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Evaluating the impacts and benefits of sheldgeese on crop yields in the Pampas region of Argentina: A contribution for mitigating the conflicts with agriculture

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ABSTRACT

Conflicts between waterfowl and agriculture are common in many nations around the world. However, these birds can also provide a variety of benefits that humanity can obtain from nature. There are three migratory and endemic sheldgeese (Ruddy-headed Goose *Chloephaga rubidiceps*, Ashy-headed Goose *Chloephaga poliocephala* and Upland Goose *Chloephaga picta*) which are species of conservation concern in Argentina. Sheldgeese are in constant conflict with the agricultural practices in the Pampas region of Argentina. The objective was to measure possible damages and benefits due to geese grazing on winter wheat crops during different growth stages, in the southeast of Buenos Aires province, Argentina. We established a stratified random plot design in nine fields, where we placed geese exclosure plots and plots without exclosure, allowing sheldgeese to graze. From May to September, we visited each field every two weeks. We performed transects where we counted and collected feces in order to estimate the grazing intensity. We analyzed the total concentration of Nitrogen (N) and Phosphorus (P) in the feces in the period before and after the wheat emergence. We also performed microhistogical analysis to evaluate sheldgeese diet in these two periods. During the crop growth and at harvest, we evaluated possible damages (wheat cover, percentage of eaten plants, percentage of eaten tillers, chlorophyll content, grain yield per plot, harvest index, weight of 1000 grains) and benefits (number of tillers per plant, percentage of weed cover, protein content) of geese grazing. We found that sheldgeese grazing varied along the different visits and among the experimental fields. Geese grazing negatively affected the wheat cover but there was no effect on the final yield. The input of nutrients provided by sheldgeese feces was higher in the period after the crop emergence, when they only ate wheat. Results on the birds' diet showed that they fed on weeds before wheat emergence thus providing an ecosystem service. In this study, we found elements that could help to shed light on the real impact of sheldgeese in crops and discovered some benefits that these birds could be providing to crops in the Pampas ecoregion.

1. Introduction

Conflicts between waterfowl and agriculture are common in many nations around the world (Amano et al., 2004; Borman et al., 2002; Pedrana et al., 2014; Petkov et al., 2017). Geese feed on high-quality forage in agricultural lands (Fox and Abraham, 2017; Owen, 1972a) and are accused of reducing agricultural production in grasslands and annual crops (Owen, 1990; Petkov et al., 2017; Wallin and Milberg, 1995). However, farmers generally overestimate the effect of grazing geese on crop yields (Macmillan et al., 2004). Peoples' responses to the negative interaction with wildlife vary considerably. There are numerous factors to take in consideration, including how accurately the level of damage is evaluated and how severe the damage is considered to be, both of which impact on the perceived level of conflict (Dickman, 2010; Simonsen et al., 2017). As a first step towards resolving the human-geese problem, we need to evaluate the level of damage caused by rigorously measuring the effects on the crop yield. Therefore, different parameters such as crop growth stages, locations, timing and

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grazing pressures should be taken into account (Fox et al., 2017; Macmillan et al., 2004; Nilsson et al., 2016; Petkov et al., 2017).

In order to comprehend the integrated agriculture-sheldgeese conflict, we have to take into consideration not only the damages but also the benefits these birds can be providing to agricultural ecosystems. Agricultural ecosystems are primarily managed to optimize the provisioning of food, fiber, and fuel (Zhang et al., 2007). These ecosystems depend upon a wide variety of supporting and regulating services (Millenniu Ecosystem Assessment (MA), 2005; National Research Council (NCR), 2005) that determine their underlying biophysical capacity (Wood et al., 2000). Waterfowl such as geese can provide a variety of benefits or Ecosystem Services (ES) (Green and Elmberg, 2014). An ES is a benefit that humanity can obtain from a natural process of the ecosystem (Díaz et al., 2005; Whelan et al., 2008). Three types of ES can be defined under the guidelines of the Common International Classification of Ecosystem Services (CICES version 4.3) (Haines-Young and Potschin, 2013): 1) Provisioning such as food, feathers, fuel, fiber and medicines; 2) Regulation and Maintenance such as pollination, seed dispersal, pest control, nutrient cycling and soil formation; and 3) Cultural such as aesthetic, spiritual, educational and recreational (Haines-Young and Potschin, 2013). There are examples of geese providing meat (subsistence hunting for livelihood, recreational shooting) (Buij et al., 2017; Green and Elmberg, 2014) and in supporting and regulating services which are recorded in several studies. Geese can promote nutrient cycling (Navedo et al., 2015) and increase the decomposition of the residual surface of crops with their grazing (Bird et al., 2000; van Groenigen et al., 2003). Birds' aggregation can contribute to the input and nutrient flow of an ecosystem (Josens et al., 2009; Whelan et al., 2008) and act as links between two habitats (Manny et al., 1994; Sekercioglu, 2006). Geese and other waterfowl provide cultural services, acting as flagships of conservation and the human interest in watching waterfowl during migration or in wintering sites has helped the protection of some of their habitats (Green and Elmberg, 2014).

The Pampas region in Argentina is a temperate grassland ecosystem and one of the richest agricultural areas of the world, covering about fifty-two million hectares of productive organic soils (Solbrig, 1997; Soriano, 1991). In the last decades, most of the original grasslands were replaced by croplands, mainly soybean, and sown pastures for livestock (Aizen et al., 2009; Grau et al., 2005). These changes had negatively affected many native species and the ES that could have been obtained (Azpiroz et al., 2012; Codesido et al., 2011). The three migratory and endemic species of sheldgeese (Ruddy-headed Goose *Chloephaga rubidiceps*, Ashy-headed Goose *Chloephaga poliocephala* and Upland Goose *Chloephaga picta*) are clear examples of this. These birds remain in their wintering areas in the southern Pampas (Argentina) from May to September, and breed in southern Patagonia (Argentina and Chile) from October to April (Pedrana et al., 2015, 2018a). Sheldgeese are herbivorous and usually feed on pastures or cereal crops (Martin et al., 1986; Summers and Grieve, 1982; Summers and McAdam, 1993) causing constant conflict with the agricultural activities. In 1931, the Argentine government declared sheldgeese as an "agriculture plague" and allowed hunting of the three species without restriction throughout its entire distribution (Blanco et al., 2003; Blanco and De la Balze, 2006; Chebez, 2008; Martin et al., 1986). In 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 due to the estimates of the last decade that indicated a dramatic decline in numbers (Blanco et al., 2003; Chebez, 2008; Pedrana et al., 2018b).

To resolve the human-wildlife conflict not only an ecological but also a social-economic approach should be considered (Tscharntke et al., 2005). It will involve an understanding between managers and stakeholders (Tombre et al., 2013) and a solid assessment of the degree of crop yield reductions caused by grazing geese. Also, an evaluation of the benefits these species might provide to agricultural ecosystems (Balvanera et al., 2006; Sekercioglu, 2006) could help alleviate the conflict. Previous studies of sheldgeese in the area show that there is no evidence of significant damage to the crop due to sheldgeese grazing (Omaña, 2016; Tracanna and Ferreira, 1984). However, there is a discord between the perceived problem of geese grazing on wheat yields in the Pampas ecoregion and the actual problem so the agriculture-sheldgeese conflict continues (Blanco et al., 2003; Pedrana et al., 2018b). In order to help solve this disagreement, we measured potential damages due to sheldgeese grazing on winter wheat during the growth stages and yield crop. We also calculated the probable benefits provided by these species in the southeast of Buenos Aires province, Argentina.

The present study has the following specific objectives: 1) to quantify the potential damages of sheldgeese grazing on the wheat cover, the percentage of eaten plants and tillers, the chlorophyll content and yield determinations during the different stages of wheat; 2) to evaluate if there are differences in these measurements with different grazing intensity; 3) to quantify the probable benefits provided by sheldgeese in terms of nutrients input (natural fertilizer), percentage of weed cover and items in the diet (weed controller), and number of tiller per plant (a tillering effect) on wheat production.

2. Materials and methods

2.1. Fields and experimental plots

This study was conducted in nine experimental fields in Buenos Aires province (Fig. 1a), in the plains of the Austral Pampas (Fig. 1b) (Bilenca and Miñarro, 2004; Cabrera, 1994). This area is characterized by low to moderate undulations (Bilenca and Miñarro, 2004; Soriano et al., 1991). Pristine vegetation was dominated by grassland steppes of several species of *Stipa* spp. and *Piptochaetium* spp. (Soriano et al., 1991). Nowadays, the land has been intensively modified by anthropogenic activities, with large areas of cereal crops and pastures (Paruelo et al., 2001). The mean annual temperature is 10–20 °C and the mean annual rainfall is between 400 and 1600 mm (Soriano et al., 1991). The fields were located in Tres Arroyos (38°22′26″ S and 60°16′47″ W) and San Cayetano departments (30°7′59.99″ S and 66°40′59.99″ W) (Fig.1c), which are part of the IV Region of the wheat production (Abbate et al., 2017). The nine experimental fields were within the highest habitat suitability area of all sheldgeese species (Pedrana et al., 2014) (Fig. 1d). The habitat suitability areas for sheldgeese were defined by Pedrana et al. (2014) as areas of low elevation surrounded by waterbodies. Landscapes composed of croplands and grazing fields are preferred environments, while centers of human activity (regions with greater road accessibility) have a negative impact on the species distribution (Pedrana et al., 2014). All fields were cultivated with wheat and had similar management and agricultural practices (Table A.1, Appendix). Diammonium phosphate (DAP) was applied at planting (100–150 kg/ha) and Nitrogen fertilizer was applied in the tillering stage of the crop (150–200 kg/ha). In addition, herbicides were applied at different stages of the crop.

In May 2017, we established a stratified random plot design in each field. We placed exclosure plots to avoid geese grazing (hereafter control plots, n = 47) and plots without the exclosure (hereafter grazing plots, n = 116). More plots without exclosure were placed in the fields because at the beginning of the study we could not predict in which plots sheldgeese were going to feed. The number of experimental plots on each field varied based on the size and shape of each of them (Table A.1, Appendix). All 1m^2 plots included five rows of wheat. Control and grazing plots were separated at least 100 m from each other. In the control plots, we placed cages of thin wire of 1 × 1 x 0.40 m with a 29 x 10 cm rectangular mesh. Previous studies showed that there was no effect on bird grazing around the cages (Omaña, 2016). As sheldgeese are almost the only species on the area that formed big flocks in winter and have a territorial behavior (Pedrana et al., 2014), we assumed that grazing effect of other bird species was negligible in this study. The

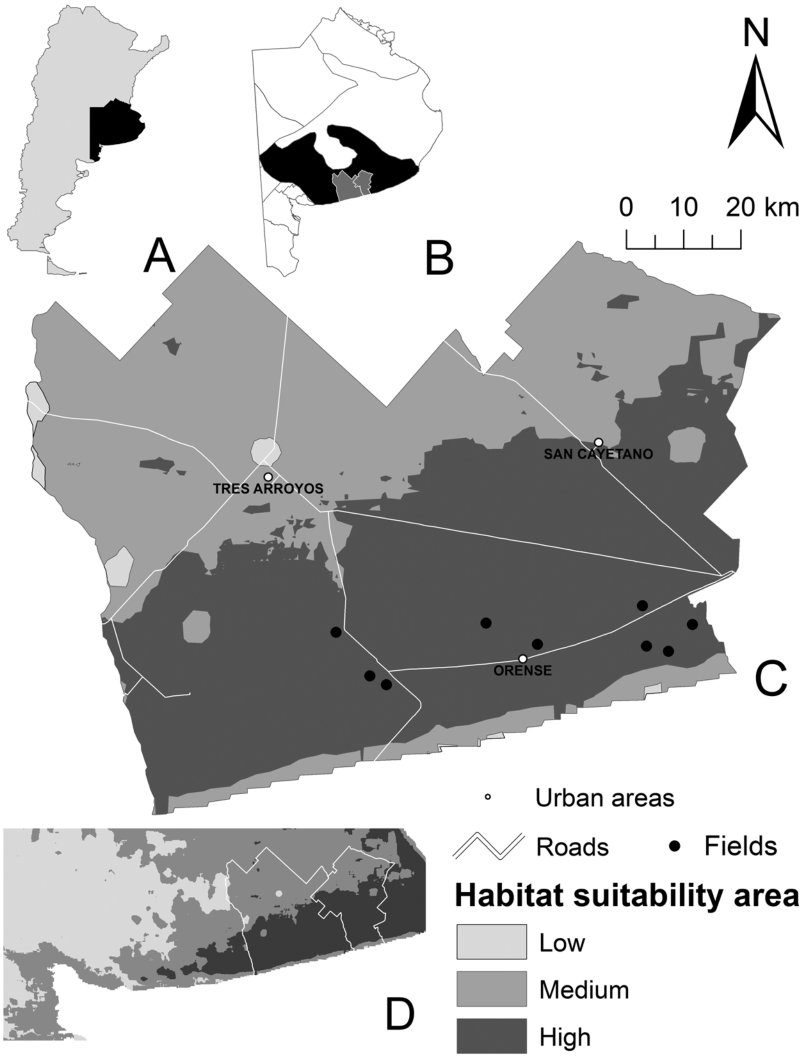

Fig. 1. A) Map of Argentina (grey) and Buenos Aires province (black). B) Location of the Austral Pampas (black) in the Buenos Aires province (white) and San Cayetano and Tres Arroyos departments (grey). C) Map of San Cayetano and Tres Arroyos departments with the main urban areas (white circles), the experimental fields (black circles) and the roads (white lines). The colors represent the category of the habitat suitability areas suggested by Pedrana et al. (2014). D) Habitat suitability map of all sheldgeese species in the southeast of Buenos Aires province (Figure modified from Pedrana et al., 2014) and San Cayetano and Tres Arroyos departments (delimited with white lines).

grazing plots were marked with small stakes, so we could find them in all posterior visits. Placement of marking stakes has been found to have no effect on geese grazing in pastures (Owen, 1972a) and crops (Omaña, 2016). Each plot was separated more than 50 m from the edge of the field to reduce the edge effect (Van Der Graaf et al., 2005). After geese departure, the cages were removed and all plots were marked using tall wooden posts. From May to September, we visited each field every two weeks, performing in total six visits. The first (30thMay 2017) and second visits (15th June 2017) were done before the crop emerged and sheldgeese have already arrived to the study area. The 3rdvisit corresponded to the pre-tillering stage (1st July 2017) and the 4th (24th July 2017) and 5thvisit (15th August 2017) were done during the tillering stage (Miralles et al., 2014). The last visit (6thvisit, 1st September 2017) was done during the late tillering stage and sheldgeese had already migrated. All these visits corresponded to the vegetative stages of wheat. We manually harvested all plots in December (15th–20th December 2017), when the wheat had reached physiological maturity.

2.2. Sheldgeese grazing intensity

To estimate sheldgeese grazing intensity in each field and in every visit, we performed a line transect which was randomly distributed to cover all different environments inside each field. The transect length was proportional to the size of each field (mean length = 4.25 ± 1.31 km) and the width was 4 m. In each transect, we counted and collected all fresh sheldgeese feces in every visit. Goose droppings remain visible for at least two weeks depending on the environmental conditions and dropping densities provide a good indicator of the goose-use over an area (Madsen and Boertmann, 2008). Grazing intensity was estimated independently from the plots. To estimate the density of sheldgeese (grazing intensity) in each field in every visit we did the following calculations. First, we used the number of feces counted on each transect and then we extrapolated to the size of each field. Thus, we obtained the number of feces per area of each field. Secondly, we multiply this number by the defecation rate of the Upland Goose calculated as one feces every 4 min (Summers and Grieve, 1982). We used the defecation rate of the Upland Goose because it was the most abundant species of the three sheldgeese. Then we multiply by the 8 h per day that sheldgeese spend grazing (Personal observations) to estimate the number of sheldgeese in each field. Similar studies have used dropping density as an indicator of grazing pressure on the fields (Bachman, 2008; Owen, 1972b).

2.3. Potential damages of sheldgeese grazing on wheat

We measured wheat cover at ground level performing a digital analysis of photographs (Mullan and Barcelo Garcia, 2012) during the period where the sheldgeese were in the study area (3rd, 4th and 5th visit). To obtain the photograph, we constructed a lightweight mounting of wood, which consisted of a vertical stake of 150 cm and a horizontal one of 50 cm long. At the end of the horizontal stake, we mounted the camera pointing vertically downward 1.5 m above the ground. This configuration allowed us to take color photographs (4128 × 3096 pixel) of each plot (Louhaichi et al., 2001). We analyzed the photographs using the free software *ImageJ* (Ferreira and Rasband, 2012; Schneider et al., 2012). Firstly, we adjusted the different parameters of the image (threshold of hue, brightness and saturation). To separate the wheat plants from the soil, we used the "Default thresholding method" (Ferreira and Rasband, 2012). We used the same values of these parameters for each visit and each field because of changing light and environmental conditions of the field. Secondly, we transformed this image into a black (representing the plants) and white (representing the dark soil) picture. Since the moisture content of the soil surface can varied throughout the field and thus, changing the threshold value, we examined the original photograph and the black and white classification side by side on a computer screen and adjusted the threshold until the classification was acceptable. Finally, we calculated the total area of the image and the area occupied by the dark pixels (plants) and obtained the percentage of vegetal cover.

In each plot, we counted the total number of plants and eaten plants (i.e. plants that have a fraction of their leaves cut by sheldgeese) to obtain the percentage of eaten plants per plot (another indicator of sheldgeese grazing) in the 3rd, 4th and 5th visit.

The content of chlorophyll in the leaves was measured in a non-destructive and indirect way using a portable handheld optical meter (SPAD) on the standing crop. The SPAD measures the chlorophyll content through light transmittance and compensates for differences in the thickness of the sheet. This content is an indirect measurement of the nutrient status of the plant (Filella et al., 1995; Mullan and Mullan, 2012). To determine if the chlorophyll content varied between the control and grazing plots over time, we performed two measurements in each plot. The first measurement was done in the first week of the vegetative stage (3^{rd} visit) and the second one, in the late tillering stage (6^{th} visit) (Gandrup et al., 2004). Each measurement was the average of the chlorophyll content of five plants randomly chosen.

The percentage of eaten tillers was evaluated in the late tillering stage (6^{th} visit) by collecting 30 cm of plants of each plot (10 linear centimeters of each one of the three central rows). We gathered each plant with the root in order to identify the number of tillers of each plant. The samples were placed in paper bags to allow the moisture to escape. We counted the total number of tillers per plant and the number of eaten tillers (i.e. tillers that have a fraction of their leaves cut by sheldgeese) in the lab to obtain the percentage of eaten tiller per plot.

In December, when the crop reached physiological maturity, we manually harvested samples of each plot. On one hand, we harvested 30 cm of wheat (10 linear centimeters of each one of the three central rows), cutting all the plants without the root. We recorded fresh and dry weight of the samples after drying them in a drying oven with constant temperature (60–65 °C for 48 h). We counted the number of spikes and the sample was threshed to get the dry weight of the grain. With this information, we were able to calculate the grain yield per plot (Kg of grain per plot) and the harvest index (HI = dry weight of the grain/ dry weight of the plant). On the other hand, we cut only the spikes of 60 cm of each of the three central rows of the plot, and let the samples air dry and threshed them. One part of the 60 cm sample was dried in an oven (60–65 °C for 48 hs) to obtain the weight of 1000 grains and the number of grain per m^2. The other was used to obtain protein content (see Section 2.4).

2.4. Probable benefits of sheldgeese grazing on wheat

We collected fresh feces in each transect (see Section 2.2) during each visit and refrigerated them in individual plastic bags. We then pooled 15 feces in one sample in order to increase the volume. The feces were analyzed to evaluate the total concentration of Nitrogen (N) and Phosphorus (P) at the Soil Fertility Lab of INTA EEA-Balcarce. N concentration was determined using dry combustion and N thermo-conductivity detections (LECO, 2010) and the P concentration was measured colorimetrically by the method of Murphy and Riley (1962). We compared the nutrient input of sheldgeese feces in two contrasting situations when sheldgeese were grazing in the fields before and after the wheat emergence. Taking into consideration that the defecation rate for these species is 1 feces per 4 min and that sheldgeese graze constantly during 8 h per day, we extrapolated the concentration of N and P using the density estimation for the three species in the high suitability area (density estimation = 0.2 in./ha, Pedrana et al., 2018b, Fig. 1d).

A microhistological analysis of 30 fresh feces before and 30 after the wheat emergence (Hansen et al., 1977; Lindström, 1994) was performed to evaluate sheldgeese consumption of weeds. This technique is suitable for geese feces because they have a low digestibility rate (Martín, 1984; Owen, 1975). Briefly, 20 slides were prepared with each sample composed by 30 feces and 40 microscopic fields at 40x were observed in each slide (800 microscopic fields observed of each sample). Plant identifications were made at the species level when possible comparing with a reference collection, which was also collected in the field.

We tested the effect of geese grazing on the weed cover by visually estimating the percentage of weed cover in each plot in the 3^{rd}, 4^{th} and 5^{th} visit. Since the number of weeds was very low in all plots (1.02 ± 1.7% on average), it was impossible to evaluate them performing a digital analysis of photographs (see Section 2.3).

Considering that grazing pressure at intermediate intensities can stimulate plant production (Lorenzen and Madsen, 1986; Van Der Graaf et al., 2005), we tested if geese grazing had a positive effect on the percentage of tillers (tillering effect). We counted the number of tillers per plant from the collected samples (see the percentage of eaten tillers in Section 2.3). These samples were taken when the sheldgeese had already migrated and the wheat was in the late tillering stage (6th visit).

Finally, we took a sub-sample of 40 g from the 60 cm harvested sample (see Section 2.3) and we quantify the total protein content as a measure of the industrial grain quality. The protein content was determined according to the Near Infrared Spectroscopy (NIRS) method using an Apparatus DS 2500 (FOSS, Hillerod, Denmark).

2.5. Statistic

We tested if grazing intensities varied among the different visits and the experimental fields using a Generalized Linear Mixed Model (GLMM). To evaluate the effect of the timing of the visit we considered "visit" (three level categorical variable: 3^{rd}, 4^{th} and 5^{th}) as a fixed-effect variable and "field identity" as a random effect. To evaluate the effect of the field, we used "field identity" (categorical variable) as a fixed-effect variable and "visit" as random effect. In addition, we tested by a LDS Fisher the differences in grazing intensity between fields and timing of visits.

We also used GLMMs to test the effect of treatment, grazing intensity and visit using different response variables (wheat cover, percentage of eaten plants, percentage of eaten tillers, number of tillers per plant, number of grain per m^2, weed cover, chlorophyll content, grain yield per plot, HI, weight of 1000 grains and proteins). We considered three fixed-variables (two level categorical variable for treatment: grazing and control; a continuous variable: grazing intensity, and visit) and "field identity", "sub-area identity" and "plot identity" when we tested trend over time, as nested random effects. "Grazing Intensity" is the estimated density of sheldgeese for all the plots in the fields at every visit, calculated from the fresh feces count (see Section 2.2). At the late tillering stage (6^{th} visit) and at harvest, we considered the grazing intensity as the cumulative density of sheldgeese recorded in each visit. We also considered the interaction of all fixed-effects. In all the models, we controlled the non-independence of samples from the same field by declaring "field identity" (i.e. the identity of each field) as a random effect and the non-independence of control and grazing plots located on the same zone of the field by declaring "sub-area identity" as a random effect. The sub-areas are zones of each field which were previously defined due to agronomic similarities (e.g. soil depth, irrigation and compaction). We considered the proximity of the plots inside these zones as a random effect in order to avoid differences in the measurements due to agronomic factors. To test trends over time when sheldgeese were present in the study area (3rd, 4th and 5thvisits), we used the fixed-effect "visit" and "plot id" (i.e. the identity of each plot) as a random effect. We used a correlation of Compound Symmetry to model the residuals of the random effects in each time. We evaluated all possible models and we compared competitive ones using Akaike Information Criterion (AIC). All the analysis were done in R studio (R Development Core Team 2017) using package lme4 and nlme.

We analyzed and compared each nutrient in the sheldgeese feces in the two contrasting situations (before and after the crop emergence) using a T-Student test (Zar, 1984).

3. Results

We finally used 41% of the grazing plots (47/116) and 53% of the control plots (25/47) (Table A.1, Appendix). Some of the plots were discarded because there were no sheldgeese grazing during the entire growth season and others were flooded. Moreover, from the original nine fields, we finally performed the analysis in only eight of them (F9 was excluded).

3.1. Sheldgeese grazing intensity

During this study, 21 transects were done. In most of the fields we performed one transect in each visit, except in field F2 where weather conditions did not allow us to access the place during the 3rd visit (Table 1). We assumed that sheldgeese used all fields, since we always observed fresh feces in all of them.

We excluded F8 from grazing intensity analysis, since the seedtime was at the end of the wintering season (Appendix, Table A.1).

Table 1
Estimated density of sheldgeese (*Chloephaga* spp.) per field as a measure of grazing intensity, calculated from the fresh feces count in the transects performed in each visit on eight experimental wheat (*Triticum* spp.) fields, in the southeast of Buenos Aires province, Argentina (21 transects in total, mean length = 4.25 km ± 1.31 km). Field: agricultural fields used in this study. Visit: 3rd, 4th and 5thcorrespond to visits performed during the vegetative stages.

Field	Visit	Feces per transect	Density of feces per field	Estimated density of sheldgeese per field
F1	3rd	357	10473	87
	4th	1304	27690	231
	5th	737	20163	168
F2	4th	170	5853	49
	5th	0	0	0
F3	3rd	1524	37867	316
	4th	1100	18147	151
	5th	735	15193	127
F4	3rd	384	11636	97
	4th	109	1820	15
	5th	0	0	0
F5	3rd	0	0	0
	4th	1380	31724	264
	5th	101	2829	24
F6	3rd	89	2920	24
	4th	12	419	3
	5th	0	0	0
F7	3rd	40	1163	10
	4th	76	1706	14
	5th	0	0	0
F8	5th	220	2366	20

Table 2
The effects of field identity and the visits (vegetative stages of wheat) on sheldgeese grazing intensity in the southeast of Buenos Aires province, Argentina. Parameter estimates and *p* values are taken from GLMM with visit and field identity as random effect (Model 1 and Model 2 respectively). Stepwise deletion to remove non-significant variables (interactions first) was performed, such that parameter estimates and *p* values are for the simplest model containing each variable.

Model	Response variable	Fixed effects	Estimate ± SE	*p*
1	Grazing intensity	Intercept	5.03 ± 0.2	< 0.001
		F2	−1.87 ± 0.15	< 0.001
		F3	0.2 ± 0.06	0001
		F4	−1.47 ± 0.1	< 0.001
		F5	−0.52 ± 0.07	< 0.001
		F6	−2.89 ± 0.2	< 0.001
		F7	−3.01 ± 0.21	< 0.001
2	Grazing intensity	Intercept	3.75 ± 0.41	< 0.0001
		Visit 4	0.26 ± 0.06	< 0.0001
		Visit 5	−0.56 ± 0.07	< 0.0001

Therefore, we only had one estimation making comparison impossible. Thus, we only worked with seven fields. Grazing intensity significantly varied among fields (Model 1 in Table 2) and visits (Model 2 in Table 2). Five fields significantly differed in the grazing intensity during the entire wintering season (LSD Fisher, $p < 0.05$, Fig. 2a). F1 and F3 were the most grazed fields (F1: 153 ± 31, F3: 187 ± 38; Fig. 2a). F6 and F7 were the only fields that did not differ in the grazing intensity and the ones that had the lowest density (F6: 9 ± 2, F7: 8 ± 2; Fig. 2a). Taking in consideration the seven fields, the grazing intensity significantly differed between visits (LSD Fisher, $p < 0.05$; Fig. 2b). More sheldgeese per field were estimated in the 4thvisit (55 ± 22) and the smallest estimation was in the 5th visit (24 ± 10; Fig. 2b).

3.2. Potential damages of sheldgeese grazing on wheat

The percentage of wheat cover significantly decreased with the grazing intensity in all visits (Model 1 in Table3). Plots exposed to geese grazing had significant lower wheat cover in comparison with control plots (Model 1 in Table 3).

The percentage of eaten plants increased significantly in plots exposed to geese grazing in compared with control plots, but only at the end of the tillering stage (5th visit; Model 2 in Table 3). Also, we found a significant effect of the grazing intensity in relation to the percentage of eaten plants at the beginning of the tillering stage of the wheat (4th visit), showing an increase of the percentage of eaten plants (Model 2 in Table 3).

We found that the chlorophyll content varied between the pre-tillering stage (3rd visit) and the tillering stage (6th visit), showing an increase with the crop growth (Model 3 in Table 3). In addition, we found a non-significant effect of geese grazing (Model 3 in Table 3).

The percentage of eaten tillers significantly increased with the grazing intensity and in plots exposed to geese grazing (Model 4, Table 3).

There were no significant differences in treatment or grazing intensity for all response variables regarding wheat yield (grain yield per plot, harvest index, weight of 1000 grains, and number of grains) (Model 5, 6, 7 and 8 respectively in Table 3).

3.3. Probable benefits of sheldgeese grazing on wheat

Fresh samples of sheldgeese feces before (n = 270) and after (n = 375) the wheat emergence were analyzed. The average weight of each sample composed by 15 dried feces was 15.68 ± 1.1 g before and 12.62 ± 0.39 g after the crop emergence. We found significant differences for both nutrients between the two contrasting situations (N: t = -5.89, df = 39, $p < 0.0001$; P: t = -4.72, df = 26, $p < 0.0001$). The

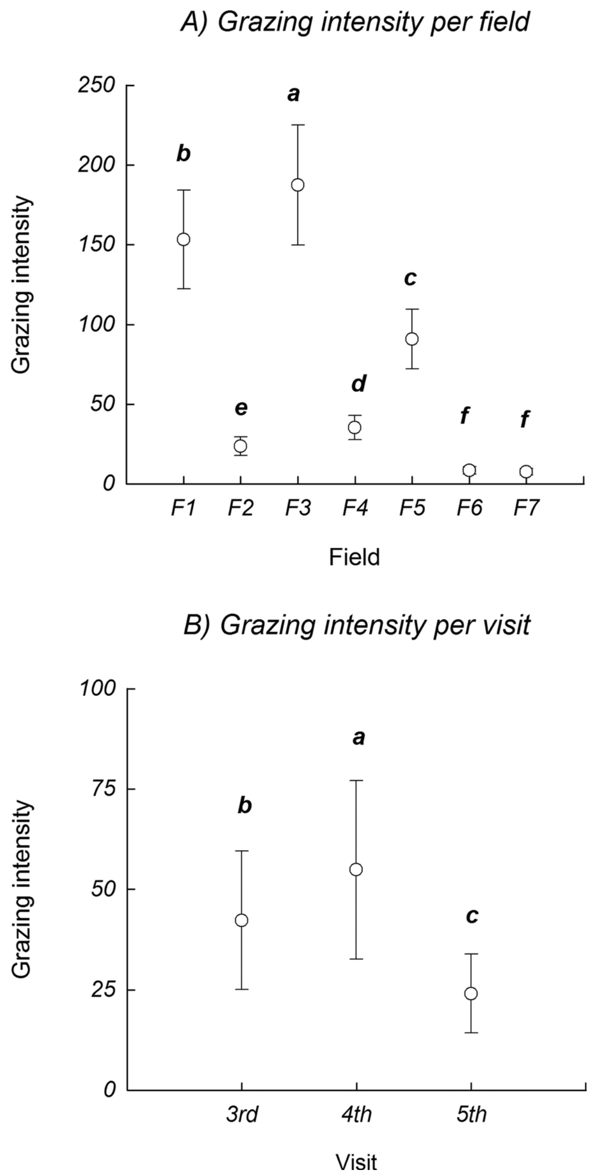

Fig. 2. (A) Grazing intensity per field. Three transects were performed in all the fields, except for F2 where only two transects were done. (B) Grazing intensity per visit. Six transects were performed in the 3rd visit, seven transects in the 4th visit and eight transects in the 5th visit.
The bars represent the standard error. Means with different letter significantly differ ($p < 0.05$) by LSD Fisher.

feces contained 1.78 ± 0.16% of N and 0.49 ± 0.02% of P before, and 3.1 ± 0.15% of N and 0.63 ± 0.01% of P after the wheat emergence. These results showed an increased in both nutrients in the period after the wheat emergence. Based on our field observations, sheldgeese spent at least 30 days since their arrival in the area before the wheat emergence, and more than two months after the wheat emergence until they left the wintering areas and migrated further south. The amount of nutrients excreted by sheldgeese for the study area was estimated in 14,571 kg of N (0.01 kg/ha) and 4,077 kg of P (0.004 kg/ha) before and 44,905 kg of N (0.04 kg/ha) and 9,170 kg of P (0.009 kg/ha) after the wheat emergence.

Microhistological analysis of sheldgeese feces before the wheat emergence showed that these birds forage on at least 13 species of plants, all of them considered weeds (Table A.2, Appendix). The Poaceae (34.82%) and Scrophulariaceae (21.81%) were the most consumed families; and *Loliumsp* (30.5%) and *Veronica arvensis* (21.8%) were the most eaten species. The samples from the period after the crop emergence showed that they consumed only wheat.

Weed cover did not show any differences between grazing and control plots nor with the grazing intensities in each visit (Model 1, 2 and 3 in Table 4).

The number of tillers per plant did not vary significantly between grazing and control plots, neither with the grazing intensity (Model 4 in Table 4).

Finally, we found that the protein content of the grains had a small but significantly increased in grazing plots, but did not vary with the grazing intensity (Model 5 in Table 4).

4. Discussion

Around the world, populations of geese are increasing, overlapping their feeding areas with agricultural fields, thus increasing the areas of conflict (Fox and Madsen, 2017; Nilsson et al., 2016). On the contrary, in Argentina sheldgeese are dangerously declining. Although hunting is banned, the sheldgeese conflict on the Pampas ecoregion still remains (Blanco et al.,2003; Pedrana et al., 2018b). Our study provided new and meaningful information to understand and find solutions to this controversial issue. We found evidence of the real impacts of sheldgeese grazing in wheat and the benefits they provide to crops in the Pampas ecoregion

4.1. Sheldgeese grazing intensity

The grazing intensity was different in each field and visit. The differences observed for grazing intensity between fields during the wintering season could be due to environmental factors that can influence bird abundances, such as distances to the roost (Pedrana et al., 2018a), or the landscape around the field (Harrison et al., 2017; Pedrana et al., 2014). We found that sheldgeese grazed fields in a heterogeneous way. This might result from a patch selection (inside each field), which can be driven by a perceived predation risk, selecting areas with a clear view to detect an approaching predator (Harrison et al., 2017). The grazing intensity per field was smaller at the end of the wintering season. Shariati Najafabadi (2017) documented that Barnacle geese spend less time eating when they are close to their migration date. Another possible explanation is the nutritional quality of plants throughout the crop cycle. Therkildsen and Madsen (1999) found that *Anser brachyrhynchus* and *Branta leucopsis* gradually switched to low-quality food as high-quality food became depleted when foraging on winter wheat. Although the protein content of the wheat leaves had a significant effect on geese grazing selectivity, the length of individual leaves also affected this selectivity (Therkildsen and Madsen, 1999).

The grazing intensities estimated in this study were much smaller than the ones reported in other studies of geese grazing (Patterson et al., 1989; Summers, 1990), even though we used the cumulative droppings. The field that presented the highest grazing intensity showed 0.46 droppings/m^2. Patterson et al. (1989) and Summers (1990) found a yield reduction in wheat fields with densities higher than five droppings/m^2 and 22 droppings/m^2, respectively.

4.2. Potential damages of sheldgeese grazing on wheat

We did not find a significant grain yield loss due to sheldgeese grazing, similarly to other studies done in the same region (Omaña, 2016; Tracanna and Ferreira, 1984). On the contrary, many studies of geese damage on crops around the world showed different impacts on yield (Fox et al., 2017; Patterson et al., 1989; Summers, 1990). These studies found that grazing intensity interacted with other factors, such as the timing of grazing in relation to the crop growth stages and weather conditions (Fox et al., 2017; Kahl and Samson, 1984; Petkov et al., 2017).

We measured the effects of the different grazing pressures in the yield and on the growth stages of the crop. Although we found a

Table 3
The effects of treatment, visits and grazing intensity on wheat cover, percentage of eaten plants, chlorophyll content, percentage of eaten tillers, grain yield per plot (Kg of grain per plot), harvest index (HI), weight of 1000 grains (P1000), number of grain per m^2 and its component variables for the potential damages caused by sheldgeese grazing on wheat in the southeast of Buenos Aires province, Argentina. Parameter estimates and *p* values are taken from GLMM or LME, fitted by restricted maximum likelihood, with field identity, sub-area identity and, in some cases, plot identity as random effects. Fixed effects are treatment (control vs. grazing), grazing intensity and visits. Visits 3rd, 4th and 5th correspond to visits performed during the crop vegetative stages and visit 6th correspond to the late tillering stage. Step-wise deletion to remove non-significant variables (interactions first) was performed, such that parameter estimates and *p* values are for the simplest model containing each variable.

Model	Response variable	Fixed effects	Estimate ± SE	*p*
1	Wheat cover	Intercept	1.23 ± 0.17	< 0.0001
		Treatment (grazing)	−0.62 ± 0.28	0.03
		Visit 4	0.97 ± 0.16	< 0.0001
		Visit 5	2.45 ± 0.14	< 0.0001
		Grazing intensity	0.002 ± 0.001	0.03
		Treatment (grazing) x Visit 4	0.36 ± 0.29	0.22
		Treatment (grazing) x Visit 5	0.47 ± 0.27	0.88
		Visit 4 x Grazing intensity	−0.002 ± 0.001	0.04
		Visit 5 x Grazing intensity	−0.006 ± 0.001	< 0.0001
2	Percentage of eaten plants	Intercept	2.65 ± 0.26	< 0.0001
		Treatment (grazing)	0.74 ± 0.28	0.01
		Visit 4	−0.88 ± 0.27	0.002
		Visit 5	−0.88 ± 0.27	0.002
		Grazing intensity	0.0004 ± 0.001	0.7
		Treatment (grazing) x Visit 4	0.38 ± 0.43	0.38
		Treatment (grazing) x Visit 5	1.35 ± 0.4	0.001
		Visit 4 x Grazing intensity	0.005 ± 0.002	0.007
		Visit 5 x Grazing intensity	0.0007 ± 0.002	0.75
3	Chlorophyll content	Intercept	28.8 ± 1.92	< 0.0001
		Treatment (grazing)	−1.01 ± 2.7	0.7
		Visit 6	15.54 ± 2.08	< 0.0001
		Grazing intensity	0.02 ± 0.01	0.16
		Treatment (grazing) x Visit 6	1.62 ± 3.01	0.6
		Visit 6 x Grazing intensity	−0.02 ± 0.01	0.06
4	Percentage of eaten tillers	Intercept	15.34 ± 2.53	< 0.0001
		Treatment (grazing)	12.57 ± 3.66	0.001
		Grazing intensity	0.05 ± 0.008	< 0.0001
5	Grain yield per plot	Intercept	0.7 ± 0.05	< 0.0001
		Treatment (grazing)	−0.015 ± 0.07	0.83
		Grazing intensity	−0.014 ± 0.34	0.33
6	HI	Intercept	0.4 ± 0.009	< 0.0001
		Treatment (grazing)	−0.014 ± 0.01	0.2
		Grazing intensity	0.00003 ± 0.01	0.18
7	P1000	Intercept	39.64 ± 0.92	< 0.0001
		Treatment (grazing)	−0.13 ± 0.9	0.88
		Grazing Intensity	−0.001 ± 0.002	0.67
8	Number of grains per m^2	Intercept	7.98 ± 0.025	< 0.0001
		Treatment (grazing)	0.009 ± 0.027	0.75
		Grazing Intensity	−0.00002 ± 0.00007	0.79

significant decrease in the wheat cover and an increase in the number of eaten plants in the grazing plots, it was not enough to produce differences on the wheat yield. Moreover, there was no effect of geese grazing in none of the parameters estimated during the harvest (grain yield per plot, harvest index, the weight of 1000 grains, number of grain per m^2). We could explain these results with the grazing optimization hypothesis, which describes the reaction of plants to increase herbivory (Fox et al., 2017; Mcnaughton, 1979; Van Der Graaf et al., 2005). This hypothesis predicts that grazing at intermediate intensities stimulates plant production. It also improves the net primary production of grazed plants over that of ungrazed (Van Der Graaf et al., 2005). Confirmation of this hypothesis around the word is limited to certain ecosystems and varies with plant species (Belsky, 1986; Fox et al., 2017; Van Der Graaf et al., 2005). In our research, results of the number of tillers per plant and the crop yield parameters could confirm the grazing optimization hypothesis. Despite the damage done to the crop in the first stages, the plants were compensating the negative effect. On the contrary, we did not find any evidence of overcompensation of the plants. This could be due to the small amount of sheldgeese in the area that were unable to exercise an intermediate grazing pressure.

Other evidence found in our study was that the eaten plants decreased with crop growth and that the period of sheldgeese eating was even shorter than the farmers previously suspected.

4.3. Probable benefits of sheldgeese grazing on wheat

There are many studies that highlight the Ecosystem Services that birds, in general, and waterfowl in particular, can provide to different environments (Buij et al., 2017; Green and Elmberg, 2014; Whelan et al., 2008). In Australia, waterbirds help the colonization of temporary wetlands by transporting invertebrates and plants across them (Green et al., 2008). Some species of Anatidae can provide an economic benefit by reducing the abundance of weeds, consuming their seeds (van Groenigen et al., 2003). Similarly, Paulin (2004) found that the Canada goose (*Branta canadensis*) serve as seed dispersal and soil fertilizer. The mechanism where plants can profit from nutrient input by feces or urine was studied in different ecosystems (Kitchell et al., 1999; Manny et al., 1994; Somura et al., 2015). In some weather conditions, the input of nutrients from goose feces may enhance plant growth (Fox et al., 2017). In our study, although nutrient input by sheldgeese feces was small compared to agricultural fertilizer applications, it was an extra contribution. Abdul Jalil and Patterson (1989) found similar results, concluding that the amount of nutrient supplied by feces of *Anser anser* and *Anser brachyrhynchus* was negligible (23.02 kg/ha) in

Table 4
The effects of treatment, visits and grazing intensity on weed cover, number of tillers per plant, protein content and its component variables for the probable benefits caused by sheldgeese grazing on wheat in the southeast of Buenos Aires province, Argentina. Parameter estimates and *p* values are taken from GLMM or LME, fitted by restricted maximum likelihood, with field identity, sub-area identity and, in some cases, plot identity as random effects. Fixed effects are treatment (control vs. grazing) and grazing intensity. Visits 3rd, 4th and 5th correspond to the crop vegetative stages and visit 6th correspond to the late tillering stage. Step-wise deletion to remove non-significant variables (interactions first) was performed, such that parameter estimates and *p* values are for the simplest model containing each variable.

Model	Response variable	Fixed effects	Estimate ± SE	p
1	Weed cover (3^{rd} visit)	Intercept	0.35 ± 0.31	0.27
		Treatment (grazing)	0.18 ± 0.42	0.65
		Grazing intensity	0.0009 ± 0.002	0.68
2	Weed cover (4^{th} visit)	Intercept	0.38 ± 0.21	0.07
		Treatment (grazing)	0.39 ± 0.27	0.16
		Grazing intensity	−0.007 ± 0.001	0.28
3	Weed cover (5^{th} visit)	Intercept	1.53 ± 0.55	0.009
		Treatment (grazing)	0.22 ± 0.65	0.74
		Grazing intensity	0.008 ± 0.006	0.16
4	Number of tillers per plant	Intercept	5.38 ± 0.78	< 0.0001
		Treatment (grazing)	0.28 ± 0.5	0.57
		Grazing intensity	−0.002 ± 0.001	0.09
5	Protein content	Intercept	9.89 ± 0.23	< 0.0001
		Treatment (grazing)	0.45 ± 0.06	< 0.0001
		Grazing intensity	0.0002 ± 0.0006	0.77

comparison with fertilizer application (137 kg/ha). In addition, Summers (1990) found that feces from *Branta b. bernicla* could add 9 kg/ha of N compared to 690 kg/ha of N applied by fertilizers. An important consideration to take into account is that sheldgeese consumed and defecated in the same habitats. Thus, they may affect the nutrient cycling system. However, to evaluate the net contribution further studies should also consider the amount of nutrient sheldgeese remove from this system.

The protein content of the grains in grazing plots was higher than in control plots. This fact might be due to a contribution of inorganic nitrogen provided by geese droppings to the soil (Fox et al., 2017). However, the true reason for this result remains unknown and further research should consider this.

The marked difference between the nutrients input before and after the wheat emergence may be explained due to the differences in their diet. The sheldgeese diet before the wheat emergence was principally composed of weeds and after was solely composed of wheat. This transition might be due to the improvements in nutritional quality and quantity of the agriculture crop (Fox and Abraham, 2017). Geese grazing has been reported to increase weed abundance in crop fields (Patterson et al., 1989), but our experimental plots showed that grazing did not affect the weed cover. We found that sheldgeese were helping to reduce the abundance of weeds and especially a very problematic one, *Lolium* sp., which was the most consumed species. This weed is widely spread in Buenos Aires province and severely affects wheat crops causing yield loss (Gigón et al., 2017). The main agriculture problem is that this plant is resistant to the glyphosate (Gigón et al., 2017; Yanniccari et al., 2009, 2016), the most widely used herbicide in the world (Vila-Aiub et al., 2008). Sheldgeese grazing this plant could help reduce its abundance, especially in May and June, the germination's months in the area (Gigón et al., 2017). It could also reduce the use of herbicides, contributing to a more sustainable approach. It is important to highlight that after the wheat emergence sheldgeese only ate wheat, but the weeds availability was very low. Therefore, new studies of sheldgeese diet should explore different management practices, such as an agro-ecological approach where there are more plant species available.

5. Conclusions

Despite the fact that this study was only one year long, the results highlighted the fact that sheldgeese grazing did not have a negative effect on crop yields. The wheat yield and damages were calculated by independent methods and provided the same conclusions.

The encouraging results of the diet samples showed the positive effects that sheldgeese were providing in their wintering grounds. The input of nitrogen and phosphorus to the nutrient cycling system and the consumption of weeds should be considered as benefits provided by sheldgeese to the agroecosystem. Future studies should focus on isotopic analysis of the nitrogen provided by bird feces, in order to determine the origin of the nitrogen uptake by plants.

Perceived damage to crops by wildlife not only has a negative effect on species conservation, but it also leads to complex secondary effects. This includes stakeholders' hesitation to the introduction of new protected areas or conservation initiatives and the delay of conservation measurements for other species or environments (Dickman, 2010). Although the three species of sheldgeese are protected by law, there are still farmers which considered them harmful for their activities and as a consequence they performed illegal lethal methods to control them (e.g. hunting and aircraft persecution) (Bernad et al., 2014; Prario Fioriti, 2016). We found evidence that sheldgeese do not produce economical damage on wheat crops, which could lead to a change of attitude of farmers towards these species. This fact could resolve part of the conflict, helping not only sheldgeese conservation but many others species that inhabit the same area.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.agee.2019.04.002.

References

Abbate, P.E., Cardós, M.J., Campaña, L.E., 2017. El trigo, su difusión, importancia como alimento y consumo. In: Divito, G.A., García, F.O. (Eds.), Eds.), Manual del Cultivo de Trigo. International Plant Nutrition Institute, Argentina, pp. 7–19.
Abdul Jalil, S., Patterson, I.J., 1989. Effect of simulated goose grazing on yield of autumn-sown barley in north-east Scotland. J. Appl. Ecol. 26 (3), 897–912.
Aizen, M.A., Garibaldi, L.A., Dondo, M., 2009. Expansión de la soja y diversidad de la agricultura argentina. Ecol. Austral 19, 45–54.
Amano, T., Ushiyama, K., Fujita, G., Higuchi, H., 2004. Alleviating grazing damage by white-fronted geese: an optimal foraging approach. J. Appl. Ecol. 41, 675–688. https://doi.org/10.1111/j.0021-8901.2004.00923.x.
Azpiroz, A.B., Isacch, J.P., Dias, R.A., Di Giacomo, A.S., Fontana, C.S., Palarea, C.M., 2012. Ecology and conservation of grassland birds in southeastern South America: a review. J. Field Ornithol. 83, 217–246. https://doi.org/10.1111/j.1557-9263.2012.00372.x.
Bachman, D.C., 2008. Managing Grassland Pastures at Humboldt Bay National Wildlife

Refuge for Aleutian Geese. Humboldt State University.
Balvanera, P., Pfisterer, A.B., Buchmann, N., He, J.S., Nakashizuka, T., Raffaelli, D., Schmid, B., 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services: biodiversity and ecosystem functioning/services. Ecol. Lett. 9, 1146–1156. https://doi.org/10.1111/j.1461-0248.2006.00963.x.
Belsky, A.J., 1986. Does herbivory benefit plants? A review of the evidence. Am. Nat. 127, 870–892. https://doi.org/10.1086/284531.
Bernad, L., Pedrana, J., Maceira, N.O., Isacch, J.P., 2014. Los cauquenes como patrimonio natural: Una visión agroecosistémica. Aves Argentinas N&C, pp. 14–17.
Bilenca, D., Miñarro, F., 2004. Identificación de áreas valiosas de pastizal (AVPs) en las pampas y campos de Argentina, Uruguay y sur de Brasil. Fundación Vida Silvestre Argentina, first ed. Buenos Aires.
Bird, J.A., Pettygrove, G.S., Eadie, J.M., 2000. The impact of waterfowl foraging on the decomposition of rice straw: mutual benefit for rice growers and waterfowl. J. Appl. Ecol. 37, 728–741.
Blanco, D.E., De la Balze, V., 2006. Harvest of migratory geese *Chloephaga* spp. in Argentina: an overview of the present situation. In: Boere, G.C., Galbraith, C.A., Stroud, D.A. (Eds.), Waterbirds Around the World. The Stationery Office, Edin-burgh, UK, pp. 870–873.
Blanco, D.E., Zalba, S.M., Belenguer, C.J., Pugnali, G., Rodríguez Goñi, H., 2003. Status and conservation of the ruddy-headed goose *Chloephaga rubidiceps* Sclater (Aves, Anatidae) in its wintering grounds (Province of Buenos Aires, Argentina). Rev.Chil. Hist. Nat. 76, 47–55.
Borman, M.M., Louhaichi, M., Johnson, D.E., Krueger, W.C., Karow, R.S., Thomas, D.R., 2002. Yield mapping to document goose grazing impacts on winter wheat. Agron. J. 94, 1087–1093.
Buij, R., Melman, T.C., Loonen, M.J., Fox, A.D., 2017. Balancing ecosystem function, services and disservices resulting from expanding goose populations. Ambio 46 (2), 301–318.
Cabrera, A.L., 1994. Regiones Fitogeográficas argentinas. In: Kugler, W.F. (Ed.), Enciclopedia argentina de agricultura y jardinería, Tomo II, Fascículo 1. Acme, Buenos Aires, Argentina.
Chebez, J.C., 2008. Los que se van. Fauna argentina amenazada, Tomo 2. Albatros, Buenos Aires, Argentina.
Codesido, M., González-Fischer, C., Bilenca, D., 2011. Distributional Changes of Landbird Species in Agroecosystems of Central Argentina. Condor 113, 266–273. https://doi.org/10.1525/cond.2011.090190.
Díaz, S., Tilman, D., Fargione, J., 2005. Biodiversity regulation of ecosystem services. In: Hassan, H., Scholes, R., Ash, N. (Eds.), Ecosystems and Human Well-Being: Current State and Trends. pp. 297–329.
Dickman, A.J., 2010. Complexities of conflict : the importance of considering social factors for effectively resolving human – wildlife conflict. Anim. Conserv. 13, 458–466. https://doi.org/10.1111/j.1469-1795.2010.00368.x.
Ferreira, T., Rasband, W., 2012. ImageJ User Guide IJ 1.46r. IJ 1.46r. https://doi.org/10.1038/nmeth.2019.
Filella, I., Serrano, L., Serra, J., Peñuelas, J., 1995. Evaluating wheat nitrogen status with canopy reflectance indices and discriminant analysis. Crop Sci. 35, 1400–1405.
Fox, A.D., Abraham, K.F., 2017. Why geese benefit from the transition from natural vegetation to agriculture. Ambio 46, 188–197. https://doi.org/10.1007/s13280-016-0879-1.
Fox, A.D., Madsen, J., 2017. Threatened species to super-abundance: the unexpected international implications of successful goose conservation. Ambio 46, 179–187. https://doi.org/10.1007/s13280-016-0878-2.
Fox, A.D., Elmberg, J., Tombre, I.M., Hessel, R., 2017. Agriculture and herbivorous waterfowl: a review of the scientific basis for improved management. Biol. Rev. 92, 854–877. https://doi.org/10.1111/brv.12258.
Gandrup, M.E., García, F.O., Fabrizzi, K.P., Echeverría, H.E., 2004. Evolución de un índice de verdor en hoja para evaluar el status nitrogenado en trigo. RIA 33, 105–121.
Gigón, R., Vigna, M., Yanniccari, M., 2017. Manejo de malezas problema Raigrás (*Lolium* spp.) Bases para su manejo y control en sistemas de produccións. REM - AAPRESID, Rosario.
Grau, R.H., Ade, M.T., Gasparri, I.N., 2005. Globalization and soybean expansion into semiarid ecosystems of Argentina. Ambio 34, 265–266. https://doi.org/10.1579/0044-7447-34.3.265.
Green, A.J., Elmberg, J., 2014. Ecosystem services provided by waterbirds. Biol. Rev. 89, 105–122. https://doi.org/10.1111/brv.12045.
Green, A.J., Jenkins, K.M., Bell, D., Morris, P.J., Kingsford, R.T., 2008. The potential role of waterbirds in dispersing invertebrates and plants in arid Australia. Freshw. Biol. 53, 380–392. https://doi.org/10.1111/j.1365-2427.2007.01901.x.
Haines-Young, R., Potschin, M., 2013. CICES V4. 3–Revised Report Prepared Following Consultation on CICES Version 4, August-December 2012. EEA Framework Contract No EEA (p. 34). IEA/09/003.
Hansen, R., Foppe, T., Gilbert, M., Clark, R., Reynolds, H., 1977. The Microhistological Analysis of Feces As an Estimator of Herbivore Dietary. Composition Analysis Laboratory. Range Sc. Depart. Colorado Sta. Univ., Colorado, USA.
Harrison, A.L., Petkov, N., Mitev, D., Popgeorgiev, G., Gove, B., Hilton, G.M., 2017. Scale-dependent habitat selection by wintering geese: implications for landscape management. Biodivers. Conserv. 27, 167–188. https://doi.org/10.1007/s10531-017-1427-4.
Josens, M.L., Pretelli, M.G., Escalante, A.H., 2009. Censos de aves acuáticas en sus colonias reproductivas en Lagunas del sudeste de la Provncia de Buenos Aires. Hornero 24, 7–12.
Kahl, R., Samson, F., 1984. Factors affecting yield of winter wheat grazed by geese. Wildl. Soc. Bull. 12, 256–262. https://doi.org/10.2307/3781991.
Kitchell, J.F., Schindler, D.E., Herwig, B.R., Post, D.M., Olson, M.H., Oldham, M., 1999. Nutrient cycling at the landscape scale: the role of diel foraging migrations by geese at the Bosque del Apache National Wildlife Refuge, New Mexico. Limnol. Oceanogr. 44, 828–836. https://doi.org/10.4319/lo.1999.44.3_part_2.0828.
LECO, 2010. Organic Application Notes. (Accessed September 2010). http://www.leco.com.
Lindström, L.I., 1994. Estudio microhistológico de las especies de gramíneas que integran la dieta de vacunos en el caldenal: elaboración de una clave y su aplicación al análisis de muestras fecales. Tesis magister. Universidad Nacional del Sur Universidad Nacional del Sur.
López-Lanús, B., Grilli, P., Coconier, E., Di Giacomo, A., Banchs, R., 2008. Categorización de las aves de la Argentina según su estado de conservación. Informe deAves Argentinas/AOP y Secretaría de Ambiente y Desarrollo Sustentable, BuenosAires, Argentina.
Lorenzen, B., Madsen, J., 1986. Feeding by geese on the Filsø Farmland, Denmark, and the effect of grazing on yield structure of spring barley. Holartic Ecol. 9, 305–311. https://doi.org/10.1080/10106040108542184.
Louhaichi, M., Borman, M.M., Johnson, D.E., 2001. Spatially located platform and aerial photography for documentation of grazing impacts on wheat. Geocarto Int. 16, 65–70. https://doi.org/10.1080/10106040108542184.
Macmillan, D., Hanley, N., Daw, M., 2004. Costs and benefits of wild goose conservation in Scotland. Biol. Conserv. 119, 475–485. https://doi.org/10.1016/j.biocon.2004.01.008.
Madsen, J., Boertmann, D., 2008. Animal behavioral adaptation to changing landscapes: spring-staging geese habituate to wind farms. Landsc. Ecol. 23, 1007–1011. https://doi.org/10.1007/s10980-008-9269-9.
Manny, B.A., Johnson, W.C., Wetzel, R.G., 1994. Nutrient additions by waterfowl to lakes and reservoirs: predicting their effects on productivity and water quality. Aquat. Birds Trophic Web Lakes 121–132. https://doi.org/10.1007/978-94-011-1128-7_12.
Martin, S.I., Tracanna, N.A., Summers, R., 1986. Distribution and habitat use by Sheldgeese populations wintering in Buenos Aires province, Argentina. Wildfowl 37, 55–62.
Martín, S., 1984. La avutarda magallanica (*Chloephaga picta*) en la Patagonia: su ecología, alimentación, densidad y control. Idia 6, 429–432.
Mcnaughton, S.J., 1979. Grazing as an optimization process: grass-ungulate relationships in the serengeti. Am. Nat. 113, 691–703.
Millenniu Ecosystem Assessment (MA), 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.
Miralles, D.J., González, F., Abeledo, L.G., Serrago, R.A., Alzueta, I., García, G., de San Caledonio, R., Lo Valvo, P., 2014. Manual de trigo y cebada para el Cono Sur: procesos fisiológicos y bases de manejo, Primera edición. Orientación Gráfica Editora, Buenos Aires.Manual de trigo y cebada para el Cono Sur: procesos fisiológicos y bases de manejo, Primera edición. Orientación Gráfica Editora, Buenos Aires.
Mullan, D., Barcelo Garcia, M., 2012. Crop ground cover. In: Pask, A.J.D., Pietragalla, J., Mullan, D.M., Reynolds, M.P. (Eds.), Physiological Breeding II: a Field Guide to Wheat Phenotyping. CIMMYT, Mexico D.F, pp. 46–53.
Mullan, D., Mullan, D., 2012. Chlorophyll content. In: Pask, A.J.D., Pietragalla, J., Mullan, D.M., Reynolds, M.P. (Eds.), Physiological Breeding II: a Field Guide to Wheat Phenotyping. CIMMYT, Mexico D.F, pp. 41–43.
Murphy, J., Riley, H.P., 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta 27, 31–36. https://doi.org/10.1016/S0003-2670(00)88444-5.
National Research Council (NCR), 2005. Valuing Ecosystem Services: Toward Better Environmental Decision-Making. National Academy Press, Washington, DC.
Navedo, J.G., Hahn, S., Parejo, M., Abad-Gómez, J.M., Gutiérrez, J.S., Villegas, A., Sánchez-Guzmán, J.M., Masero, J.A., 2015. Unravelling trophic subsidies of agroecosystems for biodiversity conservation: Food consumption and nutrient recycling by waterbirds in Mediterranean rice fields. Sci. Total.Environ. 511, 288–297.
Nilsson, L., Bunnefeld, N., Persson, J., Månsson, J., 2016. Large grazing birds and agriculture — predicting field use of common cranes and implications for crop damage prevention. Agric. Ecosyst. Environ. 219, 163–170. https://doi.org/10.1016/j.agee.2015.12.021.
Omaña, J., 2016. Efecto de la presencia de cauquenes o avutardas silvestres (*Chloephaga spp*.) sobre el rendimiento del cultivo de trigo. Tesis de grado, Universidad Nacional de Mar del Plata, Facultad de Ciencias Agrarias, Balcarce, Argentina.
Owen, M., 1972a. Some factors affecting food intake and selection in white-fronted geese. J. Anim. Ecol. 41, 79–92. https://doi.org/10.2307/3507.
Owen, M., 1972b. Movements and Feeding Ecology of White-Fronted Geese at the New Gounds, Slimbridge. J. Appl. Ecol. 9 (2), 385–398.
Owen, M., 1975. An assessment of fecal analysis technique in waterfowl feeding studies. J. Wildl. Manage. 39, 271–279. https://doi.org/10.2307/3799903.
Owen, M., 1990. The damage-conservation interface illustrated by geese. Ibis (Lond. 1859) 132, 238–252.
Paruelo, J.M., Jobbágy, E.G., Sala, O.E., 2001. Current distribution of ecosystem functional types in temperate South America. Ecosyst. 4 (7), 683–698.
Patterson, I., Abdul Jalil, S., East, M., 1989. Damage to winter cereals by Greylag and pink-footed geese in north-east Scotland. J. Appl. Ecol. 26, 879–895.
Paulin, J.B., 2004. Positive Benefits and Negative Impacts of Canada Geese. Fact Sheet FS1027. Rutgers Cooperative Research and Extension. Rutgers-Cook College Resource Centre, Rutgers, NJ.
Pedrana, J., Bernad, L., Maceira, N.O., Isacch, J.P., 2014. Human-Sheldgeese conflict in agricultural landscapes: Effects of environmental and anthropogenic predictors on Sheldgeese distribution in the southern Pampa, Argentina. Agric. Ecosyst. Environ. 183, 31–39. https://doi.org/10.1016/j.agee.2013.09.029.
Pedrana, J., Seco Pon, J.P., Isacch, J.P., Leiss, A., Rojas, P.O., Castresana, G., Calvo, J., Bernad, L., Muñoz, S.D., Maceira, N.O., Pütz, K., 2015. First insights into the migration pattern of an Upland goose (*Chloephaga picta*) based on satellite tracking. Ornitol. Neotrop. 26 (3), 245–253.

Pedrana, J., Pütz, K., Bernad, L., Seco Pon, J.P., Gorosabel, A., Muñoz, S.D., Isacch, J.P., Matus, R., Blank, O., Lüthi, B., Lunardelli, M., Rojas, P., 2018a. Migration routes and stopover sites of Upland Geese *Chloephaga picta* in South America. Avian Biol. Res. 11, 89–99.

Pedrana, J., Bernad, L., Bernardos, J.N., Seco Pon, J.P., Isacch, J.P., Muñóz, S.D., Maceira, N.O., 2018b. Winter population size estimations of three migratory Sheldgeese in the Southern Pampas, Argentina. Waterbirds 41, 16–21. https://doi.org/10.1675/063.041.0103.

Petkov, N., Harrison, A.L., Stamenov, A., Hilton, G.M., 2017. The impact of wintering geese on crop yields in Bulgarian Dobrudzha : implications for agri-environment schemes. Eur. J. Wildl. Res. 63 (4), 66–78. https://doi.org/10.1007/s10344-017-1119-0.

Prario Fioriti, A., 2016. Los cauquenes (*Chloephaga spp.*): ¿Qué percepción tienen los productores?. Tesis de grado. Universidad Nacional de Mar del Plata, Facultad de Ciencias Agrarias, Balcarce, Argetina.

Schneider, C.A., Rasband, W.S., Eliceiri, K.W., 2012. NIH Image to ImageJ: 25 years of image analysis. Nat. Methods 9, 671–675. https://doi.org/10.1038/nmeth.2089.

Sekercioglu, C.H., 2006. Increasing awareness of avian ecological function. Trends Ecol. Evol. 21, 464–471. https://doi.org/10.1016/j.tree.2006.05.007.

Shariati Najafabadi, M., 2017. Migration Timing and Stopover Selection for Barnacle Geese Branta leucopsis. University of Twentehttps://doi.org/10.3990/1.9789036543187.

Simonsen, C.E., Tombre, I.M., Madsen, J., 2017. Scaring as a tool to alleviate crop damage by geese: revealing differences between farmers' perceptions and the scale of the problem. Ambio 46 (2), 319–327.

Solbrig, O.T., 1997. Towards a Sustainable Pampa Agriculture: Past Performance and Prospective Analysis. DRCLAS Working Paper Series. pp. 6–96/97. .

Somura, H., Masunaga, T., Mori, Y., Takeda, I., Ide, J., Sato, H., 2015. Estimation of nutrient input by a migratory bird, the Tundra Swan (*Cygnus columbianus*), to winter-flooded paddy fields. Agric. Ecosyst. Environ. 199, 1–9. https://doi.org/10.1016/j.agee.2014.07.018.

Soriano, A., 1991. Río de la Plata Grasslands. In: Coupland, R. (Ed.), Natural Grasslands: Introduction and Western Hemisphere. Elsevier, Amsterdam, The Netherlands, pp. 367–407.

Soriano, A., León, R.J.C., Sala, O.E., Lavado, S., Deregibus, V.A., Cauhepé, M.A., Scaglia, O.A., Velázquez, A.C., Lemcoff, J.H., 1991. Río de la Plata Grasslands. In: Coupland, R.T. (Ed.), Ecosystems of the World 8A, Natural Grasslands, Introduction and Western Hemisphere. Elsevier, New York.

Summers, R.W., 1990. The effect on winter wheat of grazing by Brent geese Branta bernicla. J. Apply. Ecol. 27 (3), 821–833.

Summers, R.W., Grieve, A., 1982. Diet, Feeding Behaviour and Food Intake of the Upland Goose (*Chloephaga picta*) and Ruddy- Headed Goose (C. rubidiceps) in the Falkland Islands. J. Appl. Ecol. 19, 783–804.

Summers, R.W., McAdam, J.H. (Eds.), 1993. The Upland Goose: a Study of the Interaction between Geese, Sheep and Man in the Falkland Islands. Bluntisham Books, Huntingdon, U.K.

Therkildsen, O.R., Madsen, J., 1999. Goose grazing selectivity along a depletion gradient. Ecography (Cop.) 22, 516–520. https://doi.org/10.1111/j.1600-0587.1999.tb01280.x.

Tombre, I.M., Eythórsson, E., Madsen, J., 2013. Towards a solution to the goose-agriculture conflict in North Norway, 1988-2012: the interplay between policy, stakeholder influence and goose population dynamics. PLoS One 8. https://doi.org/10.1371/journal.pone.0071912.

Tracanna, N.A., Ferreira, L., 1984. Evaluación de los efectos sobre el rendimiento en grano de cultivos de trigo pastoreados por avutardas (*Chloephaga* sp.). Plan de Estudios y Control de Avutardas.Evaluación de los efectos sobre el rendimiento en grano de cultivos de trigo pastoreados por avutardas (*Chloephaga* sp.). Plan de Estudios y Control de Avutardas.

Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. Ecol. Lett. 8 (8), 857–874.

Van Der Graaf, A.J., Stahl, J., Bakker, J.P., 2005. Compensatory growth of Festuca rubra after grazing: Can migratory herbivores increase their own harvest during staging? Funct. Ecol. 19, 961–969. https://doi.org/10.1111/j.1365-2435.2005.01056.x.

van Groenigen, J.W., Burns, E.G., Eadie, J.M., Horwath, W.R., Van Kessel, C., 2003. Effects of foraging waterfowl in winter flooded rice fields on weed stress and residue decomposition. Agric. Ecosyst. Environ. 95, 289–296.

Vila-Aiub, M.M., Vidal, R., Balbi, M.C., Gundel, P.E., Trucco, F., Ghersa, C.M., 2008. Glyphosate-resistant weeds of South American cropping systems: an overview. Pest Manag. Sci. 64, 366–371.

Wallin, E., Milberg, P., 1995. Effect of bean geese (*Anser fabalis*) grazing on winter wheat during migration stopover in southern Sweden. Agric. Ecosyst. Environ. 54, 103–108.

Whelan, C.J., Wenny, D.G., Marquis, R.J., 2008. Ecosystem services provided by birds. Ann. N. Y. Acad. Sci. 1134, 25–60. https://doi.org/10.1196/annals.1439.003.

Wood, S., Sebastian, K., Scherr, S.J., 2000. Pilot Analysis of Global Ecosystems: Agroecosystems. International Food Policy Research Institute and World Resources Institute, Washington, DC. https://doi.org/10.3109/10717544.2013.779332.

Yanniccari, M., Istilart, C., Giménez, D., 2009. Evaluación de la resistencia a glifosato de una población de *Lolium perenne L.* del sur de la provincia de Buenos Aires. II Congreso Iberoamericano de Ciencias de las Malezas. Lisboa – Portugal Vol. II. pp. 521–524.

Yanniccari, M., Vila-Aiub, M., Istilart, C., Acciaresi, H., Castro, A.M., 2016. Glyphosate resistance in perennial ryegrass (*Lolium perenne* L.) is associated with a fitness penalty. Weed Sci. 64, 71–79. https://doi.org/10.1614/WS-D-15-00065.1.

Zar, J.H., 1984. Biostatistical Analysis, second ed. Prentice Hall, USA.

Zhang, W., Ricketts, T.H., Kremen, C., Carney, K., Swinton, S.M., 2007. Ecosystem services and dis-services to agriculture. Ecol. Econ. 64, 253–260. https://doi.org/10.1016/j.ecolecon.2007.02.024.