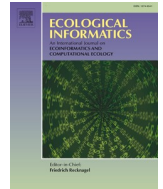




Contents lists available at ScienceDirect

Ecological Informatics

journal homepage: www.elsevier.com/locate/ecolinf

Identification of dialects and individuals of globally threatened yellow cardinals using neural networks

Hernan Bocaccio^{a,*}, Marisol Domínguez^{b,c,d}, Bettina Mahler^{b,c}, Juan C. Reboresca^{b,c}, Gabriel Mindlin^{a,e}

^a Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Física, Ciudad Universitaria, 1428 Buenos Aires, Argentina

^b Departamento de Ecología, Genética y Evolución, FCEyN, Universidad de Buenos Aires, Argentina

^c Instituto de Ecología, Genética y Evolución de Buenos Aires (IEGEBA), UBA-CONICET, Buenos Aires, Argentina

^d Unit of Evolutionary Biology/Systematic Zoology, Institute of Biochemistry and Biology, University of Potsdam, Germany

^e CONICET - Universidad de Buenos Aires, Instituto de Física Interdisciplinaria y Aplicada (INFINA), Ciudad Universitaria, 1428 Buenos Aires, Argentina

ARTICLE INFO

Keywords:

Yellow cardinal
Bird species conservation
Deep learning
Birdsong dialects
Individual identification

ABSTRACT

Audio-based analysis of bird songs has proven to be a valuable practice for the growth of knowledge in the fields of ethology and ecology. In recent years, machine learning techniques applied to audio field recordings of bird calls have yielded successful results in studying population distributions and identification of individuals for their monitoring in a variety of bird species. This offers promising possibilities in the study of social behavior, biodiversity, and conservation strategies for birds. In this work, we trained deep learning models, directly from the sonograms of audio field recordings, to investigate the statistical properties of vocalizations in an endangered bird species, the Yellow Cardinal, *Gubernatrix cristata*. This research marks the first successful application of this method to an endangered species. Our results indicate the presence of vocal signatures that reflect similarities in songs of individuals that inhabit the same region, determining dialects, but which also show differences between individuals. These differences can be exploited by a deep learning classifier to discriminate the bird identities through their songs. Models trained with data labeled by regions showed a good performance in the recognition of dialects with a mean accuracy of 0.84 ± 0.04 , significantly higher than the accuracy obtained by chance. Precision and recall values also reflected the classifier's ability to find alike vocal patterns in the songs of neighboring individuals. Models trained with data labeled by individuals showed an accuracy of 0.63 ± 0.03 , significantly higher than that obtained by chance. However, the individual discrimination model showed greater confusion with neighboring individuals. This reflects a hierarchical structure in the characteristics of the Yellow Cardinal's vocalization, where the intra-individual variability is lower than the inter-individual variability, but it is even lower than the variability obtained when individuals inhabit different regions, providing evidence of the existence of dialects. This reinforces the results of previous works but also offers an automated method for characterizing cultural units within the species. Along with genetic data, this method could help better define management units, thereby benefiting the success of reintroduction of individuals of Yellow Cardinal recovered from the illegal trade. Moreover, the novelty of individual discrimination using neural networks for the Yellow Cardinal, which has limited data availability, shows promise for non-invasive acoustic monitoring strategies with potentially relevant implications for its conservation.

1. Introduction

The Yellow Cardinal, *Gubernatrix cristata*, is currently listed as an endangered species according to the International Union for Conservation of Nature (IUCN) Red List (BirdLife International, 2018). This passerine bird belonging to the Thraupidae family (Barker et al., 2013),

is endemic to the southern regions of South America (Ridgely and Tudor, 1989), including the south of Brazil (Beier et al., 2017; Beier and Fontana, 2019; Bülau et al., 2021), Uruguay (Azpiroz et al., 2012; Domínguez et al., 2017), and central Argentina, where the largest populations have been found (Domínguez et al., 2017, 2020). The global population is estimated to be between 1000 and 2000 mature individuals,

* Corresponding author.

E-mail address: hbocaccio@gmail.com (H. Bocaccio).

<https://doi.org/10.1016/j.ecoinf.2023.102372>

Received 19 May 2023; Received in revised form 6 November 2023; Accepted 8 November 2023

Available online 10 November 2023

1574-9541/© 2023 Elsevier B.V. All rights reserved.