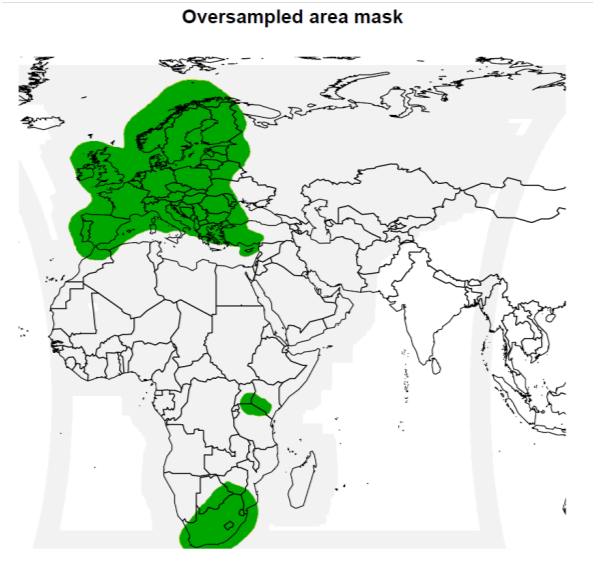
Description automatically generated**App. S2 Figure 34. Response curves for Kelp Gull Larus dominicanus. Models with background points selected from the entire AEWA area (black lines), from Africa (red lines) and from the species' range (blue lines). The figure shows response curves for the four most important variables.



App. S2 Figure 35: Performance of models based on different background extents for 34 dispersive African species (AEWA: background for the entire AEWA extent (including Africa-Eurasia), Africa: including the extent of Africa and flyway: including of the extent of the species’ flyway). Groups that are significantly different in performance are indicated by different letters in the whisker box.



## App. S2Figure 36. Sampling density in the AEWA study area. The map shows areas with high (red) and low (yellow) sampling density measured as the number of occupied 10x10km grid cells within a buffer of 500 km around each cell where waterbird observations were available from.

App. S2 Fig 37: Binary map showing over and under-sampled areas. The mask is based on the sampling density map (Fig. 36) and was binarized using a threshold of 1050 observations.

Chart

Description automatically generatedApp. S2 Figure 39: Boxplots of model performance measured by the AUC values by season.