Expansion and intensification of row crop agriculture in the Pampas and Espinal of Argentina can reduce ecosystem service provision by changing avian density

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ABSTRACT

In Argentina, the rapid expansion and intensification of row crop production that has occurred during the last 20 years has resulted in the loss of habitat and spatial heterogeneity in agroecosystems. One of the principal effects of industrialized row crop production is the loss of avian diversity and associated ecosystem services that benefit crop production. To better understand the response of bird species to the intensification and expansion of row crop agriculture in Argentina, and the potential effects on the provision of ecosystems services, we analyzed the relationship between short- and long-term changes in agricultural land use on the densities of six bird species (Milvago chimango, Caracara plancus, Tyrannus savana, Zenaida auriculata, Molothrus bonariensis, and Sturnella superciliaris) using data from a large-scale, long-term avian monitoring program in central Argentina. Species densities responded individually to long-term landuse changes; T. savana and M. chimango densities were positively related to an increase in the annual cropping area, whereas C. plancus and S. superciliaris were positively related to the area of non-plowed fields. M. bonariensis and Z. auriculata (considered crop pests) showed a weak relationship with land use. None of the species exhibited response to short-term changes in land-use. Although generalist species can apparently adapt to a diversity of open habitats, species that provide pest control services were also related to semi-natural habitats and thus likely to suffer from land transformation associated with intensive agricultural management. Our results, as well as those found in similar systems, denote strong inferential evidence that the disappearance of remnants of natural and semi-natural habitats in heavily transformed agricultural landscapes will have a substantial negative effect on the provision of pest control services provided by avian abundance and diversity.

1. Introduction

Land use changes and conversion of natural habitats are transforming the earth’s surface at a fast pace, particularly due to modern agriculture and forestry practices (Foley et al., 2005; Ramankutty et al., 2008). The expansion and intensification of row crop production has been particularly evident in Argentina, where the cultivated area increased 45% between 1990 and 2006, with half of the increase devoted to genetically modified soybean (Aizen et al., 2008; Oesterheld, 2008); at the same time, the use of fertilizers increased by 400% (FAO, 2010; Thompson, 2007).

Although row crop expansion has occurred most dramatically in the Chaco region of northern Argentina (Grau et al., 2005; Zak et al., 2004; Grau and Aide, 2008; Gasparri and Grau, 2009), the process has also been evident in the Pampas (a region with more than a century of agricultural use) and Espinal ecorregions, where pastures, natural grasslands and forests historically used for cattle grazing have been converted to row crop production (Vigliizzo et al., 1997; Paruelo et al., 2005; Baldi and Paruelo, 2008). The expansion of cultivated land has been related to a combination of climate change (increasing precipitation), increasing global demand for agricultural products, national economic policies, and new technologies (genetically modified seeds, agrochemicals, machinery) (Vigliizzo et al., 1997, 2004; Grau et al., 2005; Grau and Aide, 2008; Zak et al., 2008). Concurrently, crop management has become increasingly intensified (Hall et al., 2001; Vigliizzo et al., 2004; Thompson, 2007).
In Argentina, the main negative effects from the recent intensification and expansion of row crop agriculture include agrochemical contamination, soil degradation, biodiversity loss, high rates of deforestation and fragmentation in the Chaco, and grassland conversion in the Pampas that has resulted in spatially simplified landscapes (Zaccagnini and Calamari, 2001; Paruelo et al., 2005; Boletta et al., 2006; Codesido et al., 2008; Baldi and Paruelo, 2008; Oesterheld, 2008; Gasparri and Grau, 2009).

Habitat loss and the reduction of spatial heterogeneity are of concern due to their negative effects on biodiversity and have been attributed to a substantial reduction in avian species richness in agroecosystems (Alkorta et al., 2003; Benton et al., 2003; Jackson et al., 2007). For example, in England four-fifths of bird species, particularly habitat specialists, have undergone population declines relative to habitat loss and reduced spatial heterogeneity in agricultural landscapes (Robinson and Sutherland, 2002). Large-scale studies in European agroecosystems illustrate a reduction in species richness of birds associated with the loss of semi-natural habitats and increased fertilizer use (Donald et al., 2001, 2006; Billeter et al., 2008).

In the Pampas and Espinal ecoregions of Argentina, region-wide habitat conversion has resulted in changes in the composition of avian communities and decreases in species richness. Avian species richness in the Pampas is positively associated with the proportion of natural vegetation and negatively associated with the proportion of cultivated land (Schrag et al., 2009), and the relative abundance of most bird species decreased along a gradient of increasing transformation from grazing to row-crop dominated landscapes (Filioy and Bellocq, 2007a). Areas still predominantly used for grazing (with greater habitat availability for grassland-dependent species) show higher avian species richness than areas primarily used for row crop production (Codesido et al., 2008). In the Espinal region, avian species richness decreased with decreasing size of woodland patches (Bucher et al., 2001); however, small remnants were capable of supporting relatively high species richness (1-ha patches retained up to 50% of birds species) (Dardanelli et al., 2006).

Bird responses to the expansion of row crop production have been shown to be dependent upon functional groups, with insectivore and raptor species demonstrating a greater sensitivity to increasing areas in row crops than granivores (Carrete et al., 2009; Zaccagnini et al., 2011). In addition, species-specific responses within functional groups are variable. For example, a study of raptor communities in Argentina suggested a negative response to habitat transformation, but three species (Coragyps atratus, Elanus leucurus, Falco sparrowius) peaked in relative abundance in a mosaic of transformed and natural habitats. Moreover, Milvago chimango increased with increasing habitat conversion and the presence of another species (Circus buefoni) increased in grassland-dominated landscapes (Carrete et al., 2009; Pedrana et al., 2008).

Other examples include decreasing population and distribution of the Pampas meadowlark (Sturnella defilippi) associated with grassland conversion and overgrazing (Fernández et al., 2003), and greater survival of the spotted tinamou (Nothasa maculosa) in agroecosystems in the province of Buenos Aires in a mixed landscape of pasture and agriculture compared to an agriculture-dominated landscape (Thompson and Carroll, 2009). Species-specific variations in response to habitat area were also illustrated for birds in Espinal woodlands within agroecosystems in Entre Ríos where the relative abundance of most species decreased with decreasing patch size (Calamari and Zaccagnini, 2007).

What are the consequences of changes of avian species diversity on agroecosystems? Biodiversity is a key component of agroecosystems. Plant and animals regulate the flux of energy and matter (water, nutrients) and most associated ecological processes (e.g., seed dispersion, pollination) that are fundamental for the sustainability and resilience of agroecosystems (Altieri, 1999). Birds are particularly important components of agroecosystems, exhibiting the most diverse range of ecological functions among vertebrates. Their high diversity of adaptations and life histories, high numbers and mobility allow birds to regulate many ecosystem processes and to respond very quickly to changes in resource levels (Şekercioğlu et al., 2004; Şekercioğlu, 2006). As a consequence, birds provide several ecosystem services that are important for the function and sustainability of agroecosystems, including regulating (seed dispersal, pollination, pest control, carcass and waste disposal) and supporting services (nutrient deposition, ecosystem engineering) (Şekercioğlu, 2006; Whelan et al., 2008).

Although most of these services are difficult to quantify, pest control is one of the most important services to agricultural production provided by birds, with several studies showing substantial decreases of pest species and increases in crop production related to the predatory activities of birds (see review in Whelan et al., 2008). Predation by insectivorous birds reduced pest damage levels in coffee plantations by 1–14%, increasing the production value by US$44–$105/ha in 2005/2006 (Kellermann et al., 2008). Moreover, the use of nesting boxes to attract great tits (Parus major) reduced caterpillars densities and fruit damage while increasing apple yield by 66% (Mols and Visser, 2002). Research on the controlling effects of raptors on rodents and avian agricultural pests is limited (Şekercioğlu et al., 2004); however, the importance of rodents in the diet of raptors suggests that these birds are beneficial species for agriculture (Whelan et al., 2008). For example, higher numbers of diurnal raptors around soybean fields decreased population numbers and growth rate of house mice (Mus domesticus) (Kay et al., 1994).

Functional richness theory relates the level of ecosystem services provided by birds to the diversity of species providing it. More species represent a larger number of adaptations and henceforth a more efficient use of the resource. As a consequence, species richness is considered to be directly related to the level of service provided (Philpott et al., 2009). Common species (usually the most abundant), however, have the greatest effect on ecosystem processes (Gaston, 2010) and subsequently the level of ecosystem services provided by those species also depends on the abundance of those species (Şekercioğlu et al., 2004; Swift et al., 2004; Wilby et al., 2005).

Expansions and intensified management of rows crops are expected to continue to significantly alter habitat quality, quantity, and configuration in Argentina; hence, assessing and determining the implications of these landscape-modifying processes for the provision of ecosystem services, via the effects on avian populations, are imperative to ensure the provision of those services. For this purpose, we used data from a long-term, large-scale monitoring program to analyze the short- and long-term relationship between densities of a suite of avian species (which provide pest control services) and the expansion and intensified management of row crops in the Argentine Pampas and Espinal agroecosystems, assuming a direct relationship between bird abundance and the level of pest control service (Philpott et al., 2009; Swift et al., 2004; Wilby et al., 2005).

2. Methods

2.1. Study area

The study area comprised 128,200 km² of the Pampa and Espinal ecoregions (Cabrera, 1994) characterized by annual mean minimum and maximum temperatures of 13 °C and 23 °C, respectively (Soriano, 1992) and 1000 mm of mean annual precipitation (Ferreira et al., 2001; Messina et al., 1999; Podestà et al., 2002). This
area is the principal agricultural production region in Argentina, increasingly dominated by annual row crops (wheat, soybean, sunflower, sorghum and corn) and has been highly modified due to agricultural expansion and intensification (León et al., 1984; Viglizzo et al., 2004).

The Espinal portion extends irregularly from the center of province of Santa Fe, northeastern Córdoba and northern Entre Ríos and supports remnant xerophilic woodlands dominated by Prosopis nigra, Acacia caven, and Geoffroea decorticans. These woodland remnants are isolated and immersed in an agricultural matrix. The Pampean portion covers southern Santa Fe, south-central Córdoba and central Entre Ríos provinces, and is dominated by grasslands mainly composed of Stipa sp., Briza sp., Bromus sp., Poa sp. (Cabrera, 1971).

2.2. Data analysis

We analyzed the relationship between avian species abundance and land use change using two sets of variables: estimates of species density (dependent variables) and environmental factors (independent variables). Using these variables we conducted two analyses representing the short and long-term effects of habitat conversion on species densities.

2.2.1. Bird species density estimation (dependent variables)

In January each year from 2003 to 2009 (austral breeding season) we surveyed 47 transects (routes), located along unpaved secondary and tertiary roads within different agro-production zones (areas differing in land use, land cover and economic activities) in east-central Argentina. Transect locations were chosen using a geographically-stratified systematic design that consisted in applying a 30 km × 30 km grid over a map of the study area and defining eight strata consisting of agro-production zones and provincial boundaries (Fig. 1). Within each stratum, grid cells were selected systematically (every other cell) with the number of cells proportional to the area of each zone. Within each cell the route and the direction for the route to be surveyed were randomly selected among all possible alternatives (Zaccagnini et al., 2010).

Each route had 30 permanently marked points, spaced at 1 km intervals, with the first point on the route randomly placed. At each point six avian species were surveyed between 6:00–11:00 am and 15:00–20:00 pm using distance sampling (Buckland et al., 2001) by a pair of experienced observers. At each point one observer determined the distance to and number of each species detected during a 3-min period whereas the other observer recorded data on land use. Laser rangefinders were used to measure distances to individual birds or to the center of flocks.

We selected 6 species based upon their extensive distribution within the study area and relatively high number of detections. Two species were insectivores (Fork-tailed flycatcher Tyrannus savana, White-browed blackbird Sturnella superciliaris) and two were raptors (Chimango caracara Milvago chimango and Southern crested-caracara Caracara plancus), whose diet includes rodents and insects. We also included two species that are considered crop pests (Shiny cowbird Molothrus bonariensis and Eared dove Zenaida auriculata) to compare their response to land use change with that of species providing pest control services. This comparison can have important management implications if management to enhance pest control by birds also has a positive influence on the abundance of pest species. Species densities were estimated for each year using DISTANCE 5.0, a computer package for the analysis of distance sampling data that corrects for incomplete detection in density estimates (Buckland et al., 2001; Thomas et al., 2002).

After exploratory analysis of the data (sensu Buckland et al., 2001; Thomas et al., 2002, including histograms of the distance data under several grouping factors to detect and correct for the presence of heaping, evasive movement, outliers) we set the truncation distance w at 250 m, the distance that included 90% of detections for all species combined and manually selected 7 distance intervals with cut off points based on the distribution of observations at different distances. Density estimates were derived with detection models using a combination of 3 monotonic, decreasing key functions (uniform, half-normal, and hazard rate) and 2 adjustment terms (cosine and polynomial) and best models chosen using Akaike Information Criteria (AIC) and model weights. To facilitate multi-species analysis we selected one model (half normal key function + cosine adjustment term) for estimating density of all species based on its better performance for the majority of species. Given a relatively low number of detections for some species during each year we estimated the detection probability function globally (e.g., all years combined) for each species, and estimated density for each year on each route using stratification (by year) and post-stratification (by route) (Buckland et al., 2001).

2.2.2. Environmental (independent) variables

2.2.2.1. Land use. Land use was recorded annually at each transect point in a 200–m radius circle centered on each point, as estimates of percent cover of five land-use classes (Schrag et al., 2009). Land-use classes included: (1) annual crops (i.e., soybeans, sorghum, sunflower, wheat, corn); (2) managed pastures (both annual and perennial species); (3) non-plowed fields, including (a) agricultural fields that have been resting for more than a season covered with a mixture of herbaceous and grassy vegetation, or (b) natural and semi-natural grasslands used for cattle ranching; (4) forest (both native and exotic species); and (5) other uses (including, but not limited to, aquatic habitats). The percent cover for all points was averaged among the 30 observation points to obtain a single value for each transect per year.

2.2.2.2. Enhanced vegetation index. Enhanced vegetation index (EVI), which provides a consistent and permanent comparison of temporal changes in vegetation is a MODIS (Moderate-Resolution Imaging Spectroradiometer) product MOD13Q1 (image acquisition every 16 days) with a 250–m spatial resolution (http://modisland.gsfc.nasa.gov/vi.htm). EVI measures the amount of photosynthetic tissue as an index of plant productivity that corrects for distortions in the reflected light caused by airborne particles as well as ground cover below the vegetation (Jiang et al., 2008). For each year, we extracted the EVI value for the pixel containing each sample point and averaged those values to obtain a single value per transect.

2.2.2.3. Precipitation. Precipitation data for each transect were collected from the nearest meteorological station of the Instituto Nacional de Tecnología Agropecuaria (INTA). Since avian abundance may have been associated with precipitation before sampling, we included mean monthly precipitation from September to January for each year.

2.2.2.4. Latitude and longitude. Latitude and longitude for the central point of each survey transect (Gauss–Kruger zone 3) was included in the analysis to account for large-scale spatial patterns that could mask the relationship between avian densities and land use (e.g., gradient in species abundance related to variations in the geographic distribution) and account for potential correlation of other variables that could be responding similarly to the same large-scale gradients.

2.2.3. Statistical analyses

We used regression analysis to investigate the relationship among species densities (dependent variables) and environment
variables (independent variables). We divided the analysis into two parts to assess the long-term and short-term relationship between bird densities and habitat variables. We analyzed the long-term relationship using the mean values from 2007 to 2009 for both dependent and independent variables, trading space for time to establish a gradient representing the long-term transformation from totally transformed areas to those dominated by natural vegetation. For the analysis of the short-term relationship between bird densities and habitat variables we used regression analysis of the changes in mean densities and habitat values between 2003-2005 and 2007-2009 to explore species response to land use change during the study period.

Throughout the analysis we used the same approach that included three steps. In the first step, we tested for correlations among independent variables using a Pearson’s correlation matrix for explanatory variables to avoid collinearity issues and discarded habitat variables that showed high levels of correlation ($r \geq 0.70$). In the first part of the analysis (long-term temporal effects), rainfall and annual crops were correlated with longitude and proportional forest area, respectively, above 0.7 Pearson correlation coefficient. Hence, we included rainfall instead of longitude in the models, because rainfall accounts for an east–west gradient, whereas for the area in annual crops and forest we selected the variable that best explained species density for each particular species. In the second part of the analyses (short-term temporal effects), we included all variables plus latitude and rainfall instead of longitude. We did not use a change variable for forest, because there was an alteration in the sampling protocol related to the estimation of forest cover during the period of the entire study.

In the second step of the analysis, we fitted multiple regression linear models using the variables selected in the first step. First, we fitted a full model using all habitat variables and then we used step-wise selection to eliminate non-significant variables and obtain a reduced model (Chatterjee, 2001). We used the full and reduced models as a measure of variance in species densities given our set of explanatory variables. Assumptions of linear regression were verified. If necessary, densities were log-transformed to meet linearity assumptions. Spatial autocorrelation of the model residuals were tested with a semi-variogram randomization analysis (Isaaks and Srivastava, 1989). The full and reduced models were used to estimate the variance in densities accounted for in the analysis and the direction of the effects of the independent variables.

In the third step, we assessed the importance of each individual variable in explaining species density. Stepwise selection has limitations since it identifies one best model (among several that could explain the responses equally well) and does not provide information about the amount of variance explained by each variable (Whittingham et al., 2006). Since our main focus was to understand the habitat variables that most affected bird densities rather than fitting the best explanatory model, we used best subsets and hierarchical partitioning analysis to assess the importance of variables included in the models.

The best subset method uses Bayesian Information Criterion (BIC) to obtain a subset of models that best explains the response. The approach performs an exhaustive search of all possible models and the maximum number of predictors allowed is specified a priori (Miller, 1990). Fitting several models instead of one “best”

![Fig. 1. Study area and location of survey transects.](image1)

![Fig. 2. Variation in mean densities during 2007–2009 for the six bird species included in the study. The black line inside each box is the median, the lower and upper edges of the boxes are the 0.25 and 0.75 quantiles, and the lines represent the range of the data. Outliers are denoted with a circle.](image2)
Fig. 3. Distribution of mean bird densities and percentage of annual crops in the study area during the period 2007–2009. Maps of the proportional annual crop area were obtained by extrapolation of the 2007–2009 mean for each survey transect using inverse distance weighting.
model highlights which variables are repeatedly chosen in the best models, and whether they have a consistent effect on the response variable (i.e., negative or positive coefficient). We used three variables to fit the model and considered the 10 best models explaining bird densities obtained in each best subsets analysis. We then counted the number of times that each variable was included in the 10 best models to determine an importance value of each variable in the model subset. We performed one subset analysis for each bird species in both parts of the analysis.

Hierarchical partitioning analysis calculates the percent of variance of the full model explained by each variable when all other variables are included in the model. For estimated densities of each bird species, all possible models based on different combinations of the habitat variables were fit. For each fitted model the variable of interest was dropped and the model was fitted again. The importance of that variable was calculated as the average change in $R^2$ when the variable was dropped from all of the fitted models (MacNally, 2002).

For each bird species we presented results of both hierarchical partitioning and best subset analysis for each habitat (explanatory variables) included in the analysis. Best subset analysis indicated which variables were most strongly associated with bird densities (importance value) and hierarchical partitioning analysis indicated the proportion of variance explained by each variable of the total variance included in the full model. We also included the full and reduced models.

3. Results

3.1. Trends in species densities and distributions

During 2007–2009 $Z$. auriculata had the highest density, with an average of 12 individuals per ha, whereas for the same period estimates of mean density for $T$. savana, $M$. bonariensis and $S$. superciliiarsis were similar to one another but much lower than $Z$. auriculata (Fig. 2). The two raptor species, $M$. chimango and $C$. plancus, had the lowest densities (less than 1 individual per ha). Furthermore, densities of $Z$. auriculata, $T$. savana and $M$. bonariensis were highly variable across survey transects (Fig. 2).

The spatial distribution of species density showed three different patterns across the study area. Densities of $S$. superciliiarsis, $M$. chimango, $C$. plancus and $T$. savana were highest in the west-central portion of the study area, where land use is dominated by row crop agriculture. This distribution pattern was most strongly related to land use for $S$. superciliiarsis and $M$. chimango, whereas a weaker relationship between land use and density for $C$. plancus and $T$. savana was observed (Fig. 3). Densities of $Z$. auriculata and $M$. bonariensis were not related to the proportion of cultivated area, with the density of $Z$. auriculata decreasing along a north–south gradient and the density of $M$. bonariensis showing a weak tendency to decrease along a north–east gradient (Fig. 3). Between 2003–2005 and 2007–2009, the average estimated densities of most species were stable; however, $Z$. auriculata and $M$. bonariensis exhibited a tendency towards increasing densities between these periods (Fig. 4).

3.2. The relationship between land use and species density

3.2.1. Long-term effects

During the 2007–2009 period, the density of $S$. superciliiarsis was most strongly related to land use, followed by that of $M$. chimango (multivariate models explaining about 60% and 40% of the variation in estimated densities, respectively; Table 1). Estimated densities of $C$. plancus and $T$. savana were related to land use at an intermediate level (multivariate models explaining 30% of the variation in estimated densities), whereas $Z$. auriculata and $M$. bonariensis exhibited the weakest relationship (multivariate models explaining 21% and 14% of the variation in estimated densities, respectively) (Table 1; Fig. 5).

Estimated densities of $S$. superciliiarsis demonstrated a strong negative relationship to increasing forest area and precipitation, whereas the density of $M$. chimango was positively related to the annual cropping area and negatively to rainfall (Table 1; Fig. 5). Densities of $T$. savana and $C$. plancus were positively and most strongly related to the area of non-plowed fields (Fig. 5). In addition, $T$. savana density was negatively related to latitude (increasing density towards the south) and $C$. plancus density decreased with increasing forest area and rainfall (Fig. 5).

$Z$. auriculata and $M$. bonariensis densities were not explicitly related to land use at the scale of analysis. Latitude (with a positive effect) was the most important variable explaining distributions, but only explained 20% of the variation in estimated densities in both the full and reduced models. $M$. bonariensis, however, also exhibited a negative relationship with rainfall along an east–west gradient (Table 1; Fig. 5).

3.2.2. Short-term effects

Changes in land use did not clearly explain changes in species densities between the 2003–2005 and the 2007–2009 periods, with the multiple models equally explaining a small proportion of the variation in densities. The species with the largest change in density (36%) was $M$. bonariensis, although a reduced multivariate model including latitude, change in the area of annual crops and change in EVI explained only 14% of the variation (Table 2). Latitude explained 65% of the variation within the model and was present in all models in the best subset analysis ($M$. bonariensis densities tended to increase northward).

For $C$. plancus, a multivariate model including changes in the area of non-plowed fields and pastures, EVI, and rainfall explained 26% of the variation in density ($p < 0.05$; EVI was the most important variable, accounting for 35% of the variation explained in the model and was included in 9 of the 10 models in the best subset analysis. $C$. plancus density tended to increase in areas that underwent increases in EVI between 2003 and 2009 (Table 2).

Changes in estimated densities of $M$. chimango and $S$. superciliiarsis were very low. $M$. chimango density tended to increase with an increase in rainfall and pastures (Table 2); the multivariate model
Table 1
Response of bird densities to long-term agricultural expansion in the Pampas and Espinal ecoregions. Full multiple regression models and reduced models (fitted by stepwise selection) explaining mean densities for the period 2002–2007 of six birds species, p-values and $R^2$ of each model are shown. For each model, variables included are presented with the sign of the effect, the slope parameter and the variable name. An * indicates a significance level of $p < 0.05$ and a ** indicates marginal statistical significance (0.05 < $p < 0.06$). Non-significant statistical results for the models are indicated as ns.

<table>
<thead>
<tr>
<th>Species/models</th>
<th>Model structure</th>
<th>$R^2$</th>
<th>p-Value</th>
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<td><strong>M. chimango</strong></td>
<td>Full model</td>
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Table 2
Response of bird densities to short-term agricultural expansion in the Pampas and Espinal ecoregions. Full multiple regression models and reduced models (fitted by stepwise selection) explaining change of mean densities of six birds species between the period 2002–2004 and 2007–2009, p-value and $R^2$ of each model are shown. For each model, variables included are presented with the sign of the effect, the slope parameter and the variable name. An * indicates a significance level of $p < 0.05$ and a ** indicates marginal statistical significance (0.05 < $p < 0.06$). A * symbol indicates a variable representing the change between the 2002–2004 mean and 2007–2009 mean. Non-significant statistical results for the models are indicated as ns.

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<th>p-Value</th>
</tr>
</thead>
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<td><strong>M. chimango</strong></td>
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<tr>
<td>Reduced model</td>
<td>-0.012</td>
<td>0.29</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>
including changes in the area in pasture and rainfall explained 12% of the variation in densities and rainfall, and pasture area accounted for 45% and 35% of model variation, respectively. Precipitation was included in 9, and area in pasture in 6 of the 10 models, respectively, in the best subset analyses. For S. superciliiaris, a model including changes in EVI alone explained 14% of variation of changes in density, with density increasing with increasing EVI. Estimated densities of T. savana and Z. auriculata showed no relationship with changes in habitat variables (Table 2).

4. Discussion

In the Pampas and Espinal ecoregions of Argentina, the density of bird species is related to long-term expansion of row cropping, with species exhibiting different responses to the expanding row crop area in a species-specific manner. Subsequently, the process of land conversion is likely affecting the provision of pest control services via effects on bird species densities. Species density varied with dominant land use, suggesting that locations with similar species richness could differ in species density among sites.

The patterns of species densities in relation to land use reflect life history traits adapted to open habitats. S. superciliiaris and M. chimango, the two species with densities most strongly associated with land use (particularly annual crop area), are adapted to a variety of environments, but mainly to open habitats. S. superciliiaris is associated with cultivated fields and grassland habitats (Camperi et al., 2004) and its presence has been related to increased annual crop area (Schrag et al., 2009); however, another research work found no positive relationship with agricultural intensification (Filloy and Bellocq, 2007a). M. chimango is tolerant to human disturbance and is strongly associated with agriculture (Bellocq et al., 2008; Carrete et al., 2009; Filloy and Bellocq, 2007a) but negatively affected by urbanization (Garaffa et al., 2009). Grassland habitat is also an important factor determining the presence of M. chimango (Filloy and Bellocq, 2007b; Leveau and Leveau, 2004), which could also explain the association with non-plowed fields.

Both C. plancus and T. savana exhibited a strong positive relationship with non-plowed fields, indicating a preference for natural or semi-natural habitats. In Pampas agroecosystems, the presence of C. plancus has been shown to be negatively related to agriculture intensification (Carrete et al., 2009; Filloy and Bellocq, 2007a) and associated with grassland habitats (Pedrana et al., 2008; Schrag et al., 2009), which likely explains the strong positive association with non-plowed fields in our study area. T. savana showed a similar positive relationship with the area of non-plowed fields and to a lesser extent to annual crop area. T. savana adapts to a variety of habitats, including open and rural areas, but has been found to be negatively associated with intensified agriculture (Filloy and Bellocq, 2007a).

Interestingly, the two species considered agricultural pests (Z. auriculata and M. bonariensis) were weakly related to land use. Both species are likely reacting to factors operating at different scales than that of our study and are adaptable to different kind of habitats, including anthropogenic environments (Milesi et al., 2002). Other studies found M. bonariensis not to be affected by intensified agriculture in the Pampas region, whereas Z. auriculata responded negatively (Filloy and Bellocq, 2007a). Higher densities of Z. auriculata are related to landscapes combining forest patches and agricultural land (Bucher, 1990).

Our study species responded to differences in land cover and land use, that which can be interpreted as representative of the long-term effect of land use changes on species density related to agricultural intensification in the Pampas and Espinal. However, species density was not associated with short-term land use changes, which has two possible explanations. On one hand, the changes in land use that occurred during the study period were not sufficiently large to affect populations of common species, since the ecological plasticity of birds (particularly mobility) allows them to adapt to short-term environmental changes (Lemoine et al., 2007). On the other hand, bird populations may exhibit time lags in the response to changes in land use (Brooks et al., 1999; Chamberlain et al., 2000). Many of the studies that best illustrate the effects of changes in agricultural management on avian communities were conducted in Europe, where the process of intensified management has occurred more slowly, over a longer period of time (starting in the late 1940s) (Donald et al., 2001; Stoate, 1996; O’Connor and Shrub (1986). However, studies in African landscapes with a history of transformation comparable to our study area showed a fast response of bird communities to agricultural intensification, suggesting that a time lag of a few decades is expected (Laube et al., 2008; Malan and Bennb, 1999). The key point is that bird densities are responding to land use changes in the long-term, indicating that at some point accumulated changes will have an effect on bird density.

Analysis of diets in the ecoregion support the important role that T. savana, S. superciliiaris, P. plancus, and M. chimango may have in pest control. The stomach content of T. savana was found to be composed of 90% of insects, mainly Coleoptera, Diptera, Ephemeroptera and Odonata (Alessio et al., 2005), whereas for S. superciliiaris, insects represented 93% of stomach contents, with Lepidoptera, Coleoptera and Orthoptera being the dominant orders (Camperi et al., 2004). Insects were also most common in the diet of P. plancus (69.5%), followed by mammals (23.9%) and birds (5%), although mammals accounted for the highest proportion of biomass (Vargas et al., 2007). For M. chimango, insects were found to represent 96% of all prey items, whereas carrion amounted to 48% of ingested biomass. Since many of its prey are crop pests, M. chimango is considered to play a beneficial role for humans (Biondi et al., 2005).

Despite the dominance of crop pests in the diet of many bird species, predation should result in increased crop yields through pest removal or by limiting pest activity through fear, to be considered as providing an ecosystem service (Şekercioğlu, 2006). Many studies have found increased densities of crop pests (particularly insects) when bird predation is removed, which suggests the importance of birds as beneficial species for agriculture (Mols and Visser, 2002; Tremblay et al., 2001). Results of diet analysis suggest that a local extinction or a substantial reduction in density of our study species could reduce the provision of pest control services. Nevertheless, experiments measuring changes in the levels of predation and the response of pest densities and crop yields are urgently needed in the Pampas and Espinal ecoregions.

Based on our data and analysis, it appears that species that can provide pest control services are able to adapt to different levels of agricultural intensification, although density is related to the presence of natural or semi-natural habitat as well, mostly non-plowed fields. Therefore, the loss of remnants of natural habitat in intensively managed agroecosystems might reduce the density of species that potentially provide pest control services.

Experimental and field studies have found that the level of ecosystem service associated with beneficial fauna is a direct function of the diversity of species that provide services (Phillpot et al., 2009; Wilby et al., 2005). This is of concern for our study since in the Pampas and Espinal regions most studies found a decrease in avian species richness associated with an increase in the row crop area, with richness of insectivorous birds being particularly sensitive to row crop expansion (Codesido et al., 2008; Schrag et al., 2009). Consequently, even though many common bird species that potentially provide pest control services can increase in density along with the occurrence of agricultural expansion, a certain level of pest control service could be lost from the local extinction of less common bird species.
Fig. 5. Summary of regression analysis of densities for focal species. White bars represent results of best subset analysis (number of times a variable entered the 10 best models). Black bars represent results of hierarchical partitioning analysis (percent of the variability explained by each variable when all variables are included in the model). Signs (+, positive; –, negative) indicate the relationship of explanatory variables with bird densities.
species in agricultural systems, as well as a loss in redundancy in the insectivore community as a whole.

Our findings and the results from other research on avian species richness indicate the need for developing management and conservation plans that address the maintenance of bird-related pest control services in our study area. The agricultural expansion and intensification in recent decades have had a critical effect on the composition and configuration of agricultural landscapes. Soybean expansion in particular has resulted in the loss of former natural and seminatural pastures, the loss of forest remnants, and the elimination of linear habitats such as field margins, erosion control contours and roadside vegetation (Baldi and Paruelo, 2008; Paruelo et al., 2005; Oesterheld, 2008).

The importance of habitat remnants as reservoirs for avian biodiversity has been mentioned in numerous studies, indicating that the conservation of even small remnants of natural or seminatural habitats helps to maintain a relatively high proportion of avian diversity. In the Espinal ecoregion, several studies showed the importance of small forest patches in retaining a substantial proportion of bird diversity within agroecosystems (Bucher et al., 2001; Dardanelli et al., 2006). In addition, in the Espinal region avian diversity, species richness, and diversity (particularly of insectivores) were higher in field margins than in the interior, as well within fields with vegetated terraces and field borders compared to fields without such features (Di Giacomo and López de Casenave, 2010; Goijman and Zaccagnini, 2008; Solari and Zaccagnini, 2009).

Similarly, in an agriculture and grassland matrix in the Pampas, most bird species used field margins, particularly grassland and tree-dominated field edges, more frequently in relation to their availability in the landscape (Leveau and Leveau, 2004).

The importance of the presence of habitat remnants in agroecosystems in our study area and other regions provide strong support for the development of management actions that take into account the potential importance of the pest control services provided by avian biodiversity. It is particularly evident that habitat and crop management towards maintaining the ecosystem services provided by birds needs to be undertaken at different scales. Most agricultural management decisions are made at the field scale and the effects of these decisions (e.g., eliminating vegetated borders) on ecosystem processes may function synergistically to overshadow the importance of regional factors (Viglizzo et al., 2004). Although this suggests that the most effective management would be that applied at the field-level, given spatial interactions and fluxes of elements between habitat, crop patches and human elements, management at the landscape scale also needs to be considered (Termsorshuizen and Opdam, 2009).

5. Conclusions

The apparent flexibility of many common bird species that potentially provide pest control services in adapting to large-scale row crop expansion in the agricultural landscapes of the Pampas and Espinal ecoregions of Argentina suggests that there may be a considerable level of resiliency within those systems for the maintenance of the related ecosystem services. However, the positive association of the analyzed species with remnants of habitat, and the negative effects of row crop expansion on many less common or rare bird species, indicates the need for management to ensure the long-term maintenance of avian diversity and community redundancy for providing adequate levels of bird-related ecosystem services. In addition, the lack of short-term effects of row crop area encroachment on bird abundance indicates a potential time lag that could result in future changes in avian densities even if no further changes in land use occur. The almost total elimination of remnant habitat in areas of agricultural intensification will likely result in the loss of avian pest and pest control service. However, the conservation of habitat remnants and landscape features within the agroecosystem matrix would require a considerably small amount of productive area, while maintaining a substantial proportion of avian diversity, and in turn the potentially highly valuable services provided by that diversity.

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dos, 54


