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Human–Sheldgeese conflict in agricultural landscapes: Effects of environmental and anthropogenic predictors on Sheldgeese distribution in the southern Pampa, Argentina

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ABSTRACT

Sheldgeese species are currently the subject of serious conservation concern and have been a source of historical conflict with agricultural interests. Here we assess the relative effects of environmental and anthropogenic predictors on Sheldgeese (Ruddy-headed Goose *Chloephaga rubidiceps*, Ashy-headed Goose *Chloephaga poliocephala* and Upland Goose *Chloephaga picta*) distribution in the southern Pampas at different spatial scales. These birds were declared an “agriculture plage” by the government and this conflict with humans has been so far resolved with species persecution. We evaluate whether its current wintering distribution is shaped by anthropogenic disturbances or whether it can be better explained by differences in topography and preference for wetlands, or by landscape composition and configuration. We characterized the study region using 17 potential predictors related to environmental, human and landscape characteristics. We built habitat-suitability models to examine the relative effect of the variables on the regional occurrence of Sheldgeese. We performed vehicle surveys in southern Buenos Aires province, in two years (2011–2012), surveying 9200 km of roads and recording 281 Sheldgeese flocks. Generalized additive models were used to model the presence/absence of Geese in 250-m cells. The habitat suitability models of Sheldgeese suggest that: (1) areas of low elevation surrounded by waterbodies are one of the main positive drivers of species distribution, (2) centers of human activity, which are regions with greater road accessibility, have a negative impact on species distribution, (3) heterogeneous landscape composed of croplands and grazing fields are preferred environments.

1. Introduction

Habitat loss and fragmentation, urbanization, introduction of exotic species and harvesting by humans are the most frequently types of human-induced changes affecting organisms all over the world (Vitousek et al., 1997; Pimm and Raven, 2000; Seabloom, 2002). Consequences of these anthropogenic effects pose a challenge for many species, which are forced to adapt in a very short time. Although the extent to which these environmental changes actually affect ecosystems and wildlife population processes is still largely unknown. It is clear how species respond to habitat structure and human pressures resulting from complex interactions and can be noticeable in many ways and at different spatial scales (Gehring and Swihart, 2003; De Angelo et al., 2011). For instance, current geographical ranges of some species may reflect not only their habitat preferences but also human disturbance (Caughley and Gunn, 1996; Pedrana et al., 2011). There is empirical evidence that many species avoid human disturbance and their population sizes can be negatively affected by human activities. As a consequence, there is an urgent need to understand their response toward human pressures at different spatial scales.

Multi-scale approaches have been traditionally employed in the study of habitat preferences (Johnson, 1980), since ecological patterns depend on the spatial scale at which they are analyzed (Wiens, 1989). The wide use of geographical information systems (GIS) and the development of more powerful statistical methods

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(Guisan and Zimmermann, 2000; Scott et al., 2002) have allowed researchers to develop new techniques to model species' expected distribution based on habitat preference, quality and availability, and then estimate the impact of anthropogenic predictors on the species distribution (Naves et al., 2003; Rhodes et al., 2006). This can be facilitated by species distribution models (SDM) which allow researchers to build empirical models. These link field observations to landscape-scale explanatory predictors selected from a set of ecologically plausible candidate variables, based on statistically or theoretically derived response surfaces (Jeganathan et al., 2004; Gottschalk et al., 2007; Rodríguez et al., 2007). The resulted distribution models are used to construct habitat-suitability models that are then mapped over the geographical space, creating habitat-suitability maps. Applications of SDM methods include quantifying environmental niches, assessing the impact of climate, land use, and other environmental changes on species distribution (cf. Scott et al., 2002).

After the European colonization, the temperate grasslands ecosystems of the Pampas region in Argentina have progressively become one of the most important regions of grain and beef production. The introduction of domestic livestock in the XVI century and agriculture by the end of the XIX century have intensely transformed the original landscape (Bilenca and Miñarro, 2004; Paruelo et al., 2005; Baldi et al., 2006). Several areas of the original Pampas grasslands were replaced by sown pastures for livestock and croplands, with a particular expansion of soybean in the last few decades (Grau et al., 2005; Aizen et al., 2009). This has led to a great loss and degradation of grassland habitat, producing a simplification of the landscape (Ghersa and Leon, 1998). Human-induced habitat homogenization in the Pampas agroecosystems, hunting pressures and introduction of exotic species have negatively affected many native bird species (Codesido et al., 2011; Azpiroz et al., 2012). However, certain grassland species may be more tolerant and even benefit from such changes, thriving in these new habitats. (Echeverría et al., 2006; Pedrana et al., 2008; Isacch and Cardoni, 2011). This could be the case with the three endemic migratory Sheldgeese species (Ruddy-headed Goose *Chloephaga rubidiceps*, Ashy-headed Goose *Chloephaga poliocephala* and Upland Goose *Chloephaga picta*). The geese winter mainly in the southern Pampas where they feed on crops and pastures (Blanco et al., 2003). The fact that these species are more flexible in their habitat preferences does not necessarily ensure their survival. Local farmers have traditionally decimated geese populations (Blanco and De la Balze, 2006). In1931 these birds were declared an "agriculture plague" by the Argentine government and have been consistently killed ever since (Blanco et al., 2003; Chebez, 2008; Petracci et al., 2010). Although there is limited data on Sheldgeese ecology, hunting of all species has been encouraged across the entire range, and allowed without restrictions (Martin et al., 1986; Blanco and De la Balze, 2006). Only as recently as 2008 all species were considered as endangered by the Argentine government (López-Lanús et al., 2008) and hunting was forbidden but is still promoted in several outfitters. The human-Sheldgeese conflict in agricultural landscapes and the endangered status of these species make it necessary to study the role of different environmental and anthropogenic drivers on the regional distribution of the species for a proper management of their populations. Our aim was to assess the relative effects of environmental and anthropogenic predictors on Sheldgeese distribution in the southern Pampas at the different spatial scales and to produce distributions maps of the species for the southern Buenos Aires province using habitat-suitability models. To do this we tested three different hypotheses that could account for the spatial distribution of Sheldgeese in the study area. The "environmental hypothesis" states that Sheldgeese distribution principally reflects the availability of lowland environments surrounded by water bodies (Summers and Grieve, 1982; Martin et al., 1986; Pedrana et al., 2011). This hypothesis predicts a higher probability of detecting this species in areas of low elevation close to streams and lakes. The anthropogenic disturbance hypothesis (hereafter "human hypothesis") presumes that illegal hunting and frequent disturbances are more frequent around areas of easy access and centers of human activity making these places less suitable for the species survival, and varies according to land use (e.g. croplands and pasturelands). According to this hypothesis there is a lower probability of Sheldgeese occurrence near urban areas and paved roads. The landscape composition and configuration hypothesis (hereafter "landscape hypothesis") postulates that the homogenization of the southern Pampas region through the conversion of native grasslands to croplands and sown pastures for livestock (Bilenca and Miñarro, 2004), affects Sheldgeese distribution. We tested the hypothesis that a combination of landscape metrics representing spatial heterogeneity can explain a large proportion of the variability on the occurrence of the species.

2. Material and methods

2.1. Study area

The study was conducted in the southern Pampas and Espinal of Argentina (between 36.46° to 41.04°S, and 63.39° to 58.62°W) with and extent of 106 000 km^2. The climate is subhumid-humid mesothermal with a mean annual temperature of 10 to 20 °C and a mean annual rainfall between 400 and 1600 mm (Soriano et al., 1991). The area is characterized by low to moderate undulations, which include the mountains of the Ventania System, dissected by lakes and marshes and large areas of crops and pastures for livestock grazing. Pristine vegetation was dominated by grassland steppes of several species of *Stipa* spp. and *Piptochaetium* spp. (Soriano et al., 1991) and Caldén forest, *Prosopis caldenia*, mainly in the south of the study area (Cabrera, 1994). However, this landscape has been intensively modified by anthropogenic activities. The main land use is agriculture (Paruelo et al., 2001), predominantly winter crops such as wheat (*Triticum aestivum*), oats (*Avena sativa*), barley (*Hordeum vulgare*) and rye (*Secale cereale*) and summer crops such as soybean (*Glycine max*), sunflower (*Helianthus annuus*), maize (*Zea mays*) and sorghum (*Sorghum graniferum*).

2.2. Study species

Sheldgeese species are migratory and endemic species of South America. From September to March they migrate to southern Patagonia (Argentina and Chile) where they breed and rear their chicks, while from April to August they winter mainly in the southern Pampas (Argentina), which is considered critical because of the interaction between species and agricultural activities. There is also a sedentary population on the Falkland Islands (Summers and Grieve, 1982; Summers and McAdam, 1993). Sheldgeese are herbivorous and feed on pastures or cereal crops (Summers and Grieve, 1982; Martin et al., 1986; Summers and McAdam, 1993). During the migratory season, and especially during winter, Sheldgeese are killed in large numbers due to unregulated hunting and persecution by farmers (Blanco and De la Balze, 2006; Petracci et al., 2010). Yet the magnitude of damage to crops or pastures caused by grazing geese has been studied only in the Falkland Islands (Summers and McAdam, 1993), where it has been suggested that livestock benefits geese by controlling shrub regeneration and maintaining a high proportion of green pastures, whereas sheep benefit by eating goose feces that have similar digestibility and nitrogen content to high-quality grass.

In the last decades, all Sheldgeese have shown evidence of marked decline in wintering areas (Blanco et al., 2003; Chebez,

2008) and only as recently as 2008 the Ruddy-headed Goose was listed as “Critically Endangered”, Ashy-headed Goose as “Endangered”, and Upland Goose as “Vulnerable” (López-Lanús et al., 2008) and hunting was forbidden.

2.3. Field survey

We used road surveys from a vehicle to record the occurrence of all Sheldgeese species because of the open nature of the pampas environment and the large size of the region (Travaini et al., 2007; Pedrana et al., 2011). Road surveys were performed during two consecutive wintering seasons (June to July 2011 and June to July 2012). Using vector data of road coverage, we randomly selected 110 survey tracks (road segments) that summed to 4600 km of transects during the first year. During the second year, we surveyed the same survey tracks surveyed in the previous year. Approximately 90% of the survey tracks were dirty and secondary roads with very low traffic density (i.e. fewer than ten vehicles per day).

Surveys were performed by two observers from a vehicle driven at a maximum speed of 50 km/h during daylight (from 9 a.m. to 16 p.m.). We did not perform census in the late afternoon since the light was not good enough for species identification thus avoiding potential bias of missing individuals that were moving from feeding areas to resting grounds (Pedrana et al., 2011). All Sheldgeese species have a common social structure, especially in winter when they feed in large flocks. When one Sheldgeese flock was sighted we recorded flock size, species composition and gender when possible (e.g. we only recorded gender of Upland Goose since the other two species do not present sexual dimorphism), as well as, habitat type (control points) in which the flock was located. We previously identified four main categories of habitat types: cropland, grazing land, native habitat, and wetland.

We measured the distance to the flock center with a laser rangefinder (Bushnell 450 rangemaster), as well as the angle of the animal relative to our bearing. We obtained our bearing relative to north from the inertial compass in the GPS unit (Mio Digiwalker P550, http://www.mio.com). Distance and angle in relation to North and relative to our bearing allowed us to obtain the actual positions of Sheldgeese flock.

Sheldgeese sightings information and census track location were collected in a PDA synchronized with a GPS unit using the free software Cybertracker (http://www.cybertracker.co.za).

2.4. Landscape variables

We characterized the study region using 17 potential predictors related to environmental, human and landscape characteristics (Table 1).

A land-cover map was constructed for the study area based on the four parameters of the normalized difference vegetation index (NDVI) curves derived from Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on board NASA’s Terra and Aqua spacecraft. NDVI satellite images were provided every 16-day maximum value composites at 250-m spatial resolution (http://modis-land.gsfc.nasa.gov/vi.html). We calculated the four parameters from the seasonal curves of NDVI using 24 scenes of satellite data (from June 2011 to July 2012): Integrative Normalized Difference Vegetation index corresponding to the sum of positive NDVI values over a year from June 2011 to June 2012 (NDVII), annual maximum values of the NDVI over a year (Max_NDVI), annual minimum values of the NDVI over a year minimum NDVI values (Min_NDVI), and interannual variability in productivity calculated as =(Max_NDVI − Min_NDVI)/NDVII. These parameters have been reported as a plausible way for describing vegetation parameters relevant for wildlife (Pettorelli et al., 2005) and to capture important features of ecosystem functioning for temperate ecosystems (Paruelo et al., 2001; Alcaráz et al., 2006). We used the Iterative Self-Organizing Data Analysis (ISODATA) method to generate different signatures, which is an unsupervised iterative classification technique that uses minimum distances to assign an individual pixel to a cluster (using Erdas Inc, 1999). A new mean is defined in each iteration based on the location of the pixel included in the cluster in the space defined by the NDVI attributes. Then all outcome clusters were assigned to four different categories of habitat type: cropland, grazing land, native habitat and wetland. An error matrix was created to test the accuracy between cluster assignation and current land-cover types based on 850 control points that were taken during the field survey (see section Field survey). We obtained an overall accuracy of 78% and the users’ accuracy (error of commission) was 80%, 74%, 70%, and 80% for wetland, grazing land, native habitat and cropland, respectively. The overall Kappa Statistic was 0.7.

Because the perception of the landscape by birds is often related to their daily movements patterns between the feeding (e.g. crops and pastures) and resting areas (e.g. waterbodies or wetlands) (Martin et al., 1986; Pedrana, personal communication) we included one neighbourhood scale related to the approximate distance these birds travel each day: circles with radius of 6 km (i.e. mean value between Sheldgeese sightings and the nearest waterbody). Then we extracted landscape variables from the land-use map with Fragstats (version 4.0, http://www.umass.edu/landeco/research/fragstats, McGarigal et al., 2012). For each 6-km radius circle, 11 landscape indices were calculated, based on the 250 × 250 m land-cover map pixels and were classified as: (1) Edge metrics (e.g. total edge for each land-use category), (2) Area metrics (e.g. total class area for each land-use category), (3) Diversity metrics (Patch richness), and (4) Shape metrics (Fractal dimension index) (Table 1).

Distances from each 250-m cell to the nearest urban settlement, the nearest pavement road, the nearest waterbody (e.g. lakes, ponds and flooded areas), and the nearest body of moving water (e.g. rivers and streams) (taken from Instituto Geográfico Nacional, Argentina, http://www.ign.gob.ar) were calculated in a GIS (IDRISI Taiga, Eastman, 2009) (Table 1). We acquired topographic data (altitude and slope) from the Shuttle Radar Topography Mission (SRTM; http://www2.jpl.nasa.gov) (Table 1).

Multicollinearity of landscape predictors can make interpretation of alternative models difficult (Lennon, 1999). We considered two predictors to be collinear when the Spearman rank correlation coefficient (Rs) was >0.6. Among strongly correlated predictors (i.e. redundant information in an alternate way), we retained those with the clearest ecological meaning for the species (Austin, 2007).

2.5. Presence data

We used presence–absence data collected through our surveys, thus tracks recorded with GPS units defined the route of our survey. We used the distance to Sheldgeese species that were sighted to estimate the area effectively covered. We used the software DISTANCE 6.0 to fit a detection function to the distance data (Thomas et al., 2010). A 300-m buffer on both sides of the track was chosen to define the effective area surveyed as 85% of all sightings were within this area. Presence/absence modeling requires defining units in which presence or absence is recorded. For this purpose, we overlaid the surveyed tracks with 300-m buffers on top of a grid of 250 × 250 m cell size, given by the spatial resolution of NDVI data. Then, the original 153 and 128 sheldgoose sightings register in 2011 and 2012, respectively were also overlaid and grid cells with more than one sighting were considered a presence and all remaining cells were considered absence.

Table 1
Description of the variables used in the predictive distribution models developed for the three Sheldgeese species in the southern of Buenos Aires province, Argentina.

Hypothesis	Variable	Variable description
Environmental	Altitude	Mean elevation in meters above sea level of the focal cell obtained from the Shuttle Radar Topography Mission Elevation (SRTM)
	Slope	Terrain slope in percentage in a 250-m pixel acquired from the SRTM
	Distance.stream	Straight line distance (km) to the closest natural and man-made bodies of moving water
	Distance.lake	Straight line distance (km) to the closest natural or man-made waterbody surrounded by land
Human	Distance.urban	Straight line distance (km) to the nearest urban center
	Distance.road	Straight line distance (km) to the nearest pavement road
	Land.use	Habitat-type map was constructed for the study area based on the four parameters of the NDVI curve using SODATA method and categorized in four categories: cropland, grazing land (principally, sown pastures), native habitat (natural grasslands and scrublands, in general degradeted) and wetlands
Landscape	Crop.area	Sum of the areas of all cropland patches in a circle of 6-km radius around a focal cell
	Grazing.area	Sum of the areas of all grazing land patches in a circle of 6-km radius around a focal cell
	Wetland.area	Sum of the areas of all wetland patches in a circle of 6-km radius around a focal cell
	Native.area	Sum of the areas of all native habitat patches in a circle of 6-km radius around a focal cell
	Crop.edge	Sum of the lengths of all edge segments involving cropland patches in a circle of 6-km radius around a focal cell, divided by the total landscape area
	Grazing.edge	Sum of the lengths of all edge segments involving grazing land patches in a circle of 6-km radius around a focal cell divided by the total landscape area
	Wetland.edge	Sum of the lengths of all edge segments involving wetland patches in a circle of 6-km radius around a focal cell divided by the total landscape area
	Native.edge	Sum of the lengths of all edge segments involving native habitat patches in a circle of 6-km radius around a focal cell divided by the total landscape area
	Patch.richness	Number of patch of the land-use types categories present in a circle of 6-km radius around a focal cell
	DF	Index of fractal dimension was calculated as 2 times the logarithm of patch perimeter divided by the logarithm of patch area in a circle of 6-km radius around a focal cell

We found a high correlation between the predictors Distance.urban and Distance.road ($r_s = 0.89$). We chose Distance.urban as the best variable representative of these predictors.

2.6. Model construction and model validation

We generated two data sets, one for calibrating and another for evaluating the occurrence models (hereafter the construction and evaluation data sets; e.g. Guisan and Zimmermann, 2000). The construction data set consisted in the presence–absence cells registered in 2011 and the evaluation data in the presence–absence cells registered in 2012.

Model construction is made on the construction data set by fitting generalized additive models (GAMs, Hastie and Tibshirani, 1990) using a binomial error and a logistic link to determinate which landscape variables are most likely to affect Sheldgoose occurrence. GAMs are used extensively in species' distribution modeling because of their strong statistical foundation and ability to realistically model ecological relationships (Austin, 2002). For this purpose, we used a resampling scheme (Pedrana et al., 2011), due to the relatively different number of presences ($n = 115$) and absences ($n = 34\,121$), randomly selecting 115 out of the 34 121 cells with absence. This procedure was repeated 100 times. In each repetition the cells with presence were the same while cells with absence were sampled without replacement. Predictors for the models were selected by a backward–forward stepwise procedure (by using the step.gam routine in S-PLUS 2000, Mathsoft, 1999). The Akaike's Information Criterion (AIC) was use to retain a term (Sakamoto et al., 1986). From the 100 models built with the resampling procedure, we selected those that ranked as the best model >10 times. We then repeated this resampling procedure with each of the selected models, in which the predictors were fixed, but the degrees of freedom of the splines were allowed progressively to be reduced from three to one. Again we retained the models that were selected >10 times. Finally, we used the unique matrix with the complete construction data set in which original prevalence was maintained (Jiménez-Valverde and Lobo, 2006) to compare the alternative models within each hypothesis that were as good as the best model in terms of AIC (Burnham and Anderson, 2002). We considered as competing models those for which the differences between AIC and the AIC of the best candidate model (the one with the smallest AIC) was $\Delta \leq 2$ (Burnham and Anderson, 2002).

The same procedure was used to build a general model starting with all relevant variables retained in the best models for each hypothesis. The general model tested simultaneously the relative predictive power of all environmental factors.

Model evaluation is made on the validation data set, by comparing predicted to observed values using preferentially a threshold-independent measure, such as the curve (AUC) of the receiver operating characteristic (ROC) plot, which was computed for each of the 100 models (Murtaugh, 1996). For this purpose, we used also a resampling scheme (Pedrana et al., 2011), due to the relatively different number of presences and absences. The AUC ranges from 0 (when model discrimination is not better than random) to 1 (perfect discriminatory ability, Pearce and Ferrier, 2000). Predictive models are considered usable if AUC ≥ 0.7 (Harrell, 2001).

2.7. Habitat-suitability maps

We used the most parsimonious model for each hypothesis to build habitat-suitability maps of all Sheldgeese species in the southern Buenos Aires province, Argentina. Predictions to the entire southern Buenos Aires province were calculated in S-Plus using the predict.gam procedure (Mathsoft, 1999) and illustrated on probability maps using IDRISI Taiga (Eastman, 2009).

3. Results

On 9200 km of road surveys we registered 281 sightings of Sheldgeese flocks, comprising a total of 29 991 individuals (Table 2). We recorded 16% more sightings in 2012 than in the previous year, but the overall survey individuals were almost invariable across the survey years. Almost the 60% of individuals register belong to the species Upland goose (27% were females and 33% were males), 19% to Ashy-headed goose and less than a 1% to the Ruddy-headed goose (Table 2). The remaining 20% of the individuals were classified as Undetermined, usually because the individuals were too far a way to identify the species or the visibility was not the optimal.

3.1. Model fitting and evaluation

The most parsimonious GAM model of Sheldgeese presence among those testing the environmental hypothesis incorporated three variables: Altitude, Distance.stream and Distance.lake (Model 1 and 2 in Table 3). As predicted by this

Table 2
Number of individuals and number of sightings of the three species of Sheldgeese and undetermined individuals, surveyed during two consecutive wintering seasons (June to July 2011 and June to July 2012) in the southern of Buenos Aires province, Argentina.

Sheldgeese species	2011		2012	
	No sightings	No individuals	No sightings	No individuals
Female upland	110	4203	136	3972
Male upland	113	5358	142	4375
Ashy-headed	58	3017	70	2676
Ruddy-headed	8	60	13	133
Undetermined	21	2355	61	3761
Total	128	14 993	153	14 917

hypothesis, the probability of Sheldgeese occurrence decreased with the mean terrain elevation and with distance to the closest stream and lake (Fig. 1a).

The variables Distance.urban and Land.use were retained in the best model among those testing the human hypothesis (Model 3 and 4 in Table 3). The probability of Sheldgeese occurrence increased with the distance to nearest urban center and was greater in cropland category in compare with the other land-use types (Fig. 1b).

The best model among those being evaluated under the landscape hypothesis included: Grazing.area, Crop.area, Grazing.edge and Patch.Richness (Model 5–8 in Table 3). Sheldgeese occurrence was negatively associated with the amount of grazing land edges, while it was positively related with the total of cropland area, with land-use type's richness and slightly positively with the total of grazing land area (Fig. 1c). This effect was observed within 1500 ha, and was reversed beyond this area, producing a bell-shaped relationship (Fig. 1c).

When all relevant predictors retained in the best models for each hypothesis were considered simultaneously in a model of Sheldgeese presence, the general model included: Altitude, Crop.area, Crop.edge, Distance.urban, Distance.stream and Distance.lake (Model 9–11 in Table 3). The general model supported partially the three hypotheses and showed the more mean full variables included in them (Fig. 1d). However, these variables did not alter the identity, sign or the strength of the predictor effects, except a new variable, Crop.edge, was incorporated in the most parsimonious final model.

The mean AUC of the best models for each hypothesis and the general model ranged from 0.72 ± 0.02 to 0.79 ± 0.02 for the independent evaluation dataset (Table 3), indicating good discrimination ability and could be considered useful for predicting the distribution of the species.

3.2. Habitat-suitability maps

The habitat-suitability map of Sheldgeese occurrence taking into account all the effects contained in the best model among those testing the environmental hypothesis (Model 1 in Table 3), demonstrates that the probability of Sheldgeese presence increases toward the east boundary of southern Buenos Aires province, and areas of high probability of occurrence are associated with watercourses and lakes, scattered across northern and eastern part of the region (Fig. 2a). Low probability areas are concentrated in the center of the region, corresponding with the mountains of the Ventania System (Fig. 2a).

The habitat-suitability map of Sheldgeese occurrence constructed with predictions of model 3 evaluating the human hypothesis (Table 3) demonstrates that areas of low probability of Sheldgeese occurrence were situated mostly around urban areas, scattered across the entire region (Fig. 2b).

The habitat-suitability map of Sheldgeese occurrence considering variables retained in the best landscape model (Model 5 in Table 3), states that high probability areas are specially concentrated in the east of the province (Fig. 2c); whereas low probability areas are distributed across the south of the study area (Fig. 2c).

Finally, the habitat-suitability map of Sheldgeese occurrence generated taking into account all relevant effects enclosed in the best general model (model 9 in Table 3) shows almost the same pattern explained in the habitat-suitability map build with the landscape hypothesis, although we could also distinguish low probability areas focus in the center of the region associated with high elevation terrain (Fig. 2d).

4. Discussion

Conflicts between goose populations and agriculture are common in many countries around the world as they forage on pastures and croplands (Borman et al., 2002; Amano et al., 2004; Fox et al., 2005; Wisz et al., 2008; Wood et al., 2013). Sheldgeese wintering in the Argentine Pampas are not an exception; in fact they have been a source of historical conflict with agricultural interests (Blanco and De la Balze, 2006). Geese populations in the northern Hemisphere are mostly increasing (Abraham et al., 2005; Fox et al., 2005) unlike what happens in Argentina, where Sheldgeese populations currently represent a serious conservation concern (López-Lanús et al., 2008). Our results highlight the key factors influencing the current distribution of Sheldgeese in their main wintering grounds, allowing us to draw conclusions about the causes of their decline. The habitat suitability models of Sheldgeese suggest that: (1) areas of low elevation surrounded by waterbodies are one of the main positive drivers of species distribution, (2) centers of human activity, which are regions with greater road accessibility, have a negative impact on species distribution, (3) heterogeneous landscape composed of croplands and grazing fields are preferred environments.

There was a clear support for the environmental hypothesis, indicating that the regional distribution of Sheldgeese's wintering grounds is mainly driven by altitude and proximity to waterbodies. The link between Sheldgeese and the proximity of streams, lakes and/or ponds might indicate not only the distribution of productive grounds but also their strict dependency on water in their resting sites (Summers and Grieve, 1982; Martin et al., 1986; Pedrana et al., 2011). Geese species in other regions also show a strong dependence to feed near wetlands or coastal habitats that they use as roosting grounds (Carboneras, 1992; Smith et al., 1999). These types of habitats could be important for the species as they are likely to provide a safe virtually predation and scaring free due to the fact that are difficult to access (Summers and McAdam, 1993). Other

Table 3
GAM models obtained by stepwise selection for each hypothesis on the variables influencing Sheldgeese occurrence and the general model. For each competing models, the Akaike Information Criterion (AIC) and the difference between AIC of the current model and the most-parsimonious model (Δ AIC) are given. The most parsimonious model for each case are marked in bold and mean area-under-the-curve (AUC) values computed for 100 replicate parameterizations of the models with an independent validation database are given. All 100 replicates had AUC ≥ 0.7. *S* (variable name) denotes variables selected as smoothing splines with 3 degrees of freedom.

Code	GAM Models	AIC	Δ AIC	AUC ± se
	Enviromental hypothesis			
1	Altitude + Distance.stream + *s*(Distance.lake)	**389**	**0**	**0.72 ± 0.02**
2	*s*(Altitude, 3) + Distance.stream + *s*(Distance.lake)	391	2	
	Human hypothesis			
3	*s*(Distance.urban) + Land.use	**460**	**0**	**0.73 ± 0.02**
4	Distance.urban + Land.use	462	2	
	Landscape hypothesis			
5	*s*(Grazing.area) + *s*(Crop.area) + *s*(Grazing.edge) + Patch.Richness	**442**	**0**	**0.79 ± 0.02**
6	*s*(Grazing.area) + *s*(Crop.area) + *s*(Wetland.edge) + Patch.Richness	443	1	
7	*s*(Grazing.area) + *s*(Crop.area) + *s*(Crop.edge) + Patch.Richness	443	1	
8	*s*(Grazing.area) + *s*(Crop.area) + *s*(Wetland.area) + Patch.Richness	444	2	
	General model			
9	Altitude + *s*(Crop.area) + *s*(Distance.urban) + Distance.stream + *s*(Distance.laker) + Crop.edge	**372**	**0**	**0.74 ± 0.02**
10	*s*(Altitude) + *s*(Crop.area) + *s*(Distance.stream) + *s*(Distance.lake) + *s*(Crop.edge)	373	1	
11	*s*(Altitude) + *s*(Crop.area) + Distance.urban + *s*(Distance.stream) + *s*(Distance.lake) + *s*(Crop.edge)	374	2	

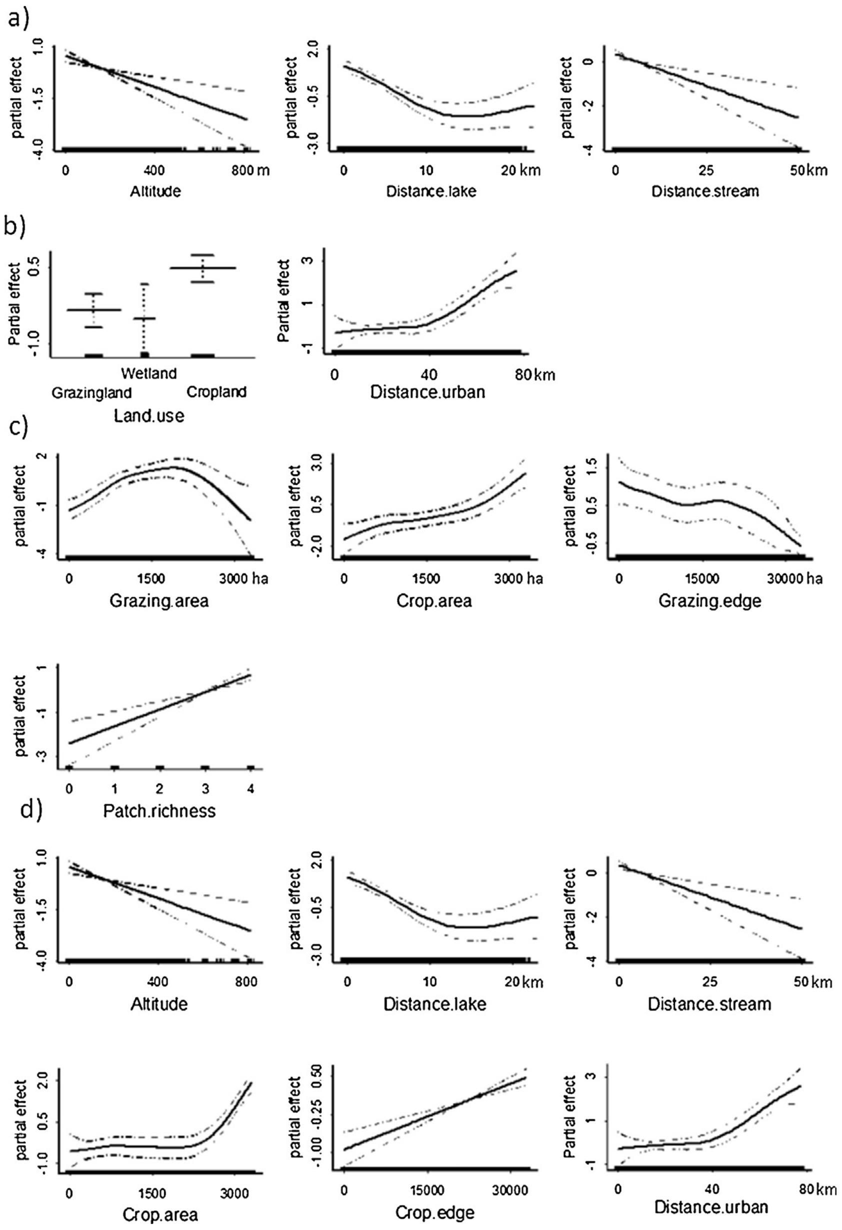

Fig. 1. Partial effects of the predictors included in the most-parsimonious model for each alternative hypothesis about the variables influencing Sheldgeese presence: (a) environmental hypothesis (Model 1 in Table 3), (b) human hypothesis (Model 3 in Table 3), (c) landscape hypothesis (Model 5 in Table 3) and (d) general model (Model 9 in Table 3). Dashed lines represent 95% confidence intervals for the mean effect.

studies have shown that the presence of geese is significantly less likely as elevation increased (Jensen et al., 2008; Wisz et al., 2008; Virkkala et al., 2010). Areas of low probability of Sheldgeese presence were clearly concentrated in the center of the region, matching the location of the hill areas of the Ventania Systems. On the contrary, we found a positive link between low areas and Sheldgeese presence. Although it is not clear that geese respond to elevation per se, it is likely that elevation correlates with certain landscape components or soil quality features (more productive environments typically occur in lowlands) which may have implications for goose habitat selection (Wisz et al., 2008).

The local effects of disturbance by hunting (Tamisier et al., 2003), recreational activities (Mallord et al., 2007; Cardoni et al., 2008) and roads (Fahrig and Rytwinski, 2009) are well established, although some bird species frequently prefer anthropogenic habitats (i.e. suburban areas) such as golf courses, parks, corporate facilities, and residences (Carboneras, 1992; Ayers et al., 2010). In our study, the human hypothesis was important to explain the negative relationship between Sheldgeese presence and proximity to urban areas. Human populations along with road accessibility in urban centers increase disturbances which lead to a low probability of Sheldgeese presence. Such behavior has also been seen in swans (Rees et al., 2005). In addition, thanks to a long history of hunting in the Sheldgeese's wintering areas (Blanco and De la Balze, 2006) these birds are likely to perceive humans as "predators", unlike some bird species in urban areas that become used to human presence when they are not hunted (Fox and Madsen, 1997; Nisbet, 2000; Levey et al., 2009). These results suggest that human activity has a direct and negative impact on species occurrence, probably indicating a behavior to avoid sites where the change of encountering the "human predator" is high. As all our surveys were conducted from roads, we cannot reject the possibility that Sheldgoose species avoid proximity to roads in areas where they are more frequently disturbed, for example, closer to human settlements. If this was

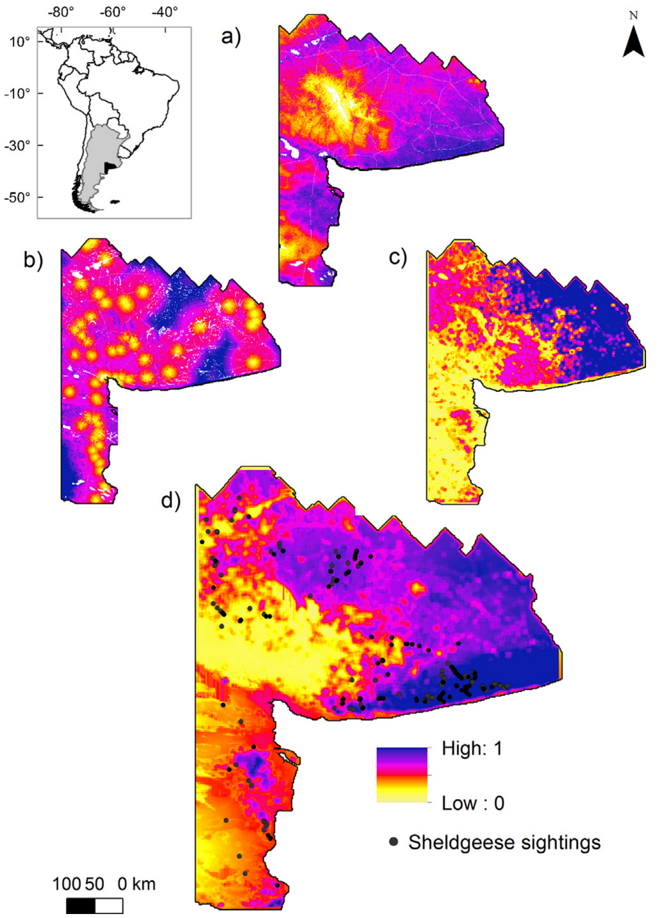

Fig. 2. Habitat-suitability maps of all Sheldgeese species constructed from the most parsimonious model for (a) vegetation hypothesis, (b) human hypothesis, (c) landscape hypothesis and (d) general model, in the southern Buenos Aires province, Argentina. Values represent the probability of Sheldgeese contact in a 250-m cell. Sheldgeese sightings are indicated by circles.

the case, urban areas would have a minor influence on regional Sheldgeese distribution. Furthermore, we found a positive association of species presence with croplands and secondary with grazing fields at a local scale. Geese flocks seem to prefer mainly landscapes dominated by these modified habitats, which could provide relatively better forage because of the use of external inputs compared to native habitats (Abraham et al., 2005; Ackerman et al., 2006; Wisz et al., 2008). Although, crops and pastures could be acting to some extent as ecological traps, defined as a poorly perceived risk of human-caused mortality in otherwise good habitats where resources are abundant (Naves et al., 2003).

By means of the models built to test the landscape hypothesis (6-km radius circle), we found a positive association between species occurrence and the richness of patch type's categories, cropland area and grazing field area; and a negative link with the amount of grazing field edges. Thus, our results suggest that Sheldgeese are more often found in heterogeneous landscape, where different habitat types are present, and within a spatial arrangement of large cropland areas and small to medium sized grazing fields ($a \leq 1500$ ha). Future scenarios of increased cropland areas for the Pampas would generate a simplification at a landscape level with negative impacts on sheldgeese habitat suitability. In Europe future scenarios of land use change are predicted to reduce habitat for pink-footed goose (Anser brachyrhynchus) populations (Wisz et al., 2008). However, they include replacement of grasslands and croplands by unsuitable land-use types for geese (e.g. woody biofuel crops, increased urbanization, and forest). The replacement of grasslands by croplands in Europe could improve foraging habitat for geese but it would increase conflicts with farmers (Wisz et al., 2008). In Argentina, predictions can follow the same path as in Europe, either decreasing habitat suitability or increasing agricultural conflicts.

When relevant predictors for all hypotheses were considered simultaneously in a model for Sheldgeese presence they matched with predictors of the particular models. The only difference was that the amount of cropland edges was retained in the most parsimonious general model, while the richness of patch types, the amount of grazing field edges and area were no longer significant. Nonetheless, the pattern remains consistent, given that both models indicate that Sheldgeese occurrence is more significant where large areas of croplands are combined with a more heterogeneous landscape. It is also worth noticing that the partial landscape model provides additional information about the composition of this heterogeneous configuration (e.g. small to medium sized grazing fields and a diversity of habitats) which is not clearly noticed in the general model.

This highlights the importance of building partial habitat-suitability maps of Sheldgeese. These could help us provide hierarchically structured recommendations based on the drivers' individual effects. It would also constitute a useful tool for action plan improvement or implementation (for tourism, recreation, and management policies) at a regional scale. For instance, the species presence is higher in low areas restricted to the eastern portion of the study area. Additionally, due to hunting Sheldgeese seem to avoid proximity to urban areas.

4.1. Implications for Sheldgeese conservation

In their wintering grounds, Sheldgeese have been traditionally hunted by farmers because they feed on crops and pastures, reason why in 1931 they were declared "agriculture plague" by the government. Furthermore, there are no field estimations of wheat losses caused by grazing geese and some researchers question its real magnitude (Martin et al., 1986). Since agriculture and domestic livestock rearing are highly important economic activities in southern Buenos Aires province, the conflict between humans and Sheldgeese is a major concern for the conservation of these species. Therefore, gaining a real perspective of the impact of goose grazing on crop production and pasture growth should be prioritized.

Although hunting of these three species is forbidden, it is still promoted in several outfitters. Monitoring of the Sheldgeese's status in their wintering grounds in southern Buenos Aires province started in 2007. Ever since, reports show an alarming decline of their population in relation to historical data (Petracci et al., 2010). According to our surveys, we can state that less than 1% of all sightings belong to the Ruddy-headed goose. These sightings were restricted to a small area of 8869 km^2 (between San Cayetano and Tres Arroyos states). This clearly supports the statement that the Ruddy-headed goose population has a very restricted distribution, not only during their breeding period (e.g. breeding pairs are concentrated in the surroundings of Punta Arenas, Chile and in the northern portion of Tierra del Fuego Island, Madsen et al., 2003) but also in their wintering areas (Blanco et al., 2003; Petracci et al., 2010). Ruddy-headed continental population has declined sharply since the 1950s, and is currently considered an endangered species in both Argentina and Chile (Blanco et al., 2003; López-Lanús et al., 2008). The population is currently estimated at around 1000 birds (Madsen et al., 2003; Blanco et al., 2003).

Our data suggest that Sheldgeese distribution is determined by environmental and anthropogenic predictors where habitat-suitability maps describe each of their relative effects. Because environmental and landscape variables are difficult to manage by agencies, the major efforts may need to be directed to manage human activities such as hunting and species persecution. Sheldgeese seem to avoid anthropogenic pressures same as many species subjected to persecution (Caughley and Gunn, 1996). Reducing disturbances (hunting and scaring) might stop these species decreasing population trends in most of their wintering grounds. Environmental and landscape habitat-suitability maps should be used to direct efforts to specific areas of the core presence of Sheldgoose species.

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