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Research Letters

Invasive potential of the pied crow (*Corvus albus*) in eastern Brazil: best to eradicate before it spreads

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ABSTRACT

Biological invasion is one of the main drivers of biodiversity loss and ecosystem damage. Invasive species are difficult to eradicate and prevention is considered the best approach. The pied crow (*Corvus albus*) was recently recorded in eastern Brazil (South America). This African bird species is being considered as a "native invader" in South Africa, and has the potential of causing serious ecological impacts. Therefore, it is important to identify the potential suitable areas and entry points of this species in Brazil. This sort of information allows for a better assessment of where surveillance is needed and if eradication procedures are required. We used ecological niche models to assess the potential distribution of the pied crow in Brazil. Models predicted high suitability for the Southeast, Central and Northeast regions of Brazil, mainly in the Atlantic Forest region. Pied crow occurrence was associated with human infrastructure. Binary models failed to include published records for *C. albus* in Brazil. However, suitable areas are found 46 km away from known occurrence records. We argue that ports are non-intentional points of entry and that surveillance measures should be put into place to prevent novel propagules from arriving and establishing in Brazil.

Introduction

Human activities are responsible for the introduction of species into localities outside species' natural ranges (Richardson et al., 2011). Species introduction can occur with and without human intention and is usually favored in human altered landscapes (Mack, 2000). Invasive species are detrimental to biodiversity and human welfare due to its negative impacts on native species, community and ecosystem processes, human health and economy (Blackburn et al., 2014). However, for an invasive species to be successful in a new environment, it needs to overcome the following barriers (Blackburn et al., 2011: i) have access to a geographic region that was inaccessible prior to human assistance; ii) establish a viable population in the new geographic region, thus overcoming potential restrictions imposed by the new environment; iii) spread to novel localities within the new environment and; iv) cause deleterious impacts (sensu Blackburn et al., 2014) in the new environment. Climate matching has been pointed out as an important predictor of successful invasions (Hayes and Barry, 2008). The reason is that introduced areas that have similar climate to the invasive species' native range are more propitious to the establishment of viable populations, because these areas will have the appropriate climatic conditions for positive population growth (Holt et al., 2005). Because the most efficient way to minimize ecological and economical damage is to prevent the establishment of invasive species (Sakai et al., 2001), species distribution models and ecological niche models can be used as predictive tools for determining the invasive potential of a species (Peterson, 2003). With these models in hand, monitoring procedures can be put into place to deter the establishment or advancement of invasive species (Venette et al., 2010).

In a recent meta-analysis review, Madden et al. (2015) pointed out that crows and ravens have an overall small negative effect on bird abundance and productivity (e.g., nesting success, brood size). However, two crow species – *Corvus splendens* and *Corvus albus* – are considered problematic. The first species has managed to establish breeding populations outside their native range in several countries, where they are responsible for

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ecological impacts (Ryall, 1992), economic loss (Kamel, 2014) and human health problems (Yap and Sodhi, 2004). The second species has yet to establish breeding populations outside of its Pan-African native range. However, in South Africa, *C. albus* has experienced a disproportionate increase in abundance and range (Cunningham et al., 2016). Scientific studies on the ecological impacts for this species are lacking, but there is a report of heavy predation pressure on a native tortoise (Fincham and Lambrechts, 2014) and of potential negative interactions with raptors (Simmons and Barnard, 2011). Indeed, it is possible that a process of "native invasion" by *C. albus* is currently happening in South Africa (Cunningham et al., 2016). This can be problematic because this species is a behavioral generalist that feeds on a wide range of organisms as well as carrion (Anjos et al., 2009). Moreover, human infrastructure can facilitate the spread of *C. albus*. For example, powerline and road infrastructure are associated with an increase in the numbers of *C. albus* in South Africa. The first probably provides the species with nesting and perching sites (Cunningham et al., 2016), while the latter provides alternative food sources via roadkills (Joseph et al., 2017).

The presence of *C. albus* in Brazil was first reported in 2004 (Silva and Olmos, 2007), and there are currently eight published records for this species in the coast of São Paulo State (Table S1; Lima and Kamada, 2009). Because this species seems to be developing into a "native invader" (Cunningham et al., 2016), and human infrastructure seems to facilitate its expansion in the native range, it is imperative to evaluate if *C. albus* is capable of establishing a viable population in Brazil. In order to do this, we developed an ecological niche model using data from the native range to identify potential suitable climate areas for population maintenance. In addition, we traced possible expansion routes of this species in Brazil based on the recent records of this species in the coast of São Paulo state. Finally, we also discuss the importance of these results to increase the current knowledge of the distribution of pied crow as a Neotropical invasive species.

Methods

Studied species and occurrence data

Crows and Ravens (Family: *Corvidae*) are medium to large birds reaching 69 cm and 2000 g. Crows are morphologically quite similar with a basic black plumage having strong beaks and legs (Anjos et al., 2009). *C. albus*, is a Pan-African large crow (45 cm, 400 g–700 g), with head, neck, upper chest, upperparts, wings, and tail black or with nuances of black, blue and purple (Anjos et al., 2009). Different from other crows, these dark parts contrast with a white collar, which extends over the breast and underparts (see Fig. 5 in Lima and Kamada, 2009). This species lives in open areas, such as grasslands, open woodlands, forest edges and savannas. It can also be found in close proximity to aquatic environments, such as riverbanks and lakeshores (Anjos et al., 2009). Pied crows avoid dense forests and deserts, can withstand high altitudes (up to 3700 m a.s.l.), but prefer lowlands where it is usually more abundant (Anjos et al., 2009). The species is also abundant in habitats associated with human settlements (Londei, 2010).

Native occurrence records (n = 42,238) were obtained from the Global Information Facility Database (www.gbif.org). Duplicate records inside the same grid and points outside geographic boundaries were removed. The remaining occurrences (n = 4482) were thinned using spatial filter analyses in order to reduce sampling bias (Boria et al., 2014), as implemented in the R package spThin (Aiello-Lammens et al., 2015). We used this procedure because biodiversity data is usually biased in areas of easy access. The thinning procedure was executed using 100 iterations and 10 km thinning distance (i.e., minimum distance between occurrence points), which resulted in 2635 occurrences. As a final step, occurrences inside grids that lacked data for at least one of the environmental variables used were removed, resulting in a final data set of 1318 occurrences records (Fig. S1 and Supplementary Methods).

Environmental data

Climate data were obtained from the WorldClim database (Hijmans et al., 2005). In order to reduce over-fitting of the models, climatic variables were selected according to the ecology of *C. albus*. We also used a principal component analysis to reduce collinearity among WorldClim variables. This was done by keeping the variable with the highest loading when variables were correlated (see Fig. S2; Table S2; and Supplementary Methods for more details on variable selection). Due to the synanthropic nature of *C. albus* (Anjos et al., 2009), we included in the final model two variables that reflect human associated landscape changes: 1) global nightlight data (NOAA's National Geophysical Data Center; available at: http://ngdc.noaa.gov/eog/dmsp/); which measures human land use, infrastructure and human access; and 2) human foot print (Wildlife Conservation Society, Center for International Earth Science Information Network, 2005; available at: http://sedac.ciesin.columbia.), which is the Human Influence Index (HII). HII is determined using data on human population density, human land use/infrastructure and human access (roads, railroads, navigable rivers and coastlines). The extent of the native area used for modeling was: 37°20′58.632″N, 51°24′46.908″E, 46°58′44.148″S, 25°21′31.5″W. Final models were projected into South America (extent: 13°22′43.032″N, 29°21′35.028″E, 55°55′10.956″S, 109°26′56.94″W) using WGS84 projection. Grid cell resolution was 0.25° degrees, corresponding to ~28 km^2 in each raster (Supplementary methods). We chose this resolution because of the species' large native distributional range (Fig. S3), high densities of occurrence records for South Africa – thus indicating possible sampling biases (Fig. S1) – and the scale of our study, which is continental (model was made using occurrence data from Africa, which was then projected into South America).

Ecological niche models (ENM) and model calibration

We used five different classes of algorithms to model the potential distribution of *C. albus* (see Supplementary methods). The algorithms were chosen according to different modeling approaches based on Bioclimatic Envelope, Distance and Machine Learning methods, which can be used to model distribution with presence only data (Franklin, 2010). These methods produce maps with continuous suitability values for each grid cell and rescale values from zero (i.e., grid unsuitable) to one (grid is suitable) when necessary. Models that presented a good fit (see below) were then combined to generate a single model (Araújo and New, 2007), which was then projected into South America to evaluate the potential invasiveness of *C. albus*. We used 75% of occurrence data (n = 988) to calibrate the models and 25% (n = 329) to validate the models, using a pseudo-absence approach to simulate absence of occurrence when necessary.

We used 100 iterations for each algorithm and used the partial area under the receiver operating characteristic curve (ROC) to measure model fit (Peterson et al., 2008). For this analysis the software "Partial ROC" (Barve, 2008) was used. The partial ROC approach is more suitable to evaluate environmental niche models because it allows one to reduce the biases generated by the pseudo-absence procedure (for details see Peterson et al., 2008). We used 10,000 iterations, and for each iteration, we re-sampled 50% of the test data (i.e. bootstrap) and accepted a 95% error (default settings). Models that had partial AUC ratio >1 were considered as

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