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Identifying the potential wintering sites of the globally threatened Aquatic Warbler *Acrocephalus paludicola* using remote sensing

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The Aquatic Warbler is a threatened Afro-Palaearctic migrant with a largely unknown distribution in the winter (non-breeding) season. Protection of wintering sites may be crucial for the conservation of the species. Previous studies have identified extensive areas of north-western sub-Saharan Africa that could potentially be occupied by the species during winter. However, these studies have not necessarily differentiated between potentially suitable and unsuitable habitat types at a spatial resolution appropriate for targeting field surveys. To identify specific sites that could be occupied by non-breeding Aquatic Warblers at a scale appropriate for targeted field surveys, we adopted a modelling approach that combined recent sightings from Djoudj, Senegal, with land cover and climate data. We produced maps of potential distribution using three maximum entropy models. While a paucity of sightings prevented a full test of these maps on independent records, the areas that were predicted to be potentially occupied included areas around which there are historical records. We suggest field surveys should be targeted towards sites in the Inner Niger Delta and a number of marshes along and away from the Niger River in Mali, and to sites in southern Mauritania.

Introduction

The Aquatic Warbler *Acrocephalus paludicola* is an Afro-Palaearctic migrant classed as globally threatened in the category Vulnerable (IUCN 2010). Its habitat associations during the breeding season are well known (e.g. Dyrcz et al. 1972, 1985, Schulze-Hagen 1991, Kozulin and Flade 1999, Tanneberger et al. 2010). Increasing conservation action on breeding grounds means habitat loss in the wintering (non-breeding) range might soon become the greatest threat to the species (BirdLife International 2008). However, the species' wintering range in Africa remains poorly mapped though it is thought to fall within north-western sub-Saharan Africa (Pain et al. 2004, Schäffer et al. 2006, Walther et al. 2007). These studies have only identified broad areas that might be suitable owing to data limitations. A recent analysis using stable isotopes and surrogate species has identified a smaller area from which sampled Aquatic Warblers might have grown their feathers (Oppel et al. in press). Currently, the suggested areas are still extensive and are not sufficiently accurate to be used to identify target areas for field surveys. Refining these distributions to identify patches of suitable habitat, rather than broad regional distributions, could help to target research and conservation resources. Recent field surveys have highlighted the importance to wintering Aquatic Warblers of areas within and around the Djoudj National Park, an Important Bird Area in north-western Senegal (BirdLife International 2008). This is currently the only known regular wintering site, but is unlikely to contain the entire world population.

Statistical models linking known species occurrences to environmental data can be used to produce maps of habitats that are potentially suitable for species (e.g. Franklin 2009). Remote sensing is increasingly being used as inputs to these models (e.g. Osborne et al. 2001, Jeganathan et al. 2004, Roxburgh and Buchanan 2010). The spatial resolution of some remote sensing data means that they can be used to make predictions of habitat suitability that have greater spatial accuracy than is possible using stable isotopes or bioclimatic modelling.

Field surveys in 2007 and 2008 in western Senegal and Mauritania collected information on presence or absence of Aquatic Warblers at almost 150 sites within the previously suggested wintering range (Pain et al. 2004, Schäffer et al. 2006, Walther et al. 2007). Here we use these data in conjunction with remote sensing and climatic data to model the distribution of potentially suitable wintering habitat to which field surveys could be targeted. Models were built using maximum entropy modelling, which is one of the best approaches when there are a small number of training points (Wisz et al. 2008, Franklin 2009). We used both known (putative) absences and pseudo-absences to develop the models. Putative absence records may improve models (Lobo 2008), but using absence data from only a small area may reduce model performance (VanDerWal et al. 2009). In an attempt to address these issues, the outputs from models built using putative absences and pseudo-absences were combined to identify potential wintering areas for the Aquatic Warbler to which field surveys could be targeted.

Materials and methods

Bird data

Bird data were collected in January and February, 2007 and 2008 (Flade et al. in press). In 2007, surveys used mist nets to determine whether birds were present. In 2008, surveys were undertaken using a mixture of mist netting and field surveys across a range of other sites, but these were all apparently unoccupied (Flade et al. in press). Aquatic Warblers were recorded at nine locations, all within Djoudj, while they were apparently absent from 138 locations. In Djoudj, Aquatic Warblers were exclusively found in waterlogged vast open grassy marshes, dominated by plants such as *Scirpus littoralis*, *Eleocharis mutata*, *Oryza longistaminata* and *Sporobolus robustus*, with none or only very few scattered bushes or trees, the water table being mostly 10–20 cm above ground (Flade et al. in press). Aquatic Warblers were not recorded in such marshes when they were not waterlogged, as birds presumably leave the area, as soon as surface water has gone. Birds were also not recorded in habitats with water tables more than 30 cm above ground, in semi-open marshes with bushes and trees, in small habitat patches of less than 20 ha, nor in cattail (*Typha* sp.) stands (Flade et al. in press).

Environmental data

A c. 1 000 000 km^2 study area between 17.5° to 11° N and 17.5° to 3° W (Figure 1), covering much of the potential wintering range of Aquatic Warbler (Pain et al. 2004, Schäffer et al. 2006, Walther et al. 2007, Oppel et al. in press), was considered. For the winter months (October–February) of 2007/08, the 10-day (dekad) maxima normalised difference vegetation index (NDVI) and normalised difference water index (NDWI) data derived from the SPOT-Vegetation instrument (a one-kilometre-resolution remote sensing sensor on-board the SPOT-4 satellite that is optimised for global-scale vegetation monitoring) were obtained from the VEGETATION website (http://free.vgt.vito.be). These were reduced through principal components analysis (PCA) to the top five components for each, which in each case explained over 95% of the variation. Additionally, annual precipitation and mean annual temperature were extracted for the study area from the Bioclim (http://www.worldclim.org). Manipulations were undertaken in ERDAS Imagine 8.5 (Leica Geosystems GIS and Mapping, Atlanta, Georgia, USA) and ArcMap 9.2 (ESRI, Redlands, California, USA).

Distribution models

Models were produced using maximum entropy modelling in MaxEnt 3.3.2 (Phillips et al. 2006, Phillips and Dudik 2008). Maximum entropy modelling produces an output map indicating the likelihood of occupancy in each cell (higher values indicating increased likelihood of occurrence). This is derived from a probability distribution produced using environmental predictor variables, presence data and either pseudo-absence data or user-specified absence data. MaxEnt generates a user-defined number (in our case 10 000) of pseudo-absences (random locations within a defined area at which the species is assumed to be absent) or can use user-specified input data (e.g. putative absences) against which to compare the environmental characteristics at the presence points. Probability distributions are produced from functions of the input variables, with the probability distribution that is most spread out or closest to uniform being selected at each stage. Through a process of machine learning, the final probability distribution that is closest to uniform (maximum entropy) is estimated.

Three slightly different model training sets were used to produce three different models, and three model outputs (Table 1). Model 1 used the nine presence records from Djoudj and the 127 locations from which birds were not recorded (some of the 138 apparent absences fell within the same 1 km square). Model 2 used the nine presence records from Djoudj and 10 000 random pseudo-absence points. Model 3 used the nine presence records from Djoudj and the records from Walther et al. (2007) that were within the study area as presence records, and 10 000 random pseudo-absences. As an independent test of models 1 and 2, the suitability predicted by the models was extracted around the 17 locations used by Walther et al. (2007) that were within the study area. Owing to uncertainty over the accuracy of the coordinates of all of these records, an arbitrary 10 km buffer around these locations was used. Default MaxEnt settings were used. This included removal of duplicate records so each location could only be entered once in modelling, 10 000 pseudo-absences (in models 2 and 3), and linear feature use (a simple model-building function). The first five components from the NDVI PCA, and the first five components from the NDWI PCA, together with temperature and precipitation, were initially considered in all of the models. Variables were retained in the models if their estimated relative contribution to the model was more than 1%. Model accuracy was assessed by the 'area under the receiver operating curve' (AUC). This is a threshold-independent characteristic that assesses model performance at all possible thresholds (cut-offs for binary classifications) by a single number that is itself comparable between algorithms (Phillips et al. 2006). Values above 0.5 indicate that models classify observations (i.e. present or absent) more accurately than expected by chance alone, with values of one indicating perfect classification. To test the consistency in the accuracy of the models, nine replicates with cross-validation were run for each model, and the average AUC and SD recorded.

Results

Models 1 and 2 (those based on the presence locations from Djoudj only) retained only the NDVI and climate variables (Table 1). The NDWI principal components contributed less than 1% to the models. The NDVI principal

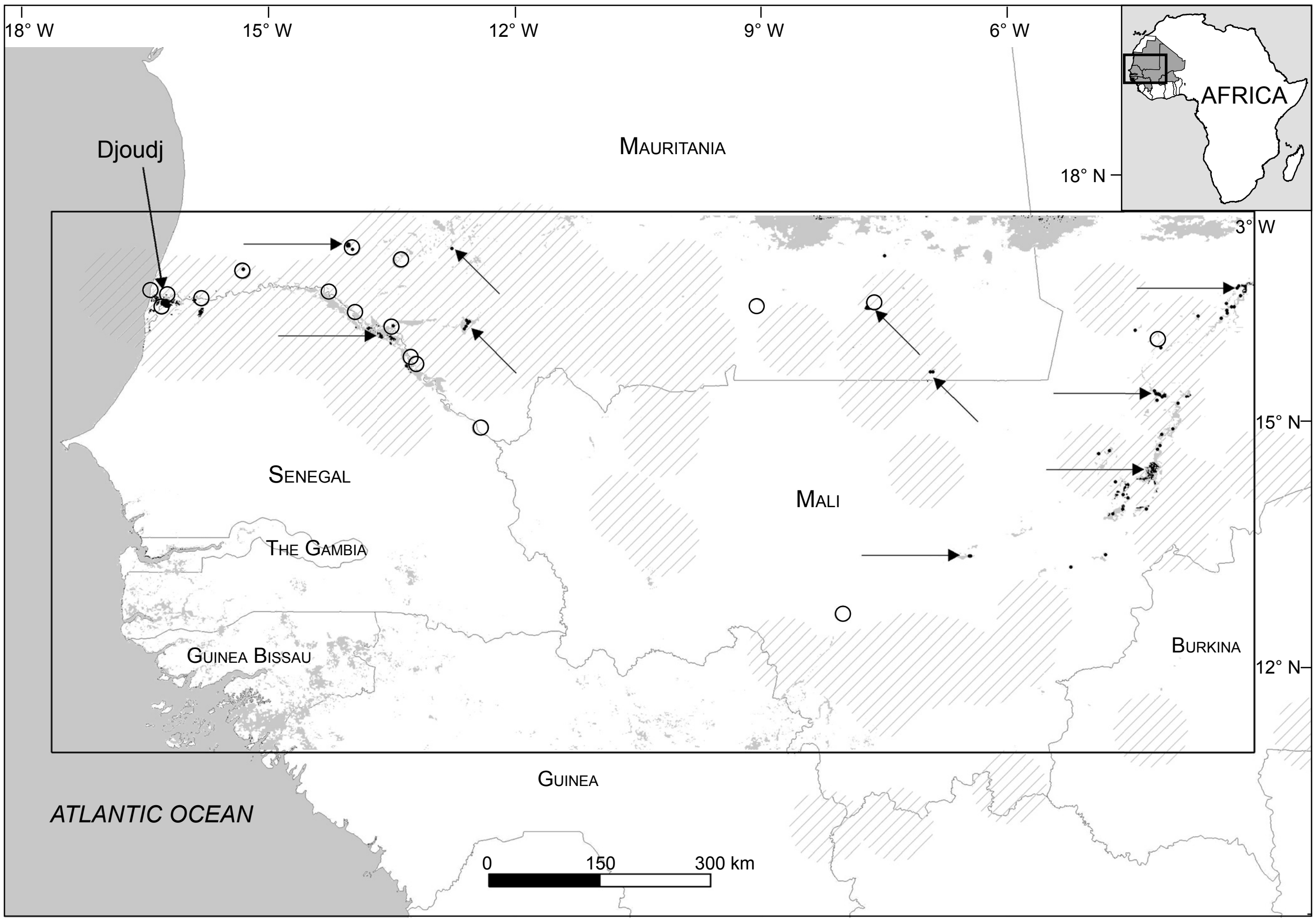

Figure 1: Distribution of potentially suitable Aquatic Warbler wintering areas based on either model 1 or model 2 (shown in grey). Areas predicted as suitable by both models appear black. Hatching indicates areas located according to stable isotopes concentration in Aquatic Warbler feathers from the breeding sites (Oppel et al. in press). Circles indicate location of historical records, while arrows indicate areas mentioned in the text for searching

Table 1: Summary of the variables included in each of the three models (numbers refer to principal components of normalised difference vegetation index [NDVI] and normalised difference water index [NDWI]) and assessments of model performance. Area under the receiver operating curve (AUC; a measure of discriminatory ability of the model, with 0.5 = random and 1.0 = perfect discrimination) and proportion area predicted to be suitable are the averages derived from sequential removal of each training point in turn. Historic records are those presented by Walther et al. (2007)

	Model 1	Model 2	Model 3
Variables	Temperature, NDVI 2,4	Temperature, precipitation, NDVI 2,4	Precipitation, NDVI 1,2,3,4, NDWI 1,2,3
AUC (SD)	0.909 (0.075)	0.999 (0.001)	0.878 (0.126)
Area ‘suitable’ (%)	18.6	0.27	20.7
Unoccupied sites ‘suitable’	28/127	21/127	127/127
Occupied sites ‘suitable’	9/9	9/9	9/9
Number of historic sites with ‘suitable’ habitat within 10 km	13/17	9/17	17/17

components contributed 91% and 76% to models 1 and 2, respectively, meaning the climatic variables contributed relatively little to models 1 and 2. By contrast, annual precipitation was the most important variable in model 3 (it contributed 53% to the model), suggesting that this model mapped the suitable climate space for the species. Model 2 (nine Djoudj presences, 10 000 random absence points) predicted the smallest extent of suitable habitat, and had the highest mean AUC (0.99). Based on the equal sensitivity and specificity threshold in MaxEnt, the model suggested that less than 0.3% of the area, or about 2 700 km^2, was potentially suitable (Figure 1). This included the nine training points, and some habitat within 10 km of 53% of the historical records (Table 1). Model 1, which was an extrapolation to the wider area of a model based on the nine Djoudj presences and the 127 putative absences from surveys, suggested 18% of the area was potentially suitable (again using the equal sensitivity and selectivity threshold value.) A large proportion of this was around the south of the study area (Figure 1). The model correctly predicted all nine of the occupied training sites as potentially suitable. However, even though it was used as training data, the model identified 28 of the apparently unoccupied sites as potentially suitable, suggesting overprediction of the area of suitable habitat, or that not all suitable habitat is occupied. Some 70% of the area predicted as suitable by model 2 was also suitable according to model 1. Approximately 1 100 km^2 (0.1% of the study area), was predicted as potentially suitable as wintering habitat by both models. Model 3, based on the nine Djoudj presences and the 17 points within the study area of Walther et al. (2007) and 10 000 pseudo-absences, predicted the largest area of potentially occupied habitat. This model, to which rainfall was a major contributor, suggested all of the areas where historic records came from were potentially suitable (Table 1). However, it also suggested that all of the areas from which birds were not recorded in 2008 (putative absences) were also suitable, suggesting either considerable over-prediction of suitable habitat or that not all suitable areas were occupied.

Discussion

By combining remote sensing and climate data with bird sightings, we modelled the potential winter distribution of Aquatic Warblers at a resolution appropriate for targeted field surveys. Three slightly different sets of training data were used, which produced different models. Two of these were based mainly on NDVI (suggesting they were modelling suitable habitat), while the third model may have described climatic conditions. The outputs of the two models based on NDVI were overlaid to identify areas for targeting field surveys towards (Figure 1). The maps produced by our analyses, although based on a small number of points from a small area, indicate that the area of potentially suitable wintering habitat for Aquatic Warblers is very restricted. These are located along the Senegal and Niger rivers, and include a number of inland water bodies, based on comparison with Global Land Cover 2000 (GLC2000; Mayaux et al*.* 2004). It could be argued that GLC2000 could be used to target surveys, instead of this dedicated analysis. However, the nine Djoudj records fall within a coarse habitat type described as ‘sparse grassland, cropland with open woody vegetation or irrigated cropland’, which in total covers some 320 000 km^2 of the study area. Consequently, this approach does not limit the search area for the species, supporting the use of a dedicated analysis.

The validity of the maps produced by models 1 and 2 for identifying potential wintering sites of the birds is supported by their prediction of suitable habitat within at least half of the locations where Aquatic Warblers had historically been recorded. Land cover changes may mean that areas that were previously occupied were no longer suitable, potentially partially explaining why some sites were not identified as suitable. Additionally, the suitable areas were predominantly within the areas suggested by projected stable isotope gradients as potential wintering zones (Oppel et al*.* in press). Some of the models may have overestimated the extent of potential habitat with, for example, areas predicted to be suitable for this species in The Gambia. However, while these areas may contain potentially suitable habitat, they fall outside the expected winter range of the species, based on previous studies (Pain et al*.* 2004, Schäffer et al*.* 2006, Walther et al*.* 2007, Oppel et al*.* in press) and recent field surveys (Flade et al*.* in press). Consequently, we suggest efforts be concentrated on the higher latitude sites.

We would caveat the results to some extent though, as the presence sample sizes used to develop two of the models were low (just nine records). However, such small presence sample sizes are around those previously shown to work reasonably well within the maximum entropy modelling framework (Phillips and Dudik 2008, Wisz et al. 2008). Some caution is also needed in interpreting the AUC values, given the high level of spatial autocorrelation, high levels of which can inflate AUC values (Veloz 2009). However, the fact that the two models to which these caveats apply predicted that there was suitable habitat within 10 km of at least 53% of the 17 historical records suggests they are describing some of the variation that may indicate areas of potential suitability to Aquatic Warblers.

Importantly, targeting field surveys to the sites identified here as containing potentially suitable habitat to confirm the presence or absence of birds in winter is now possible, and will be the next important step. Only after these searches, the models can be properly validated (and refined if appropriate). We suggest field surveys should be targeted towards sites in the Inner Niger Delta and a number of marshes along and away from the river in Mali (Figure 1). In particular, searches could be targeted towards marshes to the south of Kabara (16°36′ N, 3°6′ W), and around Lac Debo (15°18′ N, 4°9′ W) south through to Yebe (14°25′ N, 4°13′ W) then west to 14°17′ N, 4°25′ W, as well as west of Mopti (around 14°10′ N, 4°34′ W) and perhaps wetlands near Segou (13°20′ N, 6°28′ W). While there may be extensive areas of potentially suitable habitat in these latter areas, their suitability may depend on water level (M Diallo and B Niagate pers. comm.). In Mauritania, areas to consider include Lac d’Aleg IBA (17°8′ N, 14°2′ W), wetlands north of M’bout (16°10′ N, 12°33′ W), the wetlands west of Timbedra (16°22′ N, 7°41′ W) and perhaps around 16°55′ N, 13°24′ W and 15°36′ N, 6°56′ W. Along the Senegal River, a number of areas around Mbange (16°0′ N, 13°37′ W) were identified as potentially occupied, but surveys suggested that the patches of habitat in these areas may be too small to be occupied (MF pers. obs.).

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