Environment, Development and Sustainability
https://doi.org/10.1007/s10668-022-02261-2

Beef–cattle ranching in the Paraguayan Chaco: typological approach to a livestock frontier

M. J. Milán[1] · E. González[1]

Received: 10 October 2021 / Accepted: 2 March 2022

Abstract

The Paraguayan Chaco has experienced, in the last few decades, some of the highest rates of deforestation in the world. In parallel, this region has registered an increase in the number of cattle heads of 60% in the last decade. Taking into account the high environmental and socioeconomic impact of this expansion, the aim of this work was to reveal how Beef–cattle ranching is carried out and to establish a typology that allows us to identify the different land-use patterns followed by the ranches. Data were collected using face-to-face structured interviews of 80 ranch owners. In the region ranches co-exist that practise the cow–calf system, the whole-cycle system and the fattening system. In all cases, ranches are very large, pasture based, highly specialised in Beef–cattle and export-oriented. Three groups of ranches were identified, being the main differentiating drivers: (i) the availability of the different production factors, (ii) the distribution of total area, and (iii) the degree of intensification in the use of capital, labour and/or technology per unit of agricultural area. In addition, it is noted that the years of activity of the ranches are related to these drivers. The typology of ranches contributes to a better understanding of one of the most active livestock frontiers in the world and shows that the expansion process taking place in the Paraguayan Chaco is associated with an intensification of Beef–cattle systems. These results provide a useful approach to develop policies that regulate the expansion of the cattle frontier in the Paraguayan Chaco.

Keywords Tropical deforestation · Farming systems · Sustainable development · Principal component analysis

1 Introduction

The tropical dry forests of the Paraguayan Chaco, located in the west of Paraguay, have become a deforestation hotspot as a consequence of the cattle ranching expansion (Baumann et al., 2017; Caldas et al., 2015; le Polain de Waroux et al., 2018). The Gran Chaco, in which the Paraguayan Chaco is located, has, in the last few decades, experienced some

✉ M. J. Milán
MariaJose.Milan@uab.cat

[1] Department of Animal and Food Science, Universitat Autònoma de Barcelona, 08193 Bellaterra, Spain

Published online: 30 March 2022

of the highest rates of deforestation in the world: 14 million ha (12.0% of its total territory) of forests have been converted to agricultural land between 1985 and 2013 (Baumann et al., 2016; Graesser et al., 2015). More specifically, in the Paraguayan Chaco, an average annual rate of deforestation of 1.0% was reported between 1987 and 2012, with a total loss of 44,000 km^2 of forest (Baumann et al., 2017). The rate of deforestation more than doubled between 2001 and 2012, as compared to the one observed between 1987 and 2000. Fundamentally the forest is turned into grassland for animal feeding (Baumann et al., 2016, 2017; Caldas et al., 2015), making cattle ranching the main type of land-use in the Paraguayan Chaco, after forests.

Although the main driver of this expansion is the significant increase in demand for meat worldwide (Tilman & Clark, 2014), other factors that are considered drivers of the expansion of agricultural frontiers (Caldas et al., 2015; le Polain de Waroux et al., 2016, 2018; Meyfroidt et al., 2018; Piquer-Rodríguez et al., 2018) have concurred in the Paraguayan Chaco favouring the development of Beef–cattle ranching in recent decades. Among these factors, the availability of low-priced land stands out; while purchasing new land is cheaper than carrying out the tasks necessary to restore the soil, the livestock frontier will continue to advance (Kaimowitz & Angelsen, 2008; Soto & Gómez, 2012; le Polain de Waroux et al., 2016, 2018). Furthermore, improvements in accessibility (Barber et al., 2014; Rudel, 2007) created by the construction of the Transchaco route in the 1960s, and technological improvements in novel areas that improve soil productivity, such as drainage systems, or research into drought-resistant pastures that are well adapted to the climatic conditions of the Chaco (Glatzle, 2004; Glatzle et al., 2019; Schnellmann et al., 2018) are favouring the aforementioned expansion.

In addition, two drivers are considered relevant for an understanding of what has happened in the Paraguayan Chaco in the last 20 years, these being competition for the use of the land and restrictions in the legislation of certain specific, neighbouring areas. Thus, the rise in the price of soy in relation to beef created incentives to convert traditional pastures into land for soybean cultivation, driving out and displacing Beef–cattle ranching into cheaper, forested areas (Barona et al., 2010; Fehlenberg et al., 2017; Gasparri & le Polain de Waroux, 2015; Nepstad et al., 2006; Parente et al., 2019). The restrictions on deforestation legislation in neighbouring countries, and the approval in 2004 of the zero-deforestation law which affected the eastern region of Paraguay, prompted a significant number of agricultural producers and investors from Brazil, Argentina, Uruguay and eastern Paraguay to purchase large areas of land in the Paraguayan Chaco in the last decade of the last century and the first decade of the current one (Baumann et al., 2017; le Polain de Waroux, 2019).

This expansion of the livestock frontier, the activities that are being carried out and how they interact with the ecosystem, is a key process of global environmental change. The growth of bovine censuses in the Paraguayan Chaco, besides being the direct cause of the aforementioned deforestation, has also been accompanied by an increase in the area cultivated with highly productive exotic grasses such as Gatton panic (Panicum maximum) and Buffel grass (Cenchrus ciliaris), advances in beef crossbreeding creating well-adapted hybrid breeds, such as Brangus and Braford breeds that respond to the quality requirements demanded by the market, the construction of modern refrigerated slaughterhouses in the area and other related supply industries, as well as changes in the ownership and structure of the land (Baumann et al., 2016, 2017). All of this contributes to a high environmental and socioeconomic impact, which is part of the wide and current debate on food security and sustainability of livestock systems (Garnett et al., 2013; Phalan et al., 2011; Springmann et al., 2018). In this sense, knowledge and assessment of the sustainability of livestock systems are a key step in the challenge facing society today. This is more evident when we are not talking about traditional livestock systems, but rather about new systems that are occupying areas that until now were in pristine conditions.

The evaluation of the sustainability of livestock production systems requires prior knowledge of how the livestock activity is related to the environment in which it is developed and what characteristics it has in terms of structure, use and combination of resources (Díaz-Gaona et al., 2019; Stylianou et al., 2020). Moreover, the establishment of typologies is useful to understand and capture the heterogeneity of situations that arise and their underlying factors, facilitating the development of policies that are well adapted to the different co-existing realities and ensure the sustainability of such livestock production systems (Bussoni et al., 2019; Escribano et al., 2016; Milán et al., 2006; Stylianou et al., 2020; Toro-Mujica et al., 2019).

In view of the scarcity of works that have studied the livestock frontier of the Paraguayan Chaco, from the point of view of Beef–cattle ranching, we aim to improve knowledge about these livestock systems. In this work, we address the following questions: What are the main Beef–cattle production systems in the area? What factors determine them? Are there patterns across time and space in relation to the occurrence of the typologies? The answers to these questions are the first step to assess the sustainability of these livestock systems and design public policies and actions that regulate and improve the relationship between Beef–cattle ranching and its environment. Hence, our specific objective here is, on the one hand, to characterise Beef–cattle ranching in the Paraguayan Chaco and show what trends are observed and, on the other hand, to establish a typology that allows us to identify the different land-use patterns followed by the ranches.

2 Materials and methods

2.1 Study area

In Paraguay, livestock farming is one of the most significant sectors of its economy, accounting for 2.4% of its GDP in 2019 (BCP, 2021). Bovine is the predominant livestock, which has tripled is bovine, which has tripled in volume over the last 50 years, currently standing at 14.0 million head of cattle (SENACSA, 2020). The rate of increase in the bovine population has accelerated in recent years, such that between 2010 and 2020, the volume of cattle rose 24.0% (SENACSA, 2020). Most of this production was destined for exportation, which places Paraguay as the ninth largest exporter of bovine livestock in the world, with 371,000 tonnes exported in 2020 alone (USDA, 2019). Although the Paraguayan eastern region (Región Oriental) contains the majority of the bovine population, it is the western region (Región Occidental), or the Paraguayan Chaco, that has recorded the greatest increase in cattle numbers in recent years: 59.9% between 2010 and 2020 (SENACSA, 2020). The result is that currently, the bovine census in the Paraguayan Chaco amounts to 6.7 million head of cattle (SENACSA, 2020), which means an average density of 27 head per km^2, a value close to the density of neighbouring areas of Brazil (16 head per km^2 in Pará and 32 head per km^2 in Matto Grosso) and the Argentine Chaco (11 head/km^2) according to Fernández et al. (2020). Currently, three types of Beef–cattle production co-exist in the Paraguayan Chaco: (1) the cow–calf system that only carries out breeding, (2) the fattening system, which buy calves after weaning to rear them for slaughtering, and (3) whole-cycle system, which combine breeding and fattening. However, there are no statistics on which system predominates, nor how they are distributed throughout the region.

The Paraguayan Chaco forms part of the Gran Chaco, one of the largest remaining patches of forest/savanna ecosystems in Latin America. This dry woodland ecoregion covers more than 114 million hectares and is divided among Argentina (59%), Paraguay (23%), Bolivia (13%), and Brazil (5%) (Naumann, 2006). Specifically, the Paraguayan Chaco occupies 61% (246,925 km^2) of the Paraguayan territory and is divided into three departments (there being a total of seventeen in the country): Alto Paraguay, Boquerón, and Presidente Hayes (Fig. 1). This region has an exceedingly low population density; only 3% of Paraguay's population resides there (Vázquez, 2007).

The Paraguayan Chaco is characterised by a flat topography, ranging from 80 m.a.s.l. in the eastern section to 400 m.a.s.l. in the west. The average temperature is around 25ºC, with maximums reaching 40ºC. The rainy season is the warmest and lasts from October to April. The highest levels of rainfall are found on the eastern side of the Chaco (1400 mm), adjacent to the Paraguay river. These values gradually decrease as one moves away from this area, reaching the minimum in the north-western region (less than 500 mm) (REDIEX, 2009). As a result, three distinct climates (moist sub-humid in the south-east, dry sub-humid in the centre and north, and semi-arid in the west) and five ecoregions (Mereles et al., 2013) can be delineated.

The lands of the Paraguayan Chaco were home to isolated indigenous peoples until the middle of the nineteenth century, when they were almost entirely sold by the government to Brazilian, Argentine, English, and French companies after the War of the Triple Alliance (Vázquez, 2007). In the 1920s, the Paraguayan government granted certain privileges for the establishment of Mennonite colonies arriving from Canada, Russia, and Germany, who settled and lived alongside the indigenous communities. In the 1960s, due to the construction of the Transchaco route, which was the first road communication in the region, the Mennonite colonies experienced sustained growth. The improvements in infrastructure facilitated the expansion of dairy farming, which supplied milk to practically all of Paraguay, and even to some of the neighbouring countries. In the 90 s, the development of Beef–cattle farming began, with investments being made not only by the Mennonites, but also by foreigners from neighbouring countries, especially Brazilians, Uruguayans, and Argentines, who acquired large expanses of land (le Polain de Waroux, 2019).

There are several laws in place in Paraguay designed to protect natural and forest resources, particularly Law 542/95, which requires that 25% of the surface area of farming estates remains forested. In addition, Decree 18,831/86 requires that protective fringes at least 100 m wide be maintained on the margins of rivers, streams, and lakes. It is also forbidden to cut through fields with a gradient greater than 15%, nor if they do not have connectivity solutions (connectivity between forested zones), thus enforcing that in areas larger than 100 ha, forested fringes at least 100 m wide must be maintained between plots. Compliance with these regulations would imply that a farming estate would retain more than 25% of its surface area as native forest. Moreover, the conditions that must be met for planned deforestation to be approved are becoming more stringent. For example, the right to carry out deforestation in the Chaco for the purpose of livestock farming requires that this change in land use be done according to a silvo-pastoral system (Veit & Sarsfield, 2017). In 2009, there was an attempt to expand the zero-deforestation law that had been established in 2004 to protect the Atlantic forest in the eastern region to the Chaco. However, the proposed law was rejected by Paraguay's Cámara de Diputados (the lower house of parliament).

Fig. 1 Map of Paraguay and the Paraguayan Chaco region

2.2 Data collection and statistical analysis

The data used refer to 2018 and were collected by means of a farm survey carried out face-to-face by one of the authors with the owner or manager of the Beef–cattle ranch located in the Paraguayan Chaco. The criteria used to define the sample were that the ranch had more than 30 heads of Beef–cattle and a total area of 150 ha at least. Also, an attempt was made to cover the entire territory of the Chaco and to ensure that the farms were representative of different sizes and productive orientations (i.e. cow–calf, fattening and whole-cycle system) as well as to include ranches of different ages. Based on these criteria, an initial list of ranchers (20) was obtained by contacting the Rural Association of Paraguay. After contacting these ranchers, the sample was expanded using chain references (snowball sampling). The snowball referral technique is commonly employed in research when there are no official data from the reference population stratified according to the criteria that sample must meet. A total of 83 questionnaires were filled out, although 3 were discarded due to inconsistencies. Table 1 shows the final distribution of the sample. The total number of cattle ranches in the Paraguayan Chaco in 2018 was 8005 (SENACSA, 2020) without differentiating between dairy cattle or Beef–cattle ranches; thus, a sampling error of less than ± 10.9% at the 95% level of confidence was assumed.

The questionnaire to obtain the primary data was designed using 125 questions, most of them were open-ended. Some close-ended questions were also included, such as the location of the farm, and the type of company. The questions were grouped into thematic blocks related to structural (e.g. total area and its distribution, number of animals and type, number of workers and hours worked per year), productive (e.g. predominant breeds, slaughter weight and age, steers sold), economic (e.g. total income, other business activities on the ranch, destination of production) and environmental (e.g. if they used pesticides and fertilizers, types of forages cultivated, reserve area) aspects of the ranch, based on the methodology used by Milán et al., (2006, 2011), Escribano et al., (2014, 2016) and Faverin and Machado (2019). From the data obtained, a database was generated comprising a total of 165 variables (numeric and categorical), which includes the originals and the indices or variables calculated from their combination.

To characterise Beef–cattle ranching in the Paraguayan Chaco and show what trends are observed descriptive statistics (averages, correlations and frequencies of the variables)

Table 1 Characteristics of the sample

	Number of ranches
Department	
Presidente Hayes	29
Boquerón	30
Alto Paraguay	21
Productive orientation	
Cow–calf system	15
Whole-cycle system	39
Fattening system	26
Size of herd (Livestock Units)	
≤ 500	24
> 500 to ≤ 2000	30
> 2000	26
Total area (ha)	
≤ 2000	22
> 2000 to ≤ 7000	29
> 7000	29
Years of activity	
< 15 years	43
≥ 15 years	37

were calculated for the totality of the farms and for the farms grouped by productive orientation and years of ranch activity. Subsequently, a multivariate statistical analysis was used to analyse the data for the typological analysis (Gaspar et al., 2007; Milán et al., 2003; Stylianou et al., 2020).

First, a principal component analysis (PCA) was carried out in order to summarise and explain the information contained in the set of observed variables, and identifying another smaller number of unobserved variables, called components. The selection of the variables that were included in the PCA was made based on the objective of the work, an extensive review of the literature (Escribano et al., 2014; Faverin & Machado, 2019; Milán et al., 2006; Ruiz et al., 2008; Toro-Mujica et al., 2012) and a rigorous study of the original variables. To minimize the risk of farm size dominating the typology, we included several variables as proportions of total farm area or quotas per hectare farm land (Stylianou et al., 2020). This led to the selection of a set of variables indicative of distribution and use of area, physical and economic size of the ranch, productivity of production factors and intensification. These variables were checked, their correlation was calculated, and when correlations between variables were greater or equal to 0.7, the variable considered less relevant for the study was discarded (López-i-Gelats et al., 2011; Stylianou et al., 2020). This process resulted in the selection of eight variables: the utilised agricultural area (UAA; total area taken up by arable land, permanent grassland and permanent crops) in relation to the total area (UAA/TA), stocking rate (Livestock Units (LU)/UAA), the labour productivity measured through the LU and UAA in relation to the workforce (Annual Work Units = AWU; One annual work unit corresponds to the work performed by one person who is occupied on an agricultural holding on a full-time basis and is equivalent to a minimum of 1800 h worked per year), the percentage of UAA with improved pastures, the total hectares of improved pastures per LU, the total hectares of woodland (grazed and ungrazed) per ranch and the economic profitability, as measured through the income from the sale of livestock in relation to the UAA. The Kaiser–Meyer–Olkin test obtained a value greater than 0.5, and the Bartlett's test of sphericity obtained a level of significance < 0.005 (p value $= 0.000$), indicating that the variables used are suitable for the analysis and the PCA is significant (Gaspar et al., 2007; Ruiz et al., 2012; Stylianou et al., 2020). The communalities of each of the original variables and the total variance test were calculated, which allowed us to recognise the contribution of these original variables to the retained components. To improve the interpretation of the initial components, a varimax rotation was performed, which, being an orthogonal rotation method, maintains the independence of the rotated components. Finally, the components with eigenvalues greater than 1 were retained.

Subsequently, to classify the farms, a hierarchical cluster analysis was then carried out on the coordinates of the farms with the first three components (those retained in the previous step and that had an eigenvalue greater than 1). The objective of this technique is to group similar ranches together, maximizing intragroup homogeneity and intergroup diversity. Ward's linkage was used as the agglomeration method, because it minimizes the total within-cluster variance, and the squared Euclidean distance as a measure of distance between the cases. Finally, the number of clusters (groups) was determined by observing breaks (possible cutting lines) in the dendrogram and examining the incremental changes in the agglomeration coefficient.

To analyse whether there were differences between the groups obtained from the cluster analysis, as well as those previously pre-established based on the productive orientation and years of activity, we proceeded as follows: the continuous variables were contrasted by a one-way ANOVA analysis, and Levene's test was used to verify whether homoscedasticity or equality of variances between the different groups was fulfilled; in the cases in which the variances were equal, the F statistic was calculated, in those cases where equality of variances could not be assumed, Welch's test was performed, which is considered more robust in this situation. Then, as a post hoc test, the Student–Newman–Keuls mean comparison test was performed when the variances were equal and the Tamhane T2 test when equality of variances could not be assumed. For categorical variables, contingency tables and Pearson's Chi-square test were performed. All statistical analyses were performed with the IBM SPSS Statistics version 22.0 statistical programme.

3 Results

3.1 Characterisation of ranches and trends

In general, bovine expansion in the Paraguayan Chaco is being carried out through very large-scale ranches, both in terms of Livestock Units (LU) (Table 2) and area (Table 3).

Table 2 shows that average productivity takes a value similar to that observed by Costa and Rehman (2005) in cattle farms in central Brazil and close to the reference values observed in production systems with similar characteristics in the northwest of Argentina (Nasca et al., 2015). Calves are weaned at around 8 months, with an average weight of 206 kg. After fattening, steers are sold at an average age of about 26 months, with an approximate live weight of 455 kg. This value is lower than the values reported in Brazil by Ferraz and Felício (2010) and Costa and Rehman (2005), who, in similar systems, mention slaughter ages of 30–42 months. The average reproductive ratio is 35.9 cows per bull, an adequate value considering that 75.9% of ranches with breeding cows' practise artificial insemination.

Table 2 Herd sizes and most important characteristics of Beef–cattle ranches in the Paraguayan Chaco according to their productive orientation (average ± standard deviation)

	Cow–calf system ($n=15$)	Whole-cycle system ($n=39$)	Fattening system ($n=26$)	All[a]	Interval
Livestock units, LU	1616 ± 2011	3200 ± 4196	1670 ± 3317	2406 ± 3643	39–20193
Total cows	1555 ± 1881	1846 ± 2444	–	1766 ± 2288	35–12000
Total bulls	55.0 ± 62.6	59.7 ± 77.3	–	58.4 ± 73.0	1–320
Cows per bull	32.3 ± 16.9	37.3 ± 35.1	–	35.9 ± 31.0	7–200
Calves produced/cow (%)	80.1 ± 11.6	78.4 ± 10.2	–	78.9 ± 10.5	60–100
Age at weaning (months)	7.7 ± 1.5	8.2 ± 1.4	–	8.1 ± 1.4	6–12
Weaning weight (kg)	199.7 ± 19.7	208.7 ± 35.0	–	206.2 ± 31.5	140–280
Total steers		1472 ± 2112	1666 ± 2984	1550 ± 2478	55–14600
Slaughter age (months)	–	26.4 ± 5.1	26.5 ± 5.6	26.4 ± 5.3	18–40
Slaughter weight (kg)	–	455.1 ± 33.4	454.8 ± 40.1	455.0 ± 35.9	350–600

[a]The average values have been calculated only taking into account the cases in which this value is applicable; therefore, number of farms varies across variables

Table 3 Structural characteristics (area, livestock density and labour) and years of activity of Beef–cattle ranches in the Paraguayan Chaco for each group obtained in the typology (average ± standard deviation)

Variable	All ($n=80$)	Group 1[1] ($n=30$)	Group 2[2] ($n=31$)	Group 3[3] ($n=19$)	p
Years of activity	18.6 ± 17.0	11.5 ± 8.3^{a}	24.0 ± 18.3^{b}	21.0 ± 21.3^{ab}	0.003
Owner's age	50.8 ± 13.0	48.6 ± 12.0	52.9 ± 12.5	50.1 ± 15.1	0.560
Total area, TA (ha)	9464 ± 14053	14814 ± 19709^{a}	6978 ± 8681^{ab}	5072 ± 6050^{b}	0.049
Ownership area/TA (%)	88.2 ± 31.0	88.9 ± 30.8	86.8 ± 32.0	89.5 ± 31.5	0.947
Utilized agricultural area, UAA (ha)	5529 ± 8010	6874 ± 10550	5606 ± 6866	3281 ± 3920	0.313
UAA/TA (%)	65.4 ± 22.4	44.3 ± 15.3^{a}	83.9 ± 13.1^{b}	68.5 ± 14.2^{c}	0.000
Improved pastures area (ha)	3204 ± 5702	5581 ± 8175^{a}	1590 ± 2168^{b}	2085 ± 3463^{ab}	0.047
Improved pastures/UAA (%)	66.1 ± 34.6	89.3 ± 16.0^{a}	42.5 ± 29.6^{b}	67.8 ± 39.0^{ab}	0.000
Native grasslands area (ha)	1691 ± 3957	739 ± 2093	2961 ± 5421	1121 ± 2834	0.120
Native grasslands/UAA (%)	22.4 ± 31.4	7.0 ± 12.7^{a}	35.1 ± 33.0^{b}	26.1 ± 39.6^{ab}	0.000
Grazed woodland (ha)	604 ± 1644	499 ± 1620^{ab}	1048 ± 2041^{a}	48 ± 109^{b}	0.014
Grazed woodland/UAA (%)	10.8 ± 20.5	3.1 ± 7.4^{a}	22.3 ± 27.4^{b}	4.1 ± 11.2^{a}	0.003
Ungrazed woodland (ha)	3935 ± 7309	7939 ± 10411^{a}	1373 ± 2566^{b}	1791 ± 2444^{b}	0.007
Ungrazed woodland/TA (%)	34.6 ± 22.4	55.6 ± 15.2^{a}	16.1 ± 13.2^{b}	31.5 ± 14.2^{c}	0.000
Annual work units, AWU	15.4 ± 20.2	15.4 ± 20.2	10.1 ± 10.8	21.7 ± 39.2	0.259
Permanent AWU/AWU (%)	95.2 ± 13.0	96.9 ± 8.3	93.6 ± 17.4	95.1 ± 11.0	0.154
UAA/AWU (ha)	482.6 ± 424.5	481.0 ± 299.0^{ab}	599.7 ± 541.0^{a}	293.9 ± 312.7^{b}	0.034
AWU/100 ha UAA	0.41 ± 0.54	0.30 ± 0.17^{a}	0.36 ± 0.53^{a}	0.67 ± 0.82^{b}	0.050
Livestock units, LU	2406 ± 3643	2823 ± 4443	1396 ± 1585	3396 ± 4379	0.069
LU/AWU	188.2 ± 189.1	196.3 ± 167.0	143.4 ± 92.1	248.7 ± 300.6	0.155
Stocking rate (LU/UAA)	0.51 ± 0.33	0.47 ± 0.23^{a}	0.31 ± 0.15^{b}	0.91 ± 0.35^{c}	0.000
LU/TA	0.32 ± 0.23	0.21 ± 0.14^{a}	0.26 ± 0.13^{a}	0.61 ± 0.22^{b}	0.000
Improved pastures/LU (ha)	2.3 ± 3.9	4.1 ± 5.9^{a}	1.4 ± 1.0^{a}	0.9 ± 0.7^{b}	0.002
Total income/AWU ($\times 10^3$$)	77.1 ± 81.3	92.4 ± 112.1^{ab}	44.2 ± 34.8^{a}	106.4 ± 59.7^{b}	0.000
Total income/UAA ($)	231.9 ± 237.7	198.7 ± 133.8^{a}	100.3 ± 64.8^{b}	499.3 ± 323.9^{c}	0.000

Within row, averages with the same superscript (a, b, c) do not differ significantly ($p < 0.05$)

[1]Medium intensification ranches

[2]Silvo-pastoral ranches

[3]Ranches highly intensified in livestock and labour

Regarding area (Table 3) it is observed that average values are much higher than are those observed by Bussoni et al. (2019) in Uruguay and Costa and Rehman (2005) in central Brazil, although with similar values to those reported in this latter country in areas close to the frontier with Paraguay (Abreu et al., 2010). The average value obtained from the Utilised Agricultural Area (UAA) over Total Area (TA) ratio indicates that 34.6% of the area is kept in its natural state (Fig. 2), thus meeting the requirements of Paraguayan legislation (25% of nature reserve plus corridors around pastures, riverbeds and large slopes), although the average value obtained in our study is less than the 40.0% reported by Glatzle (2004). However, considering that grazed woodland represents 9.3% of the total area on average, it could be said that 43.9% of the area conserves native forests or shrubs. Of the remaining 56.1%, most is occupied by improved pastures. The predominant cultivated grass nowadays, since the 1990s when its expansion began, is Gatton Panic (Panicum maximum). This grass, which is very resistant to grazing, adapts very well to humid tropical and subtropical climates, requiring a minimum rainfall of 550 mm per year (Cabrera et al., 2001; Schnellmann et al., 2018). Other forage grasses present in the area are: Grama rhodes, Buffel Grass, Pasto Pangola, Bambatsi, Callide and Dicantio, which are used alone or mixed with each other, or with Gatton panic. These mixtures are better adapted in clay soils and with stagnant water, frequent types of terrain in the Pantanal area. Mixtures of grasses and some legumes are also frequent, one of the most common being Leucaena (Glatzle et al., 2019).

In these ranches, feeding is based upon grazing natural or improved pastures, in some farms vitamin and mineral supplements are provided, being more common in calves (Table 4). The average stocking rate (Table 3) is lower than that reported by Bussoni et al. (2019) in different types of specialised Beef–cattle ranches in Uruguay, as well as those observed in the central zone of Brazil (Costa & Rehman, 2005) and Chile (Toro-Mujica et al., 2019). As expected, stocking rate is positively correlated with the percentage of the UAA with improved pastures ($r = 0.267$; $p < 0.05$) and with the total number of Annual Work Units (AWU) ($r = 0.375$; $p < 0.01$). However, a significant and negative correlation was found between stocking rate and the UAA/AWU ($r = -0.421$; $p < 0.01$) and with the percentage of UAA with grazed woodland ($r = -0.379$; $p < 0.01$).

The total labour amounts to 14.8 AWU per ranch, on average; they are mostly hired (95.4%), youths (31.7 years on average) and male (86.1%). Average ratios indicative of labour productivity, UAA/AWU and LU/AWU are very high (Table 3), presenting values that practically double those reported in wooded rangelands in Spain by Milán et al. (2006) and Escribano et al. (2016). Although seen inversely, the job creation potential, measured as AWU/100 ha of UAA, is very low when compared with the systems

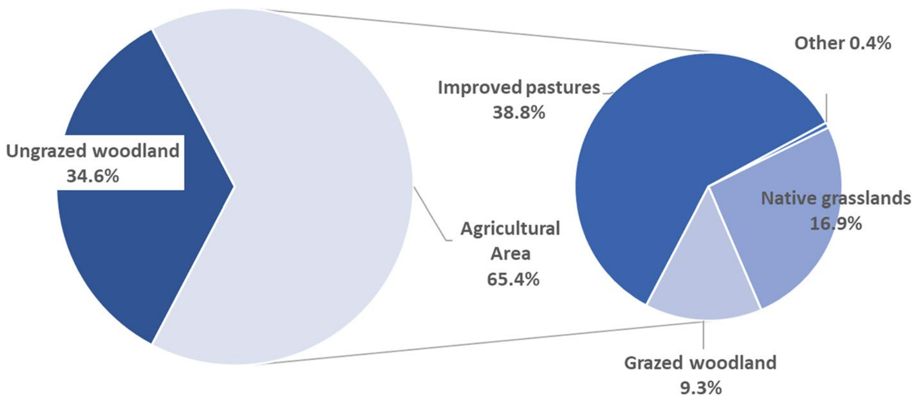

Fig. 2 Distribution of the total average area in Beef–cattle ranches in the Paraguayan Chaco

Table 4 Location and characteristics of Beef–cattle ranches in the Paraguayan Chaco for each group obtained in the typology (% of ranches)

Variable	All	Group 1[a] ($n=30$)	Group 2[b] ($n=31$)	Group 3[c] ($n=19$)	*p*
Department					0.002
Presidente Hayes	36.3	10.0	58.1	42.1	
Boquerón	37.5	46.7	29.0	36.8	
Alto Paraguay	26.3	43,3	12.9	21.1	
Ecoregions					0.003
Dry Chaco	41.3	46.7	32.3	47.4	
Humid Chaco	32.5	10.0	54.8	31.6	
Pantanal	26.3	43.3	12.9	21.1	
Productive orientation					0.042
Cow–calf	18.8	10.0	35.5	5.3	
Whole-cycle	48.8	50.0	41.9	57.9	
Fattening	32.5	40.0	22.6	36.8	
Type of company					0.299
Single-person	70.0	60.0	74.2	78.9	
Multi-person	30.0	40.0	25.8	21.1	
Manager					0.889
Owner	37.5	36.7	35.5	42.1	
Hired	62.5	63.3	64.5	57.9	
Educational level of manager					0.848
Primary or secondary studies	7.5	10.0	3.2	10.5	
Medium degree studies	10.0	10.0	9.7	10.5	
University studies	82.5	80.0	87.1	78.9	
Other business activities on the ranch	12.5	10.0	9.7	21.1	0.434
Use of pesticides	36.3	50.0	19.4	42.1	0.038
Vitaminic-mineral supplementation					
Cows and bulls	35.2	33.3	33.3	41.7	0.868
Calves	54.2	50.0	54.2	58.8	0.872
Steers	27.7	22.2	30.0	33.3	0.497
Predominant breed of cows					0.146
Braford	13.0	5.6	20.8	8.3	
Brangus	14.8	11.1	12.5	25.0	
Brahman	7.4	0.0	4.2	25.0	
Creole	53.7	66.7	54.2	33.3	
Nelore	11.1	16.7	8.3	8.3	
Predominant breed of bulls					0.288
Braford	13.0	5.6	20.8	8.3	
Brangus	18.5	22.2	12.5	25.0	
Brahman	9.3	0.0	8.3	25.0	
Creole	51.9	61.1	54.2	33.3	
Nelore	7.4	11.1	4.2	8.3	

Table 4 (continued)

Variable	All	Group 1[a] ($n=30$)	Group 2[b] ($n=31$)	Group 3[c] ($n=19$)	p
Predominant breed of steers					0.065
Braford	11.9	0.0	25.0	5.9	
Brangus	13.6	5.6	8.3	29.4	
Brahman	3.4	5.6	0.0	5.9	
Creole	64.4	83.3	62.5	47.1	
Nelore	6.8	5.6	4.2	11.8	

[a]Medium intensification ranches

[b]Silvo-pastoral ranches

[c]Ranches highly intensified in livestock and labour

mentioned above (Escribano et al., 2016), as well as with the values reported by Toro-Mujica et al. (2019) in Chile. The average age of the owner is around 50 years old, and the average years of activity of the farms is 18 years (Table 3).

In general, single-person enterprises predominate, whose manager has a high level of training, and in most farms, this manager is a hired professional (Table 4). The ranches are highly specialised in beef-cattle, with practically no other livestock species present, and the area is devoted almost entirely to the production of livestock feed. The few ranches that diversify their income do so through the selling of some agricultural product such as soybeans, wood, or raising other species, such as sheep, but always in small quantities. The ranches are highly export-oriented, which implies that they are making efforts to improve the quality of their product and comply with the international standards required by the target markets of their products. Thus, although the predominant breeds are the Creoles (Table 4), crosses between a zebu breed (Bos indicus) such as Brahman or Nelore and a Bos taurus breed such as Angus and Hereford are increasingly being used.

In Table 5, it can be seen that more years of ranch activity are significantly related to a higher UAA, percentage of UAA/TA and percentage of native grasslands plus grazed woodland over TA. Nevertheless, these ranches have a lower percentage of ungrazed woodland over TA and improved pastures per LU. There is also a trend in which the oldest ranches have more TA and LU and a lower percentage of UAA with improved pastures. Thus, while in the oldest ranches, the percentage of the total area with native grasslands plus grazed woodland is 33.8%; in the most recent ones, it does not reach 20.0%. However, in the most recent ranches, the reserve area (ungrazed woodland) is, on average, 42.7% of the TA, while this average value in the oldest ones is 25.1%. These differences are due to the fact that some of the oldest ranches are prior to the current legislation that requires maintaining more than 25.0% of the reserve area on the ranches (ungrazed woodlands), as well as to the fact that there is now greater surveillance on the part of the administration regarding compliance with the regulations.

In general (Table 6), the oldest ranches are located in the humid Chaco, with a predominance of the cow–calf and the whole-cycle systems. The newest farms are located in the dry Chaco and Pantanal, and they are smaller and dedicate a greater percentage of their area to improved pastures. Regarding the breeds, although there are no significant

Table 5 Structural characteristics (area, livestock density and labour) of Beef–cattle ranches in the Paraguayan Chaco according to their years of activity (average ± standard deviation)

Variable	Old (≥ 15 years) (n = 37)	New (< 15 years) (n = 43)	p
Years of activity	31.4 ± 17.6	7.7 ± 3.3	0.000
Owner's age	54.9 ± 13.5	47.2 ± 11.5	0.024
Total area, TA (ha)	12699 ± 18,927	6680 ± 6874	0,074
Ownership area/TA (%)	97.0 ± 12.7	80.6 ± 39.3	0.013
Utilized Agricultural Area, UAA (ha)	8327 ± 10,853	3122 ± 2630	0.007
UAA/TA (%)	74.9 ± 18.7	57.2 ± 22.3	0.000
Improved pastures/UAA (%)	58.8 ± 34.8	72.3 ± 33.6	0.083
Native grasslands/UAA (%)	26.9 ± 33.3	18.6 ± 29.5	0.239
Grazed woodland/UAA (%)	14.0 ± 22.0	8.1 ± 18.9	0.199
Native grasslands + Grazed woodland/TA (%)	33.8 ± 31.3	19.5 ± 27.0	0.032
Ungrazed woodland/TA (%)	25.1 ± 18.7	42.7 ± 22.2	0.000
Annual Work Units, AWU	18.1 ± 22.8	12.0 ± 24.5	0.253
UAA/AWU (ha)	558.3 ± 505.5	417.4 ± 332.4	0.140
AWU/100 ha UAA	0.32 ± 0.25	0.49 ± 0.70	0.155
Livestock Units, LU	3288 ± 4637	1647 ± 2294	0.056
LU/AWU	196.2 ± 131.7	181.4 ± 228.6	0.730
Stocking rate (LU/UAA)	0.48 ± 0.27	0.54 ± 0.38	0.440
LU/TA	0.35 ± 0.20	0.30 ± 0.24	0.373
Improved pastures/LU (ha)	1.30 ± 0.72	3.2 ± 5.2	0.023

differences observed, a decrease in the percentage of farms with Creole and Brahman breeds is perceived, in favour of the synthetic Brangus and Braford breeds and the Nelore breed.

3.2 Beef–cattle ranches Typology

Three principal components with an eigenvalue greater than 1 and accumulating 70.1% of the total variance were obtained from the PCA. Table 7 shows the loadings of the eight variables used in the PCA on the three retained components. The subsequent classification of the ranches according to these three components made it possible to establish three groups of ranches.

The first principal component presents high and positive correlation coefficients with the stocking rate and with the ratio of income from cattle sales per ha of UAA (Table 7), making it a component indicative of capital intensification (cattle) in relation to UAA. In Fig. 3, Beef–cattle ranches are represented in the first two factorial axes. It can be observed that all ranches in Group 3 have positive values of the first component, while Groups 1 and 2 show low or negative values for this component. The second component is positively correlated with the percentage of UAA with improved pastures and with the total area with woodlands (grazed and ungrazed), having a high and negative correlation with the percentage of UAA over TA. This component is indicative of the area distribution, differentiating ranches that have a high percentage of reserve area and, in turn, dedicate a significant part of their UAA to improved pastures, as opposed to ranches where natural grasslands

Table 6 Location and characteristics of Beef–cattle ranches in the Paraguayan Chaco according to their years of activity (% of ranches)

Variable	Old (≥ 15 years) (*n* = 37)	New (< 15 years) (*n* = 43)	*p*
Department			0.013
Presidente Hayes	51.4	23.3	
Boquerón	35.1	39.5	
Alto Paraguay	13.5	37.2	
Ecoregions			0.016
Dry Chaco	40.5	41.9	
Humid Chaco	45.9	20.9	
Pantanal	13.5	37.2	
Productive orientation			0.015
Cow–calf	29.7	9.3	
Whole-cycle	51.4	46.5	
Fattening	18.9	44.2	
Predominant breed of cows			0.344
Braford	10.0	16.7	
Brangus	10.0	20.8	
Brahman	10.0	4.2	
Creole	63.3	41.7	
Nelore	6.7	16.7	
Predominant breed of bulls			0.285
Braford	10.0	16.7	
Brangus	13.3	25.0	
Brahman	13.3	4.2	
Creole	60.0	41.7	
Nelore	3.3	12.5	
Predominant breed of steers			0.219
Braford	7.7	5.1	
Brangus	7.7	17.9	
Brahman	3.8	12.8	
Creole	76.9	51.3	
Nelore	3.8	12.8	

predominate, and UAA represents a high percentage of the TA. Figure 3 shows that all ranches in Group 1 are in the positive section of the second component and all of those in Group 2 are in the negative section of this component. Group 3 presents low or negative values for this component. The third component is highly correlated with the LU per AWU and the UAA per AWU. Therefore, this component is indicative of labour productivity.

Tables 3 and 4 present the characteristics of the different groups identified.

Group 1 (G1: Medium intensification ranches), including 30 ranches (37.5% of the sample). The largest ranches in terms of total area (14,814 ha) belong to this group, but since they have the largest amount (7939 ha) and percentage (55.6%) of ungrazed woodlands, their UAA is only slightly higher than that of the other groups (Table 3). This group has the largest area, as well as the proportion of UAA, dedicated to improved pastures; on the other hand, it presents the lowest values of area with natural grasslands

Table 7 Loadings of the variables used in the PCA on the retained principal components

	Components		
	1	2	3
UAA/AWU (ha)	– 0.510	– 0.169	**0.685**
UAA/TA (%)	– 0.116	**– 0.871**	0.085
Improved pastures/UAA (%)	0.256	**0.726**	– 0.320
Stocking rate (LU/UAA)	**0.908**	0.122	0.070
LU/AWU	0.279	– 0.006	**0.856**
Improved pastures/LU (ha)	– 0.585	0.346	– 0.272
Total woodlands (ha)	– 0.266	**0.613**	0.313
Total income/UAA ($)	**0.776**	0.123	– 0.148
Eigenvalues	2.45	1.86	1.30
Variance explained, %	28.2	23.0	18.9

Note: Factor loadings over 0.60 appear in bold

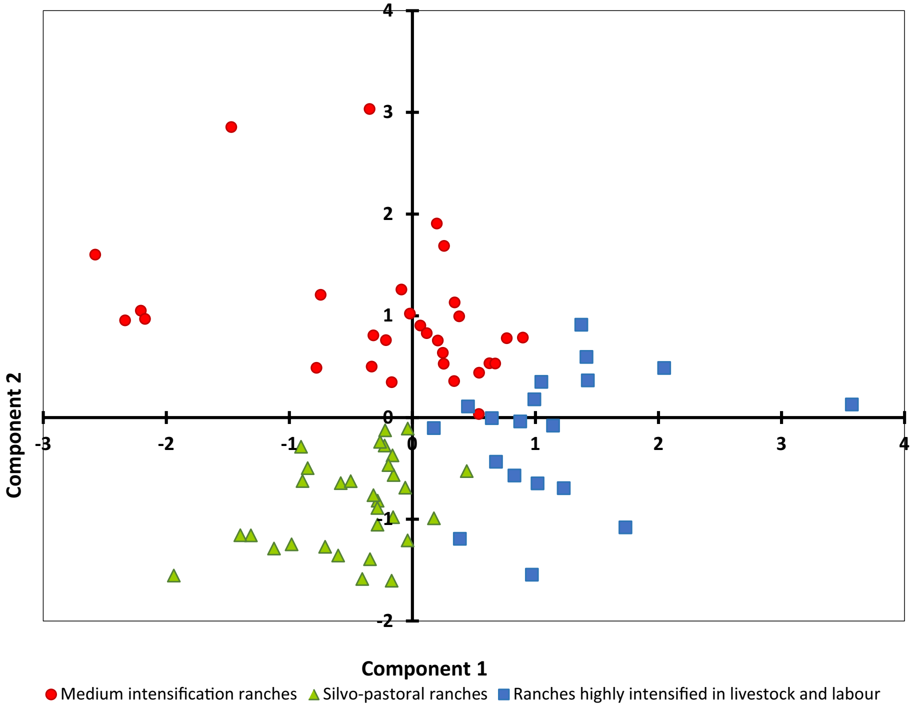

Fig. 3 Representation of farms in the first two factorial axes

(Table 3 and Fig. 4). Despite this, the average herd value is intermediate between the other two groups, as well as the stocking rate and the UAA per AWU relation. These are the youngest ranches (Table 3), they are mainly located in the departments of Boquerón and Alto Paraguay, and in the Ecoregions of Dry Chaco and Pantanal, and the whole-cycle system and fattening system predominate (Table 4).

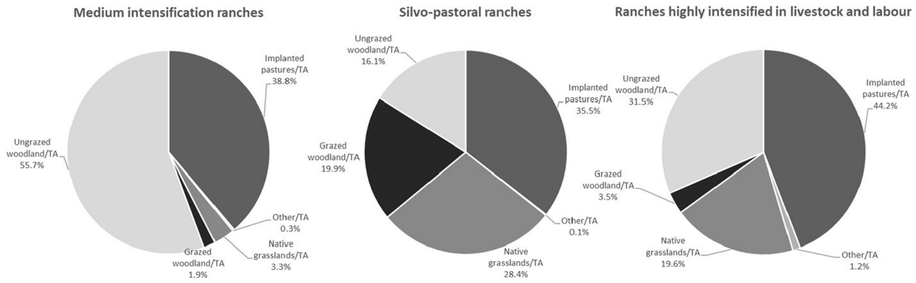

Fig. 4 Distribution of the total area of Beef–cattle ranches in the Paraguayan Chaco, for each group obtained in the typology

Group 2 (G2: Silvo-pastoral ranches), which includes 31 ranches (38.8% of the sample). Its total area is intermediate between the other groups, presenting the highest percentage of UAA (83.9%), which indicates that in this group, the average ungrazed area (reserve area) is less than 20.0% (Table 3 and Fig. 4). Regarding improved pastures, it has the smallest area, 1590 ha, and the lowest percentage of its UAA (42.5%), on average. On the contrary, it has the highest average of natural grasslands and grazing woodland, 2961 and 1048 ha, respectively, which means that 48.3% of its total area and 57.4% of its UAA are lands where agricultural intervention is minimum and which are grazed by cattle, representing a traditional silvo-pastoral system. In terms of livestock units and labour force, these are the ranches with the lowest values, so they are the ranches with the lowest stocking rate and the highest value in UAA per AWU, which agrees with being the ranches with the highest percentage of UAA devoted to natural grasslands and grazed woodland. It is the group with the lowest incomes of cattle per ha of UAA and per AWU. Although the use of pesticides is not widespread, this group is the one with the lowest number of ranches that use them (Table 4). The oldest ranches belong to this group and they are located mainly in the Departments of Presidente Hayes and Boquerón, and in the ecoregions of the Humid Chaco followed by the Dry Chaco. In this group, ranches with a whole-cycle system predominate, as well as with the cow–calf system, being the group with the lowest percentage of ranches with fattening system. Seventy-four-point-two per cent of the ranches are single-person-owned, and among their managers, there is a high percentage with university studies (Table 4).

Group 3 (G3: Ranches highly intensified in livestock and labour), includes 19 ranches (23.8% of the sample). They are the smallest ranches in terms of area (Table 3), with an average of 5072 ha of TA, and on average, the UAA represents 68.5% of this. In these ranches, although the number of ha with improved pastures is much lower than in Medium intensification ranches, and the percentage they occupy in relation to UAA is intermediate between the two groups (Table 3), it is the group that devotes the highest percentage of the total area to this use (Fig. 4). This group has the highest value of livestock units, on average 3396 (Table 3), which results in an average stocking rate of 0.91 LU/ha of UAA, a value much higher than the overall average and practically three times higher than the stocking rate observed in Silvo-pastoral ranches. The number of AWU is the highest, but despite this, labour productivity measured in LU/AWU also has the highest value (Table 3). As a result, it is the group with the highest income ratios per UAA and per AWU. The years of activity of the ranches are intermediate between the other two groups. This group is dominated by ranches with whole-cycle and fattening systems. The percentage of ranches that supplement animals is higher in this group than in the others, although there are no significant differences.

4 Discussion

Although there is great heterogeneity, Beef–cattle ranches in the Paraguayan Chaco are very large and highly export-oriented, similar to those existing in areas close to the Paraguay border (Abreu et al., 2010), even larger than those reported in other nearby areas and are classified as large and highly technological in Uruguay (Bussoni et al., 2019), central Brazil (Costa & Rehman, 2005) and in the Argentine Pampa (Faverin & Machado, 2019). The stocking rate is in the lower-middle range of those reported in other areas of South America with similar production systems (Bussoni et al., 2019; Costa & Rehman, 2005), which could suggest that there is a certain margin to increase production through intensification rather than occupying new areas. This is evident in the typology of farms that has been established, in which ranches highly intensified in livestock and labour almost triples the stocking rate of Silvo-pastoral ranches.

The main differentiating factors between the groups obtained in the typology are the availability of the different production factors (Fig. 5), the distribution of total area (Fig. 4) and the degree of intensification in the use of capital (livestock), labour and/or technology (new crop varieties or hybrid breeds) per unit of UAA (Fig. 6). Thus, three groups of Beef–cattle ranches have been differentiated: G2 represents the traditional silvo-pastoral ranches, these are ranches with almost half of their total area destined to natural grass and grazed woodland, and they are the ones that present the most extensive system; G1

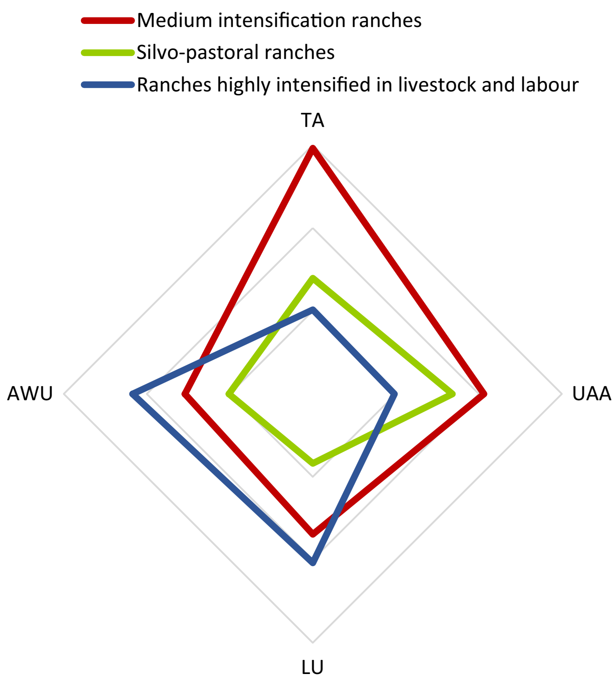

Fig. 5 Availability of production factors (*TA* total area, *UAA* agricultural area, *LU* livestock units, *AWU Labour*) for each group obtained in the typology

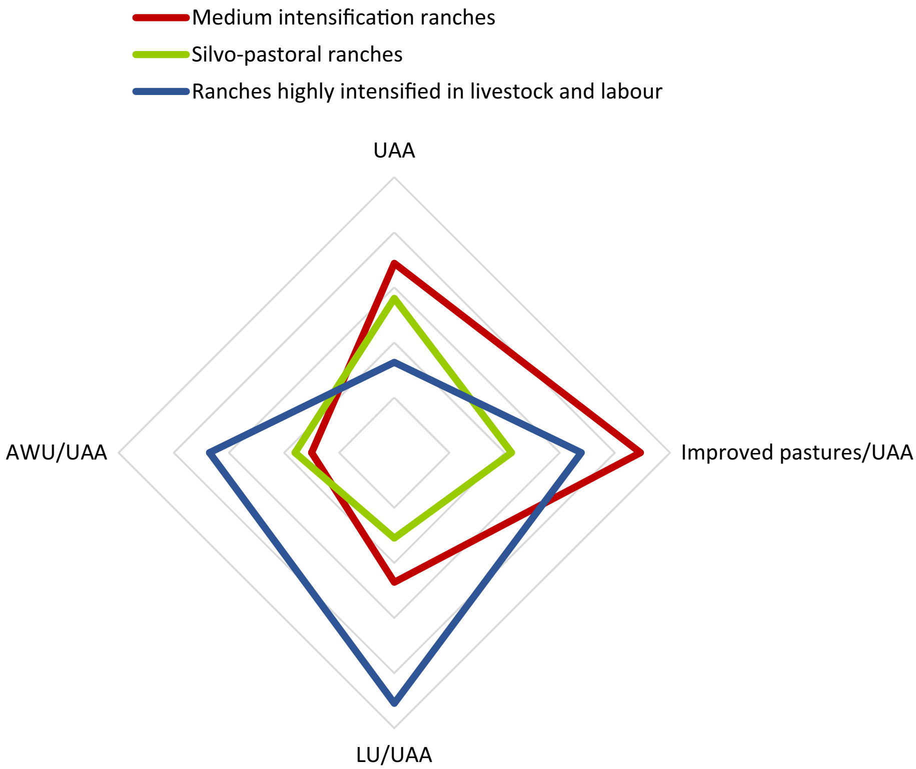

Fig. 6 Availability of agricultural area (UAA) and its relationship with the area devoted to improved pastures, livestock units (LU) and labour (AWU), for each group obtained in the typology

(Medium intensification ranches) represents ranches with a lot of available area, whose strategy is to carry out a high intensification of their UAA through the use of improved pastures, and G3 (Ranches highly intensified in livestock and labour), which includes the ranches with the smallest available area and a high use of livestock and labour per unit of UAA. These groups show different land occupation strategies which also present different environmental impacts. Silvo-pastoral systems (G2) may cause greater deforestation, carbon footprint and degradation of native grasslands (Modernel et al., 2018); however, highly intensified systems in livestock and labour (G3), due to their high stocking rate and overgrazing, can exert significant environmental pressure via manure concentration, greenhouse gas emissions and loss of biodiversity (Modernel et al., 2016; Puechagut et al., 2018). Medium intensification ranches (G1), due to the large amount of land occupied by improved pastures, can lead to a higher risk on fertilizer and pesticide use and aquifer pollution (Magliano et al., 2016). Cultivated land is also associated with increased runoff (Rodriguez et al., 2020), a decrease in soil organic carbon and loss of biodiversity (Marinaro & Grau, 2015; Modernel et al., 2016; Puechagut et al., 2018). These groups will also present different capacities to adapt to the changing environment (e.g. characteristics of demand, fluctuations in agricultural commodity prices, extreme climatic events). Attributes such as their resilience, flexibility and self-sufficiency will have to be addressed (Bernués et al., 2011) and adapted to the current specific situation of the Paraguayan Chaco to improve the three dimensions (environmental, economic and social) of sustainability in Beef–cattle production. An important question for the future of beef farming systems in the Paraguayan Chaco lies in improving environmental performance while maintaining its economic performance (Modernel et al., 2018), without forgetting the social dimension of this phenomenon. There is a growing consensus on the idea that nature conservation requires social endeavour (Bennett, 2016; Bennett et al., 2017; Zabala et al., 2018), so a better understanding of human perceptions is essential to better manage socio-environmental conflicts and ensure that interventions are supported in the long term (Zabala et al., 2018).

In the strategies followed by the ranches, a very important factor is their years of activity, which is related to the location of the farm and vigilance on compliance with the legislation. In this regard, most of the Silvo-pastoral ranches (older) are located in the Humid Chaco, and their UAA represents more than 80% of the total area, that is, on average, they do not comply with the current legislation on the reserve area. In contrast, Medium intensification ranches include the most recent ranches, most of them located in the Pantanal and the Dry Chaco. In this latter case, the percentage of UAA, with respect to the TA, does not reach 45%; therefore, they try to obtain a higher yield from the land with improved pastures.

These results suggest that the expansion process taking place in the Paraguayan Chaco is associated with the conversion of cow–calf systems, based mainly on natural grasslands, according to the land-sharing paradigm, to more intensified systems, according to the land-sparing paradigm (Balmford et al., 2015; Phalan et al., 2011). In the latter, the ranches maintain a larger reserve area, and a higher proportion of the feed coming from improved pastures and supplementation (Davis et al., 2015). In addition, it is more frequent that the phases of the productive cycle are separated. Our results show that while in Silvo-pastoral ranches, the percentage of ranches that only carry out the final phase of the cycle (fattening) is 22.6%, and the stocking rate is 0.31, in Medium intensification ranches and Ranches highly intensified in livestock and labour these values are 40.0 and 36.8%, with stocking rates of 0.47 and 0.91 LU per ha of UAA, respectively. These trends are consistent with those reported by Baumann et al. (2017), who, when analysing the relationship between deforestation in the Paraguayan Chaco and cattle-ranching expansion, observe that while during the 1990s, the rate of deforestation and expansion of pastures was not accompanied by a similar growth in the cattle herd, since 2001 the opposite has occurred, that is, the growth rate of the Beef–cattle censuses exceeds the rate of increase of the grassland areas. Therefore, an intensification of the production systems is taking place, which is reflected in the higher stocking rate observed.

This intensification of Beef–cattle systems follows the trends observed in other areas (Davis et al., 2015; Fernández et al., 2020; Latawiec et al., 2014) and, although many drivers have contributed to this (Godde et al., 2018), the most important in this particular case has been current deforestation regulations, increased land productivity and higher economic profitability. As discussed earlier, the most recent ranches are mostly located in the Dry Chaco and Pantanal and maintain a reserve area that exceeds 40.0% of the total area, on average, which could be due to the fact that there is currently greater surveillance by the administration on compliance with regulations. These more recent farms have less UAA, but dedicate a higher percentage of it to improved pastures, indicating that the expansion of the cattle frontier and the intensification of the productive systems that the Paraguayan Chaco (more specifically the departments located to the west) is experiencing, is closely related to the implementation of new technologies, in particular, the development of more resistant and productive improved pastures is a key driver in this expansion process (Glatzle, 2004; Glatzle et al., 2019; le

Polain de Waroux et al., 2018; Schnellmann et al., 2018). The environmental conditions of the Dry Chaco, which presents high temperatures and periods of scarce rainfall, are a factor that could hinder the Beef–cattle frontier (Oesterheld et al., 1999). However, Houspanossian et al. (2016) find that the deforestation pattern in the Dry Chaco was not associated with the aridity gradient, although they do report differences in the use of deforested land, observing a gradient that goes from more water-demanding crops in the east, to grasses with lower water requirements as aridity increases. Furthermore, this intensification is associated with greater economic profitability. In this regard, Costa and Rehman (2005) conclude that a certain level of overgrazing seems rational, since the economic benefits of having a higher stocking rate outweigh the increased costs of soil and vegetation restoration.

Land intensification, especially if carried out on an agro-ecological basis, can often be seen as a path towards sustainability (Latawiec et al., 2014; Milera, 2013; Painter et al., 2020; zu Ermgassen et al., 2018), since this reduces competition for land, helping to achieve the difficult balance between food security and environmental conservation (Godde et al., 2018; Meyfroidt et al., 2018; Parra-Cortés et al., 2019; Painter et al., 2020). In the specific case of Beef–cattle ranches in the Paraguayan Chaco, management practices and strategies to increase cattle-ranching productivity that are currently underused could be generalised. These included rotational grazing of native pastures (Eaton et al., 2011), crop rotation with nitrogen-fixing legumes (Glatzle et al., 2019; Latawiec et al., 2014), the use of improved high-yielding and drought-heat-tolerant forage varieties (Glatzle, 2004; Glatzle et al., 2019; Schnellmann et al., 2018), the adoption of soil conserving production practices, such as soil covering to prevent erosion, and the use of improved animal breeds and crossbreeding through artificial insemination (Ferraz & Felício, 2010). Also, the adoption of precision technologies and tools for more efficient use of irrigation water, pesticides and fertilisers could be very useful in this type of ranches to improve resource efficiency and, therefore, the sustainability of the Beef–cattle activity. Applied to animal management, precision livestock farming enables animal management to move from the group level to the monitoring and managing of individual animals (van Erp-van der Kooij et al., 2020), real-time individual animal information on animal behaviour, health, reproduction, environmental impact and production, and it allows taking immediate management measures, which can greatly improve the efficiency of such large farms (Berckmans, 2017).

Nevertheless, a short-term risk of intensification, apart from the environmental impact, is that there could be a rebound effect, the so-called “Jevon paradox”, since the rising the profitability of the land is an incentive, it stimulates the demand for more land and, therefore, the expansion of the agrarian frontier (Angelsen, 2010; le Polain de Waroux et al., 2019; Meyfroidt et al., 2018), especially when production increases can be absorbed in international markets without any negative price effects (Kaimowitz & Angelsen, 2008; Müller-Hansen et al., 2019). Therefore, Strassburg et al. (2012), Barretto et al. (2013), Müller et al. (2013) and Latawiec et al. (2014) indicate that if further deforestation is to be avoided, land intensification must be accompanied by sound and effective policies, good governance and surveillance that penalise deforestation. In this connection, Phalan et al. (2016) report some "active" land-sparing mechanisms (i.e. land-use zoning; economic instruments, such as payments, land taxes, and subsidies; spatially strategic deployment of technology, infrastructure, or agronomic knowledge intentionally targeted to certain areas rather than others; and voluntary standards and certification that reward good performance with market access and price premiums) that, implemented alone or jointly, could mitigate these rebound effects by linking yield increases to habitat protection or restoration.

5 Conclusions

The expansion of livestock frontiers and associated deforestation is a key process of global environmental change. This phenomenon is having a high environmental and socioeconomic impact, which is part of the wider and ongoing debate on food security and sustainability of livestock systems. Furthermore, while the problem is global, the challenge is contextual and location-specific.

In the specific case of the Paraguayan Chaco, this expansion is taking place through very large, highly specialised in Beef–cattle and export-oriented ranches. In all cases, livestock systems are extensive, with little dependence on external feed and agricultural resources, having an average stocking rate that is in the medium–low range of those reported in other areas of South America with similar production systems. Regarding compliance with the legislation of the area, on average, the ranches maintain 34.6% of their area without any type of intervention, although this does not happen in all cases. If grazing woodland area is added, the ranches have 43.9% of their area in which the native forests or shrubs are conserved.

The results obtained in this work suggest that the different availability of the resources of the ranches conditions the distribution of the total area, as well as the different degrees of intensification in the use of capital per unit of agricultural area, these being the main differentiating factors of the groups of Beef–cattle ranches obtained in the typology, corresponding to a Silvo-pastoral system (Group 2), which includes the oldest ranches and is the least intensive, and two systems that present a higher degree of intensification in their production system: Medium intensification ranches (Group 1), whose strategy is to carry out a high intensification of its UAA using improved pastures, and ranches highly intensified in livestock and labour (Group 3), which presents a high stocking rate and labour per unit of agricultural area. In the availability of resources, and therefore in the strategies followed by the ranches, a very important factor is their years of activity, which, in turn, is related to the location of the ranches and the vigilance in compliance with the legislation.

The analysis of what is happening in the Paraguayan Chaco and typology result contribute to a better understanding of one of the world's most active livestock frontiers and shows that the expansion process taking place in the Paraguayan Chaco is associated with an intensification of beef–cattle systems, following the trends observed in other areas. This development, along with the need to stop deforestation, is part of the wider debate on sustainable intensification according to the land-sparing paradigm. This requires further research on the trade-offs of grazing systems intensification, as well as sustainable intensification management practices and strategies, including precision livestock technologies, which increase livestock productivity without damaging the environment. Grazing systems intensification must also be accompanied by effective policies and good governance that encourage the adoption of these changes and prevent further deforestation.

Author contributions Milán M.J. and Gónzalez, E. contributed to conceptualization; Milán M.J. was involved in methodology and writing; Gónzalez, E. contributed to data collection and analysis and funding acquisition;. All authors read and approved the final manuscript.

Funding Open Access Funding provided by Universitat Autonoma de Barcelona. This work was supported by a research scholarship "Carlos Antonio López" (BECAL) to E. Gonzalez granted by the Government of the Republic of Paraguay.

Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

References

Angelsen, A. (2010). Policies for reduced deforestation and their impact on agricultural production. *Proceedings of the National Academy of Sciences of the United States of America, 107*(46), 19639–19644. https://doi.org/10.1073/pnas.0912014107

Balmford, A., Green, R., & Phalan, B. (2015). Land for food & land for nature? *Daedalus, 144*(4), 57–75.

Barber, C. P., Cochrane, M. A., Souza, C. M., & Laurance, W. F. (2014). Roads, deforestation, and the mitigating effect of protected areas in the Amazon. *Biological Conservation, 177*, 203–209. https://doi.org/10.1016/j.biocon.2014.07.004

Barona, E., Ramankutty, N., Hyman, G., & Coomes, O. T. (2010). The role of pasture and soybean in deforestation of the Brazilian Amazon. *Environmental Research Letters, 5*, 024002. https://doi.org/10.1088/1748-9326/5/2/024002

Barretto, A. G. O. P., Berndes, G., Sparovek, G., & Wirsenius, S. (2013). Agricultural intensification in Brazil and its effects on land-use patterns: An analysis of the 1975–2006 period. *Global Change Biology, 19*(6), 1804–1815. https://doi.org/10.1111/gcb.12174

Baumann, M., Piquer-Rodríguez, M., Fehlenberg, V., Gavier Pizarro, G., & Kuemmerle, T., et al. (2016). Land-use competition in the South American Chaco. In J. Niewöhner (Ed.), *Land use competition: Human-Environment Interactions* (Vol. 6, pp. 215–229). Springer. https://doi.org/10.1007/978-3-319-33628-2_13

Baumann, M., Israel, Ch., Piquer-Rodríguez, M., Gavier-Pizarro, G., Volante, J. N., & Kuemmerle, T. (2017). Deforestation and cattle expansion in the Paraguayan Chaco 1987–2012. *Regional Environmental Change, 17*, 1179–1191. https://doi.org/10.1007/s10113-017-1109-5

Berckmans, D. (2017). General introduction to precision livestock farming. *Animal Frontiers, 7*(1), 6–11. https://doi.org/10.2527/af.2017.0102

Bennett, N. J. (2016). Using perceptions as evidence to improve conservation and environmental management. *Conservation Biology, 30*(3), 582–592. https://doi.org/10.1111/cobi.12681

Bennett, N. J., Roth, R., Klain, S. C., Chan, K., Christie, P., Clark, D. A., Cullman, G., Curran, D., Durbin, T. J., Epstein, G., Greenberg, A., Nelson, M. P., Sandlos, J., Stedman, R., Teel, T. L., Thomas, R., Veríssimo, D., & Wyborn, C. (2017). Conservation social science: Understanding and integrating human dimensions to improve conservation. *Biological Conservation, 205*, 93–108. https://doi.org/10.1016/j.biocon.2016.10.006

Bernués, A., Ruiz, R., Olaizola, A., Villalba, D., & Casasús, I. (2011). Sustainability of pasture-based livestock farming systems in the European Mediterranean context: Synergies and trade-offs. *Livestock Science, 139*(1–2), 44–57. https://doi.org/10.1016/j.livsci.2011.03.018

Bussoni, A., Alvarez, J., Cubbage, F., Ferreira, G., & Picasso, V. (2019). Diverse strategies for integration of forestry and livestock production. *Agroforestry Systems, 93*(1), 333–344. https://doi.org/10.1007/s10457-017-0092-7

Cabrera, A. J. N., Stosiek, D., Glatzle, A., Shelton, H. M., & Schultze-Kraft, R. (2001). Liveweight gains of steers at different stocking rates on monospecific Gatton panic and Estrella grass pastures in the Chaco Central region of Paraguay. *Tropical Grasslands, 35*(3), 186–192.

Caldas, M. M., Goodin, D., Sherwood, S., Campos Krauer, J. M., & Wisely, S. M. (2015). Land-cover change in the Paraguayan Chaco: 2000–2011. *Journal of Land Use Science, 10*(1), 1–18. https://doi.org/10.1080/1747423X.2013.807314

Costa, F. P., & Rehman, T. (2005). Unravelling the rationale of «overgrazing» and stocking rates in the beef production systems of Central Brazil using a bi-criteria compromise programming model. *Agricultural Systems, 83*(3), 277–295. https://doi.org/10.1016/j.agsy.2004.02.011

Davis, K. F., Yu, K., Herrero, M., Havlik, P., Carr, J. A., & Odorico, P. D. (2015). Historical trade-offs of livestock's environmental impacts. *Environmental Research Letters, 10*, 125013. https://doi.org/10.1088/1748-9326/10/12/125013

de Abreu, U. G. P., McManus, C., & Santos, S. A. (2010). Cattle ranching, conservation and transhumance in the Brazilian Pantanal. *Pastoralism, 1*(1), 99–114. https://doi.org/10.3362/2041-7136.2010.007

Díaz-Gaona, C., Sánchez-Rodríguez, M., Rucabado, T., & Rodríguez-Estévez, V. (2019). A typological characterization of organic livestock farms in the Natural Park Sierra de Grazalema based on technical and economic variables. *Sustainability, 11*(21), 6002. https://doi.org/10.3390/su11216002

Eaton, D. P., Santos, S. A., Santos, M. C. A., Lima, J. V. B., & Keuroghlian, A. (2011). Rotational grazing of native pasturelands in the Pantanal: An effective conservation tool. *Tropical Conservation Science, 4*(1), 39–52. https://doi.org/10.1177/194008291100400105

Erp-van der Kooij, E., & van, & Rutter, S.M. (2020). Using precision farming to improve animal welfare. *CAB Reviews, 15*, 051. https://doi.org/10.1079/PAVSNNR202015051

Escribano, A. J., Gaspar, P., Mesías, F. J., Pulido, A. F., & Escribano, M. (2014). Evaluación de la sostenibilidad de explotaciones de vacuno de carne ecológicas y convencionales en sistemas agroforestales: estudio del caso de las dehesas. *ITEA Informacion Tecnica Economica Agraria, 110*(4), 343–367. https://doi.org/10.12706/itea.2014.022

Escribano, A. J., Gaspar, P., Mesías, F. J., & Escribano, M. (2016). The role of the level of intensification, productive orientation and self-reliance in extensive beef cattle farms. *Livestock Science, 193*, 8–19. https://doi.org/10.1016/j.livsci.2016.09.006

Faverin, C., & Machado, C. (2019). Typologies and characterization of cow-calf system the flooding pampas. *Chilean Journal of Agricultural and Animal Sciences, 35*(1), 3–13. https://doi.org/10.4067/S0719-38902019005000101

Fehlenberg, V., Baumann, M., Gasparri, N. I., Piquer-Rodriguez, M., Gavier-Pizarro, G., & Kuemmerle, T. (2017). The role of soybean production as an underlying driver of deforestation in the South American Chaco. *Global Environmental Change, 45*, 24–34. https://doi.org/10.1016/j.gloenvcha.2017.05.001

Fernández, P. D., Kuemmerle, T., Baumann, M., Grau, H. R., Nasca, J. A., Radrizzani, A., & Gasparri, N. I. (2020). Understanding the distribution of cattle production systems in the South American Chaco. *Journal of Land Use Science, 15*(1), 1–17. https://doi.org/10.1080/1747423X.2020.1720843

Ferraz, J. B. S., & Felício, P. E. (2010). Production systems – An example from Brazil. *Meat Science, 84*(2), 238–243. https://doi.org/10.1016/j.meatsci.2009.06.006

Garnett, T., Appleby, M. C., Balmford, A., Bateman, I. J., Benton, T. G., Bloomer, P., Burlingame, B., Dawkins, M., Dolan, L., Fraser, D., Herrero, M., Hoffmann, I., Smith, P., Thornton, P. K., Toulmin, C., Vermeulen, S. J., & Godfray, H. C. J. (2013). Sustainable Intensification in Agriculture: Premises and Policies. *Science, 341*(6141), 33–34. https://doi.org/10.1126/science.1234485

Gaspar, P., Mesías, F. J., Escribano, M., Rodríguez De Ledesma, A., & Pulido, F. (2007). Economic and management characterization of dehesa farms: Implications for their sustainability. *Agroforestry Systems, 71*, 151–162. https://doi.org/10.1007/s10457-007-9081-6

Gasparri, N. I., & le Polain de Waroux, Y. (2015). The coupling of South American soybean and cattle production frontiers: New challenges for conservation policy and land change science. *Conservation Letters, 8*(4), 290–298. https://doi.org/10.1111/conl.12121

Glatzle, A. (2004). Mejoramiento de forrajes tropicales: Gramíneas y leguminosas. In Felas, AGROSEMP, MAG/DISE (Eds.), *Conferencias y resúmenes de trabajos presentados en el XIX Seminario Panamericano de Semillas* (pp. 113–122). Asunción.

Glatzle, A. F., Cabrera, A. N., Naegele, A., & Klassen, N. (2019). Leucaena feeding systems in Paraguay. *Tropical Grasslands, 7*(4), 397–402. https://doi.org/10.17138/TGFT(7)397-402

Godde, C. M., Garnett, T., Thornton, P. K., Ash, A. J., & Herrero, M. (2018). Grazing systems expansion and intensification: Drivers, dynamics, and trade-offs. *Global Food Security, 16*, 93–105. https://doi.org/10.1016/j.gfs.2017.11.003

Graesser, J., Aide, T. M., Grau, H. R., & Ramankutty, N. (2015). Cropland/pastureland dynamics and the slowdown of deforestation in Latin America. *Environmental Research Letters, 10*(3), 034017. https://doi.org/10.1088/1748-9326/10/3/034017

Houspanossian, J., Giménez, R., Baldi, G., & Nosetto, M. (2016). Is aridity restricting deforestation and land uses in the south American Dry Chaco? *Journal of Land Use Science, 11*(4), 369–383. https://doi.org/10.1080/1747423X.2015.1136707

Kaimowitz, D., & Angelsen, A. (2008). Will livestock intensification help save Latin America's tropical forests? *Journal of Sustainable Forestry, 27*(1–2), 6–24. https://doi.org/10.1080/10549810802225168

Latawiec, A. E., Strassburg, B. B. N., Valentim, J. F., Ramos, F., & Alves-Pinto, H. N. (2014). Intensification of cattle ranching production systems: Socioeconomic and environmental synergies and risks in Brazil. *Animal, 8*(8), 1255–1263. https://doi.org/10.1017/S1751731114001566

le Polain de Waroux, Y., Garrett, R.D., Heilmayr, R., & Lambin, E.F. (2016). Land-use policies and corporate investments in agriculture in the Gran Chaco and Chiquitano. *PNAS, 113*, 4021–4026. https://doi.org/10.1073/pnas.1602646113

le Polain de Waroux, Y., Baumann, M., Gasparri, N.I., Gavier-Pizarro, G.I., Godar. J., Kuemmerle, T., Müller, R., Vázquez, F., Volante, J.N., & Meyfroidt, P. (2018). Rents, actors, and the expansion of commodity frontiers in the Gran Chaco. *Annals of the American Association of Geographers, 108*, 204–225. https://doi.org/10.1080/24694452.2017.1360761

le Polain de Waroux, Y., Garrett, R.D., Graesser, J., Nolte, C., White, C., & Lambin, E.F. (2019). The restructuring of South American soy and beef production and trade under changing environmental regulations. *World Development, 121*, 188–202. https://doi.org/10.1016/j.worlddev.2017.05.034

le Polain de Waroux, Y. (2019). Capital has no homeland: The formation of transnational producer cohorts in South America's commodity frontiers. *Geoforum, 105*, 131–144. https://doi.org/10.1016/j.geoforum.2019.05.016

López-i-Gelats, F., Milán, M. J., & Bartolomé, J. (2011). Is farming enough in mountain areas? Farm diversification in the Pyrenees. *Land Use Policy, 28*, 783–791. https://doi.org/10.1016/j.landusepol.2011.01.005

Magliano, P. N., Fernández, R. J., Giménez, R., Marchesini, V. A., Páez, R. A., & Jobbágy, E. G. (2016). Changes in water fluxes partition in the arid chaco caused by the replacement of forest by pastures. *Ecología Austral, 26*, 95–106.

Marinaro, S., & Grau, R. H. (2015). Comparison of animal biodiversity in three livestock systems of open environments of the semi-arid Chaco of Argentina. *The Rangeland Journal, 37*, 497–505. https://doi.org/10.1071/RJ15052

Mereles, F., Cartes, J.L., Clay, R.P., Cacciali, P., Paradeda, C., Rodas, O., & Yanosky, A. (2013). Análisis cualitativo para la definición de las ecorregiones de Paraguay occidental. *Paraquaria Natural, 1*(2), 12–20. https://paraquaria.org.py/product/analisis-cualitativo-para-la-definicion-de-las-ecorregiones-de-paraguay-occidental/

Meyfroidt, P., Roy Chowdhury, R., de Bremond, A., Ellis, E. C., Erb, K.-H., Filatova, T., Garrett, R. D., Grove, J. M., Heinimann, A., Kuemmerle, T., Kull, C. A., Lambin, E. F., Landon, Y., & le Polain de Waroux, Y., Messerli, P., Müller, D., Nielsen, J.Ø., Peterson, G.D., Rodriguez García, V., …, & Verburg, P.H. (2018). Middle-range theories of land system change. *Global Environmental Change, 53*, 52–67. https://doi.org/10.1016/j.gloenvcha.2018.08.006

Milán, M. J., Arnalte, E., & Caja, G. (2003). Economic profitability and typology of Ripollesa breed sheep farms in Spain. *Small Ruminant Research, 49*(1), 97–105. https://doi.org/10.1016/S0921-4488(03)00058-0

Milán, M. J., Bartolome, J., Quintanilla, R., García-Cachán, M. D., Espejo, M., Herráiz, P. L., Sánchez-Recio, J. M., & Piedrafita, J. (2006). Structural characterisation and typology of beef cattle farms of Spanish wooded rangelands (dehesas). *Livestock Science, 99*(2), 197–209. https://doi.org/10.1016/j.livsci.2005.06.012

Milán, M. J., Caja, G., González-González, R., Fernández-Pérez, A. M., & Such, X. (2011). Structure and performance of Awassi and Assaf dairy sheep farms in northwestern Spain. *Journal of Dairy Science, 94*(2), 771–784. https://doi.org/10.3168/jds.2010-3520

Milera, M. (2013). Contribución de los sistemas silvopastoriles en la producción y el medio ambiente. *Avances En Investigación Agropecuaria, 17*(3), 7–24.

Modernel, P., Rossing, W. A. H., Corbeels, M., Dogliotti, S., Picasso, V., & Tittonell, P. (2016). Land use change and ecosystem service provision in Pampas and Campos grasslands of southern South America. *Environmental Research Letters, 11*, 113002. https://doi.org/10.1088/1748-9326/11/11/113002

Modernel, P., Dogliotti, S., Alvarez, M., Corbeels, M., Picasso, V., Tittonell, P., & Rossing, W. A. H. (2018). Identification of beef production farms in the Pampas and Campos area that stand out in economic and environmental performance. *Ecological Indicators, 89*, 755–770. https://doi.org/10.1016/j.ecolind.2018.01.038

Müller, R., Pistorius, T., Rohde, S., Gerold, G., & Pacheco, P. (2013). Policy options to reduce deforestation based on a systematic analysis of drivers and agents in lowland Bolivia. *Land Use Policy, 30*(1), 895–907. https://doi.org/10.1016/j.landusepol.2012.06.019

Müller-Hansen, F., Heitzig, J., Donges, J. F., Cardoso, M. F., Dalla-Nora, E. L., Andrade, P., Kurths, J., & Thonicke, K. (2019). Can intensification of cattle ranching reduce deforestation in the Amazon? Insights from an agent-based social-ecological model. *Ecological Economics, 159*, 198–211. https://doi.org/10.1016/j.ecolecon.2018.12.025

Nasca, J. A., Feldkamp, C. R., Arroquy, J. I., & Colombatto, D. (2015). Efficiency and stability in subtropical beef cattle grazing systems in the northwest of Argentina. *Agricultural Systems, 133*, 85–96. https://doi.org/10.1016/j.agsy.2014.10.014

Naumann, M. (2006). *Atlas del Gran Chaco Sudamericano*. Sociedad Alemana de Cooperación Técnica (GTZ). Buenos Aires. http://redaf.org.ar/wp-content/uploads/2008/02/ATLAS_GRAN_CHACO_ES.pdf

Nepstad, D., Stickler, C.M., & Almeida, O.T. (2006). Globalization of de Amazon Soy and Beef Industries: Opportunities for Conservation. *Conservation Biology*, *20*(6), 1595–1603. https://www.jstor.org/stable/4124686

Oesterheld, M., Loreti, J., Semmartin, M., & Paruelo, J.M. (1999). Grazing, fire, and climate in grasslands and savannas, regimes and effects on primary productivity. In *Ecosystems of Disturbed Ground* (pp. 287–306). Series Ecosystems of the World, Elsevier.

Painter, L., Nallar, R., del Fleytas, M., & C., Loayza, O., Reinaga, A., & Villalba, L. (2020). Reconciliation of cattle ranching with biodiversity and social inclusion objectives in large private properties in Paraguay and collective indigenous lands in Bolivia. *Agricultural Systems, 184*(340), 102861. https://doi.org/10.1016/j.agsy.2020.102861

Parente, L., Mesquita, V., Miziara, F., Baumann, L., & Ferreira, L. (2019). Assessing the pasturelands and livestock dynamics in Brazil, from 1985 to 2017: A novel approach based on high spatial resolution imagery and Google Earth Engine cloud computing. *Remote Sensing of Environment, 232*, 111301. https://doi.org/10.1016/j.rse.2019.111301

Phalan, B., Onial, M., Balmford, A., & Green, R. E. (2011). Reconciling food production and biodiversity conservation: Land sharing and land sparing compared. *Science, 333*(6047), 1289–1291. https://doi.org/10.1126/science.1208742

Phalan, B., Green, R. E., Dicks, L. V., Dotta, G., Feniuk, C., Lamb, A., Strassburg, B. B. N., Williams, D. R., & zu Ermgassen, E.K.H.J., & Balmford, A. (2016). How can higher-yield farming help to spare nature? *Science, 351*(6272), 450–451. https://doi.org/10.1126/science.aad0055

Piquer-Rodríguez, M., Butsic, V., Gärtner, P., Macchi, L., Baumann, M., Gavier Pizarro, G., Volante, J. N., Gasparri, I. N., & Kuemmerle, T. (2018). Drivers of agricultural land-use change in the Argentine Pampas and Chaco regions. *Applied Geography, 91*, 111–122. https://doi.org/10.1016/j.apgeog.2018.01.004

Puechagut, P.B., Politi, N., Ruiz de los Llanos, E., Lizarraga, L., Bianchi, C.L., Bellis, L.M., & Rivera, L.O. (2018). Association between livestock and native mammals in a conservation priority area in the chaco of Argentina. *Mastozoologia Neotropical, 25,* 407–418. https://doi.org/10.31687/saremMN.18.25.2.0.19

REDIEX (2009). *Atlas Geografico del Chaco Paraguayo. Informe y 12 mapas temáticos*. Unidad GIS-REDIEX, Asunción, Paraguay. http://www.geologiadelparaguay.com/Atlas-Geografico-del-Chaco.pdf

Rodriguez, P., Giménez, R., Nosetto, M. D., Esteban, G., Jobbágy, E. G., & Magliano, P. N. (2020). Changes in water fluxes partition related to the replacement of native dry forests by crops in the Dry Chaco. *Journal of Arid Environments, 183*, 104281. https://doi.org/10.1016/j.jaridenv.2020.104281

Rudel, T. K. (2007). Changing agents of deforestation: From state-initiated to enterprise driven processes, 1970–2000. *Land Use Policy, 24*(1), 35–41. https://doi.org/10.1016/j.landusepol.2005.11.004

Ruiz, F. A., Castel, J. M., Mena, Y., Camúñez, J., & González-Redondo, P. (2008). Application of the technico-economic analysis for characterizing, making diagnoses and improving pastoral dairy goat systems in Andalusia (Spain). *Small Ruminant Research, 77*(2–3), 208–220. https://doi.org/10.1016/j.smallrumres.2008.03.007

Ruiz, M., Ruiz, J., Torres, V., & Cach, J. (2012). Estudio de sistemas de producción de carne bovina en un municipio del estado de Hidalgo, México. *Revista Cubana de Ciencia Agrícola, 46*(3), 261–265. https://www.redalyc.org/pdf/1930/193025294006.pdf

Schnellmann, L.P., Verdoljak, J. J. O., Bernardis, A., Martínez-González, J. C., Castillo-Rodríguez, S. P., & Joaquín-Cancino, S. (2018). El pasto gatton (*Panicum maximum* cv. gatton panic) una alternativa para el noroeste del chaco, Argentina. *Agro-Productividad, 11*(5), 118–123.

Soto, F., & Gómez, S. (2012). *Dinámicas del mercado de la tierra en américa Latina y el Caribe: concentración y extranjerización*. FAO. http://www.fao.org/3/a-i2547s.pdf

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., de Vries, W., Vermeulen, S. J., Herrero, M., Carlson, K. M., Jonell, M., Troell, M., DeClerck, F., Gordon, L. J., Zurayk, R., Scarborough, P., Rayner, M., Loken, B., Fanzo, J., & Willett, W. (2018). Options for keeping the food system within environmental limits. *Nature, 562*, 519–525. https://doi.org/10.1038/s41586-018-0594-0

SENACSA (2020). *Estadísticas Pecuarias*. Retrieved September 21, 2021 from http://www.senacsa.gov.py/index.php/informacion-publica/estadistica-pecuaria

Strassburg, B. B. N., Rodrigues, A. S. L., Gusti, M., Balmford, A., Fritz, S., Obersteiner, M., Kerry Turner, R., & Brooks, T. M. (2012). Impacts of incentives to reduce emissions from deforestation on global species extinctions. *Nature Climate Change, 2*(5), 350–355. https://doi.org/10.1038/nclimate1375

Stylianou, A., Sdrali, D., & Apostolopoulos, C. D. (2020). Capturing the diversity of Mediterranean farming systems prior to their sustainability assessment: The case of Cyprus. *Land Use Policy, 96*, 104722. https://doi.org/10.1016/j.landusepol.2020.104722

Tilman, D., & Clark, M. (2014). Global diets link environmental sustainability and human health. *Nature, 515*, 518–522. https://doi.org/10.1038/nature13959

Toro-Mujica, P., García, A., Gómez-Castro, A., Perea, J., Rodríguez-Estévez, V., Angón, E., & Barba, C. (2012). Organic dairy sheep farms in south-central Spain: Typologies according to livestock management and economic variables. *Small Ruminant Research, 104*(1–3), 28–36. https://doi.org/10.1016/j.smallrumres.2011.11.005

Toro-Mujica, P., Vera, R., Vargas-Bello-Pérez, E., Pinedo, P., & Bas, F. (2019). Trends and drivers of change of pastoral beef production systems in a Mediterranean-temperate climate zone of Chile. *Animals, 9*(12), 1135. https://doi.org/10.3390/ani9121135

Vázquez, F. (2007). Las reconfiguraciones territoriales del Chaco paraguayo: entre espacio nacional y espacio mundial. *Población y Desarrollo, 28*, 69–73. https://revistascientificas.una.py/index.php/RE/article/view/795

Veit, P., & Sarsfield, R. (2017). *Land Rights, Beef Commodity Chains, and Deforestation Dynamics in the Paraguayan Chaco*. USAID Tenure and Global Climate Change Program. https://www.land-links.org/wp-content/uploads/2017/06/USAID_Land_Tenure_TGCC_Paraguay_Risk_Assessment_June-2017.pdf

Zabala, A., Sandbrook, C., & Mukherjee, N. (2018). When and how to use Q methodology to understand perspectives in conservation research. *Conservation Biology, 32*(5), 1185–1194. https://doi.org/10.1111/cobi.13123

zu Ermgassen, E.K.H.J., de Alcântara, M.P., Balmford, A., Barioni, L., Neto, F.B., Bettarello, M.M.F., Brito, G., Carrero, G.C., Florence, E.A.S., García, E., Trevisan, E., Trajano, C., Mallaman, G.M., Strassburg, B.B.N., Valentim, J.F., & Latawiec, A. (2018). Results from on-the-ground efforts to promote sustainable cattle ranching in the Brazilian Amazon. *Sustainability, 10*(4), 1301. https://doi.org/10.3390/su10041301