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Assessing distribution and conservation potential for the Muscovy duck (*Cairina moschata*) in Argentina

Avaliação, distribuição e potencial de conservação do pato-selvagem (*Cairina moschata*) na Argentina

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Abstract

The Muscovy duck (*Cairina moschata*, Anatidae) is a waterbird with a wide distribution in America, reaching Argentina at its southernmost limit, where the species was categorized as threatened. In this study, we develop a species distribution model to analyze habitat suitability for the species in Argentina and assess its potential for geographic conservation in the country. Results show that northern Argentina offers environmentally suitable habitats for the species. At present, the Muscovy duck is not adequately protected in Argentina and although a quarter of its suitable habitat has already been lost due to human-induced changes in land-cover, the country still has a conservation potential since we have detected suitable habitats inside protected areas, where the species has not been previously recorded, and the species dependence on water lines offer additional conservation opportunities. We suggest carrying out conservation actions outside the current system of protected areas, in areas with high habitat suitability, and along water lines, involving private owners in conservation actions. There is also a need for further field research to confirm the duck's presence in the potential areas and to reveal more detailed ecological information about its habitat needs.

Keywords: suitable habitat, potential distribution models, waterbirds, threatened birds, anatidae, MaxEnt.

Resumo

O pato-do-mato (*Cairina moschata*, Anatidae) é uma ave aquática com ampla distribuição na América, alcançando a Argentina no limite sul de sua distribuição, onde encontra-se ameaçada. Neste estudo, desenvolvemos um modelo de distribuição da espécie para analisar a adequabilidade do hábitat para a espécie na Argentina e avaliar seu potencial para a conservação, considerando a geografia do país. Os resultados mostram que o norte da Argentina oferece habitats ambientalmente apropriados para a espécie. Atualmente, o pato-selvagem não é protegido de forma adequada na Argentina, e um quarto de seu habitat apropriado está sendo perdido, devido à influência antrópica na paisagem. Apesar dessas ameaças, a Argentina ainda possui potencial de conservação da espécie. Registramos habitats apropriados em áreas protegidas, onde as espécies não haviam sido previamente registradas, assim como sua dependência de ambientes lóticos, oferecendo oportunidades de conservação. Sugerimos levar adiante ações de conservação além dos atuais sistemas de áreas protegidas, em áreas com habitats altamente apropriados, e ao longo de ambientes lóticos, além de envolver os proprietários das áreas nas ações de conservação. Além disso, é necessário promover pesquisas de campo para confirmar a ocorrência da espécie nas áreas potenciais e revelar mais informações ecológicas sobre necessidades de hábitat do pato-selvagem.

Palavras-chave: habitats apropriados, modelos de distribuição potencial, aves aquáticas, espécies ameaçadas, Anatidae, MaxEnt.

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Introduction

Nowadays, extinction rates are a thousand times higher than natural ones, leading wildlife to a crisis state and threatening biodiversity (De Vos *et al*., 2015). Habitat loss and degradation are the main threats as they might cause significant range contractions (Schipper *et al*., 2008). Animal populations located at the edges of distribution face a higher probability of extinction than populations inside the core areas (Rodríguez, 2002). This characteristic prioritized peripheral species within the field of conservation (Quiroga and Premoli, 2013).

Species distribution models are tools that have acquired special relevance for the study of threatened species, as they indicate the species' potential distribution and can be applied for strategic conservation planning (Guisan *et al*., 2006; Richardson and Whittaker, 2010; Costa *et al*., 2016). Maximum entropy modeling of species geographic distributions basically relates the presence of a species with the associated environmental conditions to predict habitat suitability for the species of interest (Anderson and Gonzalez, 2011; Pearson *et al*., 2007; Philips and Dudik, 2008). As a result of the spatial information generated by the models, one can obtain the key factors affecting the distribution of rare or little-known species (Miola *et al*., 2011; Morales, 2012) to schedule management and conservation planning. Thus, describing distribution patterns is among the most important topics in ecology and biogeography (Myers and Giller, 2013) and it is a previous step to conservation planning.

Regarding birds, the International Union for Conservation of Nature (IUCN) Red List identifies 12% of the species as threatened (Baillie *et al*., 2004). Waterbirds are particularly vulnerable to habitat change because aquatic environments are highly threatened (Blanco, 1999). One of those waterbirds is the Muscovy duck (*Cairina moschata* (Linnaeus 1758), Anatidae), a species native to America. The Muscovy duck is a generalist species with an extremely large range extending from Mexico to central Argentina and Uruguay and covering tropical and subtropical climate zones at altitudes between 0 and 1200 meters above sea level. The species' typical habitat consists of wooded sites with abundant freshwater, preferably lagoons, near streams or slow-flowing rivers (Blake, 1977; Woodyard and Bolen, 1984; Howell and Webb, 1995). Muscovy ducks prefer to live in forested areas as they nest in tree cavities (Eitniear *et al*., 2015). As other cavity-nesting birds, the species is particularly sensitive to habitat change since it reduces the number of cavities available for nesting (van der Hoek *et al*., 2017). Although at the international level Muscovy ducks are categorized as Least Concern, their populations are decreasing (IUCN, 2014), and in Argentina (the southernmost limit of distribution) it is categorized as threatened and therefore, protected by national laws (López-Lanús *et al*., 2008). This species is also threatened by direct hunting for its meat (Eitniear *et al*., 2015).

International efforts started to counteract biodiversity losses by setting objectives and goals, as, for example, the convention of Kioto of 1997 and the Convention on Biological Diversity (CBD, 2010). On a national level, the implementation of national parks, natural reserves, and other protected areas have been at the forefront for the conservation of biodiversity (Primack *et al*., 2001; Wilshusen *et al*., 2002). Private reserves usually have smaller sizes than national parks, but they are present in larger numbers and they are mentioned as complementary to national areas by the "Aichi Biodiversity Targets" (CBD, 2010). Thus, when private reserves guarantee well-preserved areas, they function as a complement of strictly protected areas (Roldán *et al*., 2010). In Argentina, private properties are especially relevant for conservation, since more than 80% of the protected areas belong to private owners, whereas national and provincial protected areas only cover 7.7% of the country's surface (Moreno and Carminati, 2007).

In this study, we assess the current protection status of the Muscovy duck at its southernmost limit of distribution by presenting a habitat suitability map and by analyzing the species representation in the actual system of protected areas. We also analyze how human-induced changes in land-cover affect this environmentally suitable habitat. Thus, using a habitat suitability map and the area occupied by national and private protected areas, we calculated the percentage of the duck's distribution represented by these protected areas. We start from the premise that this species is not adequately represented by the existing system of protected areas since in Argentina it is categorized as threatened with extinction (vulnerable) (López-Lanús *et al*., 2008).

Methods

We gathered presence records of the Muscovy duck in Argentina using different sources: databases accessible on the internet from eBird (2012) and Ecoregistros (2017) (database from 1990 up to March 2017), and from fieldwork carried out by some of the authors in Salta and Jujuy provinces during the years 2014-2017. We did not include records from other regions of its distribution as this would disbalance our dataset and as we do not have the expertise to check their accuracy. Data was checked for accuracy based on the current species range provided by NatureServe Database (www.birdlife.org) and our own knowledge of the species distribution. Replicated and doubtful records were not used for modeling (e.g. captive individuals). For example, one individual was found outside the range (in Cordoba province) but it turned out to be a captive individual and, thus, it was not used for modeling.

This species was already domesticated in pre-Columbian times in America (Angulo, 1998) and later in the rest of the world (Donkin, 1989; Mason and Mason, 1984). Replicated records were not used for modeling. We used 75% of the data for training and 25% for testing the models, with 100 repetitions (Araujo and Guisan, 2006).

Species distribution models were generated using MaxEnt (Phillips *et al*., 2006). MaxEnt performs relatively well for modeling species with wide distributions (Hernandez *et al*., 2008; Norris, 2014), such as the Muscovy duck. MaxEnt uses the principle of maximum entropy and presence–background data to estimate a set of functions that relate environmental variables and provides an index for habitat suitability (Phillips *et al*., 2006). We set the program to perform both linear and quadratic features, as these generally perform better than the models considering linear features only (Anderson and Gonzalez, 2011), using the logistic output.

MaxEnt uses environmental variables as predictors. To inquire into the ecological constraints of environmental variables on the species distribution, we first ran a preliminary model using 19 bioclimatic variables available at Worldclim and two topographic variables; elevation (http://srtm.csi.cgiar.org/) and its derived slope. To include the possible influence of water on this bird, we generated two variables by creating two rasters (ArcGis10.1); distance to water lines (rivers, streams) and distance to water bodies (natural lakes, dams). Those were calculated with the Euclidean distance tool and using the water lines and water bodies available in Digital Chart of the World as basemaps (Harvard University, 2015). After final modeling, we plotted the relation between distance to water lines and water bodies and habitat suitability and indicated the areas with land cover change due to human activity. Resolution of all variables was set to 30 arcseconds (approximately 0.82 km^2 in the study area). With all the 23 environmental variables we ran 100 repetitions of a preliminary model. We present their contribution in Table 1. For the selection of variables, we tested for correlation using Pearson and for the final model we only picked out variables with a contribution to the preliminary model higher than 10% according to Jackknife (test provided by MaxEnt) and without correlation ($R < 0.7$).

The final model was run 100 times to increase statistical power and records were sampled with bootstrapping. For measuring general performance, we used the area under the receiver operating characteristic curve (AUC). AUC measures the probability that a randomly chosen presence point will rank above a randomly chosen background point (AUC = 0.5 = random; values closer to 1 means better discrimination power) and it is commonly used in SDM (Bellamy *et al*., 2013). MaxEnt is effective in indicating habitat suitability, whose geographical projection can be interpreted as the potential distribution of a species. We projected the model geographically in ArcGis10.1 and we divided habitat suitability as follows: absence (< threshold), low (threshold - 0.5), intermediate (0.5 - 0.75) and high (>0.75), using a scale of grey. By applying a threshold, we converted the probability model in a binary (presence/absence) map; using the 10-percentile training presence logistic threshold (provided by MaxEnt) commonly applied in conservation, which in this case was 0.4347.

To assess the geographic potential for the conservation of the species in Argentina, we used the Globcover map (ESA and UCLouvain 2010) to analyze how much of this potential area had already been transformed to land-covers not suitable for the species. As this is a tree cavity-nesting species we assumed the need of trees (and not shrubs) and therefore we extracted the following land-covers: croplands, shrubland (<5m), herbaceous vegetation, sparse

Table 1. Environmental variables used to run the preliminary model for *C. moschata* using 117 presence records and 23 environmental variables in Argentina.

Variable	Percent contribution
Distance to waterlines	36.1
Mean temperature of coldest quarter	25.4
Temperature seasonality	11.8
Temperature annual range	10.7
Distance to waterbodies	10.3
Slope	2.0
Minimum temperature of coldest month	1.9
Annual mean temperature	1.8
Precipitation of coldest quarter	1.8
Maximum temperature of warmest month	1.7
Mean temperature of wettest quarter	1.4
Precipitation of driest month	1.3
Precipitation of driest quarter	1.1
Precipitation seasonality	0.8
Elevation	0.8
Annual precipitation	0.5
Mean temperature of warmest quarter	0.4
Precipitation of wettest month	0.1
Isothermality	0.1
Mean diurnal range	0.1
Mean temperature of driest quarter	0
Mean temperature of coldest quarter	0
Precipitation of wettest quarter	0
Precipitation of warmest quarter	0

vegetation (<15%), artificial surfaces and bare areas (covers 11, 14, 130, 140, 150, 190 and 200; see GlobCover website: http://due.esrin.esa.int/page_globcover.php for more details on these cover types). To analyze its representation in the current system of protected areas we obtained a shapefile with official data of national and provincial protected areas of Argentina (from the Administration of National Parks) and another shapefile with records of the private reserves and surface information (RARNP, 2017). The binary map was then superimposed to calculate the protected area and to present the potential protection map for the species in Argentina.

Results

We obtained 219 records of Muscovy ducks in nine Argentine provinces. After deleting doubtful and replicated records, only 117 records (53%) were finally used for modeling (Figure 1). The most important variables without correlation selected for the final model were: distance to water lines (49.5%), mean temperature of the coldest quarter (30.3%), the range of annual temperature (12.6%) and distance to water bodies (7.7%). The results show that habitat suitability decreases with increasing distance to water lines, and it falls abruptly at 111 km approximately (Figure 2a). With increasing distance to water bodies, habitat suitability decreases at short distances and then increases between 110 and 111 km, falling abruptly beyond this point (Figure 2b).

We generated a model with a good general performance (AUC = 0.956). The Muscovy duck has suitable habitat in 536,039 km^2 or 16.3% of the total country area (Figure 3) across 10 political provinces of Argentina. The largest part of the distribution belongs to Entre Rios (16.3% of its total distribution), Chaco (14.9%), Corrientes (14.8%), Santa Fe (14.2%), Salta (13.9%), Formosa (13.8%), and to a lesser extent to Misiones (5.6%), Jujuy (2.2%), Tucuman (1.7%), and marginally Buenos Aires (<1%). Entre Rios and Corrientes are provinces with large amounts of water available (rivers and watersheds; Figure1).

A quarter (24%) of the remaining land cover is not suitable for the species due to changes in the land cover derived from human activities before 2009. Therefore, although these places are environmentally suitable for the duck, the changes in land cover turned suitable forests into shrubs and crops. Approximately 31,950 km^2 of the Muscovy duck's suitable habitat is currently inside public protected areas and 2,585 km^2 inside 108 private reserves (Figure 4). This surface is equivalent to 6.4% of the duck's distribution (private areas add 0.4% to protection). Corrientes is the province with the largest area under public protection (134,226 ha), whereas Misiones has the largest surface covered by private protected areas and with potential presence of the species (31,286.3 ha).

Discussion

We only used slightly more than half (53%) of the presence records we recompiled. This indicates the importance of filtering records when modeling distributions. Distribution models rely on the relationship between the species occurrence and climate, and may thus be highly sensitive to georeferencing errors (Feeley and Silman, 2010). Therefore, filtering based on researcher's expertise is highly recommended. Most of the discarded records were duplicated records, misidentified individuals or records with an unclear location. We also obtained 12 presence records outside the known range of the species; 80 km further west (Salta province) and nearly 200 km further south (in the border of Entre Rios and Santa Fe provinces) (Figure 1). This is probably related to poor accuracy of the species range map rather than to a range expansion of the species. Range maps are constantly updated as our knowledge of basic features is still limited and the Muscovy duck is not the exception. The habitat suitability map updates the distribution more accurately as it includes new presence records that fall out of the known range map. It suggests the presence of the duck in geographic areas where it has not been (yet) detected (e.g. Tucumán province). It also reduces the distribution in the south-central area where the species has never been recorded (Santiago del Estero province). Based on our knowledge of the species, the distribution map presented here is accurate to represent the actual distribution.

Both water lines and bodies were important variables and therefore they were included in the model, although their importance differed. Water lines explained nearly half of the model and water bodies less than 10%. Based on these results, water lines are more important than water bodies for this species, in contrast to other authors (Blake, 1977; Woodyard and Bolen, 1984; Howell and Webb, 1995) who suggested that lagoons were more important. The habitat suitability map (Figure 2) clearly follows water lines (Figure 1). This could be related to the changing water level of water bodies which changes micro-environmental variables (Samuel *et al*., 2001). Muscovy duck is an opportunistic consumer, feeding on stems, seeds, grasses, aquatic plants and leaves, small vertebrates, and invertebrates such as spiders and crustaceans (Eitniear *et al*., 2015). Waterlines could offer a higher variety of feeding opportunities and facilitate dispersion among them.

The second most important variable was mean temperature of the coldest quarter. The range of annual temperature indicates that cold may represent a limitation for the species. Therefore, if climate change offers higher temperatures, then it may favor this species. The third variable, range of annual temperature, is probably related to the fact that this species inhabits places with a broad range of temperatures.

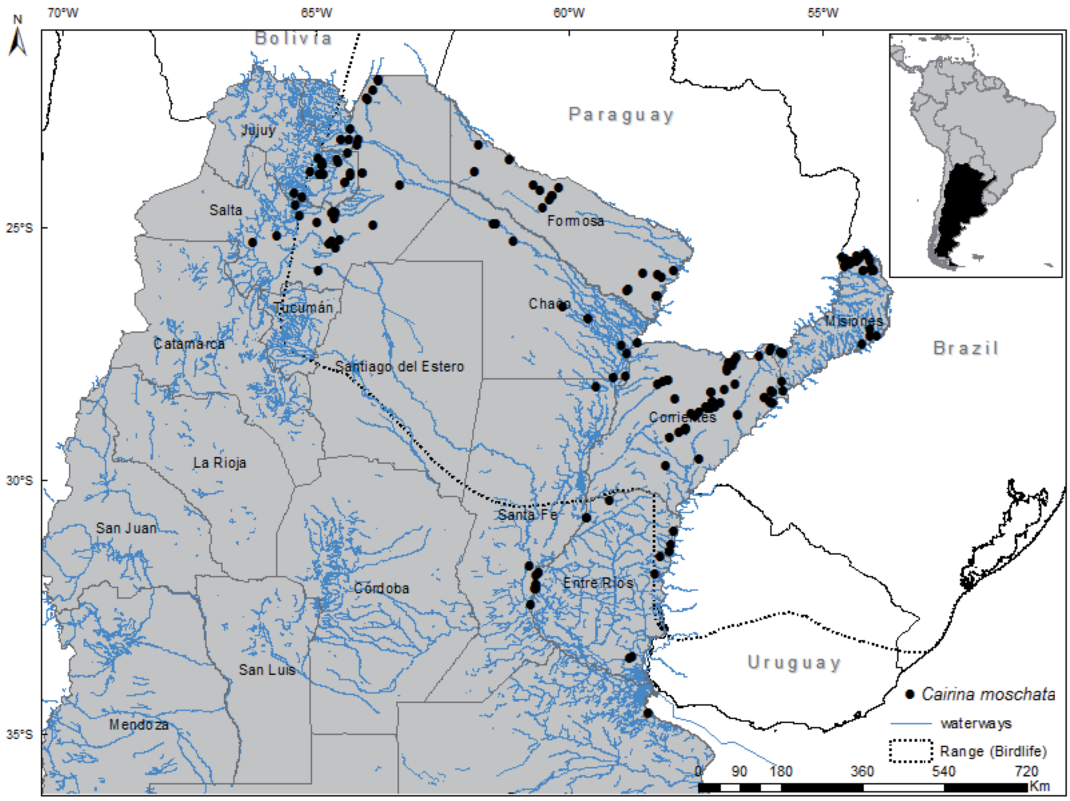

Figure 1. Presence records (black points) of *Cairina moschata* in Argentina, water courses, provincial limits and known distribution range according to BirdLife International and NatureServe Database (2012) (www.birdlife.org).

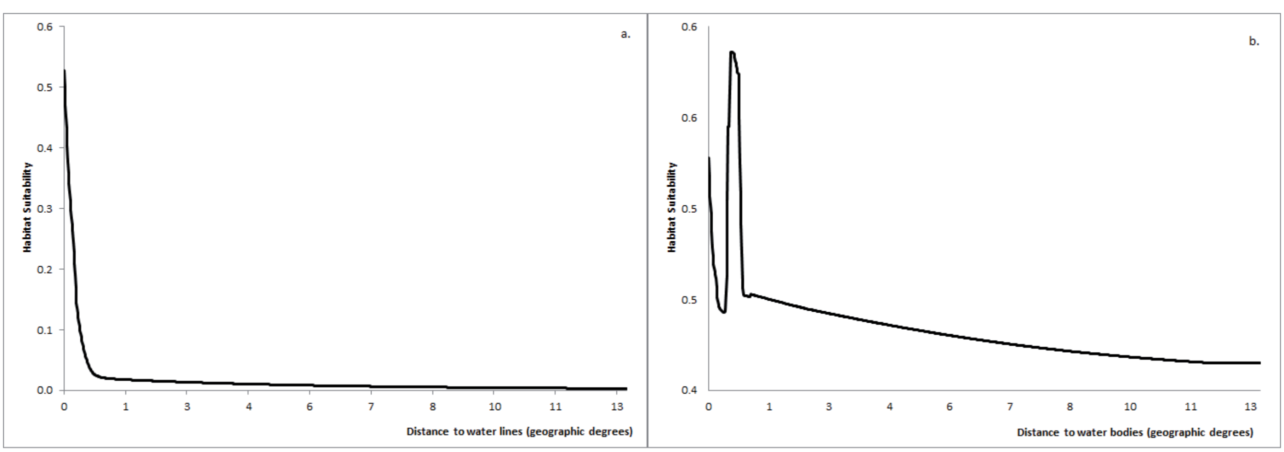

Figure 2. Relation between distance to water lines (a) and water bodies (b) and habitat suitability for *C. moschata* in Argentina, based on environmental variables and 117 presence records.

Our results indicate that in 2009 a quarter of the suitable habitat had already been lost; causing the absence of the species. Nevertheless, this is a rough estimation and it could have evolved since then, as Argentina is a productive-oriented country with high deforestation rates (Gudynas, 2008; Izquierdo and Grau, 2009). Hence, the map presented here is conservative and habitat loss would probably be greater today. It would be important to generate an updated land cover map in Argentina. The Aichi Biodiversity Targets suggests a minimum of protection of 17% to protect a species' habitat. Argentina only protects 6% of the duck's suitable habitat, which is insufficient to

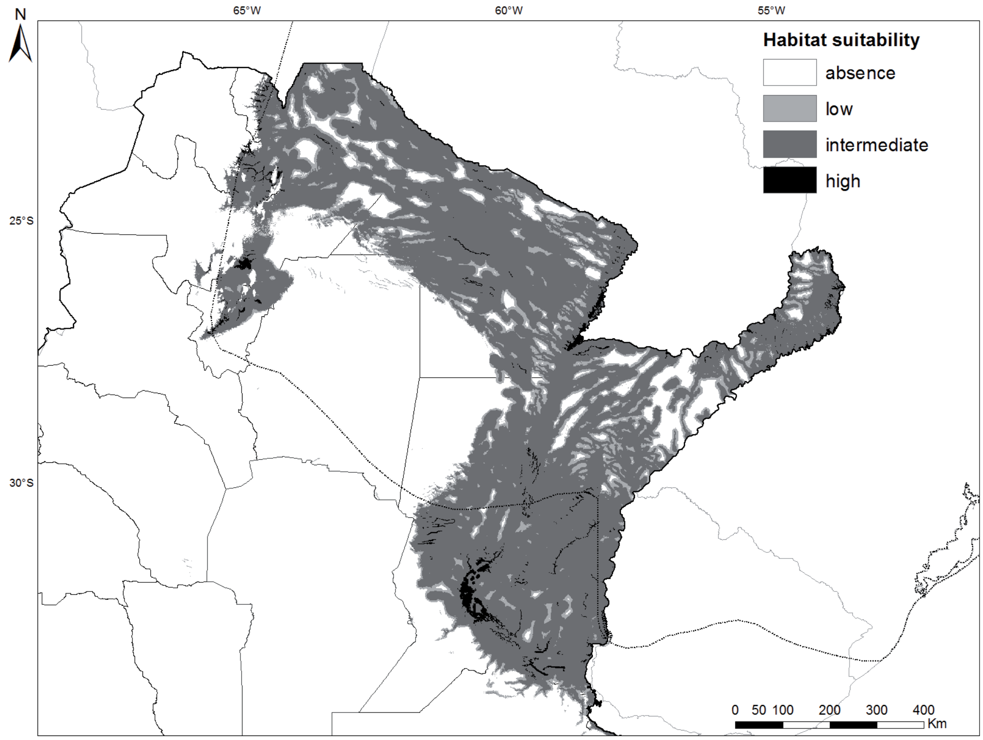

Figure 3. Habitat suitability map of Muscovy duck (*Cairina moschata*) in Argentina.

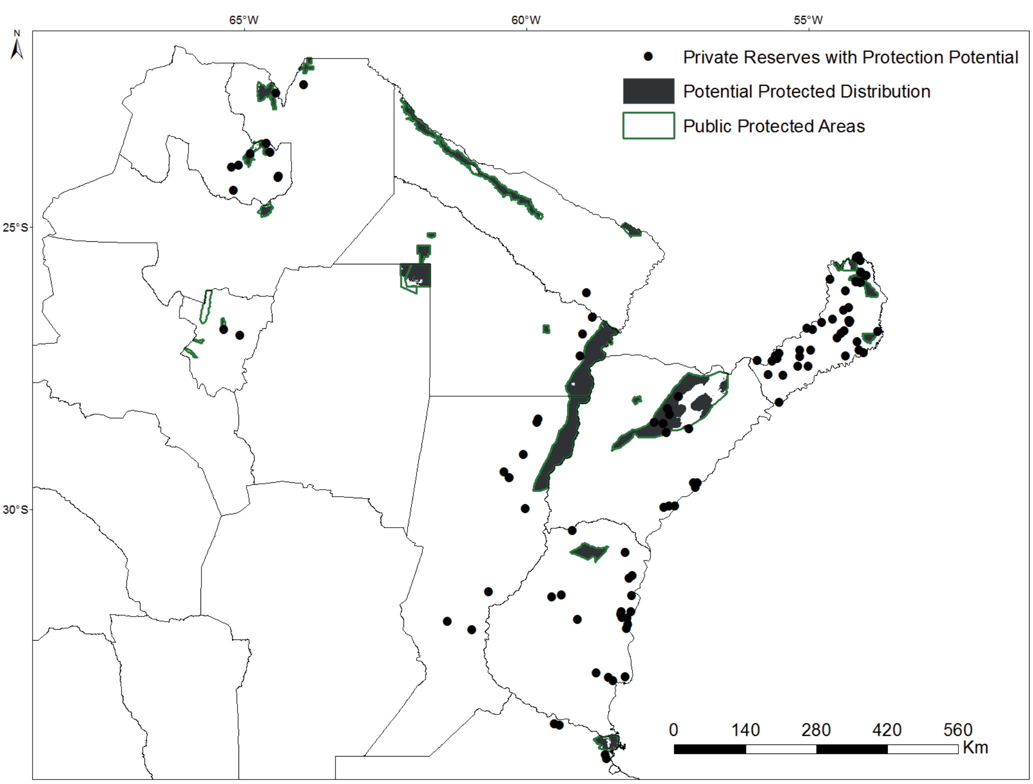

Figure 4. Conservation potential for the Muscovy duck (*Cairina moschata*) in Argentina.

ensure long-term conservation. Parks and protected areas are insufficient to sustain global biodiversity (Kamal *et al*., 2015) and this is also the case for the Muscovy duck in Argentina. Other actions that should be implemented are the prohibition and control of hunting.

Despite these threats, conservation purposes could also be fulfilled outside protected areas, where private lands might play an important role (Figgis and Figgis, 2004; McNeely and Scherr, 2001). According to our model, Muscovy ducks prefer to live up to a 110 km of distance from a water source. This could be related to the flying speed of this species and its home-range. Thus, private lands contributing to the conservation of the Muscovy duck should not only preserve water areas closer than 111 km, but also preserve natural forests with trees suitable for nesting. More ecological data is necessary to understand the specific characteristics of the nesting trees (sizes, height, etc.) and water lines (flow, speed, level of purity) used by this species. Private conservation could, therefore, contribute to effective conservation. Private properties might exist in larger numbers than national parks in terms of absolute number, but they are small in surface and therefore cannot sustain viable populations of many species, but when they assure well-preserved areas they constitute a complement to strictly protected areas.

The importance of waterlines and water bodies offer a conservation opportunity as conservation actions could be focused on these resources. Argentina adheres to the RAMSAR convention for the conservation and management of wetlands, with the goal of wise use of all wetlands and the maintenance of its ecological characteristics (Davis *et al*., 1996). The protection of these aquatic ecosystems is interesting as a way of focal protection for the species. The habitat suitability map offers a conservation tool and the areas indicated with a high probability of occurrence could be considered as priority areas for the species. We have also detected protected areas where the species has not been previously detected, with the potential for increasing the surface of protected habitats for the species. The species' presence would be first confirmed here, indicating the need for further field research and biodiversity inventories, particularly in national protected areas.

Although Argentina has conservation potential for the species on an environmental basis, other local threats such as changes in land cover could be more important and jeopardize the species. As for a lot of species, extinction in Argentina will not affect the Muscovy duck on a regional scale, but this country might be important for the protection of its marginal populations and other components of biodiversity. Argentina is at the limit of distribution for many species with broad distribution ranges such as the Black-bodied Woodpecker (*Dryocopus schulzi*). Habitat loss and retracting distribution have been reported for mammals such as jaguars (*Panthera onca*; Cuyckens *et al*., 2017). Thus, Argentina should focus on the protection of such marginal populations of the Muscovy duck. In addition to amplifying protected areas, a stricter control for hunting is mandatory. The map presented here could be incorporated in natural resource management and policy.

Both variables we created were selected by the model and a high number of the presence records were deleted, indicating the importance of identifying the right information with which to train models. This falls under the so called "garbage in, garbage out" rule for SDM (Sanders and Saxe, 2017). Other variables different from the environmental ones used here (like the presence of predators) could influence the duck distribution although they might be difficult to obtain considering the large scale of our work. As mentioned for land cover, the model could also benefit from more detailed basemaps of waterlines and water bodies. We should also put the focus on data collection for the maps. Even though internet platforms, such as eBird, might present geo-referencing mistakes; we believe that these are good predictive inputs. MaxEnt and presence-only distribution modeling have some pitfalls, pointed out by Royle *et al*. (2012). The real absence of a species is difficult to determine for mobile species as birds. For the species distribution model we assume environmental absence which implies not real absence but a non-suitable habitat. As we drew upon existing databases and fieldwork (non systematic data recording), we were not able to use other methods (such as regression or maxlike). For those reasons, other methods (as regression or maxlike) could not be used. Nevertheless, MaxEnt functioned well to accomplish our objectives. The models presented here must be considered a useful approach subject to changes and improvement. By creating relatively important variables in comparison to the environmental variables with low contribution to the model (Table 1) and by filtering presence records, we have improved the models and the scientific rigor of the MaxEnt analyses.

In summary, we assess the potential distribution of a widely distributed duck species, the Muscovy duck, *Cairina moschata*, in Argentina. The species distribution model is a powerful tool to select areas for conservation and knowledge of the geographical distribution of species is essential to assess the threat of climate change (Regan *et al*., 2000; Conrad *et al*., 2006). In the absence of indications about the possibility of increasing the number of protected areas, this work warns for the need to search for other strategies to guarantee the integrity not only of *C. moschata*, but also for its associated habitat and biodiversity. We have presented an accurate model for predicting the Muscovy duck distribution which is an essential tool for many ecological and conservation problems and we hope it will be used by decision makers.

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