Species Distribution Models As Tools for Conservation: A Case Study Using Maxent and the West Indian Whistling Duck, *Dendrocygna arborea*, in Caño Tiburones, Puerto Rico[1]

Sheylda N. Díaz Méndez[2] and Jesús A. Aguiar-Escobar[3]

Abstract: Analysis of the distribution of a species is crucial for the design of a conservation plan. This study used a species distribution model to assess the available suitable habitat of the West Indian whistling duck (WIWD), *Dendrocygna arborea*, in Caño Tiburones, a coastal wetland of significance for bird biodiversity located in the northern Puerto Rico municipalities of Arecibo, Barceloneta, and Manatí. A dataset derived from e-Bird (2003-2015) was analyzed using Maxent for 56 presence locations and six environmental variables. The results showed the diurnal habitat for *D. arborea* and it revealed that its distribution was mostly affected, first, by the distance to disturbances and, second, by precipitation. The species response curves suggest that the WIWD prefers habitats close to structures and a mean annual precipitation between 1400-1600 mm. The model revealed that only 11.13% of Caño Tiburones is a potential suitable diurnal habitat for *D. arborea*.

Keywords: Species Distribution Models, Maximum entropy, habitat selection, modeling, Maxent, West Indian Whistling Duck, *Dendrocygna arborea*, Caño Tiburones, Arecibo, Barceloneta, Manatí, Puerto Rico

Introduction

Species distribution models estimate the relationship between species records at sites and the environmental and spatial characteristics of those sites (Franklin 2009). In the last two decades, developments in the field of species distribution modelling as well as multiple methods of estimating it have been increasing rapidly, are widespread and are increasingly easy to use.

The West Indian Whistling-duck (WIWD, Figure 1), *Dendrocygna arborea* (Linnaeus, 1758) is a Caribbean endemic bird distributed throughout the West Indies (Collar et al. 1992). The WIWD is considered as a nocturnal species due to its activity in the night but is also active during the day. It is currently listed as near threatened by the International Union for Conservation of nature (BirdLife International 2020). This duck is considered an endangered bird in Puerto Rico [Departamento de Recursos Naturales y Ambientales (DRNA) 2016]. because historical surveys of WIWDs estimated the total at 60-90 individuals distributed in all of the island (Méndez-Gallardo and Salguero-Faría 2008). This was found to be an underestimate during a study in southwestern of Puerto Rico where other

---

[1] Submitted on May 1, 2020. Accepted on May 20, 2020. Last revisions received on August 30, 2020.

[2] Universidad del Turabo, Gurabo, Puerto Rico 00778. E-mail: sdiaz64@suagm.edu .

[3] Universidad Central de Venezuela, Caracas 1053, Distrito Federal, Venezuela. E-mail: j.adolfo.3@gmail.com .

DOI: 10.9784/LEB8(2)Diaz.01

Electronically available on August 31, 2020. Mailed on August 31, 2020.

researchers counted more than 150 WIWDs in Cartagena Lagoon in 2016 (Goodman et al. 2018).

Considering the shortcomings in estimating populations of WIWDs in Puerto Rico, such as no formal surveys since the 1990's and an underestimate by the Department of Natural and Environmental Resources as well as the habitat loss that may result from additional climate change, it is crucial to relate the occurrence of WIWD to a group of habitat and climatic variables. Herein, we report the results of such a study using eBird, a citizen science database of bird sightings, processed with Maxent. Maxent, which stands for maximum entropy, is an open source software that models species' distribution based on presence-absence data, maximizing the spread of the organisms in space, within the constraints of the environmental variables of the localities where the conspecifics are found.

Figure 1. An adult West Indian Whistling duck, *Dendrocygna arborea* standing on a *Rhizophora mangle* branch. This species does not exhibit sexual dimorphism; thus the external reproductive organs of individual ducks need to be examined to determine their biological gender. The individual in the photo possibly was 48-58 cm tall (see Carboneras and Kirwan 2020). Photographed by Myriam Carazo, copyrighted by Loving Photography, and herein reproduced with permission.

Methods

Study area

Caño Tiburones is recognized as one of the most important areas for birds in Puerto Rico (Méndez-Gallardo and Salguero-Faría 2008). This wetland is located in the northern coast of Puerto Rico (municipalities of Arecibo, Barceloneta, and Manatí) and covering an area of 151.5 km^2 (Figure 2).

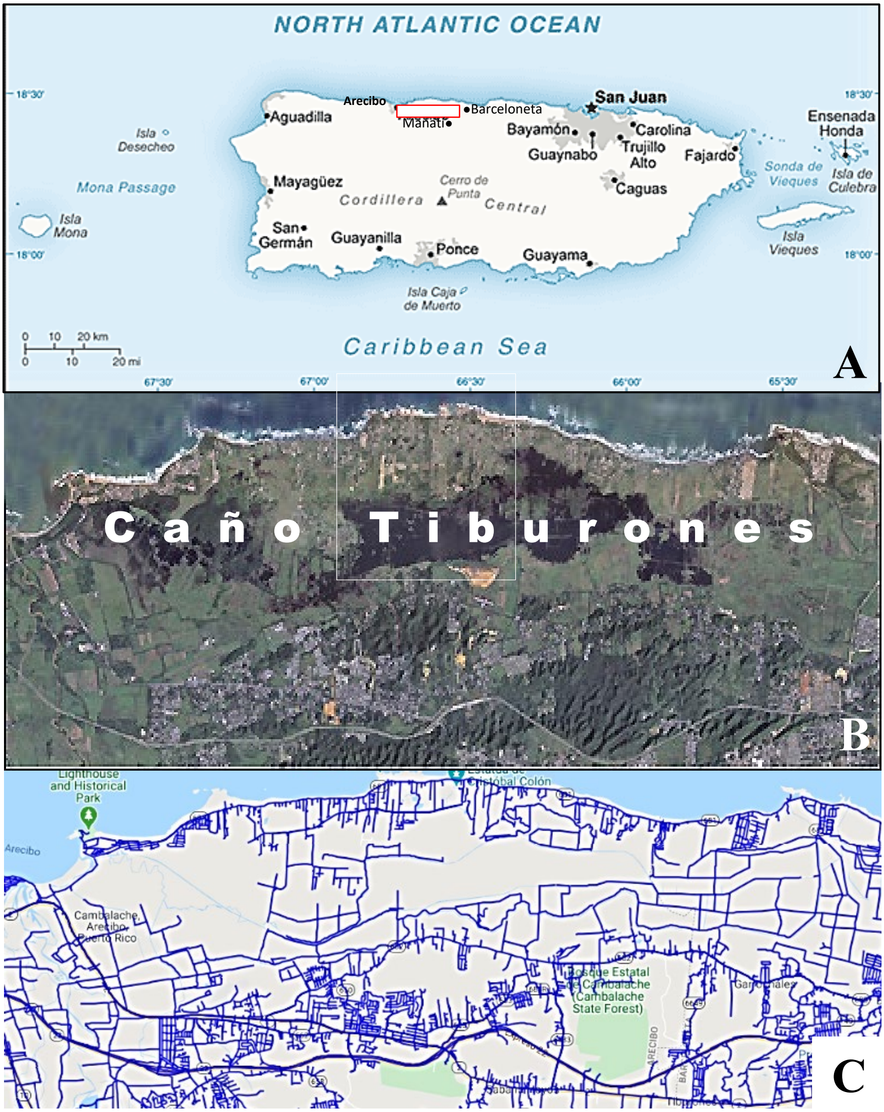


Figure 2. Caño Tiburones in the context of the island of Puerto Rico. A. Red rectangle delimits location of the 56 eBird observations within Caño Tiburones. B. Aerial photograph the same area. White rectangle circumscribes the approximate area displayed in panels A and B of Figure 3. C. Roads around Caño Tiburones (portions located in the municipality of Manatí, right of the image, not shown). The extensive road system, which in yesteryears facilitated agricultural uses, currently services an increasing human population (Zack and Cacho 1984, Quiñones-Aponte 1986) Presence records of the WIWD from eBird are depicted on Figure 5. The provenance of maps used in this figure is listed in Footnote 4.

Caño Tiburones contains the largest herbaceous wetland on the island and is one the sites that receives migratory birds, like the Piping plover, *Charadrius melodus* (Ord, 1824), an endangered species (Anonymous 2007). More than 190 species of birds have been documented in Caño Tiburones (DRNA 2016). The WIWD has also been seen in Cartagena Lagoon in the US Fish and Wildlife Refuge (Goodman 2018), located in southwestern Puerto Rico, and in Humacao Natural Reserve managed by the Department of Natural Resources, Humacao, in southeastern PR. Significant portions of Caño Tiburones lie below sea level. The coastal lagoon includes large swamps of cattail, or "yerba de Eneas", *Typha domingensis* Persoon (Typhaceae), the most common plant species in the entire system located at the ecotone of the aquatic and terrestrial environments. Upland, there are mangrove forests, salt flats, sand dunes, and coastal shrub forests communities [Departamento de Recursos Naturales y Ambientales (DRNA) 2007, Figure 3A-B]. Towards the water, there are floating and submerged aquatic plant communities (Figure 3C-D).

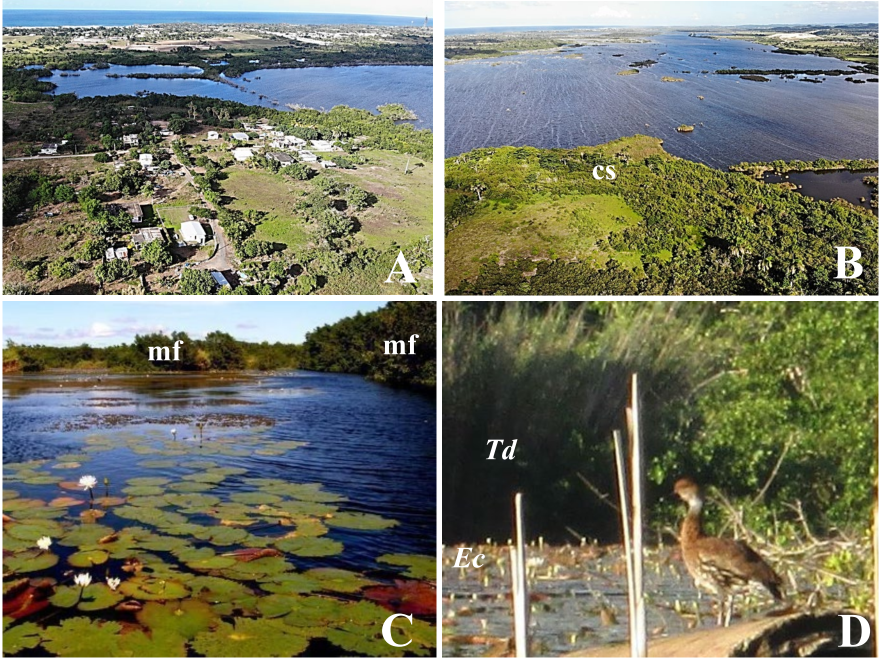


Figure 3. Caño Tiburones. A and B are approximately continuous aerial views of the area denoted by the white rectangle on Figure 2B, cs represents coastal scrub. C. Patch of water lilies, *Nymphaea* sp., an example of an emergent plant, with a mangrove forest, mf, on the background. D. A WIWD sitting on top of a large reinforced cement cylinder surrounded by *E. crassipes*, *Ec*, and a patch of *T. dominguensis*, *Td*.

Using *T. domingensis* as an ecotonal demarcation, other plant species associated with the WIWD in Caño Tiburones include wetland ferns, such as *Acrostichum aureum* Linnaeus (Pteridaceae) and *A. danaeifolium* von Langsdorff and von Fischer; emerging plants, such as "loto", or water lilies, *Nymphaea* sp. (Nymphaeaceae); floating plants, such as the water hyacinth, *Eichhornia crassipes*; and submerged estuarine plants, such as, *Ruppia maritima* Linnaeus (Ruppiaceae). On the terrestrial side, there are grasses (Poaceae), such as *Panicum aquaticum* Poiret and *Paspalum millegrana* Schrader; cyperaceans, such as *Cyperus odoratus* Linnaeus and *Eleocharis cellulose* Torrey and trees, such as "almendro", *Terminalia catappa* Linnaeus (Combretaceae), Australian "pine" *Casuarina equisetifolia* Linnaeus (Casuarinaceae, not a true gymnospermous pine), and the common mangrove community trees, namely the red mangrove, *Rhizophora mangle* Linnaeus (Rhizophoraceae), white mangrove, *Laguncularia racemose* (Linnaeus) Karl Friedrich von Gaertner (Combretaceae), black mangrove, *Avicennia germinans* (Linnaeus) Linnaeus (Acanthaceae), and the button mangrove, *Conocarpus erectus Linnaeus* (Combretaceae).

Mean annual temperature in Caño Tiburones is 26.9˚C and the annual precipitation varies between 1,000 to 2,000 mm (Vélez et al. 2019). The wet season typically occurs between the months of May to November and dry season from December to April [Departamento de Recursos Naturales y Ambientales (DRNA) 2007]. The soils are acidic, mostly organic, and hydric, which implies low permeability of water as well as permanent or seasonal waterlogging (Salles et al. 1983).[4]

Maxent models

Maxent models the distribution of a species in a geographic area uses presence-only records (Elith and Leathwick 2009). It produces a prediction of the occurrence probability of the species as it calculates the distribution of the maximum entropy based on covariates (Pearson 2007). Maxent works as a multinomial logistic regression, classifying multiclass problems with more than two possible discrete outcomes (Phillips et al. 2006). The Maxent algorithm is not sensitive to sample size and can generate species response curves in relation to environmental factors (Khanum et al. 2013).

---

[4] The map used in Figure 2A is from the Perry-Castañeda Library Map Collection, https://legacy.lib.utexas.edu/maps/cia16/puerto_rico_sm_2016.gif . The image used in Figure 2B came from Caño Tiburones 2007 Earth Explorer Landsat-7. United States Geological Survey. https://earthexplorer.usgs.gov/ The map used in Figure 2C is from data.pr.gov, https://data.pr.gov/widgets/icv9-n44d . All images on the panels of Figure 2 have been slightly Photoshopped. Panels B and C have additional labels not present in the originals. Marilyn Rivera Torres (MRT Real Estate) kindly allowed us to use aerial photos taken by a drone belonging to her that form part of Figures 3A-3B.

Maxent model assumptions

The model assumes that the data is case specific, meaning that each independent variable has a single value for each case (Phillips et al. 2006). As with other types of regressions, there is no need for the independent variables to be statistically independent from each other, however, collinearity is assumed to be relatively low, as it becomes difficult to differentiate between the impacts of several variables (Elith and Leathwick 2009). Maxent model's habitat use and distribution based on a machine learning response starts with known locations of presence records, compares the environmental predictors of those locations, and then correlates them at random points through the study area. The final assumption states that it is possible to find the maximum likelihood distribution, in a linear combination of the features (Hale 2006, Phillips et al. 2018). The model is limited by the integrated functions (e.g., Maxent by default assumes that prevalence is 0.5) and does not correct for bias in spatial, temporal, or class imbalance presence data. Maxent provides valuable insights into the diurnal habitat use by an endangered species in an Important Bird Area (IBA) in Puerto Rico (Méndez-Gallardo and Salguero-Faría 2008).

Presence data

Presence data was obtained from eBird, a citizen science project of the Cornell Laboratory of Ornithology with more than 100 million bird sightings contributed by birders around the world (Johnston et al. 2019). The data on eBird is semi-structured with unstructured data collected, but it also collects data on the observation process (e.g., duration of data collection, distance an observer traveled while collecting observations, inferring the non-detection of a species, etc.), which can be used to address many of the issues arising from citizen science data, such as preference for certain species, preference for a certain location, and preference for a certain time of the year (Altwegg and Nichols 2019, Kelling et al. 2019). A random sample of presence data from semi-structured observations are assumed in the dataset.

Observations on birds are stored and the data are accessible to investigators through the eBird Basic Dataset (www.ebird.org/science/download-ebird-dataproducts). After granted access to the database and downloading all the checklists of bird observations for the WIWD in Puerto Rico, we filtered (cleaned) the data that contained detections (presence) only for the focal species in the study area. Filtering was done using Excel for duplicate records. All records of detections of the WIWD in Caño Tiburones from 2003-2015 produced a total of 56 presence records, all diurnal sightings, for use in the Maxent model ($n = 56$). The analyses took place during 2018, after the hurricanes Irma and Maria, when fieldwork was difficult to conduct as access to Caño Tiburones was restricted. The observations from eBird were used as a baseline for determining WIWD occurrence in Caño Tiburones.

Environmental variables

We used five covariates, four of them continuous and one categorical (Table 1). Bioclimatic variables (mean annual temperature and mean annual precipitation), Human impact (Distance to Disturbance), Vegetation Cover (NDVI, Landcover), and Elevation were included in the program.

We defined Distance to Disturbance as any human-made structure composed of wood, metal, cement, or plastic that was in or close to the presence location. For each point, we measured the distance to the nearest structure using the ruler function in ArcGIS software version 10.5. Bioclimatic data had a spatial resolution of less than 1km and downloaded from the Chelsea database (http://chelsa-climate.org/).

The Normalized Difference Vegetation Index (NDVI) is a unitless variable. Its values can range from -1 to 1, with higher values indicating a greater photosynthesis index (Torres-Torres 2013). NDVI is calculated from the visible and near-infrared light reflected by vegetation and was processed as a raster layer from the Google Earth Engine (https://code.earthengine.google.com/), calculated from Landsat 7 images between 1999 and 2003.

Elevation data was obtained from the Shuttle Radar Topographic Mission (SRTM, https://earthexplorer.usgs.gov/ , accessible through Google Earth) at 30 m and was used as the only topographic variable in the model (https://earthexplorer.usgs.gov/) Landcover was obtained from the United States Forest Service at the International Institute of Tropical Forestry in San Juan, Puerto Rico. Eight land cover categories were considered to determine which had the greatest effect on WIWD geographical distribution. Land cover classification of Puerto Rico was created using Landsat 7 imagery from 1999-2003 (Gould et al. 2017).

Table 1. Covariates used in the species distribution modeling.

Variable Type	**Variable Name**	**Comments**	**Continuous or Categorical**
Bioclimatic	Mean annual temperature	Average kinetic energy, °C	Continuous
Bioclimatic	Mean annual precipitation	Amount, mm	Continuous
Anthropogenic	Distance to Disturbance	Distance, m	Continuous
Vegetation Cover	NDVI*	Value ranges between -1 to 1	Continuous
Vegetation Cover	Landcover**	PRGAP classes***	Categorical
Topography	Elevation	MASL	Continuous

* N. D. V. I. (or NDVI) = Normalized Difference Vegetation Index.

** PRGAP Land cover data documenting how much of a region is covered by forests, wetlands, impervious surfaces, agriculture, and other land and water types.

Raster layers were extracted to the same coordinate system and size and the reference layer was obtained from the US Forest Service 2007 land cover map for Puerto Rico (Gould et al. 2007). We processed the layers in ArcGIS® version 10.5 to superimpose every pixel using the same size in the raster. Every variable was transformed into an ASCII raster grid with the same pixel size (30 arc seconds) and projection (decimal degrees) for input into Maxent. The data set, including longitude and latitude (in decimals) for each location in Caño Tiburones where WIWD is reported in eBird, as well as values for each covariate in their corresponding units are provided in Appendix 1.

Model validation

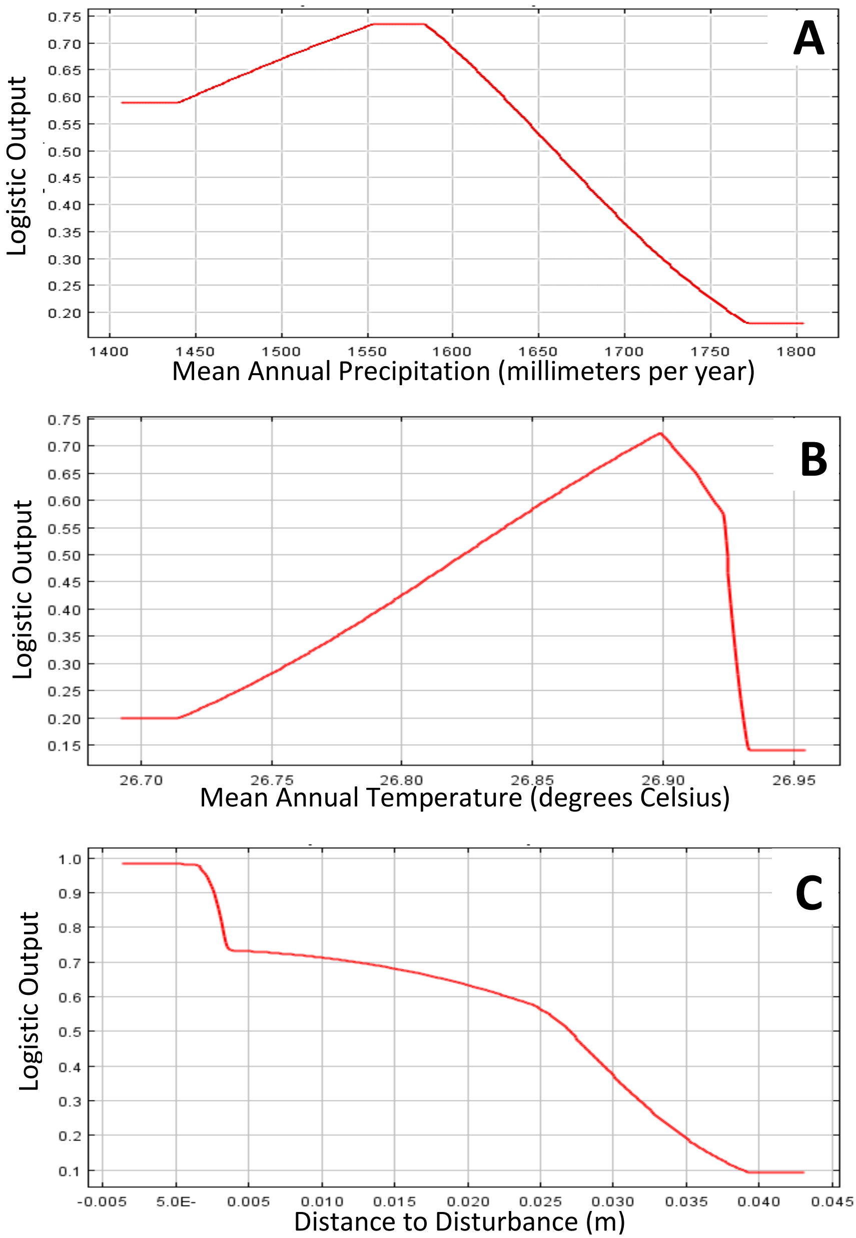
Maxent calculates both on the training presence records, and on the test records to obtain a predicted area as a function of the cumulative threshold to plot the statistical significance of the prediction using a binomial test of omission. The receiver operating characteristic (ROC) curve for the data is reevaluated on the permuted data using the Area Under the Curve (AUC) estimator. The AUC shows how well the model fits the data. An AUC > 0.5 means the model fits the data in a significantly. An AUC closer to 1 is preferred as it yields a model that fits the data better (Yang et al. 2015).

Species response curves produced represent the relationships between environmental factors and the species occurrence probability (Phillips et al. 2006). Response curves show how the predicted probability of presence changes as each environmental variable is varied, keeping all other environmental variables at their average sample value (Phillips et al. 2018).

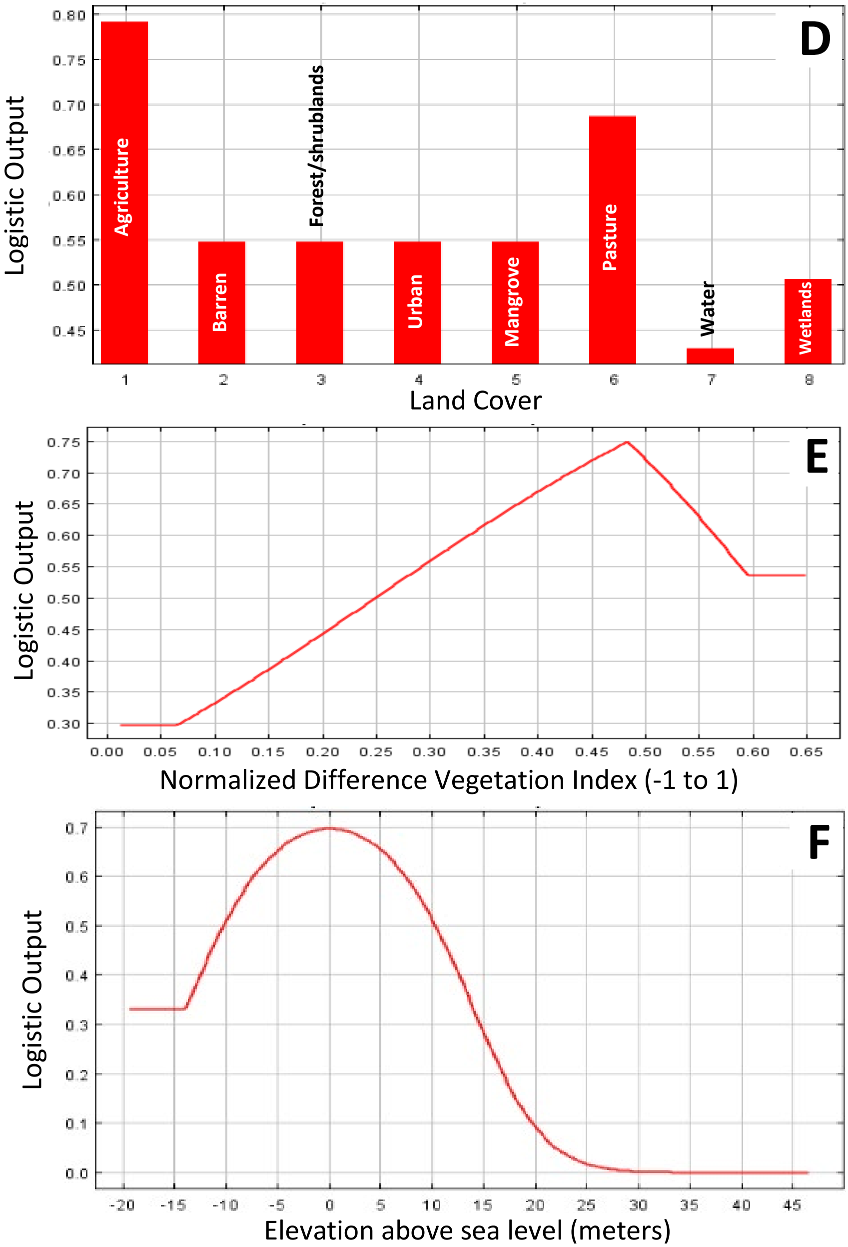
The contribution of each variable to the model is measured by the Jackknife test of variable importance, and it shows the estimates of relative contributions of the environmental variables to the Maxent model. For each covariate, the values of that variable on training presence and background data are randomly permuted and the resulting difference in training AUC is shown in a table, normalized to percentages (Yang et al. 2015). A final representation of the model is produced as a color map. It is color coded for predicted habitat with suitable conditions. The metadata of the map also shows suitable habitat as a percentage of the study area.

Results

The results were significant as the area under the curve (AUC) = 0.754. The response curves (Figure 4A-4F) indicate that distance to disturbance and temperature have sigmoidal trends while the curves for elevation and temperature have peaks in their responses (Biodiversity and Climate Change Virtual Laboratory 2015). The variable, agriculture, was the highest bar in the land cover response curve, indicating the most importance landcover for the model was agriculture, or croplands, followed by pastures (Figures 4D and 5).



Figures 4A-C. Model's response, or logistic output, of the West Indian Whistling Duck, *Dendrocygna arborea*, to different physical parameters. The greater the response, the greater the probability of detecting the duck in those conditions. A. Mean annual precipitation. B. Mean annual temperature. C. Distance to disturbance.



Figures 4D-F. Model's response, or logistic output, of the West Indian Whistling duck, *Dendrocygna arborea*, to different physical parameters. D. Land cover. E. Normalized difference vegetation index (NDVI). F. Elevation above sea level.

The Jackknife test (Figure 5) shows that distance to disturbance explains most of the total variance and was identified as the main factor affecting the spatial distribution of WIWD in Caño Tiburones, followed by precipitation as the second contributor to the model, and Normalized Difference Vegetation Index (NDVI). The variable with highest gain (56.6%) when used in isolation is distance to disturbance and, therefore, appears to have the most useful information in determining WIWDs presence in Caño Tiburones. Distance to disturbance, NDVI, precipitation, and landcover (Vegetation Cover) together accounted for 94.5% contribution to the model.

Figure 6, generated using the SDM results on the environmental variables (Figure 5), shows that Caño Tiburones has 11.13% suitable diurnal habitats for the WIWDs.

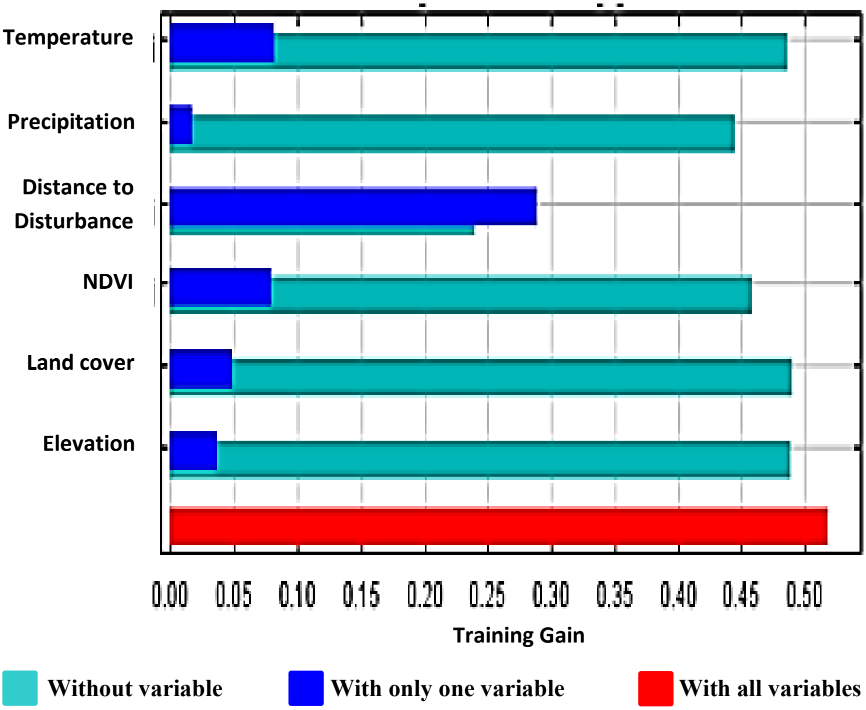


Figure 5. Relative predictive power of different environmental variables (horizontal bars) based on the jackknife of training gain in Maxent models for WIWD. Mean annual temperature, mean annual precipitation (mm), distance to disturbance (m), NDVI, land cover, and elevation (meters above sea level).

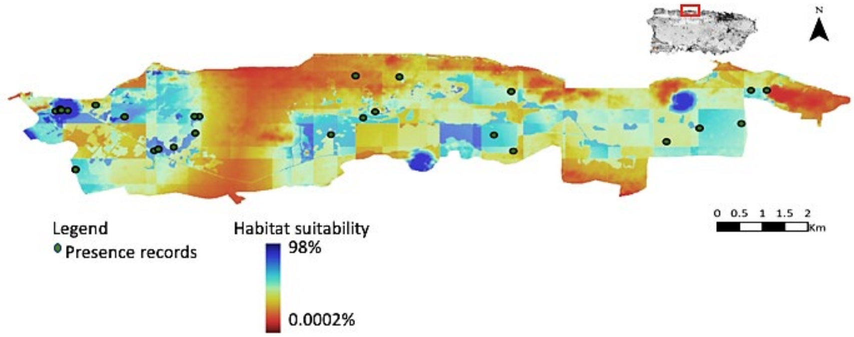


Figure 6. Model produced with Maxent of the spatial distribution of WIWD in Caño Tiburones, Puerto Rico. Dark blue areas represent suitable habitat and reddish orange to red areas represent non-ideal habitat. Black dots represent presence records from eBird for comparison of detections with the model probabilities of occurrence. Coordinates of plotted points (dark green circles) and their associated environmental conditions are listed in Appendix 1.

Discussion

This paper is part of an ongoing study of the distribution of the WIWD in Puerto Rico to produce a conservation and management plan of the species and its habitat. Herein, we modeled the distribution of an endangered species with a historically restricted range in Puerto Rico. Using eBird data from 2003-2015, the Caño Tiburones species distribution model revealed that most of the study area is not an ideal habitat for the WIWD; only 11.13% of the area is ideal habitat for the WIWDs population.

The Maxent model indicated the current WIWD distribution is influenced most by distance to disturbance (56.60%). We had initially established that any structure built in or near the study area would be considered a disturbance and it was identified accordingly. After reviewing the results, we reconsider the importance of human-built structures in the Caño Tiburones with which the WIWD was associated and acknowledge that there may be intrinsic resources associated with built structures that the WIWD requires.

It is also interesting that precipitation, a meteorological variable, was second in importance (15.4%) its and response curves show an ample range of precipitation in the WIWD habitat. This could suggest a tolerance to precipitation and possibly no change in distribution with a change in precipitation patterns in the area. Mean annual precipitation could however change the study areas' hydrology and affect the WIWD directly by affecting it habitat. The third variable of importance was land cover, specifically agriculture. This corresponds with existing data of WIWDs in Cuba, where they forage on recently planted rice seeds, seedlings, and grains before harvest (Mugica Valdés et al. 2006). The area to the southwest of Caño Tiburones is an existing rice plantation.

Caño Tiburones (Figure 7) is of great importance for the WIWD species in Puerto Rico. These findings have implications for the detection of the species in the study area regardless of the diel activity patterns of *Dendrocygna arborea*. That said, these results are still relevant and need to be included in the discussions regarding WIWDs classification, conservation, and management in Puerto Rico. Acknowledging the limitations of the study, we highlight the need of future research that includes an assessment of the distribution for the Puerto Rican archipelago to understand better habitat use during the year, considering dry/wet seasons and validating with current fieldwork to predict conservation needs for the WIWDs at a national level.

Figure 7. Main channel of Caño Tiburones located on the northwest portion of the Caño, leaving from the fireplace of the Departamento de Recursos Naturales y Ambientales (DRNA). Photo by Yahel A. Delgado Díaz.

Acknowledgments

Alejandro Ríos-Franceschi and José M. García Peña (University of Puerto Rico, Río Piedras Campus, San Juan, Puerto Rico) reviewed this paper and offered valuable suggestions. Two other colleagues, who remain anonymous, reviewed this paper, and offered additional recommendations. To all, our deeply felt thanks.

Literature Cited

Altwegg R. and J. D. Nichols. 2019. Occupancy models for citizen-science data. *Methods in Ecology and Evolution* (British Ecological Society) 10(1):8-21. https://doi.org/10.1111/2041-210X.13090

Biodiversity and Climate Change Virtual Laboratory. 2015. https://support.bccvl.org.au/support/solutions/articles/6000083216-maxent .

BirdLife International. 2020. *Dendrocygna arborea*. *The IUCN Red List of Threatened Species* 2019: e.T22679770A154611660. https://dx.doi.org/10.2305/IUCN.UK.2019-3.RLTS.T22679770A154611660.en . Carboneras, C. and G. M. Kirwan. 2020. West Indian Whistling-Duck (*Dendrocygna arborea*), version 1.0. In Birds of the World (J. del Hoyo, A. Elliott, J. Sargatal, D. A. Christie, and E. de Juana, Editors). Cornell Lab of Ornithology. Ithaca, New York, USA. https://doi.org/10.2173/bow.wiwduc1.01

Carboneras, C. and G. M. Kirwan. 2020. West Indian Whistling-Duck (*Dendrocygna arborea*), version 1.0. In, del Hoyo, J., A. Elliott, J. Sargatal, D. A. Christie, and E. de Juana (Editors). *Birds of the World*. Cornell Lab of Ornithology. Ithaca, New York, USA. https://doi.org/10.2173/bow.wiwduc1.01

Collar, N. J. [and others]. 1992. *Threatened Birds of the Americas: The ICBP/IUCN Red Data Book*. Part 2. Smithsonian Institution Press in cooperation with International Council for Bird Preservation. Third Edition. Washington, District of Columbia, USA. 1,150 pp.

Departamento de Recursos Naturales y Ambientales (DRNA). 2007. Reserva Natural Caño Tiburones. *Hojas de Nuestro Ambiente*: P-015. 2 pp. Departamento de Recursos Naturales y Ambientales. San Juan, Puerto Rico. http://drna.pr.gov/historico-2006-2015/biblioteca/publicaciones/hojas-de-nuestro-ambiente/15-Cano%20Tiburones.pdf .

Departamento de Recursos Naturales y Ambientales (DRNA). 2016. Reglamento para Regir las Especies Vulnerables y en Peligro de Extinción en el Estado Libre Asociado de Puerto Rico. San Juan, Puerto Rico. 265 pp.

Elith, J. and J. R. Leathwick. 2009. Species distribution models: ecological explanation and prediction across space and time. *Annual Review Ecological Evolutionary Systems* 40:677-97. https://doi.org/10.1146/annurev.ecolsys.110308.120159

Franklin, J., with contributions by J. A. Miller. 2009. *Mapping Species Distributions: Spatial Inference and Prediction*. Cambridge University Press. New York, NY, USA. 320 pp. https://doi.org/10.1017/CBO9780511810602

Goodman, N. S., J. C. Eitniear, and J. T. Anderson. 2018. Flock size of West Indian Whistling-Ducks (*Dendrocygna arborea*) in Puerto Rico. *The Journal of Caribbean Ornithology* 31:23-25. https://jco.birdscaribbean.org/index.php/jco/article/view/482

Gould, W. A., F. H. Wadsworth, M. Quiñones, S. J. Fain, and N. L. Álvarez-Berríos. 2017. Land use, conservation, forestry, and agriculture in Puerto Rico. *Forests* 8(7):242. https://doi.org/10.3390/f8070242

Hale, S. R. 2006. Using satellite imagery to model distribution and abundance of Bicknell's Thrush (*Catharus bicknelli*) in New Hampshire's White Mountains. *The Auk* 123(4):1038-1051. https://academic.oup.com/auk/article/123/4/1038/5562806

Johnston, A., W. M. Hochachka, M. E. Strimas-Mackey, V. Ruiz Gutierrez, O. J. Robinson, E. T. Miller, T. Auer, S. T, Kelling, and D. Fink. 2019. Best practices for making reliable inferences from citizen science data: case study using eBird to estimate species distributions. *bioRxiv* preprint first posted online Mar. 12, 2019. https://doi.org/10.1101/574392

Kelling, S., A. Johnston, A. Bonn, D. Fink, V. Ruiz-Gutierrez, R. Bonney, M. Fernandez, W. M. Hochachka, R. Julliard, R. Kraemer, and R. Guralnick. 2019. Finding the signal in the noise of citizen science observations. *BioScience* 69(3):170-179. https://doi.org/10.1093/biosci/biz010

Khanum, R., A. S. Mumtaz, and S. Kumar. 2013. Predicting impacts of climate change on medicinal asclepiads of Pakistan using Maxent modeling. *Acta Oecologica* 49:23-31. https://doi.org/10.1016/j.actao.2013.02.007

Méndez-Gallardo, V. and J. Salguero-Faría. 2008. Puerto Rico. pp. 241 - 258. In, Wege, D. C. and V. Anadón-Irizarry, with special assistance of M. Vincenty [and others] (Editors). *Important Bird Areas in the Caribbean: Key Sites for Conservation*. BirdLife International. BirdLife Conservation Series. No. 15. Cambridge, England, UK. 348 pp.

Mugica Valdés, L., D. Denis, M. Acosta, A. Jiménez, and A. Rodríguez. 2006. *Aves Acuáticas en los Humedales de Cuba*. Editorial Científico-Técnica. La Habana, Cuba. 193 pp.

Pearson, R. G. 2007. Species' Distribution Modeling for Conservation Educators and Practitioners to: Learn, Explore, Practice, Teach, Connect. Network of Conservation Educators & Practitioners. Center for Biodiversity and Conservation. American Museum of Natural History. New York, NY, USA. http://ncep.amnh.org.

Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190(3-4):231-259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Phillips. S. J., M. Dudík, and R. E. Schapire. 2018. Maxent software for modeling species niches and distributions. Version 3.4.1. Free software available for download from: http://biodiversityinformatics.amnh.org/open_source/Maxent/.

Quiñones-Aponte, V. 2006. *Water Resources of the Lower Río Grande de Arecibo Alluvial Valley, Puerto Rico*. United States Geological Survey. Water Resources Investigations Report. 85-4160. Prepared in cooperation with the Puerto Rico Department of Agriculture and the Puerto Rico Department of Natural Resources. San Juan, Puerto Rico. 38 pp. https://pubs.usgs.gov/wri/1985/4160/report.pdf

Torres-Torres, N. I. 2013. Estimation of the variations in the amount of vegetation in Caño Tiburones during different hydrologic conditions. 22 pp. In, *Advanced Geological Remote Sensing. GEOL 625*. Research Projects. Geology Department. University of Puerto Rico, Mayagüez, Puerto Rico. Accessed on June 21, 2020. http://gers.uprm.edu/geol6225/research.html

Vélez, A., J. Martin-Vide, and D. Royé. 2019. Spatial analysis of daily precipitation concentration in Puerto Rico. *Theoretical and Applied Climatology* 136:1347. https://doi.org/10.1007/s00704-018-2550-1

Yang, H., Y. Zhao, and S. Liu. 2015. Jackknife empirical likelihood for linear transformation models with right censoring. *Annals of the Institute of Statistical Mathematics* 68:1095-1109. https://www.researchgate.net/publication/282540963_Jackknife_empirical_likelihood_for_linear_transformation_models_with_right_censoring .

Zack, A. L. and A. Class-Cacho. 1984. *Restoration of Freshwater in the Caño Tiburones Area, Puerto Rico*. United States Geological Survey. Water Resources Investigations Report. 83-4071. Prepared in cooperation with the Puerto Rico Department of Agriculture. San Juan, Puerto Rico. 33 pp. https://pubs.usgs.gov/wri/1983/4071/report.pdf

Appendix 1. Data inputted to Maxext. Coordinates plotted on Figure 6.

Long	Lat	Veg_Dens	Land_cover	Elevation	Temperat	Precipita
-66.6019535	18.4682323	2772	53	0.7877	74	0
-66.6889858	18.4638158	0.3557	50	0.3061	78	0
-66.6889858	18.4638158	0.3557	50	0.3061	74.5	0
-66.6889858	18.4638158	0.3557	50	0.3061	73	0
-66.6889858	18.4638158	0.3557	50	0.3061	79.5	0
-66.6889858	18.4638158	0.3557	50	0.3061	76	0
-66.6889858	18.4638158	0.3557	50	0.3061	74.5	0.1
-66.6889858	18.4638158	0.3557	50	0.3061	71	0.45
-66.6889858	18.4638158	0.3557	50	0.3061	70.5	0
-66.6889858	18.4638158	0.3557	50	0.3061	77.5	0.18
-66.6889858	18.4638158	0.3557	50	0.3061	81	0
-66.6889858	18.4638158	0.3557	50	0.3061	72.5	0
-66.679287	18.4763528	0.2828	44	2.737	74	0
-66.6651249	18.4725267	0.4027	52	-0.8504	74	0
-66.6651249	18.4725267	0.4027	52	-0.8504	74	0
-66.6889858	18.4638158	0.3557	50	0.3061	74	0
-66.6889858	18.4638158	0.3557	50	0.3061	72.5	0
-66.6889858	18.4638158	0.3557	50	0.3061	88	0
-66.6333246	18.4861417	0.3047	50	5.386	75	0.13
-66.6889858	18.4638158	0.3557	50	0.3061	79	0
-66.6381501	18.4720501	0.3052	52	-1.5794	75	0.04
-66.6245699	18.4858364	-0.3333	50	4.7991	78	0
-66.6889858	18.4638158	0.3557	50	0.3061	77	35
-66.6889858	18.4638158	0.3557	50	0.3061	75	0.1
-66.692934	18.4776757	0.4286	50	-0.2933	71	3.45
-66.6889858	18.4638158	0.3557	50	0.3061	69	0.06
-66.6694808	18.4691278	0.5	44	-1.1517	78	0.8
-66.6889858	18.4638158	0.3557	50	0.3061	77	2.14
-66.6057301	18.4720382	0.5189	67	-1.3128	77	0
-66.6889858	18.4638158	0.3557	50	0.3061	69	0
-66.6849947	18.4791715	0.2239	50	4.4822	72	0
-66.5714836	18.4704915	0.097	54	-0.1612	72	0
-66.6889858	18.4638158	0.3557	50	0.3061	79	0
-66.692029	18.478215	0.4717	66	-1.2597	68	0
-66.5649605	18.473585	0.336134	52	-0.9203	79	0
-66.6294622	18.4774925	0.2991	24	4.413	73	0.04
-66.6023827	18.4823768	0.4977	53	-0.7568	67	0
-66.673343	18.468241	0.7377	52	-1.5258	70.5	0
-66.692057	18.478148	0.3913	66	-1.0395	70.5	0
-66.6889858	18.4638158	0.3557	50	0.3061	71.5	0.01
-66.6889858	18.4638158	0.3557	50	0.3061	74	0
-66.6889858	18.4638158	0.3557	50	0.3061	75.5	0
-66.664343	18.476477	-0.2222	67	-1.3563	74.5	0
-66.672542	18.468661	0.4118	67	-1.172	74.5	0