Managing Grasslands to Maximize Migratory Shorebird Use and Livestock Production☆

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ABSTRACT

Grasslands are important to domestic and wild animals. Migratory shorebirds are important components of coastal rangeland ecosystems. Buff-breasted Sandpiper (BBSA, *Calidris subruficollis*) and American golden-plover (AMGP, *Pluvialis dominica*) are two insectivorous, migrant shorebirds that rely on livestock-grazed grasslands in the Southern Cone of South America during their nonbreeding season, as well as on migration in North America. We studied habitat selection of these species and contrasted their needs with livestock requirements needed to develop recommendations for grazing management that benefit wildlife and livestock production. Short grass height was positively related to BBSA and AMGP abundance, with ideal grass heights from 2 to 5 cm. However, maximum livestock production is associated with grass height over 6 cm. The amount of forest cover, which is used to provide shade to livestock, was negatively related to the occurrence of both shorebird species, likely due to higher risks of predation. Grassland improvement did not affect BBSA but negatively affected AMGP abundance. Short grass habitat was selected by both shorebird species in spite of the higher arthropod biomass in taller grasslands, suggesting that other factors besides food abundance, such as the ability to detect prey and predators, are driving habitat selection. To enhance shorebird (and other wildlife) conservation and livestock production, we recommend managers adjust grazing intensity so that grass height is > 6 cm from mid-February to September, when the Nearctic migrant shorebirds are absent, and from 2 to 5 cm from October to early February when shorebirds are present. These austral summer adjustments should be restricted to paddocks with low forest cover so that livestock production in paddocks with high forest cover remains maximized. All adjustments should be evaluated by each farmer to ensure adequate economic returns are met.

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Introduction

Grasslands are used by both domestic and wild animals throughout the world (Gibson, 2009). Domestic animal husbandry frequently involves substantial modification to grasslands to maximize economic return of livestock production. Such practices may include spatiotemporal alterations of grazing livestock intensity, overseeding native grasslands with exotic grasses and applying fertilizers, burning, converting between row/grain crop agriculture and pastureland, and planting trees to provide shade for livestock, among others (Bailey, 2005). Understanding how these practices, as well as other natural characteristics of grasslands, affect wild animals is necessary for allowing wildlife and livestock managers to promote domestic animal husbandry practices that benefit both wild and domestic animals. Indeed, if done correctly, grassland management can provide positive environmental and economic benefits (e.g., Durant et al., 2008). However, most wildlife biodiversity studies have focused on conservation rather than balancing biodiversity and domestic animal production, constraining the possibilities of benefiting both wild and domestic animals (Neilly et al., 2016).

Migratory shorebirds (Charadriiformes) are important components of the biodiversity within the coastal grassland environment worldwide (Colwell and Dodd, 1997; Navedo et al., 2013). These species require coordinated conservation actions across countries that are part of either breeding, nonbreeding, or migration routes. Two species, the Buff-breasted Sandpiper (BBSA, *Calidris subruficollis*) and American golden-plover (AMGP, *Pluvialis dominica*), are insectivorous long-distance migrants that breed in the Arctic tundra in northern North

America and overwinter in coastal areas of the Río de la Plata Grasslands (Lanctot et al., 2002, 2010; Isacch and Martínez, 2003a, 2003b; Blanco et al., 2004; Isacch et al., 2005; McCarty et al., 2017). Both species have been declared a global conservation priority due to loss of nonbreeding habitat, historic overhunting during migration, and ongoing population declines (Myers and Myers, 1979; Clay et al., 2010; Blanco et al., 2004; Lanctot et al., 2016; US Shorebird Conservation Plan Partnership, 2016). During the austral spring and summer, BBSA can be found primarily in the eastern flooding grasslands of the Argentinean Pampa, Southeastern Uruguay, and Southern Brazil (Soriano, 1991; Lanctot et al., 2002). The nonbreeding distribution of AMGP matches the area occupied by the BBSA but also includes portions of southern Paraguay (Clay et al., 2010; Johnson et al., 2018). For both species, the highest concentrations of birds appear to be in the coastal grasslands used for livestock production (Lanctot et al., 2002; Clay et al., 2010).

Several studies have shown that BBSAs and AMGPs are associated with intensively grazed, natural grasslands during the austral spring and summer, highlighting the importance of rangelands and cattle management for both species (Lanctot et al., 2002; Isacch and Martínez, 2003a; Blanco et al., 2004; Isacch and Cardoni, 2011). The reasons behind this selection for short grass heights are unknown. A greater understanding of this relationship would help better manage these rangeland ecosystems (McCracken and Bignal, 1998). In other grassland regions, short grass tends to have less arthropod biomass than tall grass (e.g., Gibson et al., 1992; Kruess and Tscharntke, 2002). If this pattern is true in the Southern Cone grasslands, then the short grass must be advantageous to the shorebirds in other ways, perhaps by allowing them to capture arthropod prey easier and/or detect avian predators (e.g., Falcons) earlier than in tall grass (Colwell and Dodd, 1997). Like many shorebird species, BBSAs and AMGPs are usually observed feeding in open areas, apparently so that they can detect predators early enough to escape. Other common features in the Rio de la Plata grasslands are tree belts and plantations that provide shade to livestock (Zalba and Villamil, 2002; Bilenca and Miñarro, 2004). Such plantings are used by avian predators such as Swainson's Hawks *(Buteo swainsoni)* and other raptors as roosting and foraging perches (Sarasola and Negro, 2006). Wilson et al. (2014) showed that two grassland shorebird species in Scotland tended to avoid plantation forests, presumably because birds needed a clear view of approaching avian predators. However, the effect of trees on BBSAs and AMGPs has never been assessed on their southern nonbreeding grounds. In addition, it is unknown how shorebirds are affected by seeding of exotic grasses and applying fertilizers in native pastures (a practice called "grassland improvement," Risso and Berretta, 1997; Ferreira et al., 2011). The limited data available suggest that several grassland insectivore specialists were negatively affected by grassland improvement (Barnett et al., 2004; Azpiroz and Blake, 2009; Fontana et al., 2016), potentially due to a drop in invertebrate biomass associated with an increase in grass blade density (Barnett et al., 2004).

In this paper we address three main questions related to habitat use and livestock production by overwintering BBSAs and AMGPs near Rocha lagoon, Uruguay. First, we assessed whether land use variables such as grass height, forest cover, and grassland type (improved or natural) were related to the presence and abundance of foraging BBSAs and AMGPs over a 7-yr period. Second, we examined the effect of arthropod biomass on the density of BBSAs and AMGPs in short grass paddocks near and away from Rocha lagoon. Third, we studied the relationship between grass height and arthropod biomass to shed light on the mechanisms behind short grass selection by overwintering BBSAs and AMGPs. Based on prior studies and the information provided earlier, we predicted that BBSAs and AMGPs would select short grass pastures, change their use of pastures over time so as to remain in short grass pastures, avoid pastures with vertical structures that might harbor or obstruct the detection of approaching avian predators, use improved pastures less than native pastures, and prefer pastures with more abundant arthropod resources.

Overall, understanding how habitat structure and food abundance affects the presence and abundance of BBSAs and AMGPs is important so that managers can determine what animal husbandry practices are compatible with grassland shorebird use. This knowledge will allow wildlife biologists and rangeland professionals to look for synergy when developing recommended practices for professionals in their respective fields and, in so doing, improve the prospects of these high-priority conservation species (US Shorebird Conservation Plan Partnership, 2016) while maintaining maximum economic return in grazing land management.

Methods

Study Site

We conducted our study at two ranches (La Rinconada, 4 500 ha, and La Laguna,1 300 ha) located adjacent to Rocha lagoon, Uruguay. These ranches include habitats representative of the area and use typical animal husbandry practices common in the area. These ranches are important wintering sites for BBSAs (Lanctot et al., 2002, 2010) and AMGPs (Clay et al., 2010) within the Rio de la Plata grasslands in southern South America (Fig. 1). Both species are typically present from October to February. Rocha lagoon was designated a Western Hemisphere Shorebird Reserve Network site of "Regional Importance" in 2010 on the basis of the numbers of BBSA present during the austral summer (> 6% of global population, https://www.whsrn.org/laguna-de-rocha). The lagoon is a shallow, brackish waterbody of about 20 000 ha in size that is intermittently connected with the Atlantic Ocean when a narrow sand bar overflows. Surrounding the lagoon are sand dunes, marshlands, and grasslands (Rodríguez-Gallego et al., 2012). Grasslands in the study area can be divided into lowland and upland areas. Lowlands consist of flat plains close to the lagoon margin that periodically flood when the water level rises. Upland areas are rolling grasslands that rarely
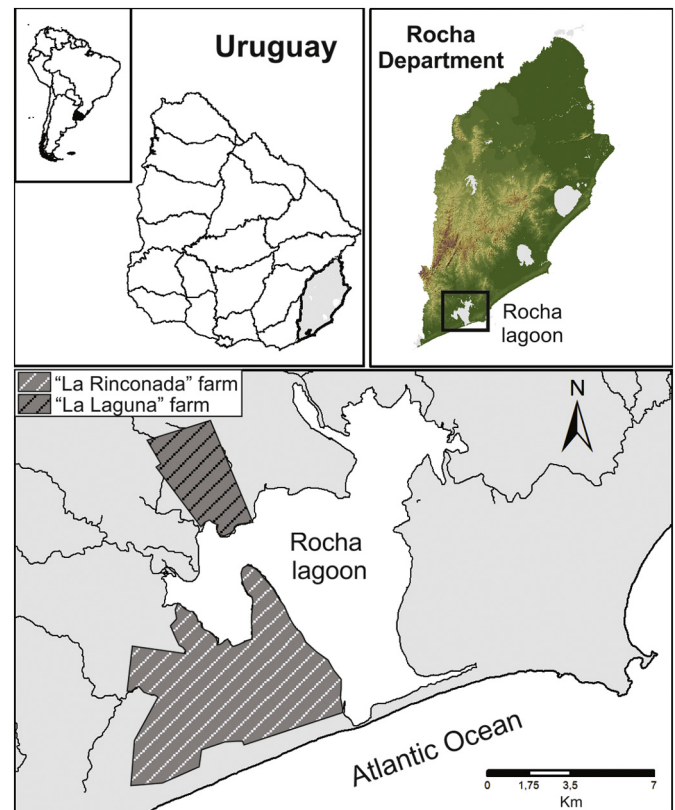
Figure 1. Location of the La Laguna and La Rinconada ranches where shorebird use and environmental variables were measured between 2006 and 2013.

flood and are used for agriculture (soybean, potatoes, and sorghum crops) or improved artificial pastures (Lapetina, 2011). Grasslands in the lagoon area are typically subdivided with fences into paddocks (i.e., pastures) of different sizes that are used for cattle and sheep grazing. Individual paddocks vary in their grass height, grassland type (improved or natural, see later), and amount of forest cover.

General Methods

We conducted three separate studies to evaluate how rangeland conditions affect the presence and abundance of BBSAs and AMGPs; the general and statistical methods of each follows.

Effects of Rangeland Conditions on BBSA and AMGP Presence and Abundance

To assess the effect of grass height, forest cover, and grassland type on the presence and abundance of BBSAs and AMGPs, we surveyed shorebirds in 16 paddocks (total area 1 913 ha) on the La Rinconada ranch (see Fig. 1) in December of 2006, 2007, 2008, and 2012. Paddocks were randomly selected and ranged in size from 32 to 345 ha (based on measures from ArcGis 10.0, Esri). Paddocks were surveyed once in December each year; shorebird numbers are relatively stable at this time of the nonbreeding season (Isacch and Martínez, 2003b). Paddocks were not surveyed during rain or when winds exceeded 25 km/hr, and as such, the date of the survey varied from year to year.

Shorebird surveys consisted of two observers simultaneously counting all visible BBSAs and AMGPs while walking along a single, fixed 700- to 1 000-m line transect (mean: 834 m, range: 600 − 800 m, standard deviation [SD]: 140 m) within each paddock. Line transects were randomly located within each paddock, and start and stop locations were identified using a Global Positioning System device. Surveys were conducted during the early morning (between 0 700 and 1 000 hr) or late afternoon (between 1 600 and 2 000 hr) when shorebirds are known to forage and thus are more visible (Myers, 1980; Aldabe, personal observation). Observations were made with 10×40 binoculars, and no correction for detectability was made, although we assumed the majority of birds were observed based on other analyses that indicated detectability was high in the relatively short grass paddocks (see later). We paid special attention to the location and movement of birds to avoid double counting the same individual and did not include flying individuals.

We estimated forest cover as the average angle occupied by trees within three 700-m radius circles located at the extremes and midpoint of each transect. To do this, we used Global Information System software and satellite images to quantify the percentage of degrees in a circle of 700-m radius that was occupied by trees. We did this in three circles per bird transect, with two circles located at each end of the transect and the third one in the middle of the transect. We then calculated the mean of these estimates to determine the average angle per transect. We used a 700-m radius because Wilson et al. (2014) had shown forest cover within this distance had the strongest explanatory effect on shorebird numbers. Each paddock was categorized as natural or improved on the basis of information provided by the landowner. Improved grasslands were grasslands seeded with exotic grasses and had fertilizers applied to maximize forage (Jaurena et al., 2016). All paddocks considered in the study were being grazed by cattle or sheep, or both. While grassland type and forest cover were static over the study period, grass height varied among years due to differences in grazing intensity. We measured grass height to the nearest cm every 100 m along each transect during each survey and used an average across the transect for the survey date in our analyses.

To model the effect of the rangeland use variables (i.e., grass height, forest cover, and grassland type) on the presence and abundance of BBSAs and AMGPs during the 4-yr study, we first analyzed if grass height and forest cover were collinear using variance inflation factor analysis (VIF); values below 5 indicate no collinearity problems (Zuur

et al., 2009). Grass height and forest cover were centered and standardized before the analyses so as to make their coefficients comparable (Schielzeth, 2010). The two species were modeled separately to account for potential ecological differences. We used hurdle models (or two-part models; Mullahy, 1986) to estimate the effect of grass height, forest cover, and grassland type on the occurrence (i.e., presence/absence) and abundance (i.e., counts) of each shorebird species. Hurdle models are a two-part GLM that considers the occurrence as a binary process that is separate from the conditional abundance modeled; the latter uses a zero truncated probability distribution (Mullahy, 1986). The underlying idea is that different ecological processes (and variables) may explain a species occurrence and its abundance (Zuur et al., 2009). We used a zero-truncated negative binomial probability distribution with a log link to model abundance and a binomial distribution with logit link to model occurrence. In abundance models, the log-transformed paddock area was used as an offset to account for the effect of the sampling area on bird counts (Fox et al., 2015). The data from each paddock in each year were considered as statistically independent data points, and thus counts across the four seasons were considered in a single statistical model. This rationale was based on the fact that grass height in the paddocks changed from year to year, and thus individual birds must decide whether to use a paddock each year on the basis of current conditions.

Arthropod Biomass Effects on BBSA and AMGP Densities

To determine whether arthropod biomass available for shorebird consumption was related to shorebird densities, we selected eight paddocks with short (< 6 cm) grass and low forest cover to remove any confounding effects of these variables on shorebird densities (forest cover was measured and included in models as a covariate to confirm it was not affecting shorebird densities). Paddocks were selected so that they had different slopes (flat or nearly flat, and with a slope clearly different from zero) and were different in distances to the lagoon, as these conditions may affect invertebrate abundance. We visually determined whether a paddock was flat or had some slope. Selected paddocks ranged from 0.1 km to 3.0 km from the lagoon edge. We surveyed birds and sampled arthropods along a single 600-m length transect weekly in each paddock from the end of December to mid-February in 2011/2012 (six surveys per paddock—one per week). Bird and arthropod sampling was done within 1 − 2 days of each other for each paddock, and all paddocks were separated by at least 1.5 km to ensure statistical independence.

We estimated arthropod biomass once a week with six pitfall traps placed 100 m apart along each paddock's 600-m transect. Pitfall traps were plastic; 20 cm deep and 11 cm wide; and filled with a mixture of ethylene glycol, water, and liquid soap. We identified each arthropod specimen to its taxonomic order using a dissecting microscope and measured their abdomen lengths with a digital caliper to the nearest 0.5 mm. We then estimated dry biomass of each arthropod individual by converting body length (mm) to biomass (mg) using Hódar's (1996; page 427) regressions. Because BBSA and AMGP food consumption is likely to be limited by the size of prey they can swallow, we restricted our estimate of arthropod biomass to those individuals < 1.5 cm in length, as this is the maximum size consumed by European Golden Plover *Pluvialis apricaria,* a slightly larger and related species (Gillings and Sutherland, 2007). As the number of active pitfall traps per paddock varied among sampling periods, as well as among paddocks, due to trampling by livestock (90% of the traps collected normally), we used the mean biomass per trap in each sampling date (week) in the statistical analysis (see later).

To model the probability of detecting birds, we first measured the distance between the observer and the bird, or center of group of birds, and the angle between the diagonal lines (observer to bird[s]) and transect line using a rangefinder and a field compass, respectively. We then estimated the probability of detecting a bird by modeling all the available distance/angle data for a given species within each paddock using program DISTANCE (Buckland et al., 2004). Different probabilities of detection
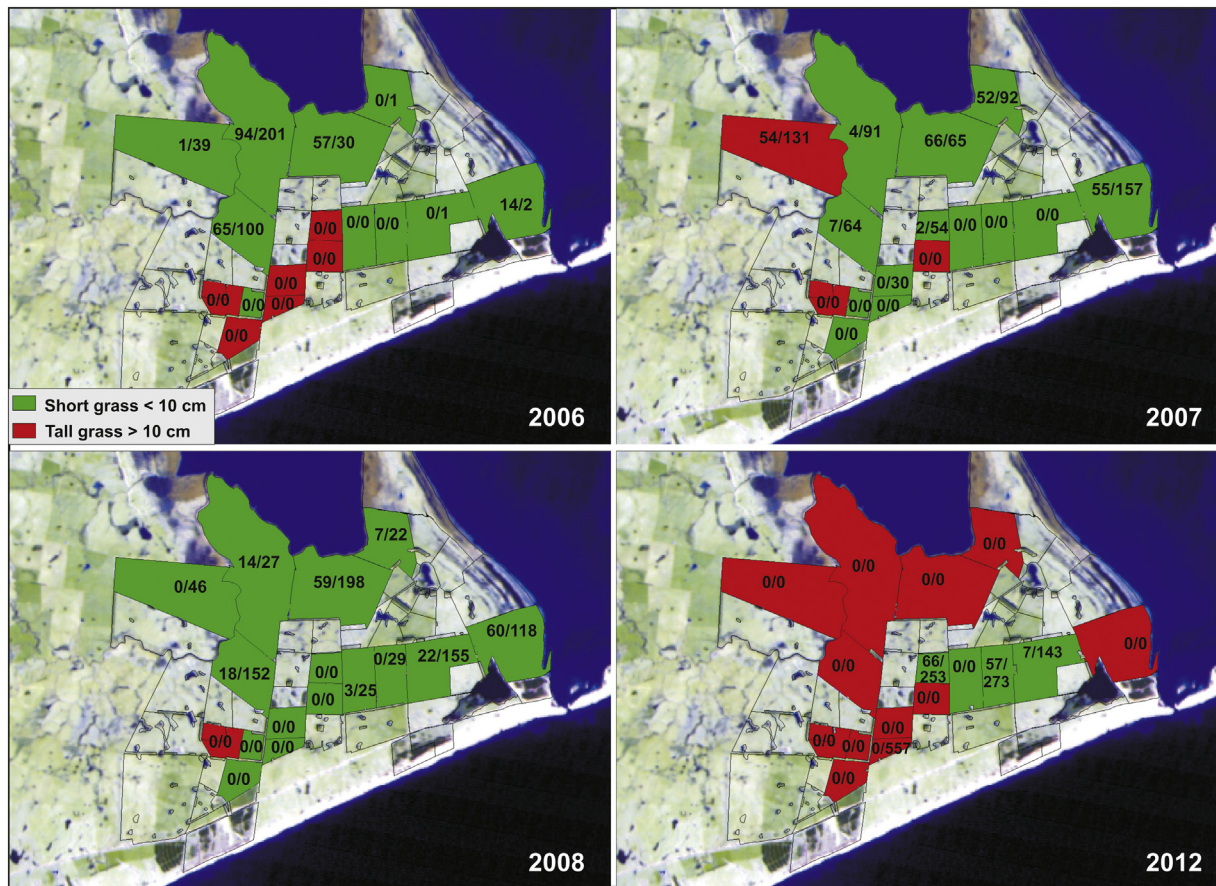
Figure 2. Number of buff-breasted sandpipers (left side of the bar) and American golden-plovers (right side of the bar) counted in each paddock during a single survey in December across 4 yr in the La Rinconada Ranch. Paddocks with no color were not sampled.

were determined using all candidate models available in DISTANCE (Buckland et al., 2004). Selection of the best model was conducted on the basis of Kolmogorov-Smirnov and Cramér-von Mises tests of goodness-of-fit, Qq plot, and Akaike Information Criterion (AIC; Burnham and Anderson, 2002). We then applied each paddock's probability of detection function to each survey to estimate the BBSA and AMGP densities within each paddock on a given survey.

To assess the effect of arthropod biomass on AMGP and BBSA densities in short grass, we calculated species-specific, linear mixed models with the bird density in each survey as the response variable and the mean arthropod biomass per week and forest cover as explanatory covariables. Because birds and arthropods were repeatedly sampled within paddocks, we used mixed models to consider the temporal correlation (West et al., 2007). Transect identity was considered as a random intercept. When fitted residuals increased with mean biomass values (nonhomogeneous variance), we modeled this with a fixed variance function structure that allows for larger residual spread when explanatory covariate increases ("varFixed" function from nlme R package; Pinheiro, 2016).

Effect of Grass Height on Arthropod Biomass and Bird Density

In a third study, we assessed arthropod biomass and bird density in four pairs of adjacent paddocks having tall (> 15 cm height) and short grass (< 6 cm height) during a 6-wk period between late December and early February in 2011/2012 and 2012/2013. Within each paddock, a 600-m length transect was randomly located and arthropods and shorebirds were sampled/surveyed weekly as described earlier. For our response variable, we used the cumulative amount of arthropod biomass in all traps over the 6-wk period. Occasionally traps were lost due to cattle trampling during the sampling week. In these cases, we standardized the number of traps and sampling days between paired

paddocks by reducing the sampling effort on the paddock with more trap days through the random exclusion of trap(s) from the same days. To assess grass height for each paddock, we determined the average grass height by measuring the height to the nearest cm every 100 m along each transect. These measurements were made once during the middle of the 6-wk period.

To determine the effect of grass height on arthropod biomass, we used a linear mixed model with cumulative arthropod biomass as the response variable and average grass height as the continuous explanatory variable. Given the nonindependence of transects in the same site, we used transect identity nested in site identity (i.e., in each site there are two paired paddocks) as a random effect. Because paddock pairs had

Table 1

Model coefficients explaining the effects of grass height and forest cover on the presence and abundance of buff-breasted sandpipers. The Count model evaluates the effect of covariables on the abundances without considering zeros, while the Zero hurdle model evaluates presence/absence as a function of covariates.

	Estimate	Std. error	z value	Pr (>|z|)
Count model coefficients (truncated negbin with log link):				
(Intercept)	−7.54	1.89	−3.97	$P < 0.0001$***
Grass height	−8.67	2.56	−3.38	$P < 0.001$***
Forest cover	−4.41	1.60	−2.75	$P < 0.006$**
Grass height * forest cover	−6.61	2.17	−3.04	$P < 0.005$**
Zero hurdle model coefficients (binomial with logit link):				
(Intercept)	−9.54	1.60	−5.94	$P < 0.0001$***
Grass height	−8.05	2.62	−3.07	$P < 0.005$**
Forest cover	−2.05	0.90	−2.27	$P < 0.05$*

*** $P < 0.001$.
** $P < 0.005$.
* $P < 0.05$.

Table 2
Model coefficients explaining the effects of grassland type, grass height, and forest cover on the presence and abundance of American golden-plovers. The Count model evaluates the effect of covariates on the abundances (without considering zeros), while the Zero hurdle model evaluates presence/absence as a function of covariates.

	Estimate	Std. error	z value	Pr (>|z|)
Count model coefficients (truncated negbin with log link):				
(Intercept)	−2.47	1.13	−2.18	P < 0.05*
Grassland type	1.43	1.30	1.10	P = 0.27
Grass height	−4.85	2.06	−2.36	P < 0.05*
Grassland type natural * grass height	4.55	2.29	1.99	P < 0.05*
Zero hurdle model coefficients (binomial with logit link):				
(Intercept)	−7.48	1.05	−7.08	P < 0.0001***
Grass height	−6.06	1.99	−3.03	P < 0.005**
Forest cover	−1.76	0.76	−2.30	P < 0.05*

no apparent differences in other land use variables (e.g., forest cover) other than grass height, no covariates apart from arthropod biomass were included in this analysis. Due to the lack of bird observations in the tall grass paddocks (all surveys = 0), we could not compare densities across paddock types. However, we generated bird densities for each short grass paddock and generated a mean and standard deviation to assess variation across the 6-wk survey period.

In all analyses, we obtained the minimally adequate model by stepwise model simplification. Each statistical model was started with the single effects and the pairwise interactions between explanatory variables. Models were then simplified by deleting nonstatistically significant terms whenever the difference in AIC between consecutive statistical models was smaller than two units (Zuur et al., 2007). All statistical models were evaluated by graphical residual analyses. All analyses were conducted with R 3.3.1 (R Development Core Team, 2016), using the "usdm" library (Naimi, 2017) for variance inflation factor analysis, the "pscl" library (Jackman, 2017) for hurdle models, the "visreg" library (Breheney and Burchet, 2017), and "ggplot2" (Wickham and Chang, 2016) for graphic visualizations. The "nlme" package (Pinheiro, 2016) was used to adjust linear mixed models. We report values as means ± 1 SD.

Results

Effects of Rangeland Use Conditions on BBSA and AMGP Presence and Abundance

Grass height varied between an average of 3.3 cm and 28.6 cm throughout the 16 paddocks across the 4 survey yr. Buff-breasted Sandpipers (BBSAs) and AMGPs both used mostly short grass paddocks and

only occasionally used tall grass paddocks above 10 cm in height (Fig. 2). Our hurdle model showed that grass height was the main driver of BBSA and AMGP probability of occurrence (Tables 1 and 2) and that AMGPs were able to use taller grasslands than BBSA. For example, for a probability of occurrence of 0.6, AMGPs need a minimum grass height of about 6 cm, while BBSAs need about 4 cm (Figs. 3 and 4). The probability of occurrence was very high (> 0.6) for both species when grass height was from 2 cm to 5 cm but dropped to near zero when grass height became > 8 cm tall (see Fig. 3).

About half of the 16 paddocks were occupied by both species in the first 3 yr (2006, 2007, 2008), but only three paddocks were occupied by both species in 2012. In the latter year, most paddocks had taller grass (height averaged 15.1 cm ± 8.1 cm in 2012 and 10.4 cm ± 10.4 cm between 2006 and 2008). As a consequence, average abundance per paddock was higher in the short grass paddocks in 2012 (32.5 BBSAs and 167.2 AMGPs) compared with the previous 3 yr (16.5 BBSAs and 43.7 AMGPs from 2006 to 2008). Therefore birds of both species tended to concentrate in the few short grass paddocks when tall grass was widespread in the ranch (see Fig. 2). However, there were two paddocks with tall grass that were used by one or both species during the study (one paddock in 2007 that had both species and another in 2012 with only AMGPs). The probability of occurrence in relation to grass height allowed us to determine habitat selection thresholds. BBSA probability of occurrence was relatively high (> 0.6) from 2 cm to 5 cm, while it drastically decreased when grass height was above 8 cm (see Fig. 3). AMGPs showed a relatively high probability of occurrence when grass height was between 2 cm and 5 cm and a very low probability of presence when grass height was above 10 cm (see Fig. 3). Even though short grass was the main driver of BBSA and AMGP habitat use, not all short grass paddocks were used, with between 25% and 39% lacking birds during each of the 4 survey yr, as forest cover also affected habitat selection of both shorebirds.

Our VIF analysis showed that grass height and forest cover had no collinearity problems (VIF between variables: 1.083). Forest cover varied from 3% to 69% among the sampled paddocks and was significantly negatively related to the probability of BBSA being present. However, the effect of forest cover on the probability of BBSA being present was one-fourth as strong as the effect of grass height (Table 1). The probability of occurrence of BBSA tended to be zero when forest cover was > 40% (see Fig. 3). In contrast to the occurrence analysis, BBSA abundance was affected by the interaction between forest cover and grass height (see Table 1). When the amount of forest cover was low, higher grass height corresponded with lower BBSA abundance (see Fig. 4), but when forest cover increased, the effect of grass height on BBSA abundance tended to disappear (see Fig. 4). Nine of the 16 paddocks were natural and seven were improved grasslands; this variable had no significant effect on the occurrence or number of BBSA detected (see Table 1).
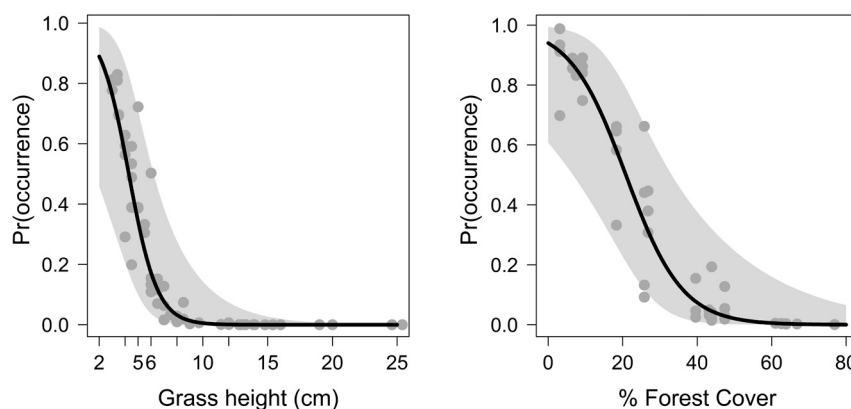
Figure 3. Hurdle model showing the negative effect of increasing grass height and increasing forest cover on the probability that buff-breasted sandpipers are present. Solid lines represent the fitted equation, and gray shaded areas represent the 95% confidence intervals around the line.
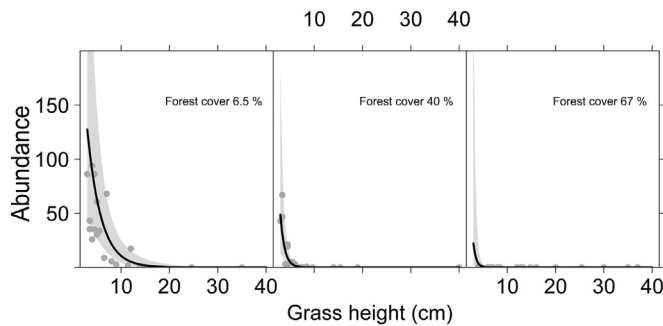
Figure 4. Hurdle model showing the relationship between grass height and different levels of forest cover on the abundance of buff-breasted sandpipers. Solid lines represent the fitted equation, and gray shaded areas represent the 95% confidence intervals around the line.

Similar to BBSA, the probability of AMGP occurrence was also negatively related to grass height and forest cover (Table 2, Fig. 5). The highest probability of occurrence for AMGPs was when grass height was between 2 cm and 5 cm, but the occurrence dropped off more slowly than observed in BBSA (see Fig. 5). Forest cover negatively affected the probability of occurrence of AMGPs (see Table 2), but unlike BBSAs, the probability of occurrence remained high in paddocks with high forest cover. Indeed, AMGPs were present in paddocks with 60% or more forest cover (see Fig. 5). Our analysis of AMGP abundance showed that grass height and an interaction of grass height and grassland type were important variables. The negative slope between grass height and AMGP abundances was 4.5 times greater in the natural grassland type in relation to the improved grassland type (see Table 2). This means that AMGP abundances decreased faster (i.e., reduced slope) with increasing grass height in improved grasslands relative to natural grasslands (see Table 2). Therefore, in natural grasslands AMGPs tolerated higher grass heights in relation to improved grasslands.

Arthropod Biomass Effects on BBSA and AMGP Densities

We collected 12 880 arthropod individuals that were potentially consumable (< 1.5 cm long) by BBSAs and AMGPs on the eight short grass, low-forest-cover paddocks sampled during 6 consecutive wk in 2011/2012. The most abundant taxon was Araneae (5 058 specimens), followed by Formicidae (3 310), Collembola (2 268), Hemiptera (854), Diptera (774), and Colleoptera (718). Arthropod dry biomass varied from 47 mg to 507 mg during the 6 weekly surveys. BBSA and AMGP densities varied from 0 to 14 birds/ha and 0 to 11.2 birds/ha, respectively, during the 6-wk survey. We failed to find a significant relationship between arthropod biomass and shorebird density for both

BBSAs and AMGPs in short-grass paddocks (BBSA: 0.009, df = 39, t-value = 1.19, $P = 0.24$; AMGP: 0.005, df = 39, t-value = 1.05, $P = 0.30$; Fig. 6). We also verified that we were successful in removing any confounding effect of forest cover on our analyses investigating arthropod biomass effects on shorebird densities, as there was no significant effect of forest cover on BBSA (-0.06, df = 6, t-value = -1.66, $P = 0.14$) or AMGP (0.003, df = 6, t-value = 0.12, $P = 0.90$) density.

Effect of Grass Height on Arthropod Biomass and Bird Density

Our analysis indicated that increasing grass height had a positive significant effect on accumulated arthropod dry biomass (df = 35, t-value = 3.919, $P < 0.001$). Despite this difference, shorebirds were only present in paddocks with short (< 7 cm) grass height (BBSA: 1.7 ± 1.1 ind/ha, AMGP: 3.8 ± 1.4 ind/ha).

Discussion

Our results support the tenet that grass height is the main driver behind the overwinter abundance and distribution of BBSAs and AMGPs in Rocha lagoon. The amount of forest cover was less important overall, but either alone or by interacting with grass height affected the presence or abundance of both shorebirds. Further, BBSA and AMGP densities were unrelated to arthropod biomass levels (i.e., both species were present in higher numbers in short grass paddocks with fewer arthropods). These results support the hypothesis that grassland shorebirds select areas to forage based not on the abundance of food but some other factor. This could be because prey (i.e., arthropods) are easier to detect in short grass paddocks or because avian predators of shorebirds can be more easily seen and thus avoided in paddocks with short grass (Colwell and Dodd, 1997; Isacch and Martínez, 2003a). On the basis of these results, we propose habitat selection thresholds that can be used for cattle grazing management that benefits both shorebird and cattle production.

In accordance with other studies, our results show that high grazing intensity is needed for maintaining suitable wintering habitat for BBSAs and AMGPs (Lanctot et al., 2002; Isacch and Martínez, 2003a; Blanco et al., 2004; Isacch and Cardoni, 2011). However, such intensive grazing may not be needed everywhere or throughout the entire year, as other species require different habitat conditions. Intensively grazed grasslands should be present in some part of the ranches, particularly during the austral summer, when the species are present (see later for discussion on grazing management; Isacch and Cardoni, 2011). Our findings suggest grass height is even more important than previously thought. Indeed, we found both species adjusted where they foraged within a ranch according to changes in grass height from year to year over the 4-yr period of our study. This adjustment was most evident in 2012 when heavy rains (255 mm precipitation vs. 121 mm average
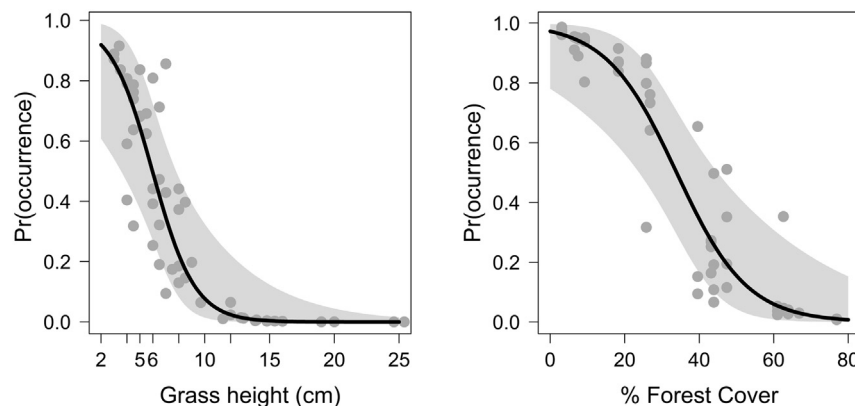
Figure 5. Hurdle model showing the negative effect of increasing grass height and increasing forest cover on the probability that American golden-plovers are present. Solid lines represent the fitted equation and gray shaded areas represent the 95% confidence intervals around the line.
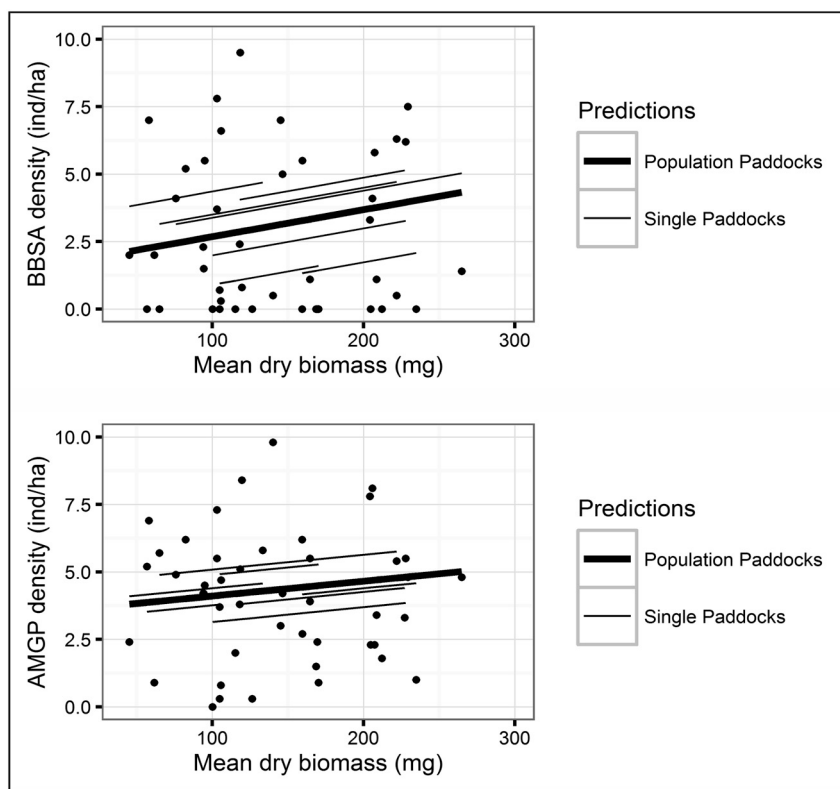
Figure 6. The predicted relationship between buff-breasted sandpipers (top) and American golden-plover (bottom) density and arthropod dry biomass as determined by the random intercept linear mixed model using data from eight short-grass paddocks sampled/surveyed between end of December to mid-February in 2011/2012. The thick line represents the fitted values for the entire population, and the other lines represent the within-group fitted curves for each of the 8 paddocks. In all cases the slope was not statistically significant different from zero.

in 2006 through 2008; data obtained from National Meteorological Institution, Montevideo, Uruguay) allowed grass to grow tall in most of the paddocks within the La Rinconada ranch; BBSAs and AMGPs left the paddocks occupied in previous years and either concentrated in greater numbers in the few remaining short grass paddocks or used nearby agricultural paddocks that had recently been harvested (Aldabe, personal observation). If precipitation increases in the future during spring, as is expected in Rocha Lagoon (Naggy 2012 unpublished results), we would predict grass heights to increase. Thus, to maintain short grass heights, rangeland professionals will need to modify grazing intensity, possibly by increasing the number of livestock within a smaller number of paddocks to keep up with faster growing grass. However, such high grazing intensities may damage grasslands in the long term. Thus, it is important to allow intensively grazed paddocks to recover after shorebirds migrate, by decreasing grazing intensities in the austral autumn and winter (see later for discussion on grazing management). This way, grassland integrity will be protected. However, if there is insufficient rainfall after high-intensity grazing, the grassland may not recover easily, requiring cattle to be completely removed from a paddock for a period of time. Rotational grazing systems, which enable high- and low-grazing intensities to coexist in a farm, would allow simultaneously having short and tall grass fields available; the latter could be used in these dry conditions to avoid long-term damage of short grass paddocks.

Our findings demonstrated that AMGPs can use taller grass areas compared with BBSA. This may be because AMGPs are physically taller than BBSAs (AMGP: 24 − 28 cm, Wiersma et al., 2017; BBSA: 18 − 20 cm, Van Gils et al., 2017) and, as a result, may be able to see approaching predators more easily in taller grass areas. Butler, Bradbury, and Whittingham (2005) reported a similar finding for farmland birds in England. AMGPs may also use taller grass areas because they employ a pause–travel searching mode when foraging (Wiersma et al., 2017;

Aldabe, personal observation); this strategy provides more head-up periods and thus may facilitate vigilance and feeding simultaneously in taller grasslands. BBSAs forage with their head down most of the time (Van Gils et al., 2017), potentially decreasing opportunities to detect predators in taller grass. These differences in grass height tolerance are important for grazing management and livestock production as 1 cm grass height means about 300 kg dry matter ha^{-1} of herbage mass for cattle production in Uruguayan ranches (Do Carmo et al., 2015).

The presence of both shorebird species was negatively affected by increasing forest cover. This finding is in accordance with other habitat selection studies of grassland shorebirds (e.g., Douglas et al., 2014; Wilson et al., 2014; Bertholdt et al., 2017). Prior researchers have suggested the avoidance of forest cover is due to forest patches being a source of predators (e.g., Masoero et al., 2016) or because birds perceive habitat obstructions as being dangerous (Cresswell, 1994; Devereux et al., 2006). This perception that predation risk is likely to increase appears to be a function of the visibility of the surroundings (Lima and Dill, 1990). The presence of obstructive cover may also require that birds increase vigilance while simultaneously decreasing their foraging rate (e.g., Devereux et al., 2006), and as a result birds may use these obstructed areas less intensively (e.g., Pomeroy et al., 2006). This idea is supported by other grassland shorebird studies on Snipe *Gallinago gallinago,* European Golden Plover *Pluvialis apricaria,* Northern Lapwing *Vanellus vanellus,* and Eurasian Curlew *Numenius arquata* that showed birds selected open paddocks instead of enclosed paddocks by hedges (Barnett et al., 2004; Gillings et al., 2007; Douglas et al., 2014). The perceived predation risk may therefore influence the local distribution and abundance of shorebirds in general (e.g., Cresswell, 1994; Pomeroy, 2006; Cresswell, 2008). Therefore, the observed negative relation between forest cover and AMGP and BBSA presence may be a reflection of the need for them to feed in open areas with high visibility and low perceived predation risk. This negative effect may have important

impacts on grassland shorebirds regional populations as planting of non-native shade trees such as *Eucalyptus* for livestock shelter is both widespread and frequent in the Rio de la Plata grasslands (Zalba and Villamil, 2002; Bilenca and Miñarro, 2004). Although more detailed behavioral work is needed to understand the mechanism behind how BBSAs and AMGPs distribute themselves within the paddocks, these findings indicate risk effects should be considered when managing habitat for the conservation of shorebird overwinter habitat in South American grassland (cf. Creel and Christianson, 2008). Besides, forested areas are frequently used by shorebird diurnal predators such as the Aplomado Falcon *Falco femoralis,* American Kestrel *Falco sparverius,* and Peregrine Falcon *Falco peregrinus* (Page and Whitacre, 1975; Bó, 1999; White et al., 2017; Aldabe, personal observation) and may thus favor direct mortality on grassland shorebirds. Both direct and indirect effects of predation (*sensu* Cresswell, 2008) on grassland shorebirds in the Rio de la Plata grasslands should be further studied.

Grassland type (i.e., improved or natural) did not affect the abundance of AMGPs when grass height was < 5 cm. However, AMGP abundance decreased faster with increasing grass height in improved grasslands relative to natural grasslands. Barnett et al. (2004) found that improved grasslands had denser grass cover than natural grasslands, potentially lessening the amount of bare ground and making prey harder to detect by grassland birds. On the other hand, local BBSA abundance and presence was not related to grassland type, which suggests that this species is only responding to vegetation height (forest cover was also important but not discussed here). This difference between species may be a result of their different foraging strategies (Van Gils et al., 2017; Wiersma et al., 2017), with BBSA spending less time vigilant and more time foraging. It seems likely that this behavioral difference is due at least in part to the ability of BBSA to rely on the more prevalent AMGPs to detect predators (Myers, 1980). This fact would allow the BBSAs to forage more successfully in the improved grasslands with more ground cover than the AMGPs and consequently eliminating any grassland type effect on BBSA foraging.

At first glance our finding that BBSA and AMGP densities were unrelated to arthropod biomass levels in eight paddocks chosen for their short grass and low forest cover was surprising. However, Stodola et al. (2014) also failed to find a similar relationship for AMGPs at a stopover site in North America. The absence or poor relationship between the density of grassland shorebirds and food abundance has also been recorded in other regions (Douglas and Pearce-Higgins, 2014; Machín et al., 2017). A possible explanation of our results is that there was not enough variation in arthropod biomass to drive changes in BBSA and AMGP densities in short grasslands. Also of interest was the discovery that AMGPs and BBSAs preferred to forage in short grass paddocks instead of tall grass paddocks, even though arthropod biomass was less. Several studies on grassland and farmland birds (including shorebirds) have shown that their food intake is maximized in short grass areas due to the easier detection of prey, as well as lower mobility costs (Butler and Gillings, 2004; Devereux et al., 2004; Atkinson et al., 2005; Butler, Whittingham, et al., 2005). More studies that include additional habitat variables such as slope and soil cover, among others, should be conducted for explaining the observed variation in shorebird densities in short grasslands.

Although our measure of arthropod abundance may not equate with food availability, this study reinforces the idea that habitat structure, rather than arthropod abundance, is a key driver of local distribution and abundances of South American grassland birds (Isacch and Cardoni, 2011; Azpiroz and Blake, 2016; Dias et al., 2017). The negative relationship between amount of forest cover and grassland birds has never been reported in South America previously and constitutes the first example of the likely importance of this variable for understanding grassland shorebird abundance and distribution. This may have important implications for grassland shorebird conservation at the regional scale. Additional work is required to understand habitat needs for BBSAs and AMGPs during the midday and nighttime periods when birds are roosting and may occupy areas away from foraging areas.

Implications

Rangeland professionals and wildlife managers must be cognizant of providing recommendations that help wildlife without hurting a rancher's economic interests. We have shown that very short grass (2–5 cm) is important for these two grassland shorebirds and that small increases in this grass height results in reduced use (although AMGPs are more tolerant of taller grasses). Unfortunately, from the livestock production perspective, this grass height may not be optimal given that livestock gain the most weight per day when grass heights are kept from 6 to 20 cm (depending on type of pasture and time of year, see Apezteguía et al., 1991; Rinaldi, 1997; Berreta, 2015). Therefore, it is clear that small changes in grass height are significant for livestock production (Do Carmo et al., 2015). Although the grass height needs of wildlife managers and rangeland professionals appear to be at odds, there are several ways to enhance both bird conservation and livestock production. First, we recommend promoting a grazing intensity that allows grass height to be maintained above 6 cm between February and September, when grassland shorebirds are absent from the wintering grounds. This would allow relative maximum livestock weight gain during 8 months of the year. Second, we recommend increasing grazing intensity so that grass height is from 2 – 5 cm between October and early February in a few, select paddocks with low forest cover. Paddocks with forest cover above 20% should be kept at taller grass heights (> 6 cm), as paddocks with this amount of forest cover are avoided by both species independently of grass height. Similarly, with regard to the management of AMGPs, paddocks that have been improved will likely have fewer birds than native paddocks if grass height is not maintained below 5 cm.

Our surveys on the La Rinconada ranch over multiple years indicate that shorebirds arriving in the spring are able to find these intensively grazed, forestless paddocks and likely concentrate in them, allowing a broad array of other paddocks to be managed for tall grass needed for livestock and other wildlife. Recognizing that this approach doesn't maximize livestock production on every paddock, it minimizes the economic losses to ranchers and allows them to proclaim their livestock as being raised in an ecologically friendly way. This approach also provides an opportunity to compensate ranchers in a direct manner (e.g., X dollars ha^{-1} of paddock managed) and the ability to evaluate the success of this approach. Alternatively, supplemental food (i.e., grains or alfalfa grown away from the paddocks) could be added to the short grass paddocks to augment cattle production. This supplement could be funded by the Southern Cone Grassland Alliance (www.alianzadelpastizal.org) through its green beef certification program or with other possible national and international support.

Forest cover provides protection to cattle from the sun during the hot summer months and as such is of paramount importance to livestock production (Bailey, 2005). Nevertheless, our study found that the amount of forest cover over 40% within a paddock decreased the probability of occurrence of both BBSAs and AMGPs. Recognizing the importance of shade to cattle, we propose several possibilities to reduce the impacts on shorebirds. First, new plantings of forest cover should be done on the edges of paddocks as opposed to in the middle to allow the maximum amount of uninterrupted paddock to be left exposed. Second, rangeland professionals should consider artificial coverings (e.g., canvas tents) that can be erected quickly and that have less vertical height and can be equipped with antiperching devices. The absence of visually obstructed areas would allow birds to see further and likely reduce the area perceived to be dangerous to the birds (Beauchamp, 2015). However, the latter should be further studied. Third, forest plantings within adjacent paddocks should be concentrated in one location so as to maximize the area free of trees. While these recommendations are a good start, we recommend further study on the area and spatial

arrangement of fields and adjoining forest cover, as well as on the economic impact of these management suggestions. For example, local relationships between livestock weight gains and grass height should be developed in order to maximize production and bird conservation.

Importantly, we recognize that there are many other wildlife species that occur in this grassland ecosystem and encourage more detailed studies on other species to assess how grassland characteristics affect their use. Ultimately the management of grasslands needs to be done in a well-designed manner so as to benefit as many wildlife species as possible while maintaining the economic viability of this ecosystem. Therefore, we propose a system of heterogeneous grazing intensity that optimizes both production and conservation of a variety of grassland birds, allowing the simultaneous existence of short and tall grass paddocks. This could be attained by promoting rotational grazing and/or other grazing system based on spatio-temporal variation of grazing intensity.

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