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How rare species conservation management can be strengthened with the use of ecological niche modelling: The case for endangered endemic Gundlach's Hawk and Cuban Black-Hawk

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Forty-six percent of tropical raptors are threatened by habitat loss and fragmentation. Tropical raptors are generally rare species. The scarce information on distribution patterns of rare species makes it difficult to establish reliable conservation plans. We used ecological niche modelling to obtain good predictions of occurrence of two case species, the rare and endemic Gundlach's and Cuban Black-hawks in Cuba, based on presence-only data. We used records from an intensive survey undertaken in natural and modified environments. Data were integrated with environmental variables using Maxent to predict species distributions. Subsequently, we overlaid the resulting predicted distributions, the land use map and the protected areas layers to establish potential suitable habitat for these endemics and to determine if a better design of protected areas than the existing one can be proposed using both hawks' distribution in the design. Gundlach's Hawk distribution was fragmented, depending on forest distribution. Cuban Black-Hawk distribution was narrow, near the coastline. Forests and mangrove represent 57% and 45% of Gundlach's Hawk and Cuban Black-Hawk model predictions, respectively. 71% of the total forest area was represented in the distribution of Gundlach's Hawk. Mangrove area overlaps 45% of the Cuban Black-Hawk distribution. Six protected areas preserved 50% and 92% of their distributions, respectively. With few presence-only data of rare species, Maxent models were statistically and ecologically significant and reliable to develop distribution maps with high predictive power. Our results highlight the importance of natural habitats for conservation efforts of these endemic species. A good conservation program should include the protection of suitable nesting areas and expand the protected areas network containing suitable habitats for both species in forest and coastal areas. We propose the use of predictive modelling tools to strengthen conservation actions not only for rare raptors but for the 238 endemic and threatened birds of the Neotropics with scarce data, small population sizes, restricted distributions and often specialist habits.

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1. Introduction

Patterns of species distribution are the result of historical and ecological factors at both temporal and spatial scales. Vegetation, climate, latitude and topographic features are the main environmental factors determining the geographic distribution of bird species (Orians and Wittenberger, 1991). Therefore, habitat characteristics condition habitat selection by birds since they must ensure the availability of food resources, nesting areas, and refuges (e.g. Cody, 1985). However, human transformation of natural ecosystems is at the present the main driver restricting the species current distribution patterns, leading to extinction cascades and population declines (e.g. Ceballos et al., 2015; Fahrig, 2003; Herremans and Herremans-Tonnoeyr, 2000; Vitousek et al., 1997). The consequences of human activity for the abundance and distribution patterns are of particular concern for rare species, mainly those with a narrow distribution, narrow habitat tolerance and small population size, because they are more prone to extinction as it is known that range size and population size are strong predictors of extinction risk (Gaston and Fuller, 2009; Purvis et al., 2000; Rabinowitz, 1981). Top-order predators (e.g. raptors) are considered rare species (Sergio et al., 2008).

Human transformation of natural ecosystems has threatened 46% (102) of all tropical raptors (222 species; Bildstein et al., 1998), 30% of which are endemics. IUCN classifies 27% (59 species) of all tropical raptors as Near Threatened, Vulnerable, Endangered, or Critically Endangered, and 23% (17 species) of the Neotropical raptors ($N = 73$ species) are threatened as well. Twenty-eight at-risk tropical raptors (47%) are restricted to islands and twenty-one at-risk species (36%) are both forest-dependent and island-restricted (Bildstein et al., 1998). Thus, many tropical and Neotropical raptors are considered rare species. The current status of a great percentage of tropical and Neotropical raptors is of special concern because many of these species will become rarest in the medium-term. Rarity and habitat specialization are traits that increase the risk of species extinction, even synergistically (Davies et al., 2004). For example, extinction rates has been found to be highest in rare, specialized lizards and snakes on Greek islands (Foufopoulos and Ives, 1999); habitat loss threatened more bird families that were specialists than families that were not (Owens and Bennett, 2000); beetle species that were both rare and specialized were especially vulnerable to extinction, with a greater reduction in their growth rates in fragments compared to continuous forest (Davies et al., 2004). In the case of diurnal raptors, habitat loss has led to a decrease in the density of raptors (e.g. Carrete et al., 2009 and Pavez et al., 2010), particularly in tropical species and specialists.

There is a substantial management and conservation interest in regional conservation agendas to protect rare species (Davies et al., 2004). Rare species have an important role in the maintenance of ecosystem function, because they contribute to the maintenance of the ecosystem diversity, serve as successful indicators of general patterns of species diversity and have a significant impact on invasion resistance, thereby affecting the ecosystem composition and functioning (Lyons and Schwartz, 2001; Lyons et al., 2005). It is known that eliminating predators and particularly top-order predators (e.g. raptors), destabilizes ecosystems producing simpler states than the initial state, supporting less biodiversity (Terborgh and Estes, 2010). Also, the loss of top predators can degrade ecosystems (e.g., Purvis et al., 2000). In general, raptors are useful as indicators of biodiversity and for monitoring environmental change (Rodríguez-Estrella and Bojórquez-Tapia, 2004).

Despite the potential consequences of human activities on tropical raptor species and endemics, there is a remarkable lack of studies on the effects of habitat loss and land use changes on their distribution and abundance in Neotropical islands. In particular, for island tropical raptors information is scarce. We are particularly concerned about the effects on rare raptor island species because they are highly prompt to extinction (e.g. Guadalupe caracara *Caracara lutosus* Abbot, 1933; Mauritius Kestrel *Falco punctatus* Cade and Jones, 1993). In the island of Cuba, the three endemic raptors Gundlach's Hawk (*Accipiter gundlachi*), Cuban Black-Hawk (*Buteogallus gundlachii*) and Cuban Kite (*Chondrohierax wilsonii*) are classified by IUCN (BirdLife International, 2013) and Red Book of Vertebrates of Cuba (Kirkconnell, 2012; Rodríguez-Santana and Viña, 2012a,b) as Endangered and Critical Endangered because of habitat loss. All these endemic raptors are rare species with restricted distribution, low abundance and specialized habits (Bond, 1956; Rodríguez-Santana, 2009). Also, two subspecies of non-endemic residents are very rare: *Pandion haliaetus ridgwayi* and *Accipiter striatus fringilloides* (Garrido, 1985; Rodríguez, 2004). These species have several isolated populations restricted to particular habitat types and have small population sizes. Cuban kite and Gundlach's Hawk are forest-dependent species and the Cuban Black-Hawk is specialized to a narrow band of coastal habitats. Specialized habits and the loss of a significant amount of natural habitat due to land use changes and fragmentation that have reduced forest coverage (now with $< 14\%$ of the island; González and Fontenla, 2007), should be certainly affecting the distribution patterns of raptors in the island (Rodríguez-Santana, 2009). If habitat changes in Cuba continue increasingly affecting the remaining suitable habitat of endangered raptors, we expect these species will become even rarer and threatened by extinction in the medium-term.

Studies on the effects of habitat changes caused by human activities on the abundance of raptors have been only recently carried out (Ferrer-Sánchez and Rodríguez-Estrella, 2015). To achieve effective conservation strategies for threatened species in modified environments at local scales we need first to analyse the effects of human activity on the species distribution, and second to use fine scale variables with a good spatial resolution in such a way they reflect the characteristics of the habitats and the landscape. The lack of this information restricts our understanding of the response of rare raptors to human activity, especially in vulnerable and fragile ecosystems such as islands (see González et al., 2008).

In recent years, a variety of statistical models have been used to predict the spatial distribution of plant and animal species (Guisan and Zimmermann, 2000; Peterson et al., 2011). Information for modelling potential distribution of rare and endangered taxa generally consists of a set of presence-only data, with few observations, and often these observations lack of location spatial accuracy (Engler et al., 2004). As a result, few predictive models have been developed for rare and endangered species of raptors (e.g. De Frutos et al., 2007; Muñoz et al., 2005 and Tsuyuki, 2008). Species distribution models are based on the assumption that the relationship between a given pattern of interest and a set of factors that might control the pattern can be quantified (Anderson et al., 2003). When few records exist with low spatial accuracy these relationships may lack of ecological and statistical significance to establish a pattern. Certainly, it is important to consider that there are errors and uncertainty in the species' distribution models because the distribution data may contain errors and there might be uncertainty in the environmental variables used to generate the models, then models may not include all environmental, ecological and historical factors that affect species distributions (Carvalho et al., 2010; Guisan and Zimmermann, 2000).

However, Maxent is a popular modelling approach to determine a species' distribution that is based on presence-only data. It has been used successfully to predict the distribution of a wide array of species (e.g. Brambilla and Saporetti, 2014; Raxworthy et al., 2003 and Yañez-Arenas et al., 2012). Of special relevance is that Maxent algorithm has been found to be robust when changes in sample sizes occur and have good predictive ability using low sample sizes (Hernandez et al., 2006). The aim of this study was to have accurate predictions of occurrence of the rare and endemic Gundlach's Hawk and Cuban Black-Hawk using ecological niche models. We expected using Maxent modelling approach would produce strong predictive models, but a condition was that environmental variables used in the models be ecologically relevant and strictly obtained and derived from good accurate maps and imagery in order to have adequate proxies for species modelling (Soberón, 2007). The resulting models can help us to establish better designs of natural protected areas and better management programs in islands (e.g. Cuba) based on relevant species such as rare species. We propose that the use of ecological niche modelling can strengthen the management and conservation actions for rare endemic raptors in particular in those areas under strong and continuous pressure from human activity (e.g. islands, coastal zones). Changes in the actual design of natural protected areas and the creation of new ones are recommended. Lastly, our approach could be useful for rare species in all biological groups, particularly those having small size populations with a relatively low number of records. The novelty or our study is the use of two rare and endemic raptor species in an island (Cuba) with different ecological requirements as case studies to show the power of the method and modelling approach and the use for conservation purposes. We believe our approach could increase the use of this kind of models where data are scarce (as for rare species, raptor species, narrow distributed species) mainly in islands, where most studies lack of data and the pressures by human activity make vulnerable the rare and endemic species and where more conservation management actions are urgently needed.

2. Methods

2.1. Study area

Fieldwork was made in the central region of Cuba, to the north of Ciego de Ávila province (22.132682°; −78.387738°; Fig. 1), including isolated cays in the coast and inland wetland. This area contains the Gran Humedal del Norte de Ciego de Ávila protected area, characterized by a low-lying, partly swampy plain. The cays along the coast of Cuba harbour diverse plant communities such as mangroves, xeromorphic coastal shrubs, deciduous forests, microphyllous evergreen forests, halophytic vegetation as well as rocky- and sandy-coast vegetation. The inner parts of the study area are covered by deciduous (mostly mesophyll) forests, evergreen forests, swamp marsh grasslands and second-growth vegetation.

Forests (15.3% of total study area), mangroves (14.3%), lagoons (8.8%), swamp marsh grasslands (5.7%) and coastal vegetation (0.8%) were considered as natural areas. Forests include deciduous, evergreen and swamp forests. Deciduous forests are widely distributed in the wetland and cays. Among the natural habitats analysed, forests were the most affected and fragmented by sugarcane cultivation, livestock ranching and agriculture. Mangroves are widely distributed in the cays and the coastline, but tourism development has reduced their distribution. Tourism in the cays has largely affected the lagoons and lakes through the construction of hotels and recreational activities, fishing and changes in water regime as a result of the desiccation and channelling of wetlands. Swamp marsh grasslands are impacted by changes in the water regime due to piping and draining of wetlands for agricultural purposes. The coastal vegetation includes shrubs and rocky- and sandy-coast plant communities. Detailed information on vegetation and habitat types can be found elsewhere (Ferrer-Sánchez and Rodríguez-Estrella, 2015).

Man-made environments were agriculture (35.3%), cattle pasture (20.5%) and urban (0.8%) areas. Crops such as rice, sugarcane and fruit trees dominate agriculture areas. The cattle pastures for livestock ranching are scattered within the wetland. In most cases, grazing patches of different sizes are inserted within forests. Finally, the urban areas include five cities and rural settlements and hotels.

2.2. Birds data

We gathered information on the presence/absence of the Gundlach's Hawk and Cuban Black-Hawk from systematic fieldwork, from February to August 2012 and 2013 in the region. Presence/absence records were obtained from 242 observation points and three roadside surveys located in natural and human-transformed areas. We used a stratified random sampling (Fuller and Mosher, 1987) to locate fixed points in two environments: natural and human-transformed. We randomly allocated the sampling points, based on the proportion of each habitat type within the natural and human-transformed areas. Point counts were separated at least 2 km from each other to decrease the probability of double counts of

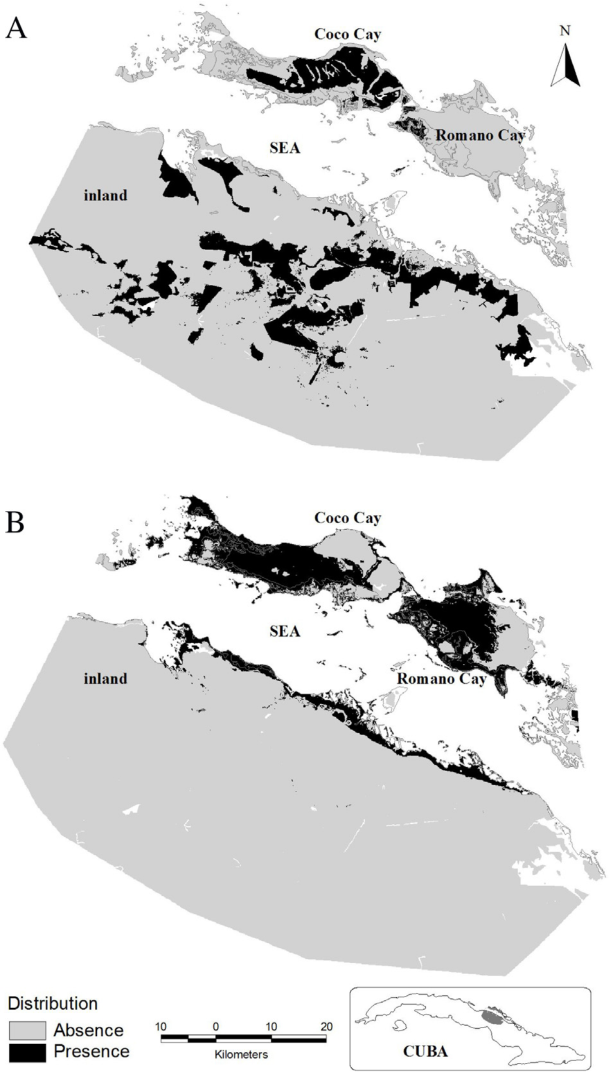

Fig. 1. Models of potential geographical distribution of two endemic raptors in north of Ciego de Ávila in the island of Cuba. (A) Gundlach's Hawk; (B) Cuban Black-Hawk.

individuals. For modelling, we used the 17 and 133 spatial records of presence of Gundlach's Hawk and Cuban Black-Hawk, respectively.

2.3. Environmental variables

We used a vegetation and land use map previously developed to identify natural and human-modified areas in the region (see Ferrer-Sánchez and Rodríguez-Estrella, 2015). As a measure of habitat heterogeneity and complexity, we also derived variables describing landscape spatial structure and heterogeneity from the land use and vegetation map. Patch size, patch shape index, richness and diversity of the landscape (McGarigal and Marks, 1995), amount of suitable habitat per species and modified habitat (Fahrig, 2013) were estimated. Mean shape index measures the average patch shape (average perimeter-to-area ratio), for a particular patch type. It is considered as measure of overall shape complexity and was initially proposed as a diversity index based on shape for quantifying habitat edge for wildlife species. Thus, the index equals 1 for square patches of any size and increases without limit as the patch becomes increasingly non-square (i.e., more geometrically complex with more habitat edge) (McGarigal and Marks, 1995).

Based on descriptions from literature we defined the amount of suitable habitat per species on the vegetation map. Therefore, suitable habitat for Gundlach's Hawk included mangroves, open woodland, forests, forest edges, swamps, wooded coasts, xeromorphic coastal shrubs and forest plantations (Garrido, 1985; Rodríguez-Santana and Viña, 2012a; Wiley, 1985). For Cuban Black-Hawk the mangrove, rocky- and sandy-coast vegetation, xeromorphic coastal shrubs, seashores and coastal forests were considered as suitable habitat (Rodríguez-Santana and Viña, 2012b; Wiley and Garrido, 2005).

Table 1
Relative contribution (%) of the environmental variables to the Maxent models of the Gundlach's Hawk and Cuban Black-Hawk distributions in the northern region of Ciego de Ávila, Cuba. The training gain without the variable and training gain with only the variable with the highest contribution of the total, respectively are parenthetically.

Variables	Species	
	Gundlach's Hawk	Cuban Black-Hawk
Forest shape index	44.1 (2.2; 1.7)	0.1
Land use	14.4 (2.3; 1.3)	1
Area of modified habitat	8.9	–
NDVI	6.6	7.1
Amount of suitable habitat for Gundlach's Hawk	6.1	–
Distance to urban zones	5.5	12.1 (2.6; 0.6)
Distance to cattle pasture	3	–
Landscape diversity	2.9	1.3
Area of Mangrove	2.9	6.4
Area of forest	2.8	1.6
Distance to farming land	1.4	–
Distance to coastline	1.2	60.1 (2.6; 1.7)
Patch richness	0.2	2.9
Area of coastal vegetation	0	3.4
Mangrove shape index	0	2.2
Coastal vegetation shape index	–	0.9
Area of urban zones	–	0.7

Modified environments like cattle pastures, agricultural areas and urbanized areas were considered as unsuitable habitats for both species because in previous studies these raptors were not frequently observed and were not related with modified environments (Ferrer-Sánchez and Rodríguez-Estrella, 2015).

We generated map layers of variables (see Appendix). Also, we examined pairwise Spearman correlation coefficients among all 25 environmental variables and from the pairs of metrics with coefficients >0.7 (Dormann et al., 2012), only the most ecologically relevant variable was retained (Fitzpatrick et al., 2013). Using this procedure, the original set of variables was reduced from 25 to 18 helping to compensate for possible over-parameterization of models and interdependence among explanatory variables caused by multi-collinearity, which would hamper model selection, parameter estimation and the interpretation of results (Grosbois et al., 2008). The 18 environmental variables (Table 1) therefore represent independent measures of the landscape features in the study area. Accordingly, they correspond to adequate proxies for modelling the Gundlach's Hawk and Cuban Black-Hawk occupancy in Cuba and are thus expected to predict the realized species distributions (Soberón, 2007).

2.4. Ecological niche modelling

Although we obtained data from our sampling design that could lead the use of robust presence/absence modelling methods (i.e. GLMs), it is essential that presence/absence records be balanced (approximately same number of presences and absences) in the database to build good statistical models. If presence/absence data are not balanced (for example for rare species where data on presences is low), then presence/absence models are not adequate and the best option is using presence-only methods (Franklin, 2009) (i.e. ecological niche modelling). Using the set of 18 environmental variables and the presence data of each rare raptor species we carried out the ecological niche models using the maximum entropy algorithm (Maxent 3.3.k) (Phillips et al., 2006). We used 70% of presence records as training data in the Cuban Black-Hawk model and 30% to test the model. In the case of the Gundlach's Hawk we used all data ($N = 17$) to build the model. We kept by default the parameter set of the software (Phillips et al., 2006). To reduce uncertainty caused by sampling artefacts, we ran 100 models (replicates) with a random seed partition and a bootstrap replicate type. Maxent logistic output was converted into binary maps using the minimum training presence (MTP) threshold value, one of the most recommended methods (Liu et al., 2005).

We evaluated Maxent predictions using the area under the receiver-operating characteristic curve (AUC). The AUC scores are interpreted as reflecting the ability of the model to distinguish presence data from background data (Phillips et al., 2006) and is one of the most widely used methods to evaluate model performance (Franklin, 2009). Although AUC is sensitive to the method by which absences are selected in the evaluation dataset among other errors (see Lobo et al., 2008), it is a valid measure of relative model performance between models for the same species and study area.

Additionally, we made an external validation of the Cuban Black-Hawk model using new field data. Presence (33 localities) and absence (123 localities) were obtained between February and August in 2012 and 2013 in the area. Selected sites for field validation included areas where models predicted absence and presence of the species. In order to measure the performance model we used a confusion matrix (Fielding and Bell, 1997), which matches records between validation and model prediction. This manner we checked out for a high overestimation (false positive—absence records have been predicted as presence) or omission (false negative—presence records have been predicted as absence) in the model. Also, we calculated the Kappa and True Skill Statistic (TSS) coefficients to evaluate the model results accuracy (Franklin, 2009).

In order to estimate the relative contribution of each environmental variable to the Maxent models we analysed the increase in regularized gain, which is added to the contribution of the corresponding variable, or subtracted from the contribution if the change to the absolute value of lambda is negative. In addition, we included the jackknife test to measure variable importance by training with each environmental variable first omitted in the model, then used in isolation. Summary values of the 100 models containing the values of the average for all parameters analysed were used. We considered the variables with the highest contribution to the models those having a relative contribution greater than 50% grouped or independently. In four graphs we wanted to show how the most important environmental variables affect the Maxent prediction. Each of the curves represents a Maxent model created using only the corresponding variable (Phillips et al., 2006).

2.5. Habitat characterization

In order to characterize the area of the potential geographic distribution of both raptors species the land use and vegetation map obtained from satellite image classification was used. This map is the most recent information for the study area. Potential distribution maps were overlapped with the land use and vegetation layer. We cut the land uses and vegetation layers following the species presence boundaries of the potential distribution maps. From this spatial information, the area represented by each land uses and vegetation types within potential distributions was calculated.

2.6. Conservation priority areas

To determine the extension of official protected area within the current distribution of the rare endemic raptors, the resulting potential distribution maps were analysed taking into account the contours of the current protected area network map of the region. The extension and percentage of the species potential distribution within protected areas was calculated. We wanted to evaluate the feasibility to propose the creation of new officially protected areas to increase the boundaries of current protected areas or to re-evaluate the conservation priority zones according to the proportion of distribution that was outside of the official protection. Analyses were made in ArcView 3.2 (ESRI Inc., USA).

3. Results

The spatial distribution of the Gundlach's Hawk and the Cuban Black-Hawk covered an extension of 896 km^2 and 703.4 km^2 respectively, accounting for 16% and 12.5% of the total study area (Fig. 1(A)–(B)). AUC scores indicated that Maxent performed well for Gundlach's Hawk (mean training $= 0.97$; SD $= 0.02$) and Cuban Black-Hawk (mean training $= 0.99$; SD $= 0.002$; mean test $= 0.8$; SD $= 0.01$). The training omission for both species was 0. While, test omission was 0.02 and the test points predicted better than a random prediction ($p < 0.0$) for the Cuban Black-Hawk model. Furthermore, external validation tests of the Cuban Black-Hawk model indicated high predictive capacity (Kappa $= 0.88$; TSS $= 0.88$). Model sensibility was 0.91 and the specificity was 0.97.

The potential distribution of the Gundlach's Hawk is fragmented in the study site, mainly depending on the forest distribution (Fig. 1(A)). There were no suitable conditions in the southeast and northeast regions for the hawk's occurrence. The potential distribution of the Cuban Black-Hawk is near the coastline, mainly concentrated in the cays region of the archipelago. The model for this species predicted that the potential distribution was very narrow, mainly in the mangrove swamp (Fig. 1(B)).

Two variables, forest shape index and land uses (forest and swamp marsh grassland), accounted for more than 50% of the relative contribution to the model of the Gundlach's Hawk. While other variables, distance to coastline (a lesser distance improve the relative probability of occurrence) and distance to urban zone (there is an optimum distance that improve the relative probability of occurrence) accounted for more than 60% of the relative contribution in Cuban Black-Hawk model (Table 1). Also, variables like patch richness and forest shape index had a low relative contribution.

Our results provide information on the variables that can affect the species distribution through the use of niche models. For instance, Gundlach's Hawk has a preference for forested habitat. Inside this habitat the species prefer the most irregular patch forests with less compact shapes (Fig. 2(A)). This means that Gundlach's Hawk can be found in forest patches with great edges or in the border of forests. In the case of the Cuban Black-Hawk, the potential occurrence of the species is more probable near the coastline and at least 3 km away from urban zones (Fig. 2(B)).

The visualization of the ecological niche models was based on the graphic relationship between the most important variables (forest shape index, land use, NDVI, distance to coastline, distance to urban zone) per species. High values of the NDVI indicate the presence of forest zones. Visual analysis of variable values in the potential distributions and the environmental dataset (availability) indicates a broad ecological range for these species in the zone (Fig. 3). This means that there exists a superposition between the range of the predicted presence and the whole environmental gradient (availability) of the most important variables. Nevertheless, descriptive statistics of variables significantly differed between the broader availability of environmental conditions and the suitable habitat conditions (potential presence) for both species

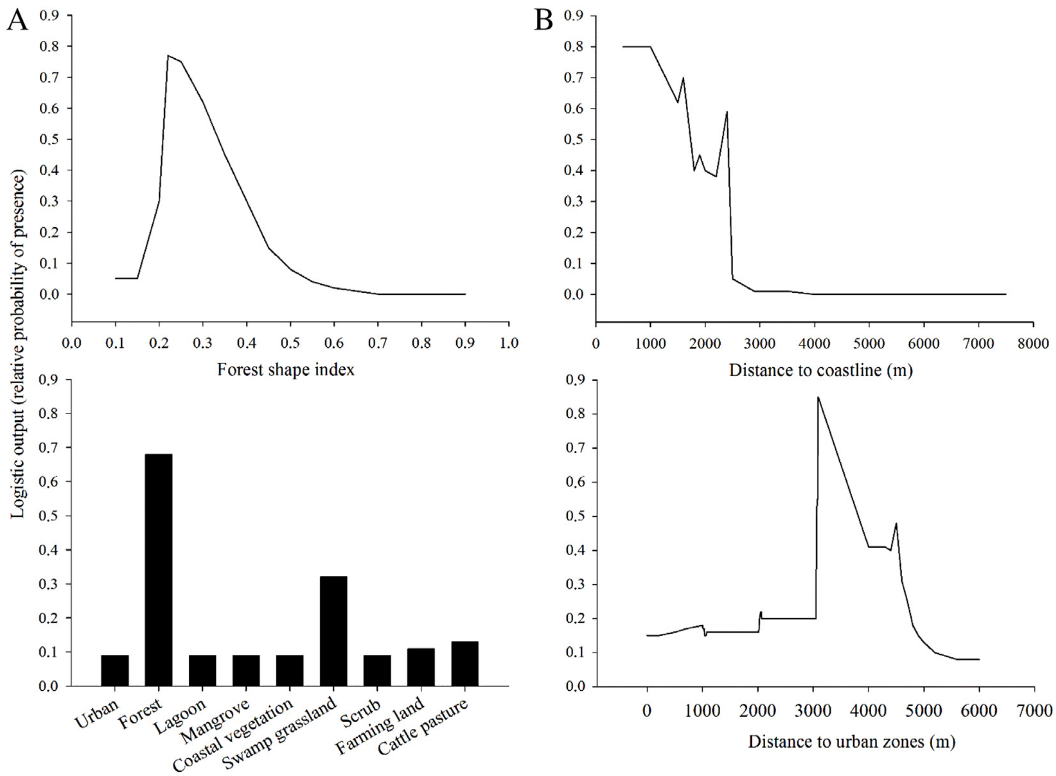

Fig. 2. Response curves of the variables with the highest contribution to the predictions of Maxent. (A) Gundlach's Hawk model; (B) Cuban Black-Hawk model.

according to the models ($p < 0.001$). This result indicates that both species select their habitat, highlighting its character as specialists.

The natural habitats occupied the 82% and 90% of the Gundlach's Hawk and the Cuban Black-Hawk potential geographic distribution, respectively. Forests and mangroves represent 57% and 45% of these predictions, respectively. Seventy-one percent of the forest area in the region is represented in the potential distribution of the Gundlach's Hawk and 13% in the Cuban Black-Hawk occurrence (Table 2). Forty-five percent of the mangrove area occupies 45% of the Cuban Black-Hawk geographic distribution. Several forest types are represented in the study area but mesophyll semideciduous forest was the most important in both distributions (Fig. 4). More than 95% of the extension of the two available mesophyll semideciduous forest types in the area was included in the predicted distribution of Gundlach's Hawk (Fig. 4). The majority of the coastal vegetation extension (59%) was represented in the potential distribution of the Cuban Black-Hawk, and mangroves and lagoons as well (Table 2). The swamp grassland represented the 67% of the area in the modelled distribution of the Gundlach's Hawk (Table 2).

Modified habitats occupied the 15.2% and 6.6% of the Gundlach's Hawk and the Cuban Black-Hawk potential geographic distribution, respectively. Within modified areas, urban zone was the best represented in both potential distributions (Table 2). In addition, 4% of the Gundlach's Hawk modelled distribution was occupied by farming land (rice-growing, several crops and sugar-cane).

At present, six protected areas exist in the study region, officially protecting 50% (451.5 km^2) of the Gundlach's Hawk and 92% (644.5 km^2) of the Cuban Black-Hawk predicted distribution. To protect the greatest possible extension of the Gundlach's Hawk geographic potential distribution we identified potential for two protected area extensions, to the east of the Ecological Reserve Centro-Oeste Cayo Coco (ERCOCC) and the southernmost boundary of the Gran Humedal del Norte de Ciego de Ávila Ramsar site (Fig. 5(A)). The potential distribution of the Cuban Black-Hawk could be protected with the boundary extension of the ERCOCC (Fig. 5(B)). We also recommend the western area of the region as a priority area for surveying the potential distribution of the Gundlach's Hawk (Fig. 5(A)) and suggest three priority survey sites for the Cuban Black-Hawk taking into account the presence of several nests in these areas (Fig. 5(B)).

4. Discussion

Ecological niche models showed a good predictive power to identify currently occupied and unoccupied locations for both rare endemic raptors. Our models can be used both for the analysis of species distribution and also to design conservation efforts towards the most important locations into protected and non-protected areas. Results of fieldwork

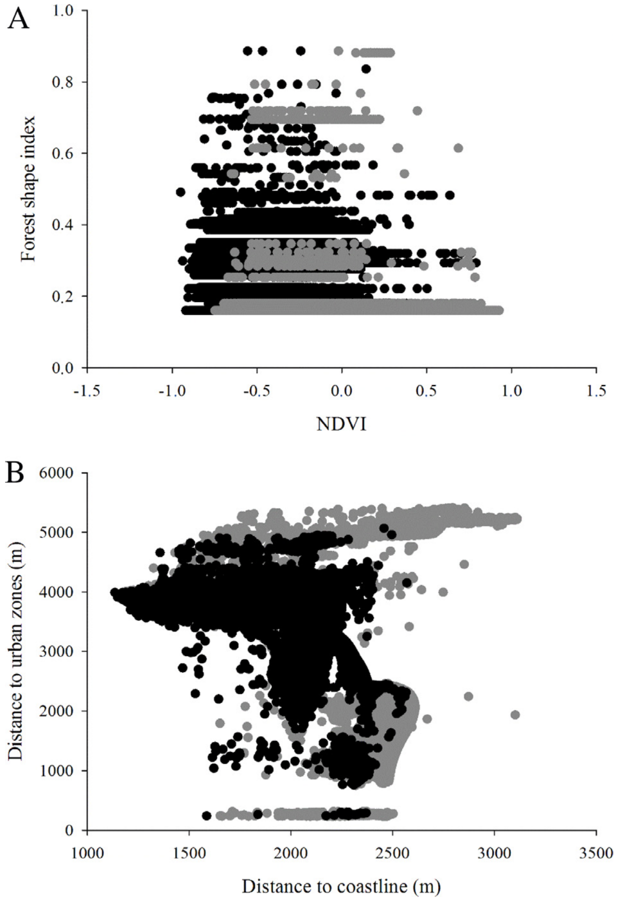

Fig. 3. Distribution of endemic raptors in ecological space. (A) Plots of normalized difference vegetation index versus forest shape index; (B) distance to coastline versus distance to urban zones. Grey circles represent the broader environmental conditions across the study area (availability); black circles represent modelled appropriate conditions (presence) for Gundlach's Hawk (A) and Cuban Black-Hawk (B).

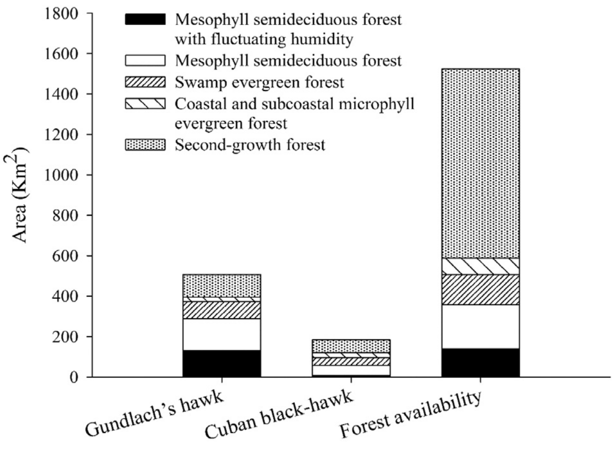

Fig. 4. Different forest types represented in the potential geographic distribution of two endemic diurnal raptors in the island of Cuba.

on habitat preferences of target species (e.g. forests, mangroves, coastal vegetation) were converted in high quality models that have implications not only for programming census and monitoring schemes for species and other research, but also for planning conservation strategies for rare and endangered raptors at the local scale and could inform about new areas in which conservation would maximize the economic and political investment devoted to their protection.

Models indicated that suitable, but unoccupied areas for both raptor species exist in the region. In the case of rare narrowly distributed species, the use of Maxent's modelling has showed that reliable models can be generated from datasets

Table 2
Area (km^2) occupied by land uses and vegetation types inside potential geographic distribution of the endemic Gundlach's Hawk and Cuban Black-Hawk in the central region of the island of Cuba. Total Area refers to the total extension occupied by the selected land uses and vegetation types in the study area. Percentage (%) represents the percentage of the land use or vegetation type contained in the species potential distribution in relation to its total extension in the study site.

Land uses	Species				Total area
	Gundlach's Hawk		Cuban Black-Hawk		
	Area	%	Area	%	
Forest	513.1	70.5	92.1	12.6	728.3
Lagoon	25.9	7.5	176.6	51.0	346.0
Mangrove	5.5	0.8	317.0	45.3	699.8
Coastal vegetation	0.3	0.7	25.2	58.6	43.0
Swamp grassland	189.6	66.9	24.0	8.5	283.2
Urban	75.9	38.0	44.9	22.5	200.0
Scrub	0.1	0	0	0	411.1
Farming land	33.4	1.8	0.3	0	1879.4
Cattle pasture	50.0	4.9	1.2	0.1	1014.8

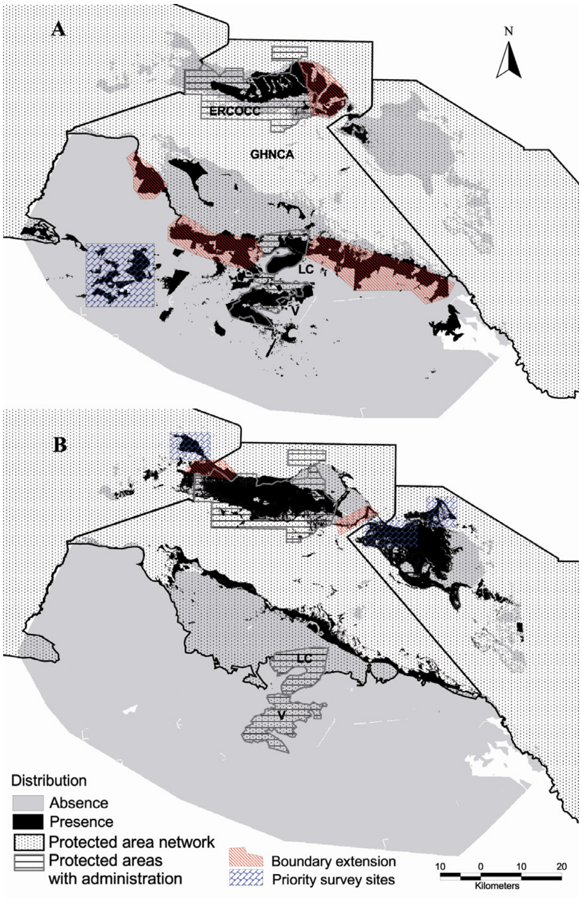

Fig. 5. Recommendations for protected area extensions and priority survey sites based on geographic potential distribution of two endemic raptors in north of Ciego de Ávila, Cuba. (A) Gundlach's Hawk; (B) Cuban Black-Hawk. ERCOCC: Ecological Reserve Centro-Oeste Cayo Coco; GHNCA: Gran Humedal del Norte de Ciego de Ávila, Ramsar site; V: Faunal Refuge El Venero; LC: Faunal Refuge Loma de Cunagua.

even with few presences (Pearson et al., 2007). Our results show that certainly with few presence-only data of rare species, models were statistical and ecologically significant and reliable to develop distribution maps with high predictive power. Models could also be useful to identify new nesting areas and sites of occurrence.

The results on predicted distributions agree with the ecological features previously reported for each species (e.g. Rodríguez-Santana and Viña, 2012a,b) and those we have found in an intensive study (Ferrer-Sánchez and Rodríguez-Estrella, 2015). The Cuban Black-Hawk has specialized habits and a restricted and fragmented distribution with greater concentration along an archipelago (Sabana-Camagüey). Habitats include the edge of coastal wetlands and marshes, salt marshes, wetlands, beaches and mangroves and also mesophilic semi-deciduous forests with fluctuating humidity surrounding coastal areas. The Gundlach's Hawk has been recorded in all regions of Cuba inhabiting a variety of forests, forest borders, swamps, wooded coasts and mountains below 800 m elevation (Garrido, 1985). This species has a distribution in fragmented habitats along the island.

The forest cover loss, habitat fragmentation and changes in land uses have greatly influenced the population status of 32 bird species in Cuba (BirdLife International, 2008), reaching the highest risky categories of the IUCN red list. Land use changes for economic development, tourism and urbanization expansion, and agricultural and livestock activity are negatively affecting the current population status of the Gundlach's Hawk and Cuban Black-Hawk at regional and local level. Habitat loss and fragmentation resulting from logging and land use changes (e.g. conversion of forests to plantations), have affected not only to endemic raptor species but probably also reduced prey availability. These species could use occasionally the edge of modified habitats for foraging and resting (Ferrer-Sánchez and Rodríguez-Estrella, 2015), but nesting sites need of large areas of natural and undisturbed preferred habitats (Ferrer-Sánchez and Rodríguez-Estrella, 2014). All nests of both species (two Gundlach's Hawk and 30 Cuban Black-Hawk's nests) observed in the area were located in natural habitats.

Habitat-specialist species like Cuban Black-Hawk and Gundlach's Hawk mostly occur in natural environments and are certainly affected by habitat degradation. Agricultural and cattle pasture areas have been considered "new habitats" created by human activities that sustain populations of both, migratory and resident raptor species. These new habitats seem attractive for some species depending on the extent of transformation, but definitively not for rare endemic specialists. In Cuba, there is an impoverishment of raptor species in urbanized areas, with only the most abundant and generalist species being present there (Ferrer-Sánchez and Rodríguez-Estrella, 2015). The low presence of endemic and rare species in modified environments and the increased abundance of generalist species in the communities are part of the overall process of biotic homogenization and of the indirect effects that changes in the species abundance and composition of the assemblage have on particular species (Feeley and Terborgh, 2008; McKinney and Lockwood, 1999; Terborgh and Estes, 2010). This situation may be worse in conditions of insularity, where endemic and specialist species have evolved tightly with the environment and have developed highly specialized habitat requirements, where there is limited or low habitat availability, in addition to the fragility of island ecosystems. Under insular conditions, land use changes can pose major threats for habitat-specialist raptors, far greater than those observed in the continental conditions.

4.1. Implications for conservation

Our study provides information regarding the potential distribution of rare endemic raptors and the way the amount of land uses and vegetation areas affect the prediction of occurrence in a region. This information is critical for the conservation of the Gundlach's Hawk and the Cuban Black-Hawk, because highlights the importance of natural habitats for any conservation plan. Currently, the protection of endemic and rare raptors in Cuba is not guaranteed by the national system of protected areas. The pattern of scarce amount of protected habitat for the Gundlach's Hawk and Cuban Black-Hawk at local scale is also observed at a national scale (Rodríguez-Santana and Viña, 2012a,b). The approach used in this study could help to make decisions on the best way to protect the habitat of these two species and to create new protected areas that contain all the habitat of these species that are rare, endemic and threatened by habitat loss.

The first step for the conservation of the endemic raptors is to reduce or prevent habitat loss and degradation in suitable and potential habitat. A second step is to protect suitable habitats that are not included in the current protection network. The coastal vegetation, mangroves and forests are decreasing in their cover area because of tourism development and land use changes, mainly agriculture. The Cuban Black-Hawk has lost 75% of its suitable habitat in Cuba and is mostly concentrated in the central region of the island (Rodríguez-Santana and Viña, 2012b), where tourism development is increasing. The Gundlach's Hawk has lost 80% of its suitable habitat in the entire island and the size of the remaining forest patches in most territories does not seem to be sufficient to ensure the presence of isolated populations (Rodríguez-Santana, 2009). Thus, if endemic species are to be preserved, conservation strategies should be directed towards maintaining natural areas as their populations' recovery depends on the existence of natural areas with little disturbance. Therefore, it is urgent to establish a conservation program particularly focused on these two species.

Most of the methodological and conservation problems that rare, endemic raptors face in the island of Cuba are similar to what the 71 Neotropical raptor species and the 19 at-risk forest-dependent and island-restricted raptors face too. Thus, our methodological approach used in this study could be useful for rare and endangered species in any other regions and especially in islands where more rare species exist. We propose the use of predictive modelling tools as the Maxent-mapping method for species of high conservation value as rare and specialized species. Ecological niche modelling can certainly strengthen the management and conservation actions not only for raptor rare species but for the 238 endemic and threatened birds of the Neotropics with scarce data, small population size, restricted distribution and often specialist habits. Establishing predictive occurrence maps and determining the priority areas for conservation make it possible to propose a change in the design of protected areas in a region, an even the expansion of the area for conservation management. Priority surveys in sites inside and outside protected areas can be established in order to have a greater impact on improving the species conservation status at large scale.

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Appendix. Map layers

We generated map layers of variables using the modules Pattern, Area and CRATIO in Idrisi Selva (Clarks Lab, Massachusetts, USA). The relative richness index and diversity of the landscape were calculated by measuring the variability in a 7 $\times$ 7 square moving window taking into account the pixel size. Also, we built distance maps from water sources, coastline, urban zones, cattle pasture and agricultural lands in the Distance module of Biomapper 4.0 (Hirzel et al., 2004). We calculated road and water sources densities using *Nearest features* and *Drainage/Lineament/Road/Density* extensions of ArcView 3.2 (ESRI Inc., USA). All these environmental variables were resampled to the WGS84 UTM coordinate system at a resolution of 100 m. A pixel size of 100 m was defined considering the average sizes of smaller patches in which birds were sighted during the fieldwork.

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