birds

Review

Avian Responses to Different Grazing Management Practices in Neotropical Temperate Grasslands: A Meta-Analysis

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Simple Summary: In the Neotropical temperate grasslands of southern Brazil, Argentina, and Uruguay, bird populations are known to be affected by cattle grazing practices. We conducted a quantitative review in order to assess how different grazing management practices impact bird abundance and richness. We compared ranches under continuous grazing management (control, CGM) to (1) ranches under technological inputs management (TIM, herbicides and exotic pastures) and (2) ranches under ecological process-based management (EPM), which include ranches that utilise controlled and rotational grazing. Our analysis showed that TIM had greater negative impacts on both bird abundance and richness than did CGM, which can be attributed to the fact that TIM simplifies vegetation structure. Compared with CGM, the effect of EPM on bird abundance is more dependent on grass height: EPM decreases the number of birds in short grasslands but increases bird abundance in tall grasslands, which can be attributed to differences in avian composition. Our results show that EPM practices contribute to the conservation of endangered tall-grass birds.

Abstract: Bird populations inhabiting the Rio de la Plata Grasslands in southern Brazil, Argentina, and Uruguay are known to be affected by livestock grazing practices. Cattle grazing can lead to changes in bird assemblages by affecting the heterogeneity of vegetation structures. We conducted a meta-analysis using studies that reported bird richness and abundance under different grazing management practices. We compared ranches under continuous grazing management (control, CGM) to (1) ranches under technological inputs management (TIM, herbicides and exotic pastures) and (2) ranches under ecological process-based management (EPM), which include ranches that utilise controlled and rotational grazing. We used random effects multilevel linear models to evaluate grazing regimen impacts. Our results indicate a negative impact of TIM on both bird abundance and richness (mean ± SE: -0.25 ± 0.07 and -0.92 ± 0.10, respectively) since the use of inputs simplifies vegetation structure and results in the loss of ecological niches. Compared to CGM, the influence of EPM on total bird abundance appears to be more dependent on grassland height, as evidenced by a decline in short grasses and increase in tall grasses. Our meta-analysis suggests that EPM practices may be beneficial for the conservation of endangered tall-grass birds.

Keywords: abundance; richness; Pampas; continuous grazing; rotational grazing; grassland conservation; ecological knowledge

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1. Introduction

Grasslands cover between 31% and 43% of the global ice-free land surface [1]. Historically, humans have used grasslands for grazing livestock or transformed them into croplands [2]. In the Neotropics, The Rio de la Plata Grasslands is one of the largest temperate grassland systems in the world [3]. The establishment of agroecosystems in the region, starting with the European colonisation in the 16th century [3,4], led to substantial changes in the structure and functioning of these ecosystems through the introduction of cattle and the use of fire [2,3,5]. During the 20th and 21st centuries, a sizeable proportion of grasslands were replaced by crops [6]. Currently, ~40% of the region remains as natural or semi-natural grasslands and is mostly used for cattle ranching. Only 1% of the region is covered by protected areas [2,7].

The traditional cattle management in the Rio de la Plata Grasslands is based on extensive continuous grazing on natural grasslands (continuous grazing management, or CGM), and it is still practiced in many areas [2,8]. Continuous grazing without adjusting stocking rates to match the forage supply and insufficient resting periods may lead to seasonal overgrazing [8,9]. In addition, continuous grazing creates spatial homogeneity by reducing tall grass areas and increasing low grass areas [10]. To address these issues, different technologies have been introduced by ranchers in the late twentieth and early twenty-first centuries [9,11]. Following the adoption of these technologies, two new types of management have been developed [9,12]. Technological input management (TIM) is based on the use of inputs such as herbicides, seeds, and fertilisers [12–14], whereas ecological process-based management (EPM) is based on ecological processes and grassland knowledge [10,15].

An example of TIM is the use of glyphosate to reduce competition and improve the winter supply of grass (e.g., annual ryegrass) [12]. However, this practice can affect grassland structure and its seed bank, leading to a further decline in the forage supply over a few years [16–18]. The degradation of grasslands due to traditional CGM and TIM underscores the need to adopt alternative management methods, like EPM, to conserve the remaining grasslands in the region [19]. EPM aims to achieve a more efficient use of the forage produced in different seasons and to improve grassland composition by regulating resting periods to ensure the seeding and establishment of cool-season grasses [9,16]. Some examples of such practices include rotational and controlled grazing, which involve the creation of paddocks with similar plant communities and the application of disturbances (instantaneous stocking rates) followed by resting periods [10,11,16]. Evidence shows that rotational grazing promotes high-value winter forage production [20] and also increases the spatial and temporal heterogeneity of vegetation structure, which creates a wider variety of habitats for biodiversity [11,21].

In the Río de la Plata Grasslands, there are 109 avian species classified as Southeastern South America grassland birds (hereafter SESA grasslands birds) [4], 22 of which are listed as threatened or near threatened [22]. Vegetation height is a highly influential factor for biodiversity in general and for grassland birds in particular. It is common to observe an assemblage of short-grass specialists, tall-grass specialists, and broad species that utilise the entire vegetation height gradient [4,23,24]. Changes in land use in the Pampean region have resulted in a decrease in the populations of some grassland birds, such as the Saffron-cowled Blackbird (*Xanthopsar flavus*) and the Bay-capped Wren-spinetail (*Spartonoica maluroides*) [22,25,26]. Different grazing management strategies lead to different grass species compositions [19], thus modifying the habitat conditions for grassland-dependent birds [27]. Therefore, the type of grazing management can affect the impact of grazing on bird diversity [4].

The spatial and temporal homogeneity induced by CGM on grasslands [10] can negatively affect the birds that rely on tall grass for food, shelter, and reproduction [28]. The application of inputs such as herbicides and seeds intensifies the degree of grassland transformation, benefiting certain generalist species (non-SESA birds) while decreasing the presence of grassland specialists, some of which are threatened [29,30]. On the contrary, the delineation of areas with similar plant communities in EPM promotes grassland heterogeneity [9] and provides a wider range of habitats for different grassland species [28]. In this regard, some studies indicate that management practices that promote spatial heterogeneity are associated with a more spatially diverse avian community [31,32].

At present, there are no comprehensive reports about the influence of different grazing management practices on grassland bird richness or abundance in the Río de la Plata Grasslands. Building upon CGM as the historical grazing management practice in the region, we conducted a meta-analysis to investigate the responses of the bird assemblage to different grazing management practices. We compared CGM to TIM and hypothesised that management practices incorporating technological inputs support lower bird richness and abundance compared to continuous grazing. In addition, we compared CGM to EPM and expected to find that EPM supports greater bird richness and abundance than CGM, particularly with respect to SESA grasslands birds.

2. Materials and Methods

2.1. Study Area

The Río de la Plata Grasslands extend over eastern and northeastern Argentina, all of Uruguay, and southern Brazil, forming an arc around Río de la Plata and occupying ~750,000 km^2 [2,3]. The region has moderate mean temperatures ranging from 14° in the south to 18° in the north [3]. Rainfall also varies from 500 mm in the southwest to 1600 mm in the northeast and is highly variable interannually [33,34]. A highly diverse grassland has been the predominant physiognomy of the region since the Quaternary [2,4].

Although the Río de la Plata Grasslands are generally considered uniform in their topography and physiognomy, it is possible to identify different ecological units according to their geological, geomorphological, edaphic, and floristic characteristics (Figure 1) [3]: Rolling Pampas, Flat Inland Pampas, West Inland Pampas, Flooding Pampas, Southern Pampas, Mesopotamic Pampas, Southern Campos, and Northern Campos. In the southern half of the region (Pampas), graminoid steppes and prairies were the original dominant vegetation (*Nassella*, *Piptochaetium*, *Aristida*, *Melica*, *Briza*, *Bromus*, *Eragrostis*, and *Poa*), while in Southern and Northern Campos, the dominant grass species belong to the genera *Paspalum*, *Andropogon*, and *Axonopus* [3,34]. Cattle ranching continues to be an important activity in the remaining grasslands, primarily in the Flooding, Southern, and Inland Pampas, as well as in the Northern Campos (Figure 1) [6,34].

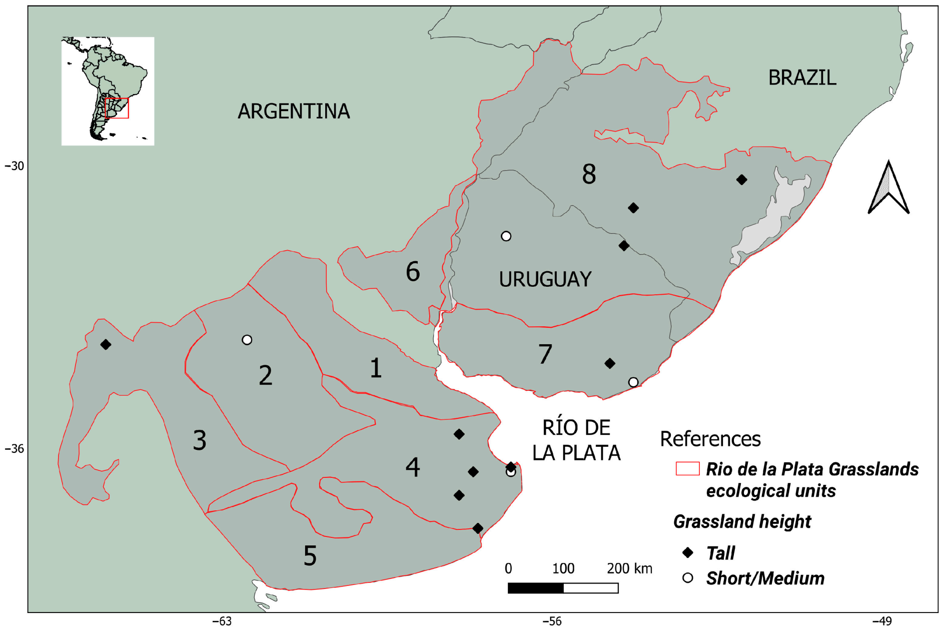


Figure 1. Río de la Plata Grasslands [3] with the location of the case studies included in the meta-analysis (black diamonds for tall grasslands and white circles for short/medium grasslands) and the ecological units (red lines). Ecological units: (1) Rolling Pampas; (2) Flat Inland Pampas; (3) West Inland Pampas; (4) Flooding Pampas; (5) Southern Pampas; (6) Mesopotamic Pampas; (7) Southern Campos, and (8) Northern Campos.

2.2. Literature Search and Data Extraction

We conducted a literature search for articles studying landbird assemblages in the Río de la Plata Grasslands under different grazing management practices following PRSIMA 2020 guidelines [35]. We conducted the search in the Scopus database and also included the first 200 results from Google Scholar in August 2023 for all kinds of publications. We used the following search string: (bird* OR avian) AND (livestock OR cattle OR ranch* OR farm* OR graz*) AND (grassland OR rangeland) AND (Pampa* OR Campos OR Argentin* OR Brazil OR Uruguay OR Paraguay). We then removed duplicates and screened the titles and abstracts of the remaining articles to identify those studying the responses of the bird assemblages to different grazing management strategies in the region. We excluded articles that did not study birds, studies that did not compare grazing management practices, and studies that did not correspond to the study area. Subsequently, we reviewed the full text of all selected articles and excluded those that did not report bird richness or abundance for CGM (i.e., control) and TIM or CGM (i.e., control) and EPM (Figure 2).

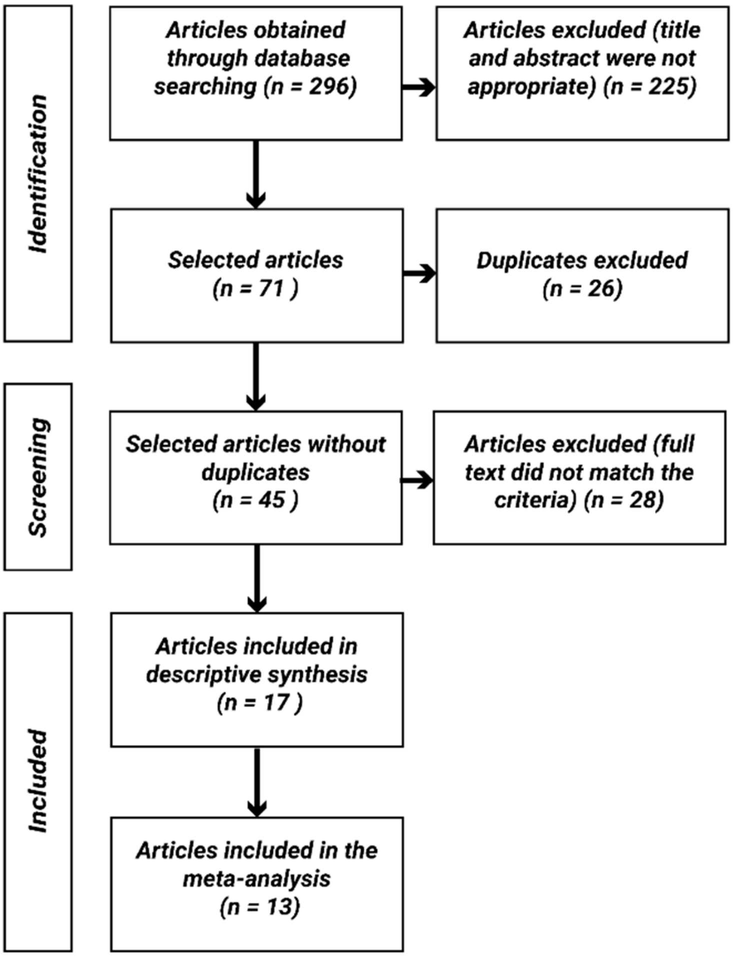


Figure 2. Flow chart of the literature search and the article selection for the meta-analysis (PRISMA 2020) [35].

For the analysis, we used all the landbird assemblages and focused on the SESA grasslands bird list [4]. The distribution area of SESA grasslands birds substantially overlaps with that of the Río de la Plata Grasslands [3]. Therefore, we adopted the classification of SESA grasslands birds [4], which categorises grassland bird species into three groups based on habitat grass height: (1) short-grass species (<20 cm), (2) tall-grass species (>40 cm), and (3) broad species (that use both short and tall grasslands or require patches of short grass in a matrix of tall grass).

For each case study described, we extracted the mean and variance for bird richness and abundance and the sample size for each grazing management technique. Additionally, when the bird species list was provided, we calculated the abundance and richness of SESA grasslands birds (total bird count, restricted to SESA grasslands bird species) [4]. We classified management practices as TIM when natural grasslands were replaced with implanted pastures (ryegrass *Lolium* spp., lotus *Lotus* spp., etc.) promoted with the use of herbicides. We classified management as EPM when one or more of the following practices were present: rotational grazing, resting grazing periods, controlled grazing, single herds, or conservative stocking rates (below 0.8 animal per hectare). In all other cases, we considered management as CGM, which is the traditional method involving long-term retention of herds in the same area without additional technological inputs or ecological knowledge-based management of the grassland. When articles presented multiple treatment comparisons, we included all those that were aligned with the focus of our study, and considered these comparisons as nested in that study [36].

Then, we employed different methods for data extraction depending on the available information in each article. When explicit estimators were provided (e.g., mean, variance, etc.), we directly extracted them from the article. When the information was presented only in figures, we used either the metaDigitise package in R [37,38] or the WebPlotDigitizer program [39] to extract the estimators. When data extraction from the article was not feasible, we contacted the authors whenever possible to request missing data. If no data could be extracted, we only included the articles for descriptive synthesis. Then, to standardise the mean, variance, and sample sizes values, we evaluated the effect size (difference in the response variable means between two management practices) by calculating the Hedges' *d* unbiased standardised mean difference [40] for each study, using the escalc function of the metafor package [41] in R [38]. Hedges' *d* is an index that allowed us to compare studies that use different sampling methodologies [42]. We extracted data about grassland height as a possible moderator variable. We classified the studied grasslands as "tall" or "short/medium" using the grass species composition reported in the articles.

2.3. Data Analysis

We included total bird richness and abundance and SESA grasslands bird abundance as response variables (the lack of studies prevented us from including SESA grasslands bird richness as a response variable). For each studied response variable, we fit a random effects multilevel linear model, which includes fixed (moderator) and random effects. This model assumes that studies have their own effect sizes and that they are selected randomly from a population of studies [42–44]. The models were fitted using the restricted maximum likelihood (REML) rma.mv function of the metafor package [41] in R [38]. When enough studies were available, we included grass height as a moderator (fixed effect) and tested the influence of this moderator using the Test of Moderators in the metafor package [41]. To account for the hierarchical dependence, we included the study ID as a random variable, since more than one study came from the same article [36,43]. We considered the effect size as small (0.2), moderate (0.5), and large (0.8) [45]. Due to the small sample sizes that result in low power in the tests, and the cost in this kind of research of type 2 errors, we used an alpha level of 0.1 to interpret the results [46,47].

The heterogeneity of effect sizes was assessed using the Q statistic [40]. To determine whether effect size and error were correlated, we examined potential publication bias through funnel plots [48] and by calculating Kendall's tau correlation [43]. Additionally, we calculated Rosenthal's fail-safe number to assess whether there was an effect due to the unpublished articles that found no differences between management practices [49].

3. Results

3.1. Descriptive Synthesis

We obtained 18 study cases from 17 different articles (one study [50] included two study cases that were independent since they corresponded to different ecological conditions). Almost half of the study cases (47%) corresponded to the Flooding Pampas in Argentina and 29% to the Northern Campos of Uruguay and Brazil (no studies were found for the Rolling, the Mesopotamic, or the Southern Pampas). More than 70% of the studies corresponded to tall grasslands while the rest of them corresponded to short or medium grasslands (Figure 1). There were 142 bird species present in the selected articles, 76 of which were classified as SESA grasslands birds (14 short-grass species, 12 tall-grass species, and 50 broad species; Appendix A).

A total of 14 of the 18 selected study cases were finally included in the meta-analysis for at least one response variable (Table 1). Two articles [51,52] were excluded since they only studied the abundances of a few species instead of the entire assemblage, and another two studies were excluded due to insufficient data [53,54].

Table 1. List of study cases included in the meta-analysis. CGM: continuous grazing management, TIM: technological input management, EPM: ecological process-based management, R: richness, A: abundance, SA: Southeastern South America (SESA) grasslands bird abundance.

Authors and Year [Reference]	Ecological Unit	Grassland Height	Management Practices	Response Variables Extracted
Agra et al. 2015 [29]	Flooding Pampas	Tall	TIM-CGM	R, A, SA
Azpiroz and Blake 2009 [55]	Northern Campos	Short/medium	TIM-CGM	R, A, SA
Brandolin et al. 2016 [56]	Flat Inland Pampas	Short/medium	EPM-CGM	A, SA
Cardoni et al. 2015 [57]	Flooding Pampas	Tall	EPM-CGM	R, A, SA
Codesido and Bilenca 2021 [28]	Flooding Pampas	Tall	EPM-CGM	R, A, SA
Codesido and Bilenca 2021 [58]	Flooding Pampas	Short/medium	TIM-EPM-CGM	R, A, SA
Da Silva et al. 2015 [59]	Northern Campos	Tall	TIM-CGM	A, SA
Dias et al. 2017 [60]	Northern Campos	Tall	EPM-CGM	R, A
Fontana et al. 2016 [30]	Northern Campos	Tall	TIM-CGM	R, A
Isacch et al. 2005 [61]	West Inland Pampas	Tall	TIM-CGM	R
Isacch and Cardoni 2011 [50]	Flooding Pampas	Short/medium	EPM-CGM	R, A, SA
Isacch and Cardoni 2011 [50]	Flooding Pampas	Tall	EPM-CGM	R, A, SA
Pírez and Aldabe 2022 [62]	Southern Campos	Tall	EPM-CGM	R
Vaccaro et al. 2020 [63]	Flooding Pampas	Tall	EPM-CGM	A, SA

3.2. Comparison Between TIM and CGM for Bird Abundance and Richness

Out of the 14 study cases included in the meta-analysis, 7 studies compared TIM with CGM. There is a small negative influence of TIM on total bird abundance compared to CGM (Figure 3A; $p < 0.01$). For this comparison, five study cases were included, and no heterogeneity was found among the effect sizes (Q test = 5.4, df = 4, $p = 0.25$). In addition, there is a small negative influence of TIM on SESA grasslands bird abundance compared to CGM (Figure 3A; $p < 0.01$). For this comparison, four study cases were included, and no heterogeneity was found among the effect sizes (Q test = 1.4, df = 3, $p = 0.71$).

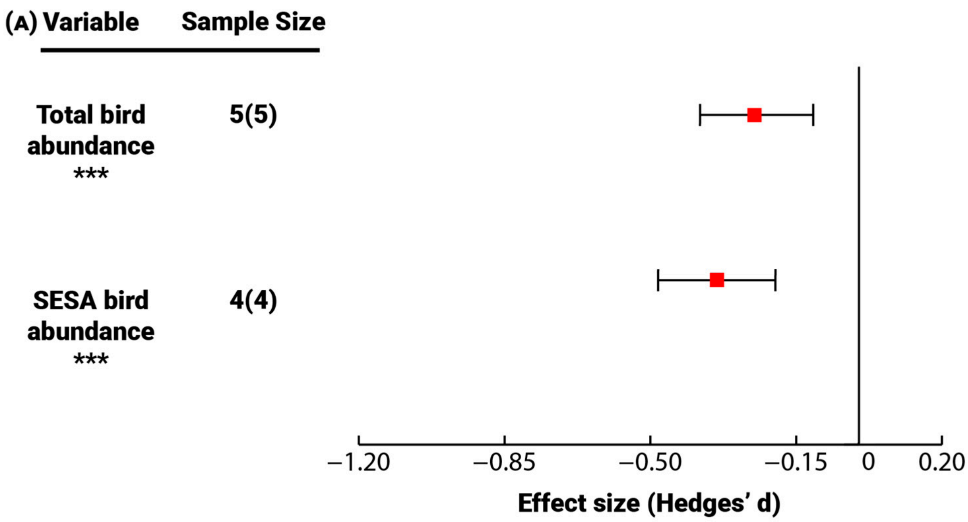
There is a large negative influence of TIM on bird richness compared to the influence exacted by CGM (Figure 3B; $p < 0.01$). For this comparison, five study cases were included, and no heterogeneity was found among the effect sizes (Q test = 4.4, df = 4, $p = 0.35$). There were not enough articles reporting SESA grasslands bird richness to analyse this variable for comparison.

3.3. Comparison Between EPM and CGM for Bird Abundance and Richness

We did not detect a greater influence of EPM on bird abundance compared to that of CGM (Figure 4A.; $p = 0.96$). For this comparison, 10 study cases were included (8 independent studies), and we found heterogeneity in the effect sizes between studies (Q test = 44.9, df = 9, $p < 0.01$). Thus, to interpret the heterogeneity in effect sizes, we included grassland height in the model as a moderator.

The influence of EPM on total bird abundance compared to CGM depends on grassland height (Test of Moderators = 3.3, df = 1, $p = 0.07$). For short and medium grasslands, we detected a negative influence of EPM on total bird abundance compared to CGM (Figure 4A; $p = 0.09$), whereas for tall grasslands we observed the opposite trend, with a positive influence of EPM on total bird abundance compared to CGM in most articles, even though the mean effect size did not differ significantly (Figure 4A; $p = 0.17$).

We did not detect a significantly different influence on bird richness from EPM compared to that of CGM ($p = 0.33$). For this comparison, eight study cases were included, and there was heterogeneity among effect sizes (Q test = 361.2, df = 7, $p < 0.01$). This heterogeneity could not be explained by including grassland height as a moderator (Test of Moderators = 0.15, df = 1, $p = 0.7$).



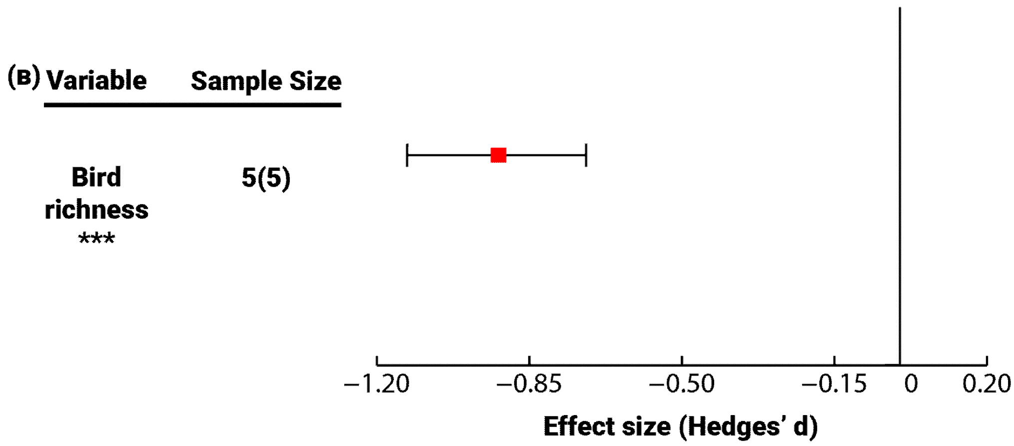


Figure 3. Mean effect size (square) of technological input management (TIM) on (**A**) total bird abundance and Southeastern South America (SESA) grasslands bird abundance and (**B**) bird richness. All variables include 95% confidence intervals (lines). Sample size indicates the number of study cases included in the meta-analysis, and the number of independent studies is given in parentheses. Significant difference among categories: NS—not significant, *** $p < 0.01$.

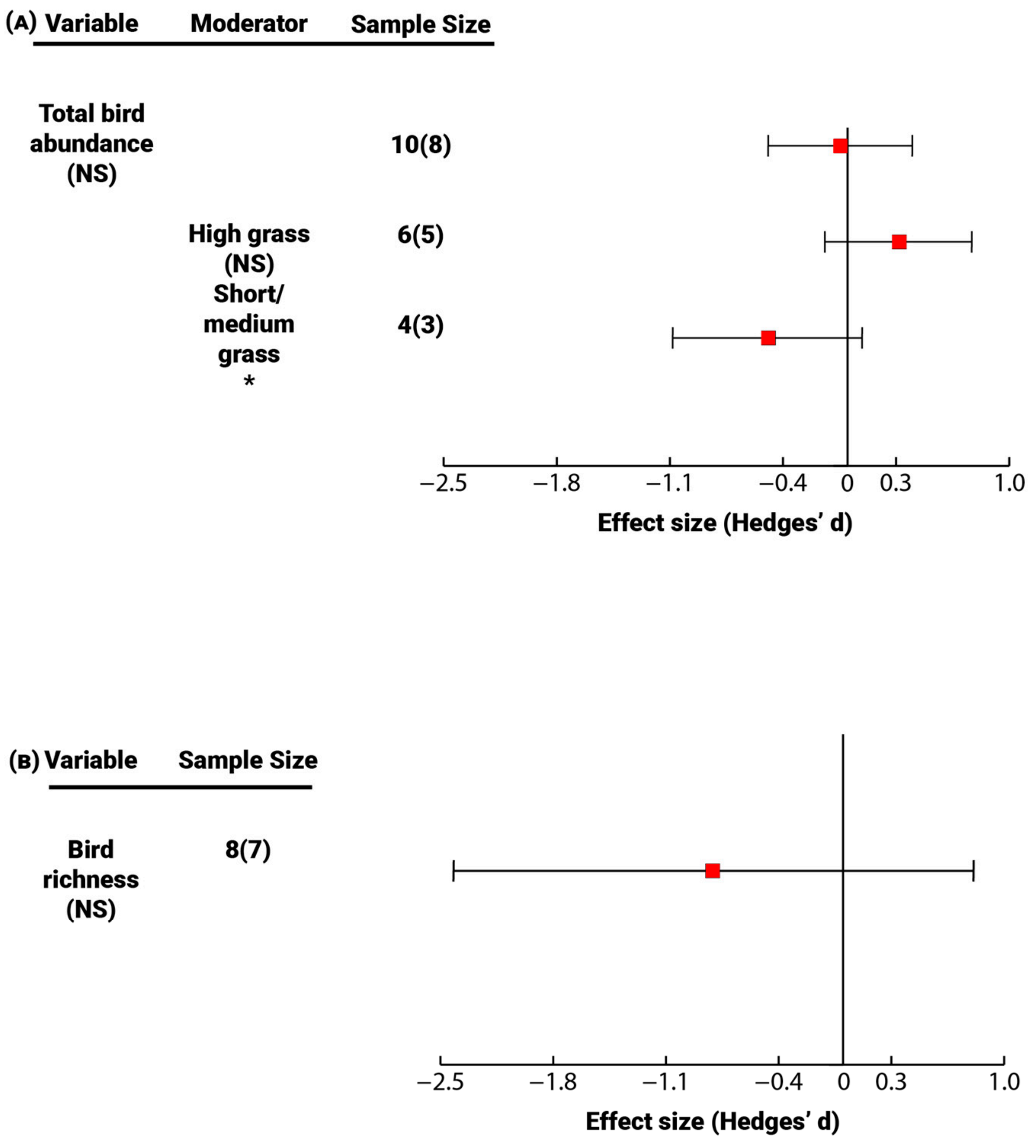


Figure 4. Mean effect size (square) of ecological process-based management (EPM) on (**A**) total bird abundance (overall effect and different grassland heights) and (**B**) bird richness. All variables include 95% confidence intervals (lines). Sample size indicates the number of study cases included in the meta-analysis, and the number of independent studies is given in parentheses. Significant difference among categories: NS—not significant, * $p < 0.1$.

3.4. Publication Bias

For both comparisons (TIM-CGM and EPM-CGM), the funnel plots showed a uniform distribution of positive and negative effects for all the variables, but they also showed a lack of studies with high standard error or lack of statistical significance (Appendix B). Nevertheless, we found no correlation between the effect size and precision for all variables (Kendall's Tau correlation test; Appendix B). For the comparison between TIM and CGM, Rosenthal's fail-safe N indicated that 24 additional studies would be needed to change the result for total bird abundance. For SESA grasslands bird abundance, 30 studies would be needed, and for richness, 168 studies would be needed. For the comparison between EPM and CGM, Rosenthal's fail-safe N was not calculated due to the lack of effect for all variables. Thus, considering the low number of studies available in the region, the risk of publication bias is very low.

4. Discussion

4.1. Comparison Between CGM and TIM for Bird Abundance and Richness

In Neotropical temperate grasslands, TIM is associated with lower bird abundance than is CGM, which is consistent with our hypothesis. TIM is associated with a transformation, or even replacement, of the grassland structure; thus, it is expected to have a more pronounced effect on birds than CGM does [64]. In addition, herbicide applications associated with TIM remove weeds that birds can use for perching and feeding [29], whereas insecticide applications reduce or eliminate arthropod populations that serve as a food source for insectivorous birds [65,66]. In this regard, there is an extreme historical case of misuse of pesticides and its impact on birds, in which direct mortality was documented in the Swainson's Hawk (*Buteo swainsoni*), which feeds on locusts targeted by chemical control [67].

Responses of the bird assemblages to TIM can be understood by the abundances of particular avian groups. One of the studies analysed here [55] found that insectivorous SESA grasslands birds (some of which face conservation issues), such as the Short-billed Pipit (*Anthus furcatus*), were more abundant in grasslands under CGM than under TIM. The same study showed that generalist species are more abundant under TIM than under CGM [55]. These species (non-SESA grasslands birds) include the Eared Dove (*Zenaida auriculata*) and are usually granivorous and associated with disturbed habitats [55]. Additionally, another study [52] found that short grass favoured higher abundances of two migratory shorebirds: the Buff-breasted Sandpiper (*Calidris subruficollis*) and the American Golden-plover (*Pluvialis dominica*). The abundance of *Pluvialis dominica* strongly decreased as grass height increased under TIM, probably because implanted pastures had a denser cover that could interfere with prey and predator detection [52,68,69]. Finally, some authors observed that broad species, such as the Great Pampa Finch (*Embernagra platensis*), were more abundant under CGM compared to TIM [30].

In accordance with our hypothesis, TIM also corresponds with lower bird richness than CGM does. In this regard, note that the application of chemical inputs simplifies the vegetation structure and leads to a loss of habitat for many species, particularly for grassland species [52,70,71]. Regarding this matter, many SESA grasslands birds were only detected in fields under CGM (Appendix A) [30]. That is the case of the Saffron-cowled Blackbird and the Ochre-breasted Pipit (*Anthus nattereri*), both of which are grassland species included in the IUCN Red List (globally threatened and vulnerable, respectively) [22] (see also [72]). Tall-grass specialists, such as the Tawny-bellied Seedeater (*Sporophila hypoxantha*), the Wedge-tailed Grass-finch (*Emberizoides herbicola*), and the Lesser Grass-finch (*Emberizoides ypiranganus*), were also detected under CGM and not under TIM. A study [58] observed lower bird richness under TIM due to the absence of SESA grasslands birds such as the American Golden-plover and the Buff-breasted Sandpiper (both present in CGM; Appendix A). Another study [29] found a higher richness of generalist species (non-SESA grasslands birds) under TIM and a higher richness of grassland species (SESA grasslands birds) under CGM (Appendix A). The latter includes species like the Brown-and-yellow Marshbird (*Pseudoleistes virescens*), the Bay-capped Wren-spinetail, and the Hudson's Canastero (*Asthenes hudsoni*), the last two of which are considered threatened in Argentina [73].

4.2. Comparison Between CGM and EPM for Bird Abundance and Richness

Grassland height helped to explain the differences between studies in the responses of bird abundance to EPM compared to CGM. On the one hand, in short grasslands, CGM maintains a greater cover of short grasses, which are used by many migratory shorebirds, such as the American Golden-plover and the Buff-breasted Sandpiper, as well as other short-grass specialists, such as the Austral Negrito (*Lessonia rufa*) and the Southern Lapwing (*Vanellus chilensis*), and broad species such as the Correndera Pipit (*Anthus correndera*; Appendix A) [50]. On the other hand, in tall grasslands, birds may be indirectly affected by the reduction in vegetation height [50], and tall-grass specialists such as the Bay-capped

Wren spinetail and the Grass Wren (*Cistothorus platensis*) are less abundant under CGM (Appendix A) [28,50,51,57].

We found no greater influence of EPM on bird richness compared to CGM. However, EPM may have a greater contribution to the retention of some grassland specialists in assemblage compositions compared to CGM [60]. EPM favours heterogeneity in vegetation structure, whereas CGM represents a constant and uniform disturbance [31]. Some tall-grass species, such as Hudson's Canastero, benefit from this heterogeneity because they require bare patches of soil for foraging [50]. Some authors [62] did not observe any species restricted to only one management practice, but they proposed that some grassland species, such as the Great Pampa Finch, the Freckle-breasted Thornbird (*Phacellodomus striaticollis*), the Brown-chested Martin (*Progne tapera*), and the Grassland Yellow-finch (*Sicalis luteola*), had greater occurrences under rotational grazing (Appendix A). In tall grasslands, although there are no differences in richness, there is a substitution of species in the assemblage. Under EPM, there is a higher representation of tall grassland birds and species of conservation concern, which are less abundant or are absent under CGM (Appendix A) [28,62].

4.3. Conservation Implications

Considering that only a small fraction of the Rio de la Plata Grasslands is contained within protected areas, management practices introduced by ranchers on their properties play a key role in grassland conservation. This meta-analysis provides a regional approach that contributes to the existing literature on the importance of adopting management practices that take into account ecological knowledge to support grassland bird conservation. We found that the responses of bird assemblages to management practices are associated with grassland height. In tall grasslands, EPM is important for the conservation of tall-grass birds. Short-grass species are dependent on grazed areas, but they are affected by grassland replacement associated with TIM. However, different studies indicate the existence of several barriers to the adoption of ecological knowledge-based practices in the region, including the lack of knowledge by ranchers, which can be addressed by extension services, and a lack of economic incentives for producers [74,75]. The poor integration of these practices suggests the need for the development of policies that create socio-economic conditions for the ranchers to adopt more sustainable management practices based on ecological knowledge [76].

4.4. Study Limitations

Although this study provides evidence of the responses of avian assemblages to grazing management practices in the region, certain limitations arise from the scarce and diverse current literature on the topic. We found only two studies that reported data about SESA grasslands bird richness [28,58], so we could not analyse this variable, which could have provided more valuable insights. In addition, it would have been interesting to compare the three management practices simultaneously, but we could only find one study that included that comparison [58]. Another limitation of this study comes from the wide variety of practices included in EPM, each one of which may affect bird assemblages differently. We included grassland height as a moderator to account for some of this variability. However, other details of management practices, such as stocking rates and the duration of resting periods, are important to quantify for a better understanding of bird responses to management practices. Some studies did not report this information and prevented us from including them as moderator variables.

5. Conclusions

Our regional meta-analysis showed some general patterns of bird abundance and richness in response to grazing management practices in Neotropical temperate grasslands. As expected, we found that TIM reduces both bird abundance and richness more strongly than CGM does. These results highlight the strong negative impact of the application of chemical inputs on bird assemblages in the region's grasslands, showcasing that these management practices are not desirable for the conservation of grassland birds, particularly for those species of regional conservation concern.

In this study, we expected to find that fields under EPM would support a higher bird abundance and richness than fields under CGM. However, EPM has a different influence on bird abundance depending on grass height, with a lower bird abundance (particularly by migrant shorebirds) in short grasslands, and a positive but not significant impact on bird abundance in tall grasslands. We did find changes in the assemblage composition between the two managing practices; in particular, tall-grass birds and species of conservation concern were more representative of fields under EPM.

Finally, these results indicate the importance of considering management practices that take into account ecological characteristics of grasslands and that promote vegetation heterogeneity in order to reconcile beef production and biodiversity conservation in Neotropical temperate grasslands.

Author Contributions: Conceptualization, M.C. and D.B.; methodology, F.N. and M.C.; software, F.N.; validation F.N. and M.C.; formal analysis, F.N.; investigation, M.C.; resources, F.N., D.B. and M.C.; data curation, F.N.; writing—original draft preparation, F.N.; writing—review and editing, F.N., D.B. and M.C.; visualisation, F.N.; supervision, D.B. and M.C.; project administration, D.B. and M.C.; funding acquisition, D.B. and M.C. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Ethical review and approval were waived for this study due to its observational nature.

Data Availability Statement: Data will be made available upon reasonable request to the lead author.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. List of species for the comparison between continuous grazing management (CGM) and technological input management (TIM) for each study included in the meta-analysis (we only present studies that included a list of species or those for which the authors provided it). * Species present in the study. SESA: Southeastern South America.

	[58]		[61]		[30]		[59]		[55]		[29]	
Species	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**
Short-grass SESA species												
Theristicus caudatus						*						
Pluvialis dominica	*	*							*		*	
Oreopholus ruficollis									*			
Vanellus chilensis	*	*		*	*	*	*	*	*	*	*	*
Athene cunicularia	*	*		*			*	*	*	*		*
Calidris subruficollis	*								*			
Geositta cunicularia							*		*			
Cinclodes fuscus	*											
Lessonia rufa	*	*										
Neoxolmis rufiventris									*			
Anthus lutescens					*		*	*				*
Anthus furcatus							*		*	*		
Tall-grass SESA species												
Spartonoica maluroides											*	
Phacellodomus striaticollis					*		*	*			*	
Polystictus pectoralis										*	*	
Cistothorus platensis					*		*					
Poospiza nigrorufa					*							
Emberizoides herbicola					*							

Table A1. *Cont.*

	[58]		[61]		[30]		[59]		[55]		[29]	
Species	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**
Emberizoides ypiranganus					*							
Sporophila hypoxantha					*							
Sporophila ruficollis										*		
Broad SESA species												
Rhea americana	*	*	*			*	*	*	*	*		
Rhynchotus rufescens			*	*	*	*	*	*		*	*	*
Nothura maculosa	*	*			*	*	*	*	*	*	*	
Nothura darwini			*	*								
Bubulcus ibis		*									*	*
Elanus leucurus											*	
Circus cinereus		*										
Circus buffoni	*	*								*	*	
Buteogallus meridionalis					*							
Cariama cristata					*		*	*				
Caracara plancus	*	*	*								*	*
Milvago chimango	*	*	*	*	*	*					*	*
Falco femoralis			*								*	
Bartramia longicauda									*			
Asio flammeus			*								*	
Colaptes campestris	*				*	*	*	*	*	*	*	*
Furnarius rufus					*	*	*	*				
Anumbius annumbi	*		*	*	*	*	*	*	*	*	*	*
Asthenes hudsoni	*	*									*	

Table A1. *Cont.*

	[58]		[61]		[30]		[59]		[55]		[29]	
Species	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**
Hymenops perspicillatus	*						*					
Xolmis cinerea					*		*	*	*	*		
Xolmis irupero			*			*	*	*	*	*		
Heteroxolmis dominicana							*	*				
Machetornis rixosa					*		*		*	*		
Tyrannus savana	*	*			*	*	*	*	*	*		
Alopochelidon fucata										*		
Progne tapera	*				*	*			*	*	*	*
Tachycineta leucorrhoa	*	*			*	*			*	*		*
Hirundo rustica		*										
Mimus saturninus					*	*	*	*				*
Anthus correndera	*	*	*	*	*						*	*
Anthus chacoensis			*	*								
Anthus hellmayri					*	*	*		*			
Anthus nattereri					*				*			
Sicalis luteola	*	*	*	*			*	*	*	*	*	*
Donacospiza albifrons					*		*					
Embernagra platensis		*			*	*	*	*		*	*	*
Ammodramus humeralis			*	*			*	*	*	*	*	*
Xanthopsar flavus					*		*					
Pseudoleistes guirahuro							*	*				
Pseudoleistes virescens	*	*			*	*	*	*	*	*	*	
Molothrus bonariensis	*		*	*	*	*	*	*	*	*	*	*

Table A1. *Cont.*

	[58]		[61]		[30]		[59]		[55]		[29]	
Species	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**
Molothrus rufoaxillaris					*	*						
Leistes loyca			*	*								
Leistes defilippii									*			
Leistes superciliaris	*	*	*		*	*	*	*		*	*	*
Non-SESA species												
Ardea alba											*	
Egretta thula											*	
Plegadis chihi	*	*										*
Phimosus infuscatus												*
Theristicus caerulescens									*			
Chauna torquata	*	*										
Syrigma sibilatrix		*					*		*	*		*
Rupornis magnirostris											*	
Chroicocephalus maculipennis		*									*	
Tringa flavipes		*										
Limosa haemastica												
Himantopus melanurus		*										
Gallinago paraguaiae									*	*		
Myiopsitta monachus	*	*					*	*		*	*	*
Calidris bairdii							*					
Patagioenas picazuro							*	*	*	*		
Zenaida auriculata	*	*					*	*		*	*	
Columbina picui							*	*				
Leptotila verreauxi							*					

Table A1. *Cont.*

	[58]		[61]		[30]		[59]		[55]		[29]	
Species	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**	**CGM**	**TIM**
Guira guira							*	*				
Tapera naevia							*					
Chlorostilbon lucidus	*											
Colaptes melanochloros							*					
Pyrocephalus rubinus							*					
Hirundinea ferruginea							*					
Satrapa icterophrys							*					
Tyrannus melancholicus							*	*				*
Pitangus sulphuratus	*						*	*			*	
Agriornis murina				*								
Progne chalybea										*		
Stelgidopteryx ruficollis									*			
Notiochelidon cyanoleuca									*			
Turdus rufiventris							*	*				
Turdus amaurochalinus							*					
Troglodytes aedon				*								
Spinus magellanicus	*						*				*	
Saltator aurantiirostris								*				
Zonotrichia capensis	*	*	*	*			*	*	*		*	*
Paroaria coronata												
Diuca diuca			*									
Sicalis flaveola	*		*				*	*			*	
Gnorimopsar chopi							*					
Agelaioides badius			*				*					

Table A2. List of species for the comparison between continuous grazing management (CGM) and ecological process-based management (EPM) for each study included in the meta-analysis (we only present studies that included a list of species or those for which the authors provided it). * Species present in the study. SESA: Southeastern South America.

	[28]		[58]		[50]A		[50]B		[63]		[57]		[56]			[60]		
Species	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM1**	**EPM2**	**CGM**	**EPM1**	**EPM2**
Short-grass SESA species																		
Theristicus caudatus																*	*	
Theristicus melanopis									*									
Pluvialis dominica		*	*	*	*	*				*								
Vanellus chilensis	*	*	*	*	*	*	*		*	*	*		*	*	*	*	*	*
Charadrius modestus					*													
Athene cunicularia			*	*					*	*			*	*		*		
Calidris subruficollis			*	*	*	*				*								
Geositta cunicularia																*		
Cinclodes fuscus			*	*	*	*	*	*			*							
Lessonia rufa			*	*	*	*		*		*	*							
Anthus lutescens									*									
Anthus furcatus													*		*	*		
Tall-grass SESA species																		
Spartonoica maluroides	*	*					*	*	*	*		*		*				
Phacellodomus striaticollis								*		*								
Polystictus pectoralis									*	*				*				
Pseudocolopteryx flaviventris		*								*								
Cistothorus platensis	*	*						*		*		*	*	*	*			*
Emberizoides herbicola																		*
Volatinia jacarina																		*
Sporophila ruficollis														*				
Sporophila cinnamomea																		*

Table A2. *Cont.*

	[28]		[58]		[50]A		[50]B		[63]		[57]		[56]			[60]		
Species	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM1**	**EPM2**	**CGM**	**EPM1**	**EPM2**
Broad SESA species																		
Rhea americana			*	*	*				*	*								
Rhynchotus rufescens		*							*	*				*				*
Nothura maculosa	*		*	*					*	*			*	*	*	*	*	*
Bubulcus ibis				*					*	*						*		
Elanus leucurus														*				
Circus cinereus	*	*		*						*								
Circus buffoni	*	*	*	*					*	*				*				
Buteo swainsoni									*									
Caracara plancus			*	*	*				*									
Milvago chimango	*	*	*	*	*	*		*	*	*		*	*	*	*	*		
Falco sparverius									*					*				
Falco femoralis	*														*			
Bartramia longicauda									*							*	*	
Asio flammeus								*						*				
Colaptes campestris		*	*	*	*	*				*				*	*	*	*	
Furnarius rufus					*	*				*								
Anumbius annumbi			*							*						*	*	
Asthenes hudsoni	*	*	*				*			*		*						
Hymenops perspicillatus	*	*	*	*		*		*		*		*						
Machetornis rixosa																	*	
Tyrannus savana			*	*	*	*		*	*	*			*	*	*	*	*	*
Progne tapera			*						*	*								
Tachycineta leucorrhoa	*	*	*	*					*	*								

Table A2. *Cont.*

	[28]		[58]		[50]A		[50]B		[63]		[57]		[56]			[60]		
Species	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM1**	**EPM2**	**CGM**	**EPM1**	**EPM2**
Hirundo rustica				*					*	*								
Petrochelidon pyrrhonota									*									
Mimus saturninus																	*	
Anthus correndera	*	*	*	*	*	*	*	*	*	*	*							
Anthus chacoensis									*									
Anthus hellmayri										*			*	*	*	*	*	*
Sicalis luteola	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*
Donacospiza albifrons		*								*							*	*
Embernagra platensis	*	*		*			*	*	*	*		*	*	*	*			*
Ammodramus humeralis								*		*						*	*	*
Agelasticus thilius	*	*					*	*	*			*						
Xanthopsar flavus														*				
Pseudoleistes virescens	*	*	*	*	*	*	*		*	*								
Molothrus bonariensis		*	*		*	*				*							*	*
Molothrus rufoaxillaris										*						*		
Leistes superciliaris		*	*	*					*	*				*	*			
Non-SESA species																		
Coscoroba coscoroba										*								
Dendrocygna viduata									*	*								
Anas bahamensis														*				
Ardea alba								*										
Egretta thula													*					
Plegadis chihi			*	*	*	*	*		*	*			*		*			
Platalea ajaja									*									

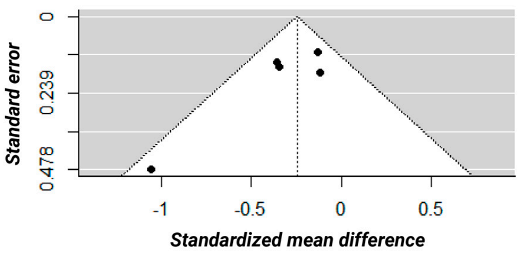
Table A2. *Cont.*

	[28]		[58]		[50]A		[50]B		[63]		[57]		[56]			[60]		
Species	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM1**	**EPM2**	**CGM**	**EPM1**	**EPM2**
Ciconia maguari							*	*	*	*	*							
Mycteria americana										*								
Rostrhamus sociabilis									*	*								
Chauna torquata			*	*		*			*	*								
Ixobrychus involucris	*																	
Syrigma sibilatrix									*	*								
Pardirallus sanguinolentus	*						*			*		*						
Porzana spiloptera		*																
Chroicocephalus maculipennis				*														
Tringa flavipes					*				*	*								
Tringa melanoleuca										*								
Limosa haemastica				*														
Himantopus melanurus				*					*									
Gallinago paraguaiae	*																	
Myiopsitta monachus			*	*														
Phalaropus tricolor					*									*				
Patagioenas picazuro														*	*			
Zenaida auriculata			*	*					*	*								
Guira guira		*												*	*			
Nycticryphes semicollaris	*	*						*		*								
Chlorostilbon lucidus			*															
Phleocryptes melanops		*								*								
Certhiaxis cinnamomeus										*								
Limnornis curvirostris										*								

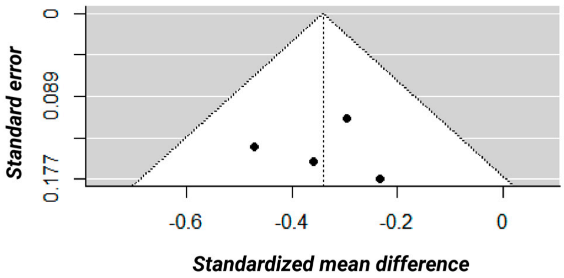
Table A2. *Cont.*

	[28]		[58]		[50]A		[50]B		[63]		[57]		[56]			[60]		
Species	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM**	**CGM**	**EPM1**	**EPM2**	**CGM**	**EPM1**	**EPM2**
Pseudocolopteryx sclateri										*								
Serpophaga munda														*				
Pyrocephalus rubinus										*							*	
Satrapa icterophrys		*								*								*
Tyrannus melancholicus		*																*
Pitangus sulphuratus		*	*	*	*	*	*		*	*								*
Knipolegus lophotes																		*
Progne chalybea									*									
Progne elegans									*									
Troglodytes aedon										*								
Spinus magellanicus			*	*						*								
Zonotrichia capensis	*	*	*	*					*	*		*	*	*	*	*	*	*
Sicalis flaveola			*							*								
Sporophila caerulescens										*								
Agelaioides badius																	*	
Chrysomus ruficapillus										*								
Sturnus vulgaris										*								

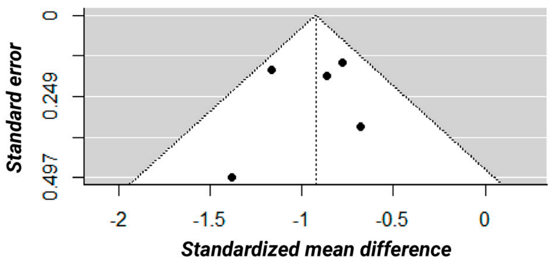
Appendix B



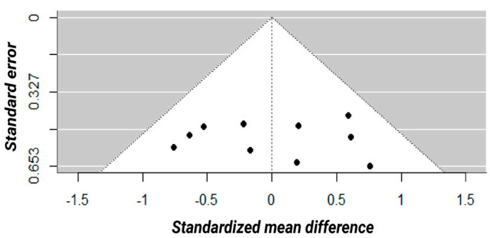
(**A**)



(**B**)



(**C**)



(**D**)

Figure A1. Funnel plots with the relation between standardized mean difference and standard error for (**A**) total bird abundance (technological input management–continuous grazing management); (**B**) Southeastern South America (SESA) grasslands bird abundance (technological input management–continuous grazing management); (**C**) bird richness (technological input management–continuous grazing management); and (**D**) total bird abundance (ecological process-based management–continuous grazing management).

For the comparison between TIM and CGM, we obtained the following values of correlation between effect size and precision: total bird abundance (Kendall's Tau = −0.4, p = 0.5), SESA grasslands bird abundance (Kendall's Tau = 0.3, p = 0.8), and richness (Kendall's Tau = −0.2, p = 0.8). For the comparison between EPM and CGM, we obtained the following value: total bird abundance (Kendall's Tau = −0.02, p = 1).

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