

Mapping Landscape Phenology Preference of Yellow-Billed Cuckoo With AVHRR Data

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Abstract—We mapped habitat for threatened Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) in the State of Arizona using the temporal greenness dynamics of the landscape, or the landscape phenology. Landscape phenometrics were derived from Advanced Very High Resolution Radiometer (AVHRR) Normalized Difference Vegetation Index (NDVI) data for 1998 and 1999 by using Fourier harmonic analysis to analyze the waveform of the annual NDVI profile at each pixel. We modeled the spatial distribution of Yellow-billed Cuckoo habitat by coupling the field data of Cuckoo presence or absence and point-based samples of riparian and cottonwood-willow vegetation types with satellite phenometrics for 1998. Models were validated using field and satellite data collected in 1999. The results indicate that Yellow-billed Cuckoo occupy locations within their preferred habitat that exhibit peak greenness after the start of the summer monsoon and are greener and more dynamic than “average” habitat. Identification of preferred phenotypes within recognized habitat areas can be used to refine habitat models, inform predictions of habitat response to climate change, and suggest adaptation strategies.

Introduction

The Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) is a neo-tropical migrant bird that travels north from Central and South America into the southwestern United States to nest during the summer. Riparian forest and woodland nesting habitat of this threatened species has declined in the western United States over the past century. As a result, Western Yellow-billed Cuckoos have been petitioned for possible listing under the 1973 Endangered Species Act.

Riparian habitats contain dense, water-loving deciduous species including cottonwood (*Populus fremontii*) and willow (*Salix gooddingii*)—vegetation preferred by Yellow-billed Cuckoo. In central and southern Arizona, there is a marked contrast between the riparian vegetation and the surrounding arid and semi-arid upland vegetation that dominates most of the landscape. This contrast produces strong vegetation reflectance signals that can be detected by satellite remote sensing both in terms of the strength of the signal due to the difference in vegetation type and density and also in terms of the temporal pattern of the greenness dynamics, or landscape phenology.

The objectives of this study were to identify characteristic phenology patterns preferred by Yellow-billed Cuckoo as captured by satellite data and use these characteristics to map preferred habitat of the Yellow-billed Cuckoo in the State of Arizona.

Data

The Yellow-billed Cuckoo field data used in the models came from a state-wide census (Johnson and others 2010). The satellite data used are the Advanced Very High Resolution Radiometer (AVHRR) 1-kilometer resolution Normalized Difference Vegetation Index (NDVI) bi-weekly composites. These data are sensitive to biophysical vegetation characteristics, including biomass and percent cover (Huete and others 2002). The riparian vegetation map was created by the Arizona Game & Fish Department (AZGF) in 1994 (www.land.state.az.us). For this study, we created two binary images: all riparian (RIP) vegetation and riparian Cottonwood-Willow (CW) vegetation. We excluded any riparian vegetation in the far north and northeast of the state because no bird sightings were reported in those areas.

Methods

Five sets of point data were compiled including 78 survey locations with Yellow-billed Cuckoo present for 1998; 43 survey locations with birds absent for 1998; point-sampling polygons of CW vegetation; point-sampling polygons of RIP vegetation; and 360 bird sightings for 1999.

Phenometrics were derived by applying a Fourier harmonic analysis to the temporal AVHRR NDVI profiles at each image pixel in the State of Arizona (Jakubauskas 2001; Wallace 2002). Fourier analysis expresses a complex curve as the sum of an “additive term” and simple cosine waves of different frequencies. Three new images each representing a phenometric were created: (1) the amount of greenness—the “additive term” component that is the best fit of a flat line to the profile and is related to the vegetation productivity; (2) dynamics or variability of the greenness—the magnitude of the first frequency component that is the amplitude of the single cosine

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wave that fits the annual profile best; and (3) the timing of peak green-up—the phase of the first frequency component that is the position of the peak of the single cosine wave that fits the annual profile best, rescaled to represent a day of the year (DOY) between 0 and 365.

The phenometrics were sampled and summarized for each of the 5 point data sets. Two-tailed Student's t-tests were performed to identify the phenometrics that were significantly different in the survey locations with Cuckoos present compared to the other point locations; these phenometrics were used to create Cuckoo phenology preference models. We rescaled the phenometrics based on the statistical distribution of the values at the set of 1998 Cuckoo presence data to create uniform units of the standard deviation distance (SDD) by calculating the difference between the phenometric and the mean value observed at the 1998 Cuckoo sightings divided by the observed 1998 standard deviation.

Three models were created, one continuous and two categorical. For each model, each phenometric was stratified into three categories: “high” targeted to contain 50% of the sightings, “medium” with 30% (cumulative 80%), and “low” with 19-20% (cumulative >99%), as follows:

1. **Standard Deviation Distance-based Model**—The SDDs of selected Phenometrics were averaged to produce a phenology preference map based on the average SDD.

2. **Standard Deviation Stratified Model**—The SDD of each phenometric was stratified into three preference classes using the SDD values of ± 0.67 , ± 1.28 and ± 3.0 ; given a normal distribution, these cutoffs would capture cumulative percentages of 50, 80 and 99+, respectively. The three stratified phenometrics were then

summed, producing a single map with nine classes ranging from 1 = low preference to 9 = high preference.

3. **Rank-based Model**—The Rank and Percentile was calculated for each 1998 phenometric at the CW points. The 1998 CW ranks were identified for the phenometrics at the 50-80-99 SDD values observed at the 1998 bird sightings; these same ranks were then identified for the ranked 1999 CW phenometrics, and the corresponding 1999 phenometric values extracted. Each phenometric was stratified into three preference classes using these extracted values and the three maps were summed, producing nine classes from 1 = low preference to 9 = high preference.

The models were validated by determining how well they predicted Cuckoo presence in 1999. Refinements of the model based on observed phenometric relationships within and between years were also explored and applied.

Results

All three models created from phenometric values observed in 1998 were effective at predicting the locations of Yellow-billed Cuckoo sighted in 1999. We considered the standard deviation stratified model (fig. 1A) superior given it identified a less generalized mapping and predicts 64-98-100% cumulatively of the 1999 bird sightings in the High (greens)-Medium (orange)-Low (dark gray) classes, respectively. The model was then clipped to probable landscapes, from most to least limited with each a subset of the next (figs. 1B, C, D).

Examination of the statistics and histograms for the locations with Birds Present and the CW vegetation types shows the phenometrics

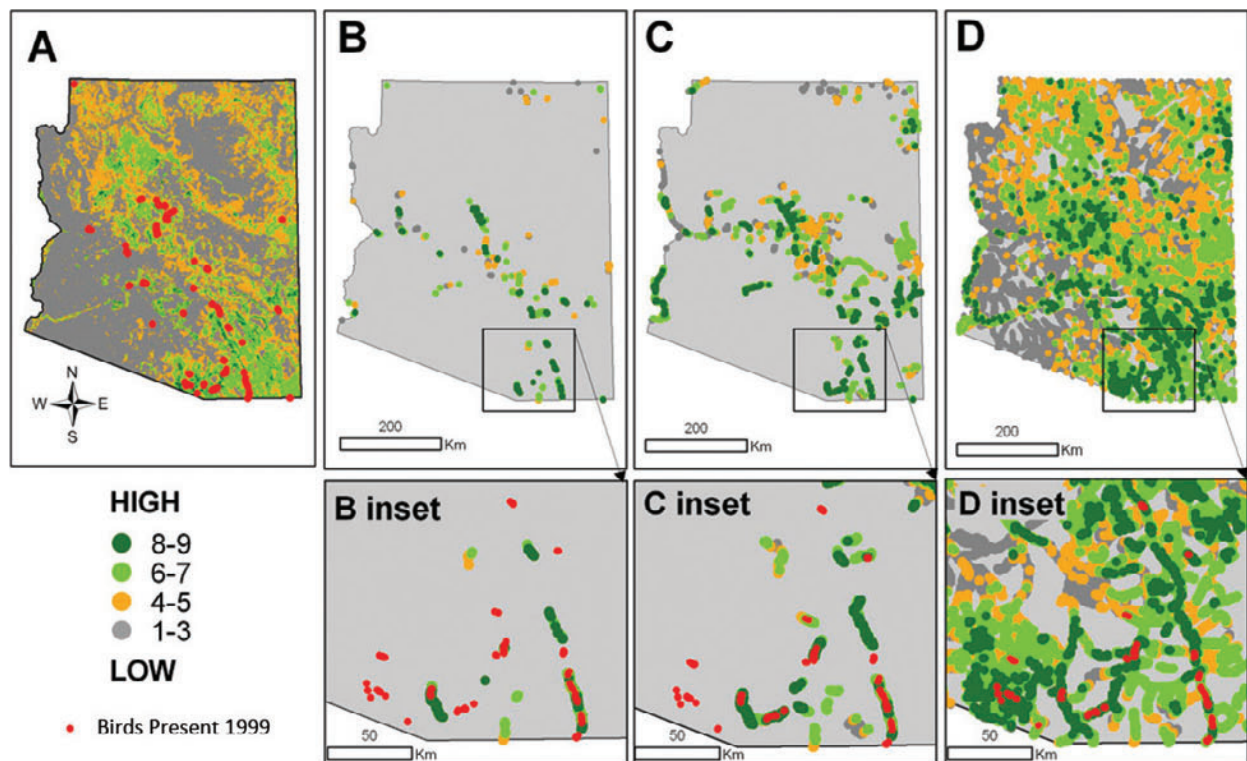


Figure 1—Standard Deviation Stratified Model, showing High-Medium-Low phenology preference classes. View B is clipped to CW vegetation, view C is clipped to RIP vegetation, and view D is clipped to the Arizona Streams Data, digitized from 1988 1:100,000 USGS topographic maps. The insets show the 1999 bird locations overlaid onto the clipped models.

of these landscapes share parallel relationships in 1998 and 1999. In both years, birds occupy landscapes that have a more variable, dynamic greenness, achieve a maximum greenness later in the year, and are significantly greener than the “average” CW vegetation. We, therefore, refined the model by averaging the observed intra-annual phenometrics offsets and created generalized models for both 1998 and 1999 that define Yellow-billed Cuckoo habitat relative to the observed phenology of the CW vegetation. These models correctly predict in High-Medium-Low classes cumulative bird presence percentages of 57-99-100 and 81-99-100, for 1998 and 1999, respectively.

Discussion

We found that Yellow-billed Cuckoo occupy locations within their preferred habitat that green up later in the year, have a more dynamic greenness and are greener than the average cottonwood-willow habitat. These could be areas of healthier and denser trees or could be a vegetation signature in the understory that reflect conditions supporting larger insects—a food that the Yellow-billed Cuckoos favor and exploit. Phenology preference models were effective at predicting Cuckoo sightings in both years, and could be refined as additional data become available. These models are successful because there is

a consistent relationship between the intra-annual phenometrics for Cuckoo sightings relative to those in their preferred cottonwood-willow habitat. It is likely that other species will exhibit similar phenotype preferences within their habitat types. Such relationships can be used to refine habitat models, predict species presence in other areas of the Southwest and better inform habitat response to climate change.

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