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THE ROLE OF STUBBLE TYPE AND SPILLED SEED BIOMASS ON THE ABUNDANCE OF SEED-EATING BIRDS IN AGROECOSYSTEMS

EL ROL DEL TIPO DE RASTROJO Y LA BIOMASA DE SEMILLAS DERRAMADAS SOBRE LA ABUNDANCIA DE AVES QUE SE ALIMENTAN DE SEMILLAS EN AGROECOSISTEMAS

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Summary.—Croplands are habitats with high availability of food resources for seed-eating birds. The use of particular fields by birds may vary considerably depending on crop type. Some crop stubbles hold high amounts of spilled grain after harvest, which may support seed-eating bird populations throughout the year. We examined the role of crop stubble type and biomass of spilled grain on species richness and abundance of seed-eating birds in the Pampas of central Argentina. During 2011-13 we sampled 166 stubble fields: 77 fields during the austral spring-summer of 2011-12 and 2012-13 (44 wheat and 33 barley stubbles); and 89 fields during the austral autumn of 2012 and 2013 (49 soybean, 27 corn and 13 sunflower stubbles fields). We recorded birds on a 700 × 100 m transect and estimated spilled grain on 1 m^2 of stubble cover in each field. Comparisons among species accumulation curves showed that wheat and barley stubbles had similar bird species richness in spring-summer, whereas in autumn, sunflower stubbles supported higher bird richness than soybean stubbles. Generalized linear mixed models revealed that the abundance of some seed-eating birds had significant associations with crop stubble types. Some species were positively associated with spilled grain biomass on particular stubble types. In general, these associations varied seasonally, being more evident in autumn than in spring-summer. Knowledge of bird species populations and their specific association with given food resources during periods when crops remain only as stubble could be a key tool to help plan management strategies designed to reduce bird impacts on agricultural crops prior to harvest, when they are most susceptible to significant levels of damage.

Key words: crop identity, croplands, granivory, pest birds, seed supply.

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Resumen.—Las tierras de cultivo son hábitats con alta disponibilidad de recursos para las aves granívoras. El uso de un determinado campo por las aves puede variar considerablemente dependiendo de la identidad del cultivo. Ciertos rastrojos tienen alta cantidad de semillas remanentes después de la cosecha, los cuales pueden sostener poblaciones de aves granívoras a lo largo de todo el año. Examinamos el rol que tienen la identidad del rastrojo y la biomasa de semillas derramadas sobre la riqueza y abundancia de aves granívoras en las Pampas de Argentina central. Durante 2011-2013 muestreamos 166 campos de rastrojos: 77 campos en las primaveras-veranos australes 2011-12 y 2012-13 (44 rastrojos de trigo y 33 de cebada) y 89 campos en los otoños australes 2012 y 2013 (49 rastrojos de soja, 27 de maíz y 13 de girasol). Dentro de cada campo establecimos un transecto de 700 × 100 m para el registro de las aves y estimamos las semillas derramadas en el suelo del rastrojo con una muestra de 1 m^2 por campo. La comparación entre curvas de acumulación de especies mostró que en primavera-verano los rastrojos de trigo y cebada presentaron una riqueza de especies similar, mientras que en otoño, los rastrojos de girasol presentaron una riqueza de especies mayor que los rastrojos de soja. Los modelos lineales generalizados mixtos revelaron que la abundancia de ciertas especies de aves granívoras tuvo una asociación significativa con la identidad del rastrojo. Algunas especies estuvieron asociadas positivamente con la biomasa de semillas existentes en un particular tipo de rastrojo. En general, estas asociaciones variaron estacionalmente, siendo más evidentes en otoño que en primavera-verano. El conocimiento de las poblaciones de aves y su asociación con los recursos alimenticios durante períodos cuando los cultivos permanecen como rastrojos, podrían ser una herramienta clave para el planeamiento de estrategias de manejo que traten de reducir el impacto de aves sobre la producción agrícola cuando los cultivos son susceptibles al daño.

Palabras clave: identidad de los cultivos, granivorismo, plagas de aves, suministro de semilla, tierras de cultivo.

Introduction

Agroecosystems have become important habitats for many bird species worldwide (Diamond, 1989; Buckingham *et al.*, 1999; McKinney & Lockwood, 1999; La Sorte, 2006). Although croplands exhibit a high frequency of perturbations and may be avoided by specialist birds (Donald *et al.*, 2006; Codesido *et al.*, 2012), these agroecosystems can still sustain many bird species, offering abundant resources for feeding and nesting (Wilson *et al.*, 1996; Moorcroft *et al.*, 2002; Anteau *et al.*, 2011; VanBeek *et al.*, 2014), particularly for seed-eating birds (Robinson *et al.*, 2001, 2004). In addition, cereal and oilseed crops may provide food with high nutritional content (Wilson *et al.*, 1996). Field crop identity is hence a significant feature in croplands, seed nutritional quality as well as seed size and shape making different crops more or less palatable for various seed-eating birds (Wilson *et al.*, 1996; Geiger *et al.*, 2014).

Croplands are an important habitat for many seed-eating birds, although habitat use intensity may vary considerably, depending on crop type and its phenological stage (Dolbeer, 1990; Díaz & Tellería, 1994; Moorcroft *et al.*, 2002; Canavelli *et al.*, 2014). After harvest, stubble fields hold greater amounts of seed than other field types (Donald & Evans, 1994; Evans & Smith, 1994; Robinson & Sutherland, 1999; Sherfy *et al.*, 2011). A significant amount of spilled seed often remains on the ground of crop stubbles after harvest, the actual amounts varying with harvest method and harvest equipment efficiency. Recent large scale adoption of non-tillage cropping methods allows spilled seed to remain uncovered and thus available to support seed-eating bird populations throughout the year (Bucher & Ranvaud, 2006). This spilled seed is a key food supply during what in the past were critical periods of food shortage, particularly when ripe crops and weeds in uncultivated habitats were unavailable (Wilson *et al*., 1996, 1999; Robinson & Sutherland, 1999; Robinson *et al*., 2004). In addition, many seed-eating birds show clear preference for a specific crop seed (Willson, 1971; Aramburú & Bucher, 1999; Whelan *et al*., 2015). Thus, different bird species may prefer certain types of seeds to others, depending on their seasonal availability in the fields (Bucher & Nores, 1976; Aramburú, 1997).

The Argentine Pampas is one of the most productive agricultural areas of the world, covering about 52 million hectares of productive organic soils, which were originally covered by grasslands (Soriano, 1991). In the recent past, this huge plain was primarily a livestock-raising area, but during the last few decades, cattle raising in the Pampas has progressively been restricted to marginal areas, and former natural rangelands and pastures have been replaced by croplands (Ghersa *et al*., 1998; Baldi & Paruelo, 2008). The most important technological innovations that increased the extent of croplands occurred in the 1990s with the simultaneous introduction of genetically modified soybeans (*Glycine* sp.) tolerant to glyphosate and no-till (direct drilling) agricultural practices (Trigo & Cap, 2003; Aizen *et al*., 2009).

There have been several studies of seed-eating birds in temperate South American croplands (*e.g*. Bruggers *et al*., 1998; Bucher & Ranvaud, 2006; Canavelli *et al*., 2014). However, most have been carried out during ripe or sprouting crop stages and particularly focused on non-passerine granivorous pest birds (Canavelli *et al*., 2014; Codesido *et al*., 2015). Information on the role of crop stubbles and availability of spilled grain as key factors underlying variation in the populations of seed-eating birds is lacking, in particular for non-passerine granivorous birds (Leveau & Leveau, 2004). Here, we test the hypotheses that 1) stubble type influences seed-eating bird species-richness and that 2) the abundance of non-passerine granivorous species is influenced by stubble type and is positively associated with the biomass of spilled grain on crop stubble fields. These hypotheses were tested in the Pampas of central Argentina, during two contrasting periods of the year (autumn and spring-summer) different crop stubble types being available in each period.

Methods

Study area

The study area extended over some 225,000 km^2 (500 km north to south, 450 km east to west; 33º-39ºS, 57º-63ºW) in the Pampas region included in Buenos Aires province, central Argentina (Figure 1). The climate is warm-temperate, with mean temperatures varying between 15 ºC in the south and 18 ºC in the north. Annual rainfall decreases from 1,000 mm in the NE to 800 mm in the SW. The natural vegetation was originally a tall grass-steppe (Soriano, 1991) but, at present, natural systems of the Pampas have been replaced by agroecosystems used for intensive crop production under no-till farming systems or for cattle grazing (Bilenca *et al*., 2012).

Types of stubble fields

This study was carried out in two austral spring-summers (December to January 2011-12 and 2012-13) and two autumns (April to June 2012 and 2013). We selected 25 sites distributed evenly throughout our study area (Figure 1). At each site and season we sampled two independent recently harvested stubble fields (at least 1,500 m apart). Thus, each site was surveyed twice each season over two years, but each sampling was carried out in different fields, in order to avoid temporal dependence among data. Croplands remained as stubble during the study periods: in spring-summer, harvested fields were dominated by cereal stubbles of wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*), whereas in autumn most harvested fields had oilseed stubbles such as soybean and sunflower (*Helianthus annuus*), and cereal stubbles of corn (*Zea mays*). Other types of harvested stubble fields, including oats (*Avena sativa*), rye (*Secale cereale*), sorghum (*Sorghum* sp.) and peanut

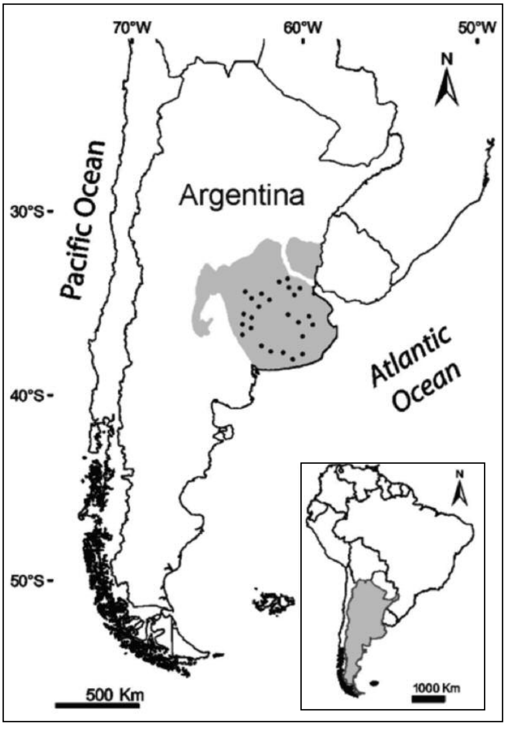

FIG. 1.—General location of the Pampas region (grey shading) in temperate South America; black dots indicate the locations of survey sites.
[Localización general de la región Pampeana (sombreado de gris) en Sudamérica templada; los puntos negros indican la ubicación de los sitios de muestreo.]

(*Arachis hypogaea*), were very rare in the study region and were excluded from data analyses. In total we analyzed 166 stubble fields: 77 fields in spring-summer (44 of wheat stubble and 33 of barley stubble) and 89 fields in autumn (49 of soybean stubble, 27 of corn stubble, and 13 of sunflower stubble). The mean area (± SE) of stubble fields was 44 ± 2ha.

Seed-eating bird counts

Bird surveys were carried out within 4 hours after dawn by the same observer (EZ). We established a single 700 m long by 100 m wide transect belt within each of the 166 stubble fields, at least 50 m from the field boundaries (Bibby *et al*., 2000). Transects were walked for *ca*. 15 min and at a constant pace, recording all seed-eating birds seen and/or heard within the transect area, including low-flying (below 15 m) birds entering or leaving the area (Azpiroz & Blake, 2009). This adds up to a sampling effort of *ca*. 2,490 min for the 166 transects. We considered particular data sets of bird counts for testing each of our hypotheses (see introduction above). For hypothesis 1, we included all seed-eating birds in our analysis. For hypothesis 2 we only considered non-passerine granivores, which are able to feed on the seeds of all the crops included, thus excluding passerine birds since most of these are unable to consume large seeds (Willson, 1971). In addition, we restricted our abundance analyses for non-passerine granivores to those species that had > 30% field occupancy (*i.e.,* percentage of fields where a certain species was present) per season (Azpiroz & Blake, 2009). Three species met these criteria in spring-summer (Eared Dove *Zenaida auriculata*, Monk Parakeet *Myiopsitta monachus* and Picazuro Pigeon *Patagioenas picazuro*) and four species in autumn (Eared Dove, Monk Parakeet, Picazuro Pigeon and Spot-winged Pigeon *Patagioenas maculosa*). In just two cases, we adjusted the sites included in the analyses for a particular species according to its geographical distribution in the study area. Thus, we adjusted our analyses for Monk Parakeet and Spot-winged Pigeon by considering only 20 sites that lay within the distribution of each species (Narosky & Di Giacomo, 1993; Bucher & Aramburú, 2014). This exclusion allowed us to avoid non-detection of these species simply because the species are absent from those sites (Codesido *et al.*, 2011; Zufiaurre *et al.*, 2016).

Characterisation of stubble fields and estimation of the biomass of spilled seed

Four habitat structural features were measured in each field, just after making our bird count: stubble height (plant height), mulch cover (percentage of ground covered by stubble mulch), stubble mulch depth and weed cover. We sampled within a 0.25 m^2 ring frame that was randomly located in four points of each field. Height and depth were measured with a tape (cm), whereas mulch cover was estimated as a percentage. The values from the four rings were averaged to characterise each field. Weed cover was estimated on an ordinal scale classifying each field into one of five categories: clean (0), few (1), some (2), many (3) and full (4) of weeds.

Simultaneously with the characterisation of stubble fields, spilled seed biomass was estimated by collecting all the seed within each of the four rings (a 1 m^2 sample per field; INTA PRECOP, 2015). Samples were air-dried and weighed using an electronic digital scale and recorded as kg/ha. All surveys were carried out within a few days after harvest, so that the amount of spilled seed on the ground was considered to have undergone negligible depletion.

Data analyses

Separate analyses were conducted for each season (spring-summer and autumn). Differences in habitat structural features of fields among stubble types were compared with ANOVA (mulch cover was arcsin transformed to accommodate to assumptions of normality and homoscedasticity) or Kruskal Wallis tests for weed cover (Zar, 1999).

To compare seed-eating bird species-richness among stubble types we used species-accumulation curves constructed from the mean of 100 randomisations of sample order (Colwell & Coddington, 1997; Colwell, 2000). Since sample size of stubbles varied among crop types, we compared the expected number of species among stubble types truncated in the lowest number of samples (Tejeda-Cruz & Sutherland, 2004). Then, simulations were run 100 times and the mean expected number of species was compared among crop types on the basis of their 95% confidence intervals, where non-overlapping confidence interval bars indicate a significant difference between means (Tejeda-Cruz & Sutherland, 2004). Species-accumulation curves for seed-eating birds were calculated using EstimateS Version 9.1.0 (Colwell, 2000).

We used generalized linear mixed models (Pinheiro & Bates, 2000) in order to analyse the relationship between abundance of non-passerine granivorous birds (number of individuals per transect) and the explanatory variables stubble type (STU, with two levels in spring-summer: wheat and barley, and three levels in autumn: soybean, corn and sunflower) and spilled seed biomass (BIO, continuous variable, kg/ha). Models included the interaction between stubble type and spilled seed biomass (STU*BIO). All these variables were specified as fixed effects. In addition, we included the random intercept "site" (*i.e.*, group of fields sampled at the same site), in order to control for variation intrinsic to each site. Since the variance was much greater than the mean, each species' abundance was fitted to negative binomial error distribution and log link function in all models (Pinheiro & Bates, 2000).

Model selection was based on information-theoretic procedures (Burnham & Anderson, 2002). We considered models with all possible combinations of predictor variables, resulting in five candidate models (null model, STU, BIO, STU + BIO, STU + BIO + STU * BIO) for each species and each season. We used Akaike information criteria adjusted for small sample size (AICc). Model comparisons were made with ΔAICc, which is the difference between the lowest AICc value (*i.e.* the best of the suitable models) and AICc from all other models. The AICc weight of a model (w_i) indicates the relative likelihood that the specific model is the best of the set of all possible models (Burnham & Anderson, 2002). We evaluated the support for individual predictor variables performance summing w_i

TABLE 1

Habitat structural features of studied stubble fields during spring-summer and autumn in the Pampas of central Argentina. Significant differences among stubble types in each season are indicated in bold (p < 0.01) and results of *a posteriori* comparisons are indicated with different letters. ANOVA or Kruskal Wallis tests (Zar, 1999). Means ± SE (ranges in parentheses).
[Características estructurales de la vegetación de los campos de rastrojos estudiados durante primavera-verano y otoño en las Pampas de Argentina central. Las diferencias significativas entre los tipos de rastrojos en cada estación están remarcadas en negrita (p < 0,01) y los resultados de las comparaciones a posteriori son indicados con letras diferentes. Análisis ANOVA o Kruskal Wallis (Zar, 1999). Media ± error estándar y rango en paréntesis.]

	Spring-summer		**Autumn**		
Season Stubble types	Barley N = 33	Wheat N = 44	Sunflower N = 13	Corn N = 27	Soybean N = 49
Stubble height (cm)	**19.3 ± 1.3 (5-35)**	**32.3 ± 1.3 (13-50)**	**27.5 ± 5.8 (0-60)** b	**45.1 ± 2.8 (6-82)** a	**9.9 ± 0.4 (3-15)** b
Mulch cover (%)	71.5 ± 3.5 (30-100)	69.3 ± 2.9 (30-100)	**30.4 ± 5.3 (5-70)** b	**72.0 ± 4.4 (10-100)** a	**68.5 ± 3.1 (15-100)** a
Mulch depth (cm)	3.3 ± 0.7 (0-25)	3.1 ± 0.3 (0-12)	**2.4 ± 0.8 (0-9)** b	**6.9 ± 1.9 (0-55)** a	**3.8 ± 0.2 (1-11)** b
Weed cover (0 = clean; 4 = full)	Median: 1 Q1: 0 Q3: 1	Median: 1 Q1: 1 Q3: 3	**Median: 2 Q1: 1 Q3: 4** a	**Median: 2 Q1: 1 Q3: 3.5** a	**Median: 1 Q1: 0 Q3: 2** b

across all models that contained the parameter being considered (parameter likelihood; Burnham & Anderson, 2002). Model-averaged parameter estimates and unconditional standard errors were calculated using information from the full set of models (Burnham & Anderson, 2002). To evaluate the support for parameter estimates, 95% confidence intervals (CI) were calculated using unconditional variances and assumed that the considered factor associated significantly with bird abundance when the CI excluded zero (Burnham & Anderson, 2002). Statistical analyses were carried out using package *glmmADMB* (Fournier, 2012) within software R (version 3.3.0; R Development Core Team, 2016). Values are reported as means ± standard errors.

Results

Characterisation of stubble fields and estimation of spilled seed biomass

Stubbles were structurally quite similar in spring-summer, even though stubble height in wheat fields was slightly higher than in barley fields ($F = 48.8$; $p < 0.01$; Table 1). On the other hand, fields were structurally different in autumn depending on stubble type: a) soybean showed significantly less weed cover than sunflower and corn ($H = 8.7$; $p < 0.01$); b) corn fields taller stubble and deeper mulch than sunflower and soybean ($H = 41.6$; $p < 0.01$ and $H = 14.9$; $p < 0.01$ for stubble height and mulch depth respectively; Table 1); and c) mulch cover was lower in sunflower than in soybean and corn stubbles ($F = 17.2$; $p < 0.01$; Table 1).

In spring-summer, biomass of spilled seed on ground of stubbles varied from 153 ± 16kg/ha for wheat to 281 ± 36kg/ha for barley, whereas in autumn, spilled seed biomass was 82 ± 32kg/ha for sunflower, 181 ± 21kg/ha for soybean and 282 ± 101kg/ha for corn.

Seed-eating bird abundance and species richness

In total, we recorded 5,522 individuals of 14 seed-eating bird species (Table 2): Thirteen species in spring-summer and 10 in autumn samples. In spring-summer, species-accumulation curves for wheat and barley stubbles were quite similar and did not show any statistically significant difference among curves (Figure 2). On the other hand, in autumn, comparison of species-accumulation curves showed significant variation of species richness among crop stubble types: sunflower showed the highest number of species per sample and soybean the lowest (Figure 2).

In spring-summer, the Eared Dove had the highest field occupancy percentage at stubble fields, followed by the Grassland Yellow-finch *Sicalis luteola*, Rufous-collared Sparrow *Zonotrichia capensis*, Picazuro Pigeon and Monk Parakeet (Table 2). In autumn, the Picazuro Pigeon showed the highest field occupancy percentage, followed by Eared Dove and Grassland Yellow-finch, Monk Parakeet and Spot-winged Pigeon (Table 2).

Non-passerine granivorous abundance associations to stubble types and spilled seed biomass

In spring-summer, two of the three non-passerine granivores considered in our analyses (Monk Parakeet and Picazuro Pigeon) were associated in their abundance in certain fields to at least one of the variables originally considered (Table 3 and 4a). The best model to explain the abundance of Monk Parakeets at study sites included the interaction of stubble type and seed biomass ($w_i = 0.359$; AICc = 210.8), showing greater abundance in wheat stubbles with greater spilled seed biomass (Coefficient estimated = 0.004 ± 0.006). Moreover, the Picazuro Pigeon was associated with stubble type

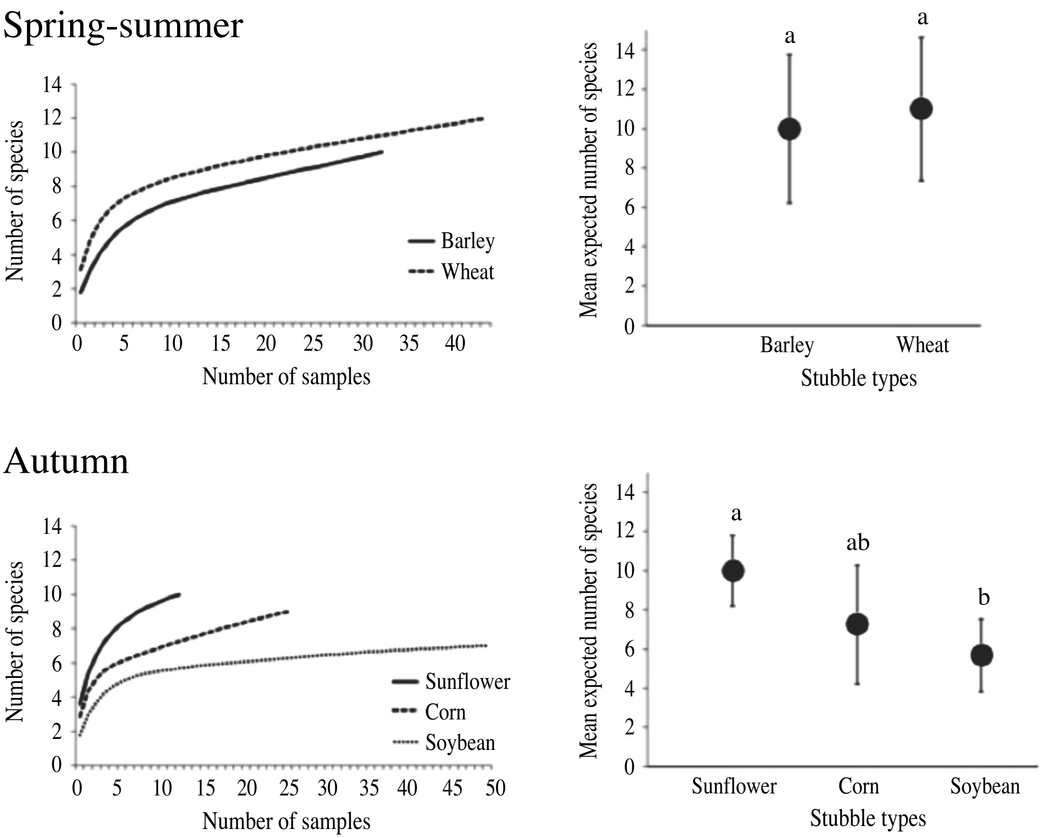

FIG. 2.—Left: seasonal variation of species-accumulation curves for seed-eating birds in different stubble types. Right: mean expected number of species based on 100 simulations in 33 samples in spring-summer and 13 samples in autumn (the lesser number of stubble fields among crops in each season) and 95% confidence intervals (bars). Means are considered to be different if the 95% confidence intervals do not overlap. Differences among stubble types are indicated with different letters (Tejeda-Cruz & Sutherland, 2004).

[Izquierda: variación estacional de las curvas de acumulación de especies para las aves granívoras en los diferentes tipos de rastrojos. Derecha: media esperada del número de especies basada en 100 simulaciones de 33 muestras en primavera-verano y en 13 muestras en otoño (el menor número de campos de rastrojos en cada estación) y el intervalo de confianza al 95% (barras). Las medias se consideraron diferentes si los intervalos de confianza al 95% no se solapan. Diferencias entre tipos de rastrojos son indicados con letras diferentes (Tejeda-Cruz & Sutherland, 2004).]

(w_i = 0.651; AICc = 223.4), showing a mean abundance in wheat stubbles (3.6 ± 1.3 individuals/transect) roughly 12 times higher than in barley stubbles (0.3 ± 0.1 individuals/transect; see Table 4a). We did not detect any association between Eared Dove abundance and the variables considered (*i.e.*, the best model was the null model; see Table 3).

In autumn, three of the four bird species considered in our analyses (Eared Dove, Monk Parakeet and Spot-winged Pigeon) were associated in their abundance with

TABLE 2

Seed-eating bird species recorded in stubble fields per season: spring-summer (N = 77) and autumn (N = 89). Mean number of individuals/transect ± SE and percentage of field occupancy; species are listed in order of total abundance.
[Especies de aves granívoras registradas en los campos de rastrojos por estación: primavera-verano (N = 77) y otoño (N = 89). Media de individuos/transecto ± error estándar y porcentaje de ocupación de los campos; las especies están ordenadas de acuerdo a su abundancia total.]

	Spring-summer		**Autumn**	
Species	Abundance (Mean ± SE)	Field occupancy (%)	Abundance (Mean ± SE)	Field occupancy (%)
Eared Dove *Zenaida auriculata*	6.4 ± 1.3	55.8	26.6 ± 7.9	46.1
Monk Parakeet *Myiopsitta monachus*	2.9 ± 0.9	31.2	8.3 ± 2.5	42.7
Grassland Yellow-finch *Sicalis luteola*	3.5 ± 0.7	48.1	6.3 ± 1.5	46.1
Picazuro Pigeon *Patagioenas picazuro*	2.2 ± 0.7	33.8	2.3 ± 0.5	48.3
Least Seedsnipe *Thinocorus rumicivorus* [a]	—	—	1.9 ± 1.1	8.9
Rufous-collared Sparrow *Zonotrichia capensis*	1.1 ± 0.2	36.3	0.1 ± 0.1	2.2
Spot-winged Pigeon *Patagioenas maculosa*	0.1 ± 0.1	7.8	0.8 ± 0.1	34.8
Rock Dove *Columba livia*	0.2 ± 0.1	6.5	0.4 ± 0.4	3.4
Grassland Sparrow *Ammodramus humeralis*	0.5 ± 0.1	27.3	0.0 ± 0.0	0.0
Blue-crowned Parakeet *Thectocercus acuticaudatus*	0.05 ± 0.05	1.3	0.2 ± 0.1	4.5
Picui Ground Dove *Columbina picui*	0.02 ± 0.02	1.3	0.04 ± 0.03	2.2
Double-collared Seedeater *Sporophila caerulescens*	0.02 ± 0.02	2.6	0.0 ± 0.0	0.0
Saffron Finch *Sicalis flaveola*	0.02 ± 0.02	2.6	0.0 ± 0.0	0.0
Hooded Siskin *Spinus magellanica*	0.01 ± 0.01	1.3	0.0 ± 0.0	0.0

[a] This migrant species is absent from the study area during spring and summer.

TABLE 3

Model-selection results based on ΔAICc comparison of generalized linear mixed model (GLMM) describing the association of each non-passerine granivorous species abundance and stubble type (STU), biomass of spilled grain (BIO) and the interaction (STU*BIO), in the Pampas of central Argentina; left: spring-summer; right: autumn. k is the number of estimated parameters. Species with over 30% field occupancy in stubble fields in each season. Models are listed in decreasing order of complexity and in each season the model with lower AICc is in bold.

	Spring-summer				Autumn			
Eared Dove								
Candidate models	k	AICc	ΔAICc	w_i	k	AICc	ΔAICc	w_i
STU + BIO + STU*BIO	6	397.3	2.86	0.071	8	498.0	6.00	0.036
STU + BIO	5	395.0	0.68	0.213	6	494.2	2.25	0.236
STU	4	381.1	0.24	0.264	**5**	**492.0**	**0.00**	**0.727**
BIO	4	396.1	1.32	0.154	4	511.9	19.99	0.000
Null model	**3**	**380.8**	**0.00**	**0.298**	3	510.3	18.31	0.000
Monk Parakeet								
Candidate models	k	AICc	ΔAICc	w_i	k	AICc	ΔAICc	w_i
STU + BIO + STU*BIO	**6**	**210.8**	**0.00**	**0.359**	8	385.3	5.21	0.042
STU + BIO	5	213.6	2.79	0.089	6	382.4	2.35	0.176
STU	4	211.3	0.56	0.272	**5**	**380.1**	**0.00**	**0.570**
BIO	4	214.0	3.20	0.072	4	384.8	4.75	0.053
Null model	3	211.9	1.10	0.207	3	382.6	2.55	0.159

at least one of the variables originally considered (Table 3 and 4b). Both Eared Dove and Monk Parakeet abundances were associated with stubble type (w_i = 0.727; AICc = 492.0 and w_i = 0.570; AICc = 380.1 for Eared Dove and Monk Parakeet, respectively). Specifically, we found that abundance of Eared Doves in sunflower stubbles (136.5 ± 41.2 individuals/transect) was approximately ten times higher than in corn stubbles (14 ± 6.4 individuals/transect) and nearly 31 times higher than in soybean stubbles (4.4 ± 1.8 individuals/transect; see Table 4b). In addition, the abundance of Monk Parakeets in corn stubbles (20.7 ± 7.8 individuals/transect) was roughly 4.5 times higher than in soybean stubbles (4.4 ± 2.1 individuals/transect) and showed intermediate values in sunflower stubbles (5.4 ± 2.4 individuals/transect; see Table 4b). The best model to explain the abundance of Spot-winged Pigeons included the interaction of stubble type and biomass (w_i = 0.936; AICc = 181.1), showing greater abundance in sunflower and corn stubbles with increasing spilled seed biomass (Coefficients

TABLE 3 (cont.)

*[Resultado de la selección de modelos basado en la comparación de ΔAICc de los modelos lineales generalizados mixtos (GLMM) que describen la asociación de la abundancia de cada especie de ave granívora no passeriforme y el tipo de rastrojo (STU), la biomasa de granos derramados (BIO) y la interacción (STU*BIO) en las Pampas de Argentina central; izquierda: primavera-verano; derecha: otoño. k es el número de parámetros estimados. Especies con porcentaje de ocupación de los campos de rastrojos > 30% en cada estación. Los modelos se muestran en orden decreciente de complejidad y en cada estación el modelo con menor AICc está remarcado en negrita.]*

	Spring-summer				Autumn			
Picazuro Pigeon								
Candidate models	k	AICc	ΔAICc	w_i	k	AICc	ΔAICc	w_i
STU + BIO + STU*BIO	6	227.8	4.38	0.073	8	326.3	6.34	0.017
STU + BIO	5	225.5	2.06	0.233	6	322.3	2.29	0.130
STU	**4**	**223.4**	**0.00**	**0.651**	5	322.7	2.71	0.106
BIO	4	230.4	7.00	0.020	4	320.4	0.39	0.337
Null model	3	230.1	6.66	0.023	**3**	**320.0**	**0.00**	**0.410**
Spot-winged Pigeon								
Candidate models	k	AICc	ΔAICc	w_i	k	AICc	ΔAICc	w_i
STU + BIO + STU*BIO					**8**	**181.1**	**0.00**	**0.936**
STU + BIO					6	190.7	9.60	0.008
STU			—		5	188.3	7.23	0.025
BIO					4	190.6	9.45	0.008
Null model					3	188.5	7.42	0.023

estimated = 0.02 ± 0.008 and 0.01 ± 0.007 respectively; Table 4b). We detected no association between the abundance of Picazuro Pigeons and the variables considered (*i.e.*, the best model was the null model; see Table 3).

DISCUSSION

Our results indicate that crop stubble types within the central Argentinan Pampas play a considerable part in explaining both the species-richness of seed-eating birds and the abundance of some non-passerine granivores as well. In addition, some species show a positive association in their abundance with certain stubble types with increasing spilled seed biomass. In general, these associations vary seasonally, being more evident in autumn than in spring-summer. This study has highlighted how variation in the type and amount of seed resources might affect species-richness and the abundance of seed-eating birds between fields.

The association of birds with stubble types is species- and season-dependent (Moorcroft

TABLE 4

Parameter likelihoods, estimates ± standard error (SE) and 95% confidence interval limits (CI) resulting from multiple model inference (Burnham & Anderson, 2002) for explanatory variables describing the association between non-passerine granivore abundance (individuals/transect) with over 30% of field occupancy and stubble type (STU, with two levels in spring-summer: wheat and barley, and three levels in autumn: soybean, corn and sunflower), biomass of spilled grain (BIO, continuous variable, kg/ha) and the interaction (STU*BIO) in the Pampas of central Argentina. Parameters with CI excluding zero are in bold. (a) Spring-summer and (b) autumn.
*[Sumatorio de los w_i de los modelos que contienen la variable considerada (Parameter likelihoods), parámetros estimados ± error estándar (SE) y los límites de los intervalos de confianza (CI) resultantes de la inferencia de múltiples modelos (Burnham & Anderson, 2002) para las variables explicatorias que describen la asociación entre la abundancia de especies de aves granívoras no paseriformes (individuos/transecto) con porcentaje de ocupación de los campos > 30% y el tipo de rastrojos (STU, con dos niveles en primavera-verano: trigo y cebada, y tres niveles en otoño: soja, maíz y girasol), la biomasa de granos derramados (BIO, variable continua, kg/ha) y la interacción (STU*BIO) en las Pampas de Argentina central. Los parámetros con intervalos de confianza (CI) que excluyen el cero están remarcados en negrita. (a) Primavera-verano y (b) otoño.]*

(a) Spring-summer

Species	Explanatory variables	Parameter likelihood	Parameter Estimates ± SE	CI	
				Lower	Upper
Eared Dove	Intercept		1.02 ± 0.62	–0.20	2.24
	STU $_{(Wheat)}$ [a]	0.55	0.47 ± 0.63	–0.37	2.10
	BIO	0.44	0.001 ± 0.001	–0.001	0.005
	STU*BIO $_{(Wheat*biomass)}$ [b]	0.07	0.0001 ± 0.001	–0.006	0.009
Monk Parakeet	Intercept		–1.92 ± 1.54	–4.94	1.10
	STU $_{(Wheat)}$ [a]	0.72	0.29 ± 1.12	–2.15	2.96
	BIO	0.52	–0.002 ± 0.005	–0.015	0.007
	STU*BIO $_{(Wheat*biomass)}$ [b]	**0.36**	**0.004 ± 0.006**	**0.0006**	**0.02**
Picazuro Pigeon	Intercept		–1.52 ± 0.71	–2.90	–0.13
	STU $_{(Wheat)}$ [a]	**0.97**	**1.87 ± 0.81**	**0.47**	**3.40**
	BIO	0.32	–0.0001 ± 0.001	–0.004	0.004
	STU*BIO $_{(Wheat*biomass)}$ [b]	0.09	0.0004 ± 0.002	–0.007	0.016

[a] Relative variable to value of stubble type (barley)
[b] Relative variable to value of interaction of stubble*biomass (barley*biomass)

TABLE 4 (cont.)

(b) Autumn

Species	Explanatory variables	Parameter likelihood	Parameter Estimates ± SE	CI Lower	CI Upper
Eared Dove	Intercept		1.43 ± 0.51	0.42	2.43
	STU (Sunflower)[a]	**1.00**	**3.46 ± 0.82**	**1.86**	**5.06**
	STU (Corn) [a]	1.00	1.23 ± 0.71	–0.16	2.62
	BIO	0.27	–0.0001 ± 0.001	–0.003	0.002
	STU*BIO (Sunflower*biomass)[b]	0.04	0.0001 ± 0.001	–0.009	0.016
	STU*BIO (Corn*biomass) [b]	0.04	0.0001 ± 0.001	–0.002	0.008
Monk Parakeet	Intercept		0.50 ± 0.70	–0.83	2.02
	STU (Sunflower)[a]	0.79	1.36 ± 1.38	–0.91	4.35
	STU (Corn) [a]	**0.79**	**1.32 ± 0.91**	**0.34**	**3.00**
	BIO	0.27	0.0001 ± 0.0008	–0.003	0.003
	STU*BIO (Sunflower*biomass)[b]	0.04	–0.005 ± 0.04	–0.45	0.22
	STU*BIO (Corn*biomass) [b]	0.04	–0.0001 ± 0.001	–0.007	0.003
Picazuro Pigeon	Intercept		0.19 ± 0.35	–0.46	1.14
	STU (Sunflower)	0.25	–0.22 ± 0.51	–2.20	0.45
	STU (Corn)	0.25	0.043 ± 0.22	–0.65	0.99
	BIO	0.48	–0.001 ± 0.001	–0.003	0.001
	STU*BIO (Sunflower*biomass)[b]	0.02	–0.0001 ± 0.001	–0.02	0.008
	STU*BIO (Corn*biomass) [b]	0.02	0.00001 ± 0.001	–0.003	0.005
Spot-winged Pigeon	Intercept		0.81 ± 0.67	–0.46	2.13
	STU (Sunflower)	0.97	–1.22 ± 1.09	–3.39	0.87
	STU (Corn)	0.97	–0.67 ± 0.74	–2.15	0.75
	BIO	0.95	–0.01 ± 0.007	–0.03	–0.003
	STU*BIO (Sunflower*biomass)[b]	**0.94**	**0.02 ± 0.008**	**0.006**	**0.03**
	STU*BIO (Corn*biomass) [b]	**0.94**	**0.01 ± 0.007**	**0.004**	**0.03**

[a] Relative variable to value of stubble type (soybean)

[b] Relative variable to value of interaction of stubble*biomass (soybean*biomass)

et al., 2002; Bright *et al*., 2014; this study). In spring-summer, the lack of differences in species-richness between cereal stubble types could be due to the similar structural features of these fields and it is likely that for most seed-eating bird species, food detectability and accessibility do not differ between stubble types. In addition, the nutritional content of wheat and barley seed is similar (USDA, 2015). However, the Picazuro Pigeon was far more abundant in wheat than in barley stubbles. A similar pattern was found for the Woodpigeon *Columba palumbus* in central England, which showed significantly greater field occupancy on wheat than on barley stubble (Moorcroft *et al*., 2002). Some studies show differences in the use of wheat and barley stubbles by certain seed-eating bird species, even though the underlying reasons are not very clear (Buckingham *et al*., 1999; Moorcroft *et al*., 2002). In our case, this may be related to the fact that wheat is typically a much more common crop in the study area than barley (mean cultivated areas during 2004-2014 were ≈ 2,800,000 ha and ≈ 477,000 ha, for wheat and barley, respectively; SIIA, 2014), and wheat also more regularly cultivated year after year, whereas barley shows considerably more inter-annual fluctuations in its cultivated area (SIIA, 2014). Thus, it is possible that some species like the Picazuro Pigeon tend to use wheat stubbles which are more regularly distributed in both space and time, and more familiar to the birds in terms of search image detection and past feeding history.

On the other hand, seed-eating bird species-richness varies among fields in autumn, when there is a mix of cereal and oilseed stubble types, with sunflower stubble showing the highest richness of birds and soybean stubble the lowest. Possible reasons for these differences include structural differences among stubble types, variations in nutritional content of seed, bird food preferences and the degree of ease in the manipulation and consumption of individual seeds (Willson, 1971; Hancock & Wilson, 2003; Butler *et al*., 2005; USDA, 2015). Both sunflower and corn stubbles had more weed cover than soybean stubbles (the latter are usually extensively sprayed with herbicides; Trigo & Cap, 2003; Aizen *et al*., 2009), and weed seeds may increase the diversity of food resources for birds (Murton *et al*., 1974; Aramburú, 1997; Robinson & Sutherland, 1999). In addition, some species, such as the Monk Parakeet, can manipulate sunflower seed and open the husk to expose the high energy, soft kernel (Spreyer & Bucher, 1998), which frequently falls to the ground and is then available to be consumed by the whole assemblage of seed-eating birds.

The high abundance of Monk Parakeets in corn stubble agrees with previous studies from the study area that had indicated that seeds of corn are the food item comprising the greatest percentage dry weight in the species' diet (Aramburú, 1997). In addition, diet preference studies have indicated that corn and sunflower seeds are heavily consumed by Monk Parakeets (Aramburú, 1997; Aramburú & Bucher, 1999). These results are in agreement with the higher abundances of Monk Parakeets in these stubble types. The Eared Dove showed high abundance in sunflower stubbles, which indicates that sunflower seed is an important component in its diet (Bucher & Nores, 1976; Bucher & Ranvaud, 2006).

Some of the studied species have previously been reported as agricultural pests in Argentina, at least within the Espinal region surrounding the Pampas (Murton *et al*., 1974; Bruggers *et al*., 1998; Canavelli *et al*., 2014). Those studies have focused on damage during the mature stage of the crop prior to the harvest, and there was a lack of information about the abundances of these species associated with other crop stages, other than those susceptible to damage. Our results show that information about the use of fields by bird populations during the stubble period of crops may contribute to management of these species, since stubble crops that remain unploughed under no-till systems provide high availability of food resources that can then sustain high numbers of some seed-eating birds that may later become a problem when crops are susceptible to damage (seedling stage, mature stage; Murton *et al*., 1974; Bruggers *et al*., 1998; Bucher & Ranvaud, 2006). Considering reported values for crop yields at the study area (Bolsa de Cereales, 2015), spilled seed biomass recorded by us in the ground of stubble fields represent losses of about 4% and 8% of wheat and barley crop yields, about 4% of sunflower and corn yields and nearly 7% of soybean yields. These estimated crop losses are in agreement with values already reported for the study area (INTA PRECOP, 2015). Thus, considering published daily food intakes estimated for some species in the study area (Murton *et al*., 1974; Aramburú & Bucher, 1999), these stubbles may offer up to ≈ 26,000 'servings' of corn seed for Monk Parakeets and ≈ 14,000 'servings' of sunflower seed for Eared Doves per hectare. These figures show that there is abundant food in the stubbles of the study area that can potentially contribute to sustaining bird populations (Bucher & Ranvaud, 2006; Canavelli *et al*., 2012), some of which may then damage crops at other stages of the crop cycle. However, technological advances in harvesting machinery, as well as efficient management practices, have shown that the amount of seed remaining in stubble fields can be significantly reduced (Robinson & Sutherland, 1999; Watkinson *et al*., 2000; Sherfy *et al*., 2011). Our results suggest that measures for reducting seed spillage during harvest, as well as crop rotation and appropriate agricultural practices conducted after harvest, can be considered as essential components in a strategy towards the regulation and management of the populations of seed-eating birds (Bucher & Ranvaud, 2006; Sherfy *et al*., 2011; Canavelli *et al*., 2012).

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