

TOPICAL REVIEW • OPEN ACCESS

# Land use change and ecosystem service provision in Pampas and Campos grasslands of southern South America

To cite this article: P Modernel *et al* 2016 *Environ. Res. Lett.* **11** 113002

View the [article online](#) for updates and enhancements.

## Related content

- [Global versus local environmental impacts of grazing and confined beef production systems](#)  
P Modernel, L Astigarraga and V Picasso
- [Tradeoffs in the quest for climate smart agricultural intensification in Mato Grosso, Brazil](#)  
Juliana D B Gil, Rachael D Garrett, Alan Rotz *et al.*
- [Evidence based review: positive versus negative effects of livestock grazing on wildlife. What do we really know?](#)  
Jennifer M Schieltz and Daniel I Rubenstein

## Recent citations

- [Anibal de Moraes \*et al\*](#)
- [Public policies for low carbon emission agriculture foster beef cattle production in southern Brazil](#)  
Newton Borges da Costa Jr. *et al*
- [Meeting global land restoration and protection targets: What would the world look like in 2050?](#)  
Sarah Wolff *et al*

## Environmental Research Letters



## TOPICAL REVIEW

## Land use change and ecosystem service provision in Pampas and Campos grasslands of southern South America

## OPEN ACCESS

RECEIVED  
8 June 2015REVISED  
29 September 2016ACCEPTED FOR PUBLICATION  
7 October 2016PUBLISHED  
11 November 2016

Original content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](#).

Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

P Modernel<sup>1,2,3,6</sup>, W A H Rossing<sup>1</sup>, M Corbeels<sup>2</sup>, S Dogliotti<sup>3</sup>, V Picasso<sup>3,4</sup> and P Titttonell<sup>1,5</sup><sup>1</sup> Farming Systems Ecology, Wageningen University, PO Box 430, 6700 AK Wageningen, The Netherlands<sup>2</sup> Agro-ecology and Sustainable Intensification of Annual Crops, CIRAD, Avenue Agropolis, F-34398 Montpellier cedex 5, France<sup>3</sup> Facultad de Agronomía, Universidad de la República, Av. E. Garzón 780, Montevideo, Uruguay<sup>4</sup> Agronomy Dept., University of Wisconsin-Madison, 1575 Linden Dr, Madison, WI, 53706, USA<sup>5</sup> Natural Resources, Environment and Eco-Regions, National Institute of Agricultural Research (INTA), Modesta Victoria 4450, CC277, San Carlos de Bariloche, Argentina<sup>6</sup> Author to whom any correspondence should be addressed.E-mail: [pablomodernel@gmail.com](mailto:pablomodernel@gmail.com)**Keywords:** ecological intensification, meat production, biodiversity, sustainability, global change, food security, Río de la Plata grasslandsSupplementary material for this article is available [online](#)**Abstract**

New livestock production models need to simultaneously meet the increasing global demand for meat and preserve biodiversity and ecosystem services. Since the 16th century beef cattle has been produced on the Pampas and Campos native grasslands in southern South America, with only small amounts of external inputs. We synthesised 242 references from peer-reviewed and grey literature published between 1945 and mid-2015 and analysed secondary data to examine the evidence on the ecosystem services provided by this grassland biodiversity hotspot and the way they are affected by land use changes and their drivers. The analysis followed the requirements of systematic review from the PRISMA statement (Moher *et al* 2009 *Acad. Clin. Intern. Med.* **151** 264–9). The Pampas and Campos provide feed for 43 million heads of cattle and 14 million sheep. The biome is habitat of 4000 native plant species, 300 species of birds, 29 species of mammals, 49 species of reptiles and 35 species of amphibians. The soils of the region stock 5% of the soil organic carbon of Latin America on 3% of its area. Driven by high prices of soybean, the soybean area increased by 210% between 2000 and 2010, at the expense of 2 million ha (5%) of native grassland, mostly in the Pampas. Intensification of livestock production was apparent in two spatially distinct forms. In subregions where cropping increased, intensification of livestock production was reflected in an increased use of grains for feed as part of feedlots. In subregions dominated by native grasslands, stocking rates increased. The review showed that land use change and grazing regimes with low forage allowances were predominantly associated with negative effects on ecosystem service provision by reducing soil organic carbon stocks and the diversity of plants, birds and mammals, and by increasing soil erosion. We found little quantitative information on changes in the ecosystem services water provision, nutrient cycling and erosion control. We discuss how changing grazing regimes to higher forage allowance can contribute to greater meat production and enhancing ecosystem services from native grasslands. This would require working with farmers on changing their management strategies and creating enabling economic conditions.

**1. Introduction**

While global demand for meat is predicted to grow in the next decades (OECD 2007), there is widespread concern about the negative environmental effects of current models of livestock production (de Vries and

de Boer 2010, Steinfeld *et al* 2010, Gerber *et al* 2013, Alkemade *et al* 2013, Petz *et al* 2014). New models of livestock production are needed to address the increasing demand for meat while preserving biodiversity and ecosystem services. Ecologically intensive agriculture has been proposed as a means to attain greater

resource use efficiency and reduced need for external inputs through increased reliance on functional biodiversity (Doré *et al* 2011, Bommarco *et al* 2012, Tittone 2014). The traditional livestock systems in the Pampas and Campos of the *Río de la Plata grasslands* region in southern South America may be considered ecologically intensive models of meat production that evolved from the early cattle production systems introduced by the European settlers. Beef cattle is produced on species-rich native grasslands with negligible amounts of external inputs (Viglizzo *et al* 2001). Over the past decades, cropping replaced substantial areas of native grassland, leading to likely irreversible destruction of vast areas of the grassland biome (Naylor *et al* 2005). Despite the historical, cultural and economic importance of these low external input meat production systems, information about the ecosystem services they provide and the changes they are subject to is limited and fragmented (Payret *et al* 2009, Medan *et al* 2011, Balvanera *et al* 2012). This knowledge gap impedes science-based assessment of their role as an alternative model of meat production and of the consequences of land use changes for the provision of ecosystem services (Baldi and Paruelo 2008, Vega *et al* 2009).

Here we systematically review the evidence on land use in the Pampas and Campos, the ecosystem services provided by the native grasslands and how these were affected by land use change in recent years. We addressed the following questions: (1) What is the current ecological and agricultural diversity in the *Río de la Plata grasslands* region? (2) How did land cover and land use change over time? (3) What is the level of ecosystem service provision by native grasslands? Based on our findings, we discuss current thinking about options for increasing meat productivity while preserving biodiversity and associated services.

## 2. Materials and methods

### 2.1. Data collection

We conducted a systematic review of land use change and ecosystems services in the *Río de la Plata grasslands* region based on peer-reviewed and grey literature. A search of peer-reviewed articles through the Web of Science (Thomson Reuters, New York, USA) was performed on 20 June 2015 with the following keywords: *Río de La Plata grasslands* (22 results); *Campos grasslands* (178 results); *Pampas grasslands* (444 results). The keywords correspond to the different colloquial names of the *Río de La Plata grasslands* region, with a focus on native grasslands. Additional search criteria were English, Spanish and Portuguese as language and publication date between 1945 and 2015. The first article was published in 1988; 53% of the articles were published after 2005. Of the resulting 644 articles, the title and/or abstract of 174 matched the scope of this study by quantifying the current state

of at least one ecosystem service; quantifying modifications in the provision of ecosystem services resulting from anthropogenic activities; or quantifying changes in land use over time.

Additional sources of information were identified through the on-line library system of Wageningen University and Research Centre. Furthermore, we contacted 15 experts on land use and ecosystem services in the *Río de la Plata grasslands* region from Argentina, Uruguay and Rio Grande do Sul (Brazil), who facilitated access to grey literature and databases published in Spanish or Portuguese. This yielded 68 additional publications, adding up to 242 publications in total.

Census data from Argentina (2002), Brazil (2006) and Uruguay (2000 and 2010) and regional surveys from Argentina (2010), Brazil (2005) and Uruguay (2012 and 2013) were used to characterise the structure of the agricultural sector in terms of farm sizes, main sources of income and land use (INDEC 2002, MGAP 2002, 2012a, SEBRAE, SENAR and FAR-SUL 2005, IBGE 2006, Antuña *et al* 2010, Calvi 2010, MGAP 2013b). Aboveground net primary production of grasslands from 2000 to 2010 was obtained from on-line data (LART 2013). Rainfall and temperature data came from meteorological stations in the region (INIA 2013, INTA 2015, Ministerio da Agricultura; Pecuária e abastecimento 2015).

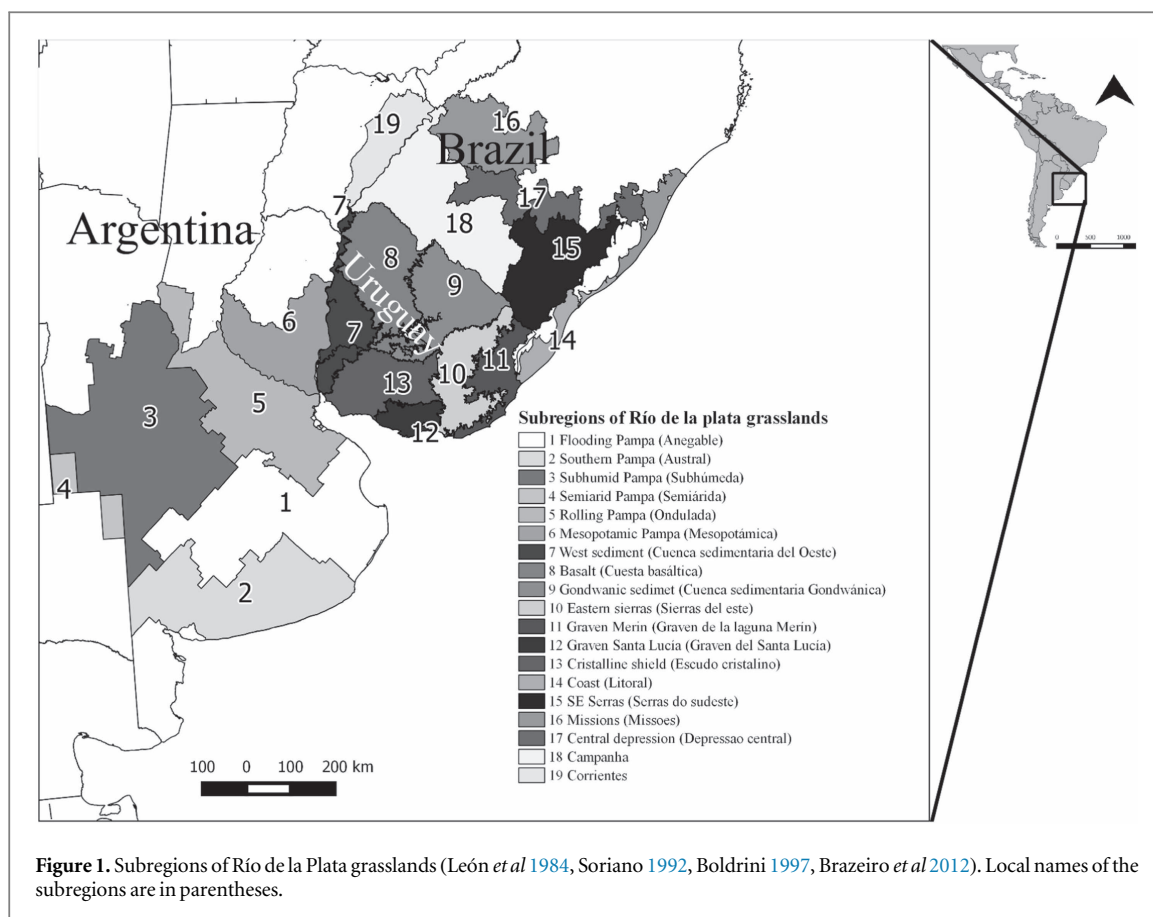
### 2.2. Data processing and strength of evidence

The definition of the geographic limits of the region and its subregions was based on the different vegetation communities reported in the literature (León *et al* 1984, Soriano 1992, Boldrini 1997, Viglizzo and Jobbágy 2010, Brazeiro *et al* 2012). Changes in land use and livestock densities were calculated from the census data and regional surveys, and mapped at the level of subregions. Maps were built using Quantum GIS Desktop 2.2.0 (QGIS 2014).

For each of the 242 articles we listed which attributes and drivers of the ecosystem services had been studied, and the resulting trends. Attributes comprised the quantitative measures of an ecosystem service (e.g. plant species richness as an attribute of floristic diversity), and drivers included the external forces that affected the value of the attributes (e.g. land use change). Observed trends in attributes were classified as increase, decrease or no change.

To ensure the credibility and reproducibility of the systematic review, we designed and reported this study according to the PRISMA statement (Moher *et al* 2009), which provides guidelines for reporting systematic reviews and meta-analyses. The items checklist for this study is included as supplementary material 1. An overview of the sources of information can be found in supplementary material 2.

The strength of evidence of each study was represented on a three-point scale based on the methods



used in the study. High strength evidence (value = 3) corresponded to studies from controlled field experiments, observations with sound methodologies, or meta-analyses; intermediate strength evidence (value = 2) included narrative reviews; and low strength evidence (value = 1) included publications based on opinion.

### 3. Diversity of beef production systems in the region

*Río de la Plata grasslands* is a region of 700 000 km<sup>2</sup> comprising parts of Argentina and Brazil and the whole of Uruguay (28°–38°S; 47°–67°W). Landscape heterogeneity in the region is reflected in subregions that are defined by vegetation communities associated with edapho-topographic characteristics (Soriano 1992, Hasenack *et al* 2010, Brazeiro *et al* 2012) (figure 1 and table 1). Climate conditions differ following southwest to northeast gradients in annual precipitation (from 700 to 1600 mm) and average annual temperature (from 14 °C to 22 °C). The climatic gradients determine the relative dominance of C3 and C4 grass species (Burkart 1975), giving rise to two major biomes: Pampas and Campos. While C3 species dominate in the Pampas of Argentina, the Campos of Brazil and Uruguay are dominated by C4 grasses, although in winter the biomass of C3 species increases

substantially in the Uruguayan Campos (Berretta *et al* 2000).

The native grasslands constitute the main source of feed for 43 million heads of cattle and sustain the livelihoods of 260 000 farm households (INDEC 2002, IBGE 2006, MGAP 2013b). Farm size in terms of land and cattle heads vary among regions (table 1). Most of the farms (81%) and 66% of the land are owned by families. The remainder is owned by corporations (INDEC 2002, IBGE 2006, MGAP 2013b).

Two types of beef production systems can be distinguished: reproduction oriented or ‘cow-calf’ systems and meat production or ‘finishing’ systems (Beauchemin *et al* 2010). Farms may be specialised in one of these types, but combinations of both on a single farm are also found (‘full cycle’ systems) (figure 2).

Cow-calf farms specialise in animal reproduction and derive their main income from selling calves and culled cows. These farms typically also raise sheep for wool or meat production (Royo Pallarés *et al* 2005), giving rise to competition between sheep and cattle for the grassland feed resource.

Finishing systems mainly fatten male calves. Farms may specialise in ‘backgrounding’ (the phase from male calf to young steer) and/or ‘fattening’ (the phase from young steer to slaughter weight). In both systems animals may be fed on native grasslands, leys or grains (feedlots), defining different production systems with distinct shares of native grassland, crop-ley rotations

**Table 1.** Characteristics of the subregions of the *Río de la Plata grasslands* region ordered by biome and country.

Biome	Country	Area (million ha) <sup>8</sup>	Subregion <sup>9,10</sup>	Dominant soil types <sup>9</sup>	Area with native grasslands (%) <sup>11</sup>	Average farm size (ha) <sup>11</sup>	Farms with cattle (%) <sup>11</sup>	Ownership (%) <sup>11,12</sup>	Main production system <sup>13</sup>	
Pampas (C3-dominated)	Argentina	9.3	Flooding (1)	Mollic Solonetz	68	605	93	70	Cattle (cow-calf)	
		8.3	Southern (2)	Haplic/Luvic Phaeozems	29	697	81	66	Crops-cattle (finishing)	
		12.9	Subhumid (3)	Phaeozems	17	526	72	66	Crops	
		1.5	Semiarid (4)	Calcaric Phaeozems	7	824	89	70	Crops	
		7.4	Rolling (5)	Phaeozems	33	222	48	59	Crops	
		3.2	Mesopotamic (6)	Phaeozems/Eutric Vertisols	50	388	84	67	Crops-cattle (finishing)	
Campos <sup>7</sup> (C4-dominated)	Uruguay	2.8	West sediment (7)	Eutric Vertisols/Phaeozems	54	357	78	59	Cattle (finishing), crops	
		3.2	Basalt (8)	Lithic Leptosols/Phaeozems	89	728	87	67	Cattle (cow-calf), sheep	
		1.2	Gondwanic sediment (9)	Haplic Luvisols/Phaeozems	79	362	65	66	Cattle (cow-calf)	
		2	Eastern sierras (10)	Phaeozems	79	294	92	67	Cattle (cow-calf), sheep	
		2.2	Graven Merin (11)	Mollic Planosols	71	393	74	63	Cattle (cow-calf), rice	
		1	Graven Santa Lucía (12)	Phaeozems	41	57	74	64	Cattle (full cycle), dairy, horticulture	
		2.6	Crystalline shield (13)	Phaeozems	69	395	93	59	Cattle (full cycle), dairy	
	Brazil	Brazil	0.7	Litoral (14)	Dystri-Ferralic Arenosols	64	126	68	81	Horticulture, rice, cattle (cow-calf)
			3.9	SE Sierras (15)	Alisols/Regosols/Lixisols	54	56	79	82	Cattle (cow-calf), sheep
			2.9	Missons (16)	Ferrasols/Leptosols/Arenosols	31	53	74	86	Crops
			3.3	Central depression (17)	Planosols/Alisols/Acrisols	44	53	71	84	Rice, cattle (finishing)
			2.4	Campanha (18)	Leptosols/Plinthosols/Phaeozems/Vertisols	70	204	82	83	Cattle (cow-calf)
			2.7	Corrientes (19)	Ferrasols/Luvisols/Solonetz	85	928	82	80	Cattle (cow-calf)

<sup>7</sup> This biome can be divided into the northern Campos, in southern Brazil and northeast Argentina, and the southern Campos in Uruguay.

<sup>8</sup> Calculated from (INDEC 2002, MGAP 2002, Berretta 2003, IBGE 2006, Viglizzo and Jobbágy 2010).

<sup>9</sup> Defined after (Soriano 1992, Boldrini 1997, Berretta 2003, Viglizzo and Jobbágy 2010, Brazeiro et al 2012).

<sup>10</sup> Numbers refer to the regions in figure 1.

<sup>11</sup> Calculated from (INDEC 2002, MGAP 2002, IBGE 2006, Viglizzo and Jobbágy 2010).

<sup>12</sup> Percentage of the area owned by farmers. The remainder is owned by corporations or rented.

<sup>13</sup> Defined after INDEC (2002), MGAP (2002), Antuña et al (2010), Viglizzo and Jobbágy (2010), SAGyP and INTA (2013), and Boldrini (2007).

(mixed crop-livestock systems) or continuous crop rotations.

Steer-to-cow ratios of less than 0.4 indicate specialisation in the cow-calf system, ratios of 0.4–1.2 indicate full cycle farm systems, and ratios greater than 1.2 specialisation in finishing beef cattle (Rossanigo *et al* 2012) (figure 2).

#### 4. Land use dynamics

Today, more than 80% of the *Río de la Plata* grasslands region is covered by native grasslands, sown pastures as part of crop-pasture rotations (leys) (Allen *et al* 2011) and annual crops (INDEC 2002, IBGE 2006, MGAP 2013b). Tree plantations and natural forests cover the remaining 20% of the area. Before the arrival of European settlers, the entire region consisted of native grasslands (Behling *et al* 2005, 2009, Tonello and Prieto 2008). After the introduction of domesticated livestock from Europe in the 16th century the ecosystem was shaped by grazing and fire (Overbeck *et al* 2006, Bernardi *et al* 2016). Tillage, sowing of exotic species and fertilisation was limited to small areas (Díaz *et al* 2006). The absence of large predators and the relatively high net primary productivity of the grasslands (Soriano 1992) allowed rapid expansion of the introduced livestock, leading to changes in the original plant and animal communities. The presence of dominant native plant species declined and tree species were introduced (e.g. *Ligustrum lucidum*, *Phoenix canariensis*, *Populus spp* and *Eucalyptus spp*) together with exotic bird species (e.g. *Furnarius rufus* and *Myiopsitta monachus*) (Bilenca *et al* 2009).

Arable farming was introduced in the region in the late 19th century. Between 1860 and 1910 the wheat area increased from 325 000 ha to 15 500 000 ha, along with a 16 fold increase in the population of European immigrants in the Argentinean Pampas and an expansion of railroads from 6 to 17 350 miles (Scobie 1964). These changes further reduced the number of native grassland species and increased the number of exotic species, many of which came in as weeds with the seeds of cereals (Ghersa and Leon 1999).

High animal stocking rates on native grasslands and subsequent overgrazing resulted in soil erosion with loss of soil carbon, and in loss of grassland species diversity (Overbeck *et al* 2007). This resulted in low grassland and meat productivity (60 kg live weight (LW) ha<sup>-1</sup> yr<sup>-1</sup>), four times less than what is achievable by improved grazing management (Carvalho *et al* 2009a, Nabinger *et al* 2011, Da Trindade *et al* 2012).

Since 1970, the area of native grasslands declined steadily due to the expansion of grain crops, especially wheat and soybean, and to a lesser extent tree plantations (Baldi and Paruelo 2008) (figure 3). Rates of land use change after 1990 were higher than during the previous 20 year-period, when more than 15% of the

native grassland area was lost (figure 3) and fragmented (Paruelo *et al* 2006).

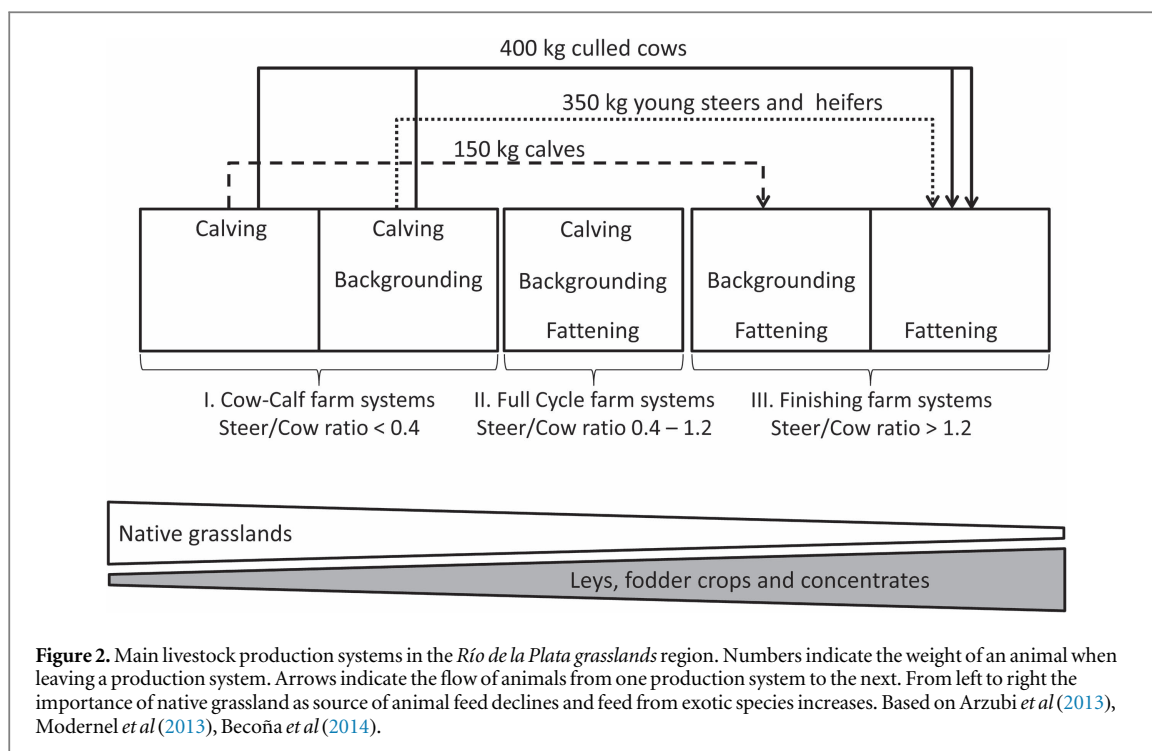
Cultivation of genetically modified, herbicide-resistant soybean was the most important reason for land use change between 2000 and 2010. The soybean area increased by 210% and the total arable cropping area by 28%, while the native grassland area decreased by 5% during this decade (figure 4(a)). This expansion was driven by favourable soybean prices, which increased 2.1 fold between 2000 and 2010 (figure 4(a)), by the relatively low production costs and by the introduction of new technologies such as no-tillage (Trigo and Cap 2004, Grau *et al* 2005, Altieri and Pengue 2006, Baldi and Paruelo 2008, Bindraban *et al* 2009, Caride *et al* 2012, Redo *et al* 2012). Despite the decrease in grassland area, cattle numbers remained stable in response to favourable beef prices (figure 4(b)).

Expansion of cropping is associated with higher land prices and increased use of agricultural inputs. For instance, in Uruguay the price of land increased sixfold and the imports of fertilisers and pesticides tripled between 2000 and 2010 (figure 5(a)). Over this period, animal production was intensified, as reflected by a 20% decrease in the slaughter age of steers due to shorter production cycles, and by 10% higher stocking rates (figure 5(b)).

Crop area increased in 16 subregions, which together represent 95% of the area of the *Río de la Plata* grassland region (figure 6(a)). In half of these subregions (denoted as 'Increase–increase'), cattle numbers increased alongside the crop area. In the other half (denoted as 'Increase–decrease'), cattle numbers decreased (figure 6(b)).

Cattle numbers and thus stocking rates increased in subregions where native grasslands constituted the dominant land use, covering more than 60% of the area (figure 7). In subregions with less than 30% native grassland area, cattle numbers consistently fell, while subregions with 30%–60% native grasslands represented a transition group (figure 7). Although feedlots were present in most subregions, the largest proportions of animals finished in feedlots were associated with subregions with less than 60% of the area under native grasslands (figure 7). There was a positive linear relationship between increase in cattle heads and proportion of native grasslands area ( $R^2 = 0.75$ ,  $p < 0.001$ ), indicating that cattle stocking rates increased in native grasslands areas, and decreased in areas dominated by crop production (intensification and relocation). This indicates that cropland expansion and livestock intensification by increased stocking rates or by an increased share of grains in the diet were spatially linked developments in the region.

Full cycle and finishing farm systems were more important in subregions where crops increased and cattle decreased (Increase–decrease subregions), and where most of the animals were grown in feedlots. Cow-calf farm systems dominated the Increase–



increase subregions, where stocking rates increased (figure 8). This increase in stocking rates in the subregions where native grasslands dominate may exacerbate overgrazing, a longstanding problem in the region (Overbeck *et al* 2007, Carvalho *et al* 2009a, 2009b).

## 5. Ecosystem services and impact of human intervention

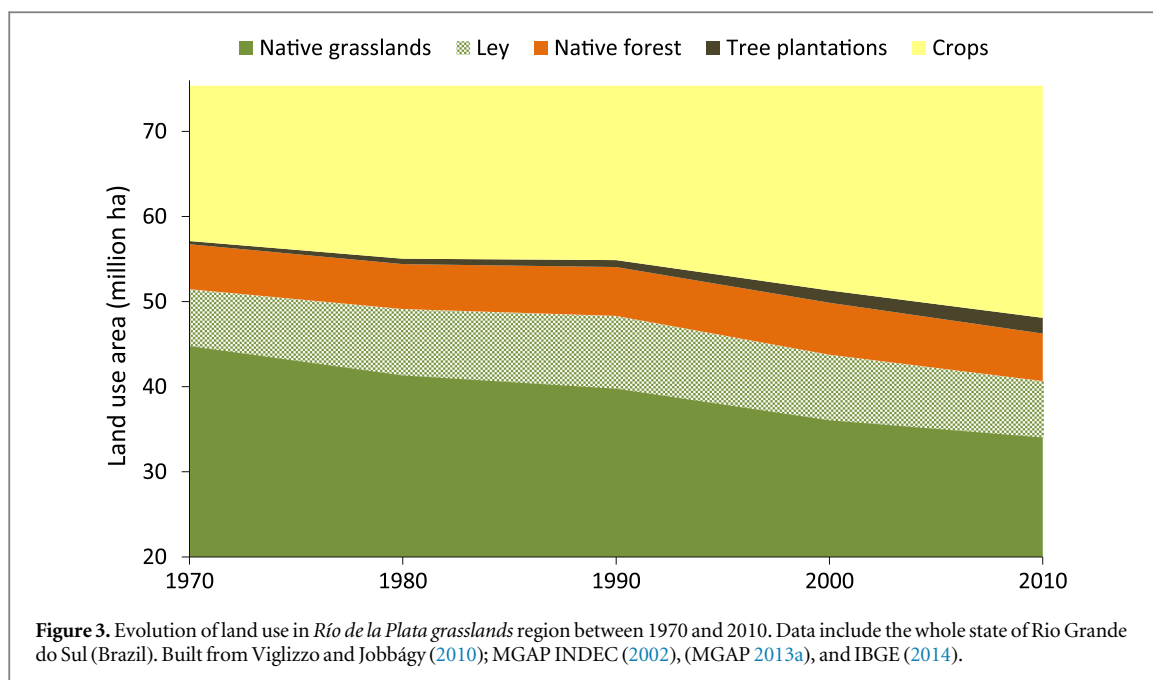
The ecosystem services reported for the *Río de la Plata grasslands* region included provisioning, supporting and regulating services. In the next sections, we summarise evidence on primary and secondary production, floristic diversity, animal diversity, climate regulation, water provision, nutrient cycling and erosion control. The drivers of change include the impacts of external inputs (fertilisers, pesticides and concentrate feedstuff for animals), fire, flooding, land use change, grazing and grazing management. The term ‘grazing’ denotes the effect of grazing as compared to grazing exclusion. ‘Grazing management’ is concerned with the decisions on the frequency and intensity with which livestock graze the paddocks. Grazing management gives rise to different levels of forage allowance ( $\text{kg DM kg}^{-1}$  animal LW), as defined by Sollenberger *et al* (2005). We considered animal stocking rate as inversely proportional to forage allowance, i.e. high stocking rate corresponds to low forage allowance. Since ‘overgrazing’ results in low forage allowance, we used ‘low forage allowance’ in the description of drivers affecting ecosystem services provision.

### 5.1. Provisioning ecosystem services: aboveground net primary and meat production

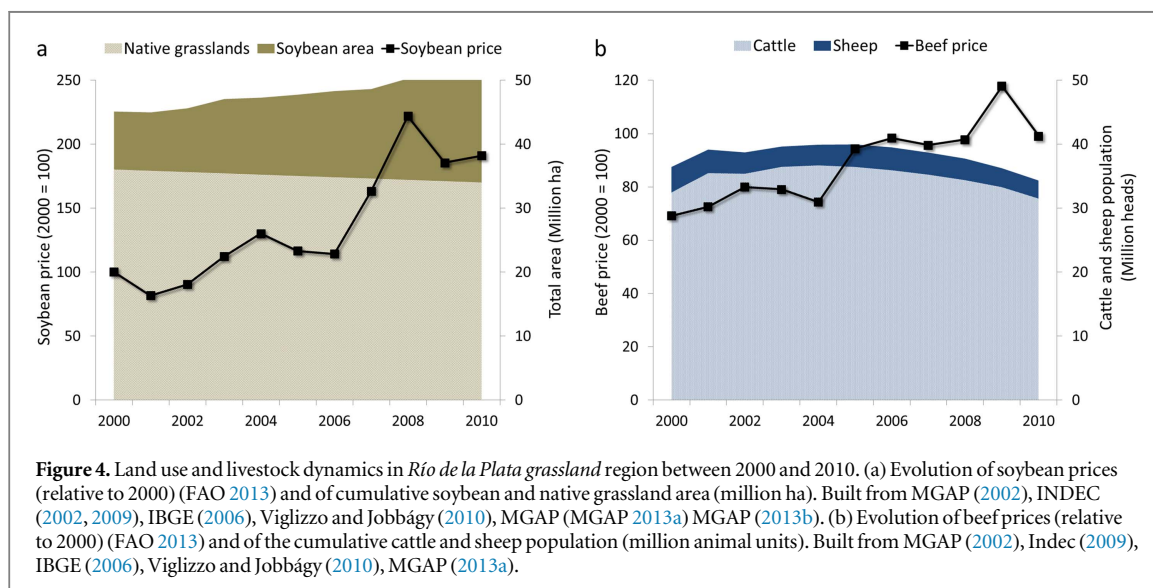
In 2012 the aboveground net primary production of the *Río de la Plata grasslands* region (either grass or grains) provided nutrition for 8% of all cattle and 17% of all sheep in the Americas using 1.6% of the area (FAO 2013). At the same time the exports from the region accounted for 3.4% of globally exported boneless meat, which was produced on 0.3% of the global land area (FAO 2013).

Analysis of aboveground net primary productivity in five subregions (*Southern and Flooding Pampas, Eastern Sierras, Basalt and Corrientes*) between 2000 and 2010 showed that between 60% and 70% of the annual production occurred in spring and summer (figure 9). Aboveground net primary production in summer was strongly determined by rainfall, which showed a high degree of inter-annual variability (AIACC 2006, Bidegain *et al* 2012).

A common practice to increase aboveground net primary productivity in the region has been to replace native grasslands by grass-legume leys (Nabinger *et al* 2000). Compared to leys, native grasslands were found to produce less biomass in average years in the more temperate southern latitudes of the region (*Southern Pampas* and *Flooding Pampas*). Aboveground net primary productivity of leys and native grasslands were similar in the Southern and Northern Campos (*Eastern Sierras* and *Basalt*) (figure 9). In the warmer and wetter northern parts of the Northern Campos (*Corrientes*), native grasslands achieved higher aboveground net primary productivity than leys (figure 9).



**Figure 3.** Evolution of land use in *Río de la Plata grasslands* region between 1970 and 2010. Data include the whole state of Rio Grande do Sul (Brazil). Built from Viglizzo and Jobbágy (2010); MGAP INDEC (2002), (MGAP 2013a), and IBGE (2014).



**Figure 4.** Land use and livestock dynamics in *Río de la Plata grassland* region between 2000 and 2010. (a) Evolution of soybean prices (relative to 2000) (FAO 2013) and of cumulative soybean and native grassland area (million ha). Built from MGAP (2002), INDEC (2002, 2009), IBGE (2006), Viglizzo and Jobbágy (2010), MGAP (MGAP 2013a) MGAP (2013b). (b) Evolution of beef prices (relative to 2000) (FAO 2013) and of the cumulative cattle and sheep population (million animal units). Built from MGAP (2002), Indec (2009), IBGE (2006), Viglizzo and Jobbágy (2010), MGAP (2013a).

## 5.2. Floristic diversity

The *Río de la Plata grasslands* were reported to comprise between 2000 and 4000 native plant species including some shrubs and trees (Bilenca and Miñarro 2004, Overbeck *et al* 2007). *Asteraceae*, *Poaceae*, *Leguminosae* and *Cyperaceae* were the most abundant families (Overbeck *et al* 2007). Since the majority of the species is endemic, the *Río de la Plata grasslands* are defined as a biome (Ferreira and Boldrini 2011). Of the 3000 plant species identified in Rio Grande do Sul, Boldrini *et al* (2009) classified 58 as ‘endangered’, 46 as ‘vulnerable’, 39 as ‘critically endangered’ and 6 as ‘apparently extinct’. An overview of the main genus, the number of species found in each subregion and the main threats for their conservation is given in table 2.

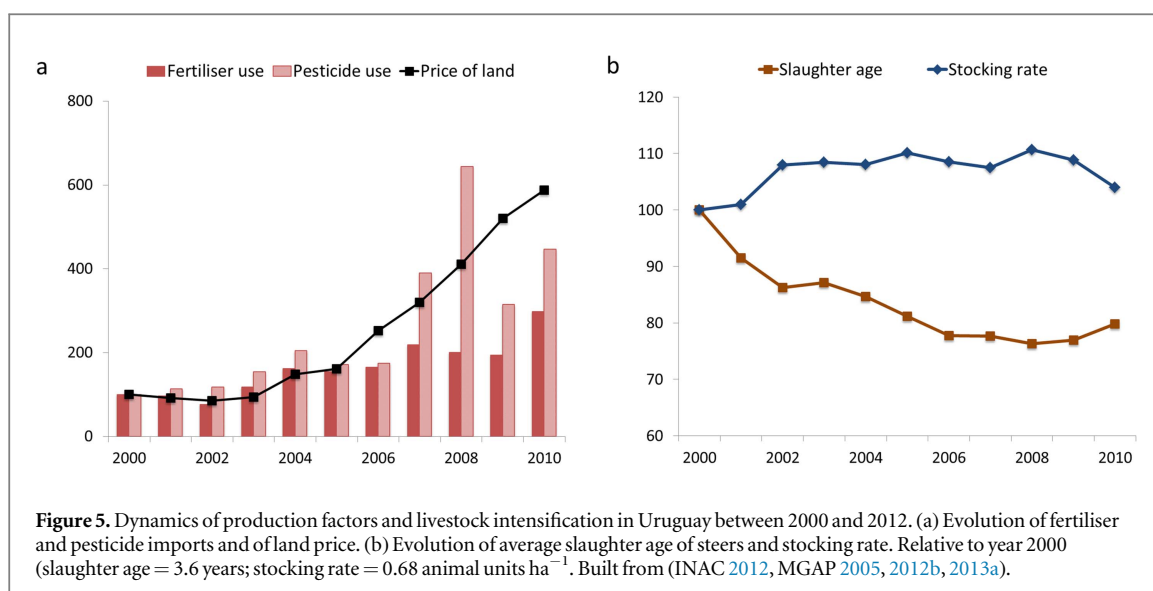
Bilenca and Miñarro (2004) identified 68 areas of high value for grassland biodiversity conservation across the region. Together the areas comprised

approximately 35 000 km<sup>2</sup> or 5% of the region. The selection of the areas was based on 276 publications that described the size of the areas, their species richness and the presence of endemic taxa, genus or threatened species.

Low forage allowance, or high stocking rates, was frequently reported as one of the main drivers of reduced grassland species diversity in the region (Chañeton and Facelli 1991, Altesor *et al* 1998, Ghersa and Leon 1999, Altesor *et al* 2005, Overbeck *et al* 2007, Loydi 2012). Other threats to floristic diversity were the invasion of exotic species, expansion of crop and ley areas and urbanisation (table 2).

## 5.3. Animal diversity

Out of 54 articles dealing with animal species diversity in the *Río de la Plata grasslands* region 36 addressed



birds, 16 mammals and 12 insects. Medan *et al* (2011) reviewed the status of animal species, reporting 300 bird species, 36 rodent species, 29 other mammals, 49 reptiles and 35 amphibians. Bilenca and Miñarro (2004) reported between 300 and 460 avian species and 70 to 90 mammal species in Río de la Plata grasslands. Three bird species (Strange-Tailed Tyrant (*Alectrurus risora*), Eskimo Curlew (*Numenius borealis*) and Austral Rail (*Rallus antarcticus*)) and three carnivore species (Puma (*Puma concolor*), Jaguar (*Panthera onca*) and Maned wolf (*Chrysocyon brachyurus*)) were considered regionally extinct due to hunting and agricultural expansion (Medan *et al* 2011).

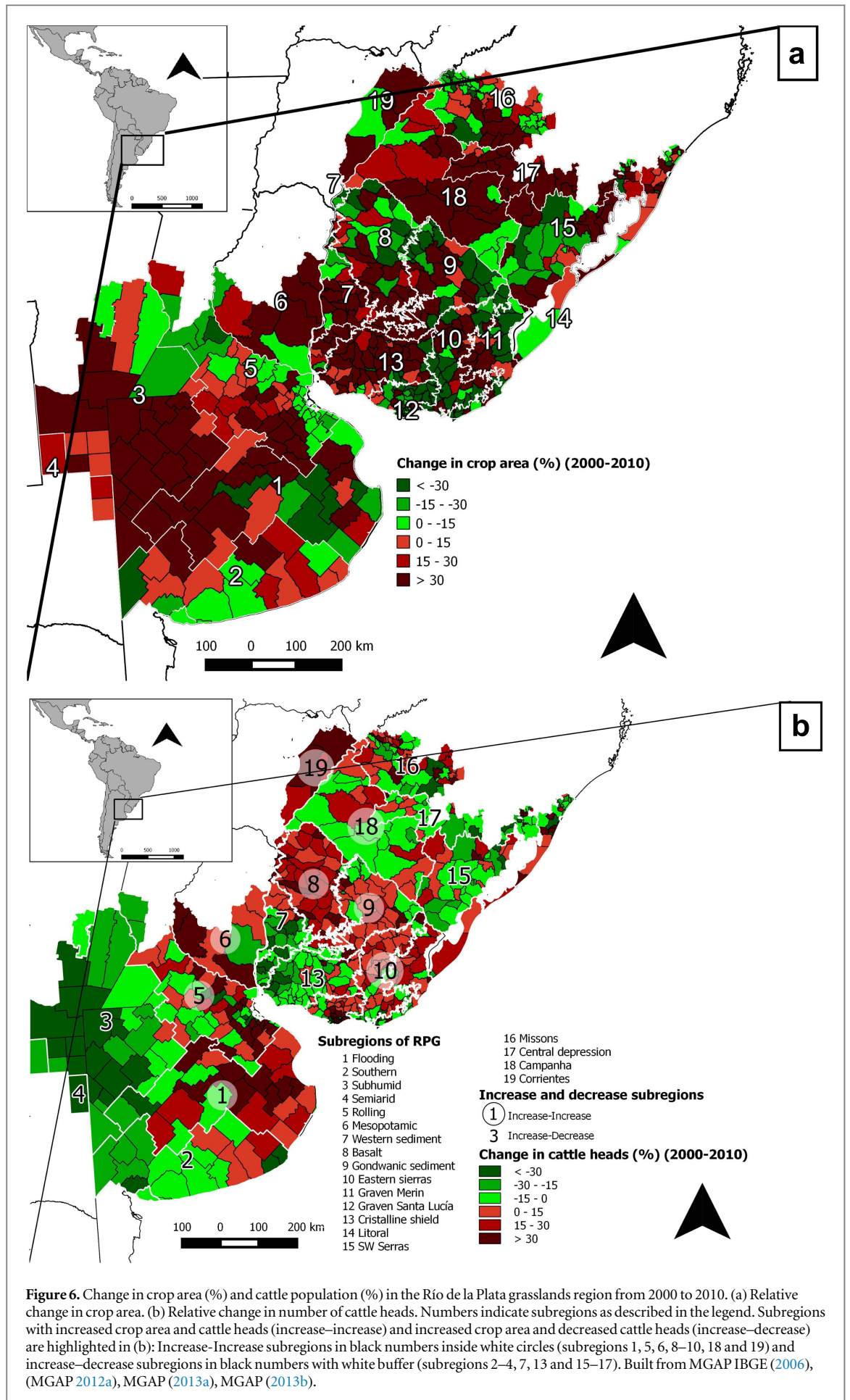
Azpiroz *et al* (2012) reviewed the available knowledge on grassland birds in southeastern South America, a region that includes the *Río de la Plata* grasslands. These authors reported 82 species that use grasslands for nesting and foraging, of which 22 were threatened with extinction. The area covered by grasslands in a given subregion was found to play an important role in the conservation of bird species. Codesido *et al* (2008) found higher bird species richness in *Flooding* than in the *Semiarid* and *Rolling Pampas*, where the area covered by native grasslands was less extended. Within the *Rolling Pampas*, bird species richness and abundance increased with the percentage of grassland area due to more space for breeding, foraging and dispersal (Cerezo *et al* 2011). Codesido *et al* (2013) found that land use heterogeneity at landscape level (expressed as the proportion of different land covers) promoted diversity and abundance of avian species. This is in contrast with Dotta *et al* (2015) who reported less diversity and richness of bird species in landscapes with higher proportions of grain and forest crops.

Bird species in *Río de la Plata* grasslands reacted differently to land use change. While some species (generalists) adapted, other species were more habitat-specific (grassland specialists) and their population size decreased (Isacch *et al* 2005, Codesido *et al* 2011,

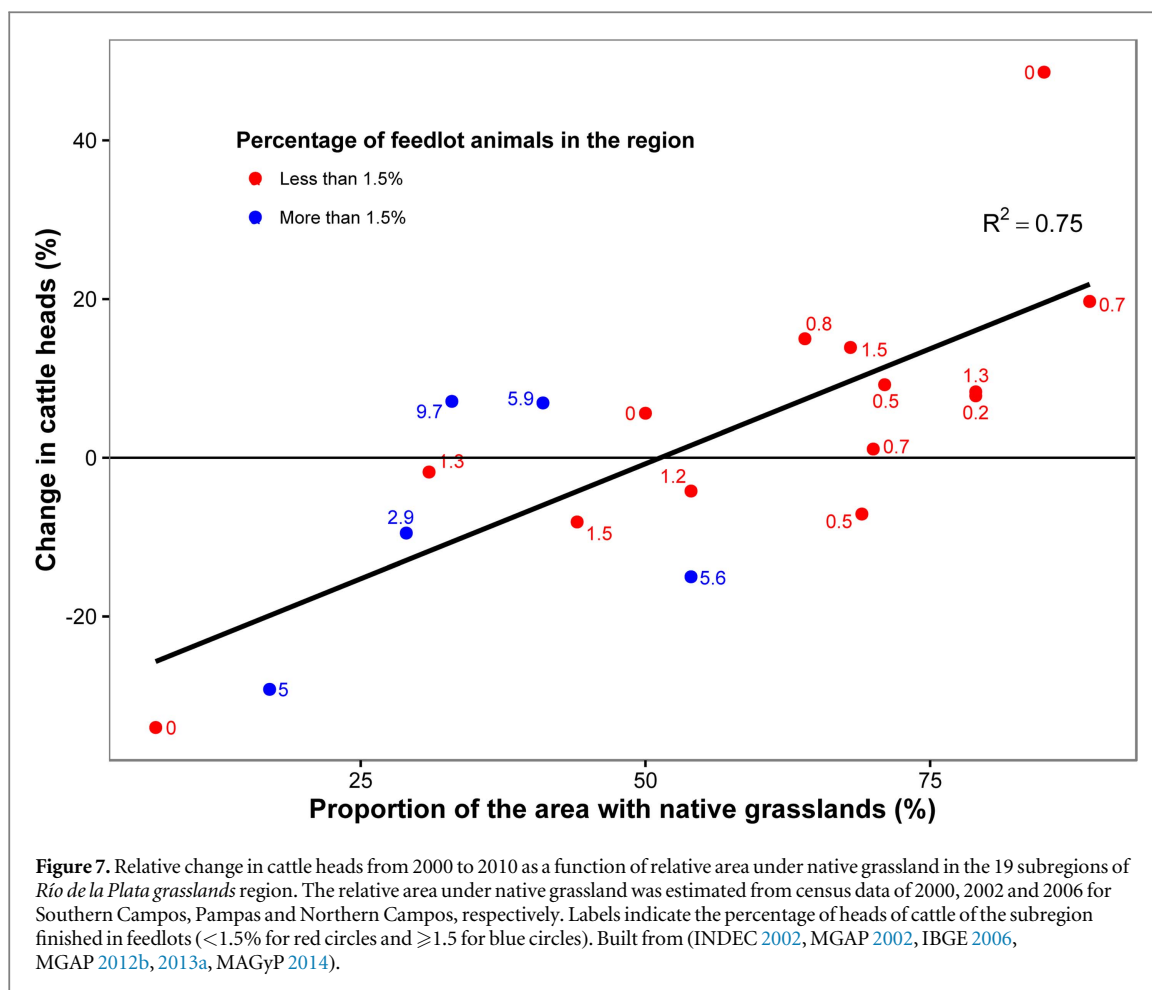
Gavier-Pizarro *et al* 2012, Codesido *et al* 2013, Abba *et al* 2015), resulting in eight bird species that were close to extinction (Blanco *et al* 2004, Fernández *et al* 2004, Gabelli *et al* 2004, Codesido *et al* 2012).

Vegetation structure affected bird species richness (Isacch *et al* 2014). Moderate grazing generated paddocks with heterogeneous vegetation structure (tussocks and a lower grass stratum). This heterogeneity was found to provide shelter and conserve certain species (Isacch *et al* 2003, Develey *et al* 2008, Isacch and Cardoni 2011, Cardoni *et al* 2012). The tussocks included tall grasses such as *Andropogon lateralis* and *Cortaderia selloana*, which enhanced bird species diversity to the extent that it is mentioned as a strategy for protecting endangered species (Zalba and Cozzani 2004, Zalba *et al* 2008, Di Giacomo *et al* 2010, Pretelli *et al* 2013). On the other hand, some migratory shorebird species depend on habitats with short grasses (Isacch and Martínez 2003). These authors emphasised the importance of sheep grazing in order to maintain low grass height.

The native grasslands of *Río de la Plata* grasslands region support several mammal species, such as the Molina's hog-nosed skunk (*Conepatus chinga*) (Castillo *et al* 2011, 2012), the Coypu (*Myocastor coypus*) (Guichon and Cassini 1999), Geoffroy's cats (*Oncifelis geoffroyi*) (Manfredi *et al* 2006, 2012) and short-tailed opossum (*Monodelphis dimidiata*) (Baladrón *et al* 2012). Landscape perturbation and land use change had different effects on the diversity, abundance, and distribution of rodent species depending on the initial fragmentation status of the landscape. The crop expansion in the beginning of the 20th century increased habitat heterogeneity in time and space, thus favouring rodent species diversity. In contrast, by the end of the 20th century a second crop expansion homogenised the landscape, favouring generalist species and decreasing the abundance of habitat-specialist species (Medan *et al* 2011).



**Figure 6.** Change in crop area (%) and cattle population (%) in the Río de la Plata grasslands region from 2000 to 2010. (a) Relative change in crop area. (b) Relative change in number of cattle heads. Numbers indicate subregions as described in the legend. Subregions with increased crop area and cattle heads (increase–increase) and increased crop area and decreased cattle heads (increase–decrease) are highlighted in (b): Increase-Increase subregions in black numbers inside white circles (subregions 1, 5, 6, 8–10, 18 and 19) and increase–decrease subregions in black numbers with white buffer (subregions 2–4, 7, 13 and 15–17). Built from MGAP IBGE (2006), (MGAP 2012a), MGAP (2013a), MGAP (2013b).



## 5.4. Climate regulation

### 5.4.1. Soil organic carbon stock

Covering less than 3% of the area of Latin America, the *Río de la Plata grasslands* are reported to store an estimated 5% of the total soil carbon stock of the subcontinent, with the second highest average soil organic carbon content in the first 30 cm of the soil ( $66 \text{ Mg ha}^{-1}$ ) after the South Chilean region ( $108 \text{ Mg ha}^{-1}$ ) (Bernoux and Volkoff 2006). Soil organic carbon stocks were estimated at  $5400 \text{ Tg}$  (0–30 cm) in the Argentinean Pampas (Galantini and Rosell 2006),  $1530\text{--}1600 \text{ Tg}$  (0–30 cm) in Rio Grande do Sul (Tornquist et al 2009) and  $2300 \text{ Tg}$  (0–100 cm, or less if the soil profile was shallower) in Uruguay (Durán 1998).

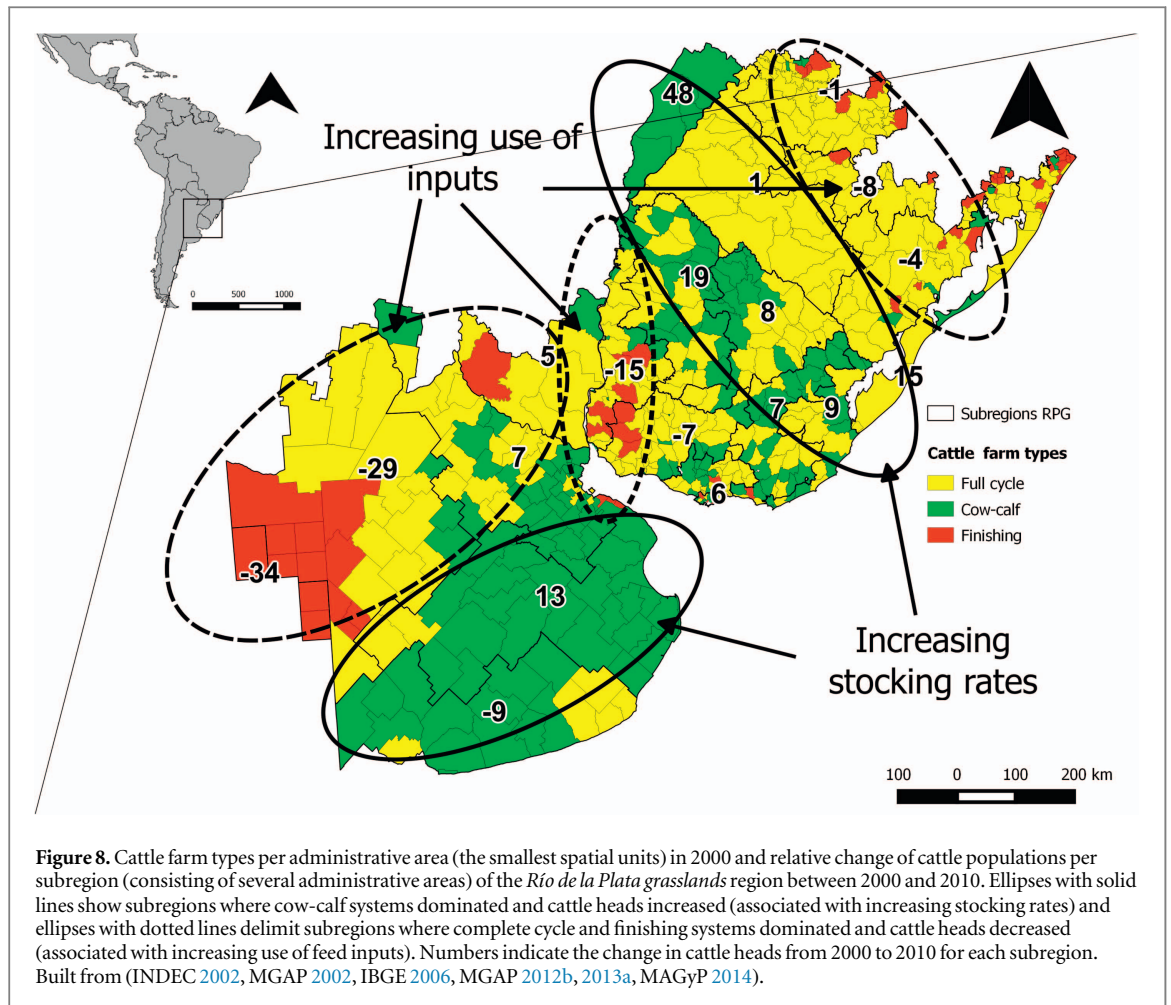
For Rio Grande do Sul, Pillar et al (2012) and Bernoux et al (2002) reported averages of soil organic carbon content of  $68$  and  $79 \text{ Mg ha}^{-1}$  (0–30 cm), while Tornquist et al (2009) reported values between  $36$  and  $162 \text{ Mg ha}^{-1}$ . Paruelo et al (2010) found lowest values of total soil organic carbon in *Basalt* and *Southern Pampas* ( $40$  and  $55 \text{ Mg ha}^{-1}$ , respectively) and highest values in *West Sediment* ( $135 \text{ Mg ha}^{-1}$ ), associated with greater soil depth in the latter subregion.

Land use change from native grasslands to crops was found to result in a decline of soil organic carbon (Sala and Paruelo 1997, Díaz-Zorita et al 2002). Losses

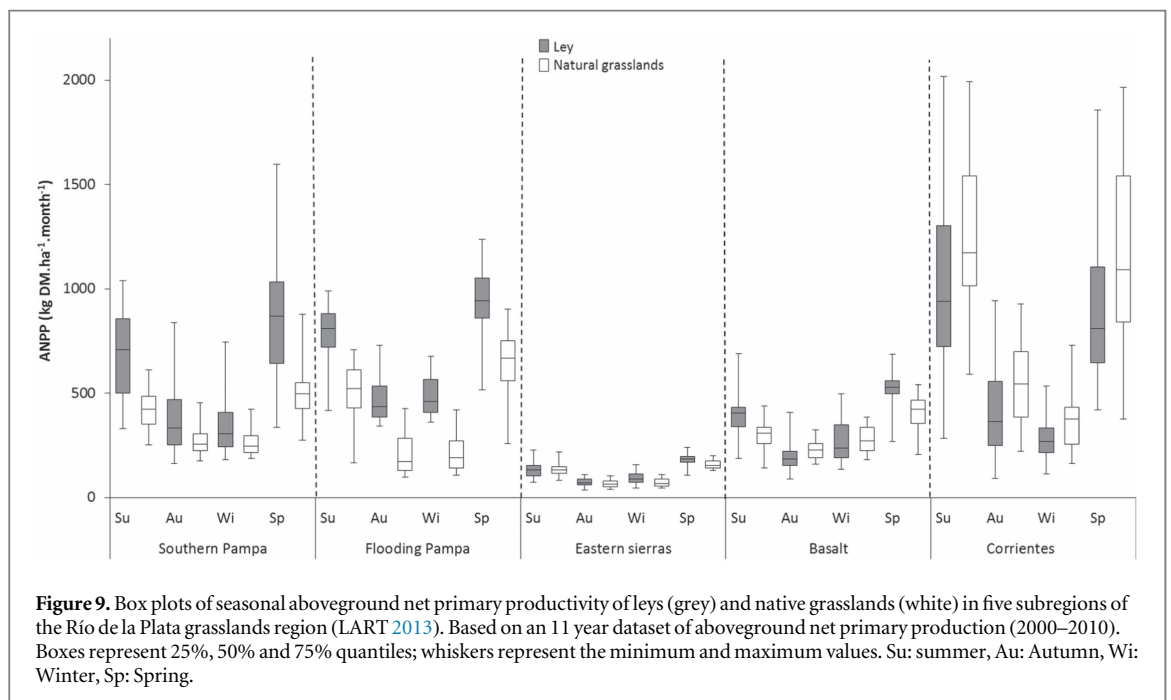
differed among subregions and periods of cultivation: 30% decline after 30 years in *Rolling Pampas* (Alvarez 2001), 16% and 32% after two and 14 years in the *Semiarid Pampas* (Noellemeyer et al 2008) and 15% after 10 years in the Northern Campos (Assad et al 2013).

### 5.4.2. Climate change mitigation

Research on greenhouse gas emissions in *Río de la Plata grasslands* region focused on identifying emission factors for enteric methane and soil nitrous oxide and estimating the carbon footprint associated with different production systems. Machado (2015) studied the effect of forage allowance of native grassland on enteric methane emission. At moderate forage allowances of  $8$  to  $12 \text{ kg DM kg}^{-1} \text{ LW}$ ,  $0.8 \text{ kg CH}_4 \text{ kg}^{-1} \text{ LW}$  gain was emitted, which increased by 170% at low forage allowance ( $4 \text{ kg DM kg}^{-1} \text{ animal LW}$ ). Muscat (2015) measured enteric methane emissions of steers grazing on native, nitrogen-fertilised, and oversown (with legumes and rye-grass) grasslands. The rate of emissions on native grasslands was  $0.58 \text{ kg CH}_4 \text{ kg}^{-1} \text{ LW}$  gain. Fertilisation ( $100 \text{ kg of nitrogen ha}^{-1} \text{ yr}^{-1}$ ) increased seasonal mean forage mass from  $2146$  to  $2541$  and oversowing to  $2393 \text{ kg ha}^{-1}$ . Gross protein content increased from 7.2% to 9.0% and 10.5% for native, fertilised and oversown grasslands respectively.



**Figure 8.** Cattle farm types per administrative area (the smallest spatial units) in 2000 and relative change of cattle populations per subregion (consisting of several administrative areas) of the Río de la Plata grasslands region between 2000 and 2010. Ellipses with solid lines show subregions where cow-calf systems dominated and cattle heads increased (associated with increasing stocking rates) and ellipses with dotted lines delimit subregions where complete cycle and finishing systems dominated and cattle heads decreased (associated with increasing use of feed inputs). Numbers indicate the change in cattle heads from 2000 to 2010 for each subregion. Built from (INDEC 2002, MGAP 2002, IBGE 2006, MGAP 2012b, 2013a, MAGyP 2014).



**Figure 9.** Box plots of seasonal aboveground net primary productivity of leys (grey) and native grasslands (white) in five subregions of the Río de la Plata grasslands region (LART 2013). Based on an 11 year dataset of aboveground net primary production (2000–2010). Boxes represent 25%, 50% and 75% quantiles; whiskers represent the minimum and maximum values. Su: summer, Au: Autumn, Wi: Winter, Sp: Spring.

As a result, grazing steers emitted 41% and 33% less methane per unit meat produced on fertilised and oversown compared to native grassland.

Perdomo *et al* (2012) reported soil nitrous oxide emission rates of 0.07 kg N<sub>2</sub>O-N-ha<sup>-1</sup> yr<sup>-1</sup> from a

native grassland, six times lower than from a continuously cropped no-till field and 54 times lower from a continuously cropped field under tillage.

The carbon footprint of beef cattle farms on native grassland ranged from 17.5 kg CO<sub>2</sub> eq kg<sup>-1</sup> LW gain

**Table 2.** Dominant genus of vascular plants and number of species in the native grasslands of the different subregions of the Río de la Plata grasslands.

Subregion	Dominant genus of vascular plants in the native grasslands	Number of species <sup>14</sup>	References	Main threats for conservation <sup>14</sup>
Rolling Pampas	<i>Stipa</i> , <i>Paspalum</i> , <i>Piptochaetium</i> , <i>Aristida</i>	1600 (374 <i>Poaceae</i> )	(Vervoort 1967, Sala et al 1984, Frangi and Barrera 1996, Lewis 1996, Rapoport 1996, Krapovickas and Di Giacomo 1998, Parera and Kesselman 2000)	Introduced exotic plant species
Flooding Pampas	<i>Bothriochloa</i> , <i>Paspalum</i> , <i>Briza</i> , <i>Sporobolus</i> , <i>Stipa</i> , <i>Panicum</i> , <i>Phalaris</i> , <i>Vicia</i> , <i>Eryngium</i> , <i>Glyceria</i> , <i>Solanum</i> , <i>Scirpus</i> , <i>Zizaniopsis</i> , <i>Typha</i> , <i>Spartina</i> , <i>Distichlis</i> , <i>Chloris</i> , <i>Salicornia</i> , <i>Limonium</i>			Exotic animal and plant species, expansion of crops and ley
Southern Pampas	<i>Stipa</i> , <i>Piptochaetium</i> , <i>Festuca</i> , <i>Bromus</i> , <i>Poa</i> , <i>Senecio</i> , <i>Plantago</i>			Overgrazing, crop expansion, exotic animal species
Semiarid Pampas	<i>Sorghastrum</i> , <i>Elionurus</i> , <i>Poa</i> , <i>Stipa</i>			Expansion of crops and ley, overgrazing
Mesopotamic Pampas	<i>Axonopus</i> , <i>Paspalum</i> , <i>Digitaria</i> , <i>Schizachyrium</i> , <i>Bothriochloa</i>			Crop expansion, urbanisation
Northern Campos	<i>Stipa</i> , <i>Paspalum</i> , <i>Setaria</i> , <i>Poa</i> , <i>Bromus</i> , <i>Piptochaetium</i> , <i>Melica</i> , <i>Trifolium</i> , <i>Carex</i> , <i>Juncus</i> , <i>Cyperus</i> , <i>Cortaderia</i>	2500 (400 <i>Poaceae</i> )	(Valls 1986, Durán 1991, Soriano 1992, Arballo et al 1999, Pacheco and Bauer 2000, Bencke 2001)	Expansion of crops and ley
Southern Campos	<i>Stipa</i> , <i>Piptochaetium</i> , <i>Aristida</i> , <i>Paspalum</i> , <i>Axonopus</i> , <i>Andropogon</i> , <i>Luziola</i> , <i>Leersia</i>	3000 (400 <i>Poaceae</i> )	(Boldrini 1997, Nabinger et al 2000)	Expansion of crops and ley, overgrazing

<sup>14</sup> Based on (Bilenca and Miñarro 2004).

(Picasso *et al* 2014) to 46.5 kg CO<sub>2</sub> eq kg<sup>-1</sup> LW gain (Ruviaro *et al* 2014). Mitigation strategies in Northern Campos have been proposed through intensification of production, mainly by increasing forage production and feed quality (Ruviaro *et al* 2014, Dick *et al* 2015). These authors propose intensification pathways based on external inputs, resulting in improvement of live-stock reproduction (weaning rate) and growth (average daily gain). Ruviaro *et al* (2014) estimated carbon footprint reductions of 42% by fertilising native grasslands, feeding animals with grains and using leys. Dick *et al* (2015) estimated reductions of 99.5% from a baseline scenario of 22.5 kg CO<sub>2</sub> eq kg<sup>-1</sup> LW gain if carbon sequestration by pastures was accounted for. Further scenarios took into account the stabilisation of soil organic carbon after 20 years of gradual increase. These scenarios achieved a reduction of 68% compared to the baseline. Although these strategies decreased carbon footprint, trade-offs existed with soil erosion, pesticide use, nutrient losses, fossil fuel energy consumption and water use efficiency (Modernel *et al* 2013, Ran *et al* 2013, Picasso *et al* 2014).

### 5.5. Water provision, nutrient cycling and erosion control

Ran *et al* (2013) found mixed crop-livestock systems in Uruguay to be more efficient in water use than beef production systems based on feedlot or native grasslands. Water use efficiencies were 15.7, 18.9 and 19.3 m<sup>3</sup> water kg<sup>-1</sup> LW, respectively.

Land use change from native grasslands to crops changed regional hydrology, reducing the lake areas in the *Flooding pampas* (Booman *et al* 2012). Afforestation in the *Flooding pampas* resulted in increased water uptake, reducing groundwater levels by about 0.5 m (Engel *et al* 2005).

Twelve studies investigated nitrogen and phosphorus dynamics in the *Río de la Plata grasslands* region. Garibaldi *et al* (2007) found that grazing increased nitrogen and phosphorus mineralisation, and soil nitrogen and phosphorus availability. Grazing did not change soil total nitrogen and phosphorus in an experiment by Chaneton and Lavado (1996). On the other hand, Lavado *et al* (1996) found that grazing decreased soil mineral nitrogen content and extractable phosphorus.

The impact of livestock systems intensification was studied with different methodologies. Goyenola *et al* (2015) found higher total, particulate, dissolved and reactive soluble phosphorus in a water stream of a catchment under forage crops, dairy cattle feeding all year around when compared to a native grassland with low stocking rate (lower than 1 head per ha). Two studies evaluated the impact of livestock facilities as source of point pollution for nutrients. Herrero and Gil (2008) sampled 409 water sources (water boreholes) of dairy farms in the Argentinean Pampas. Results showed that 50% of the samples were over the

maximum concentration of quality standards for phosphorus. Chagas *et al* (2007) compared sediment and phosphorus concentration of the runoff of three treatments: native grasslands, native grasslands with signs of soil erosion and feedlot. Sediment concentration was 38 times higher in feedlot and 3.5 times higher in eroded grassland compared to native grassland. Reactive soluble phosphorus concentration was 0.8, 0.4 and 13.4 mg l<sup>-1</sup> for native grasslands, eroded native grasslands and feedlot.

Soil erosion rates for native grasslands were lower than for croplands in all studies reviewed. For example, in well-managed native grasslands in Uruguay an average erosion rate of 2.1 Mg ha<sup>-1</sup> yr<sup>-1</sup> was reported (García Préchac *et al* 2004). On overgrazed grasslands with high levels of bare soil erosion rates of 6.2 Mg ha<sup>-1</sup> yr<sup>-1</sup> were observed (García Préchac 1992). Highest erosion rates were observed under continuous cropping with tillage, ranging from 19 Mg ha<sup>-1</sup> yr<sup>-1</sup> (García Préchac *et al* 2004, Wingeyer *et al* 2015) to 67 Mg ha<sup>-1</sup> yr<sup>-1</sup> (Jorge *et al* 2012), 3 to 9 times higher than for overgrazed grasslands. In comparison, average erosion rates of 2.3 Mg ha<sup>-1</sup> yr<sup>-1</sup> were reported for crop-grassland rotations (Clérici and García Préchac 2001).

### 5.6. Effect of drivers on ecosystem services

The most studied drivers affecting ecosystem services were land use change, grazing and grazing management, together comprising 55% of publications (table 3). A large percentage (63%) of publications dealt with the effect of the drivers on floristic diversity and animal diversity. Despite the large share of publications on grazing and grazing management (26%), the effect of these drivers on climate regulation, water provision, nutrient cycling and erosion control received little attention. In the only local study of ecosystem services quantification, Barral and Maceira (2012) evaluated the change in provision of ecosystem services by native grasslands in 1986 and 2006 in Balcarce (*Southern Pampas*). The assessment included changes in soil protection, carbon sequestration, water purification and provision, biodiversity conservation, disturbance control, waste purification and direct goods provision. Results indicate the loss in value of ecosystem services due to land use change from native grasslands to crops.

The number of publications for the Campos was 40% lower than for the Pampas. Subregions with a large proportion of native grasslands were addressed in fewer publications than those with less native grassland. While the *Flooding Pampas* (with 68% of the area under native grasslands) was studied in 49% of the publications, subregions with 70%–89% of the area under native grassland in the Campos (*Campanha, Gondwanic sediment, Corrientes, Graven Merin, Basalt and Eastern Sierras*) were studied in only 17% of publications.

The average strength of evidence is high (2.8/3) (table 4). The lowest values were found for external inputs (use of fertilisers, pesticides and feeding supplements or animal production intensification) and low forage allowance due to a lower proportion of meta-analyses than the other groups.

The drivers with clear impacts on provisioning ecosystem services were land use change, moderate forage allowance, external inputs and flooding (very likely increase), in contrast with low forage allowance (very likely decrease) (table 4).

Assessment of the literature showed a very likely decrease of supporting and regulating ecosystem services due to land use change and low forage allowance (overgrazing). On the other hand, moderate forage allowance, rotational grazing and flooding very likely increased supporting and regulating ecosystem services.

The neutral impact of external inputs on supporting and regulating services was an unexpected result. More in-depth analysis showed that nearly half of the publications dealt with greenhouse gas emissions from livestock systems. The use of external inputs generally resulted in higher aboveground net primary productivity leading to meat production with lower emission intensity. These results counterbalanced the negative effects on water provision and nutrient cycling, exotic plant invasion and bird species presented in ten papers.

## 6. Discussion

### 6.1. Impacts of current intensification trends on ecosystem services

Our results show for the first time the spatial consequences of the expansion of soybean for the *Río de la Plata grasslands* (figure 3). We found two types of changes in livestock production, both leading to intensification of livestock production. The first change concerned the increased use of grains as feed in feedlots, which was particularly concentrated in areas with less than 60% native grassland cover; the second change concerned increased stocking rates in subregions dominated by native grasslands (figure 7). The latter may aggravate overgrazing of native grasslands with negative impacts on aboveground net primary and meat productivity, diversity of plant, bird and mammal species, soil organic carbon and erosion.

The intensification of livestock systems by using grains as animal feed in feedlots was shown to decrease greenhouse gas emission intensities ( $\text{kg CO}_2 \text{ eq kg}^{-1} \text{ LW yr}^{-1}$ ) due to greater cattle growth rates resulting in increased meat productivity. At the same time, the change from grassland-based to feedlot-based finishing systems was associated with increased environmental contamination by nitrogen and phosphorus, and by pesticides, and with higher fossil fuel consumption levels (Modernel *et al* 2013, Picasso *et al* 2014). As

is shown by the coincidence of feedlots and arable cropping (figure 7), the intensification of cattle production through feedlots lead to specialisation of farming systems in which the benefits are lost of animal-crop-grassland interactions that are the mechanisms for erosion control, carbon and nitrogen sequestration, regulation of pests and diseases, reduction in energy demands and biodiversity conservation (Janzen 2011, Peyraud *et al* 2014).

Floristic and animal diversity, climate regulation and primary production were the ecosystem services most frequently studied in the *Río de la Plata grasslands*. The least studied ecosystem services were water provision and nutrient cycling, followed by meat production and erosion control (table 3). A global review of 32 publications on quantification of ecosystem services provision of global grasslands by de Groot *et al* (2012) did not include the *Río de la Plata grasslands*, indicative of the lack of information on this biome. Balvanera *et al* (2012) concluded that ecosystem service research in Uruguay is underdeveloped compared to other countries of Latin America. Research on ecosystem services of native grasslands in Argentina started only in 1990.

We found that the majority of studies on ecosystem services represented (agro-) ecological inventories and did not include analysis of any driver (table 3). If drivers were studied, land use change was addressed most often, followed by grazing and grazing management.

### 6.2. Alternative future intensification strategies

Few studies addressed alternative land use options. Strassburg *et al* (2014) investigated the carrying capacity of Brazilian cultivated pasture land and found that increasing productivity from the current 32%–34% to 49%–52% of potential productivity would enable meeting the expected growth in food demand for 2040 and spare 18 million ha of Atlantic Rainforest. They, however, did not consider native grasslands and focused their discussion on conventional intensification to increase annual meat production per unit of pasture area. Proposed measures addressed pasture productivity (number of animals per unit of pasture area) and herd productivity (annual meat production per total number of animals). Measures to increase pasture productivity included improved grass mixtures, the inclusion of legumes, reduced tillage, electric fencing, rotational grazing and the introduction of mixed crop-livestock systems. They suggested increases in herd productivity through improved breed selection, reproductive management and earlier slaughtering. Dotta *et al* (2015) showed maximum bird conservation potential in the Northern Campos of southern Brazil and northern Uruguay to be associated with light to moderate grazing on native pastures, defined as cattle ranching on mostly native grasslands with no to medium use of fertilisers and

**Table 3.** Number of publications that investigated drivers and their impact on ecosystem service provision of *Río de la Plata grasslands*.

Drivers	Ecosystem services (number of publications)							Total
	Supporting, regulating		Regulating			Provisioning		
	Floristic diversity	Animal diversity	Climate regulation	Water provision and nutrient cycling	Erosion control	Primary production	Meat production	
External inputs	3	2	5	6	0	3	2	21
Fire	9	2	0	0	0	0	0	11
Flooding	4	1	0	0	0	1	0	6
Grazing	13	4	3	3	0	8	0	31
Grazing management	13	8	0	0	0	11	1	33
Land use change	14	32	12	4	6	2	0	70
No driver <sup>15</sup>	28	19	14	0	0	8	1	70

<sup>15</sup> These publications described the status of the ecosystem service at specific moments but did not address drivers of change.

exotic grasses and stocking rates of up to 1.0 animal unit ha<sup>-1</sup>. Alternative land uses included heavy grazing and soybean or timber production. Increasing regional food output or profits by heavy grazing and increasing food and timber production was found to negatively affect grassland bird species. The authors suggest light to moderate grazing as a strategy, while accepting a reduced regional food output as the way to reconcile agricultural production and bird conservation in the region.

Research on native grassland-based systems in the region suggested that ranching based on low to medium grazing intensities may result in significantly higher meat yield than the current average. Changes implemented focused on reversing poor grassland and herd management and the resulting overgrazing. By increasing meat productivity alongside other ecosystem services displacement effects, i.e. meat production taking place elsewhere under environmentally more damaging conditions, would be avoided.

Promising practices that showed positive results in field experiments, and are now considered for dissemination to farmers include:

- Grazing systems based on moderate forage allowances to increase grassland productivity and meat production per animal and per hectare (Nabinger *et al* 2000, Carriquiry *et al* 2012, Soca *et al* 2013a, Cardozo *et al* 2015). On most of the farms this will imply reducing the stocking rates (Carvalho *et al* 2009b, Scarlato *et al* 2015);
- Matching the seasonal livestock feed demand to the biomass dynamics of the native grassland vegetation (Soca and Orcasberro 1992, Maraschin *et al* 1997, Soca *et al* 2013b);
- Adjusting forage allowance and reducing grazing pressure by sheep to avoid sward stratification by tussocks (Da Trindade *et al* 2012);

- Strategic inclusion of ley paddocks on 5 to 10% of the area to meet livestock demand for high-quality forage during reproductive or lactation phases (Royo Pallarés *et al* 2005, Soca *et al* 2013a);
- Strategic feed supplementation to female calves and cows in winter (Straumann *et al* 2008) to improve nutritional status, and therewith reproductive performance (Quintans *et al* 2012).

### 6.3. The need to engage farmers and policy makers

Implementing such ecological intensification (Doré *et al* 2011) strategies requires important mind-shifts of farmers. In a recent 3 year co-innovation project in Uruguay, Scarlato *et al* (2015) and Ruggia *et al* (2015) found that when farmers managed their production systems based on grass height instead of the number of animals they owned, meat productivity increased by 24% and farm income by 40%. Considering that the increase in soybean prices during the 2000–2010 decade was the major driver of soybean expansion in southern South America (FAO 2007), such higher incomes would provide an important mechanism to avoid conversion to cropping. Whether a 40% increase would be enough to make livestock production competitive should be investigated. In addition to productivity changes, farmers noted decreases in erosion rates associated with maintaining better soil cover.

Further testing of these ecologically intensive grassland management practices with farmers is urgent. In addition, the ecosystem services provided by native grasslands need to be recognised to open up opportunities for financial incentives, for instance through value chains that enable beef producers to participate in ‘high quality’ market segments (Tessema *et al* 2013). An on-going initiative in the region is the certification of meat produced on native grasslands. Currently, 200 000 ha of native grasslands are certified

**Table 4.** Trends in the impact of drivers on ecosystem service provision by *Río de la Plata grasslands*.

Driver	Provisioning services					Supporting and regulating services				
	Publications (N <sup>o</sup> )	Decrease (%)	Increase (%)	Strength <sup>17</sup>	Conclusion <sup>18</sup>	Publications (N <sup>o</sup> )	Decrease (%)	Increase (%)	Strength <sup>17</sup>	Conclusion <sup>18</sup>
Land use change	3	0	100	3	Very likely increase	84	87	13	2.9	Very likely decrease
Moderate forage allowance <sup>16</sup>	19	0	100	2.9	Very likely increase	8	0	100	2.9	Very likely increase
Rotational grazing <sup>16</sup>	0	0	0	0	—	4	0	100	3	Very likely increase
Low forage allowance <sup>16</sup>	4	100	0	2.5	Very likely decrease	11	100	0	3	Very likely decrease
Other <sup>16</sup>	0	—	—	—	—	11	9	91	2.9	Very likely increase
Grazing	8	40	60	2.9	Neutral/undecided	35	39	61	2.9	Likely increase
External inputs	8	0	100	2.5	Very likely increase	18	59	41	2.8	Neutral/undecided
Flooding	1	0	100	3	Very likely increase	6	20	80	3	Very likely increase
Fire	0	—	—	—	—	15	50	50	3	Neutral/undecided

<sup>16</sup> Drivers together comprising 'Grazing management'.

<sup>17</sup> Strength of evidence is an average of a three-point scale: High strength evidence (value = 3; studies from controlled field experiments, observations with sound methodologies or meta-analyses); intermediate strength evidence (value = 2; narrative reviews), and low strength (value = 1; publications based on opinion).

<sup>18</sup> Conclusion is drawn by considering the percentage of publications with positive (increase) or negative (decrease) effects on the ecosystem service provision. Very likely: 80%–100%; likely: 60%–80%; neutral/undecided: 40%–60%.

and export of certified meat has started (Alianza del Pastizal 2015).

For biomes in South America such as Amazonia and Cerrados public policies for nature conservation have been put in place (UNEP, CIUP, ACTO and CIUP 2009, Ministério Do Meio Ambiente 2015). Policy-based conservation of the *Río de la Plata grasslands*, however, is largely absent, causing Overbeck et al (2007) to call it a 'neglected biome'. In *Río de la Plata grasslands* region institutional protection of native grasslands through a national park status is limited to 0.5%, 0.3% and 0.2% of the area of Rio Grande do Sul, the Pampas and Uruguay (Bilenca and Miñarro 2004). Dotta et al (2015) reported higher values for formally protected parks in the Campos (2%). The Brazilian Legal Reserve law of 2012 stipulates that 20% of every property must be maintained under natural vegetation (Presidência da República 2012). The Convention on Biodiversity provides an international legal basis for *Río de la Plata grasslands* protection by calling for 17% of all terrestrial biomes to be formally protected by 2020 (Aichi Target 11). Current policy measures in particularly Argentina and Uruguay thus remain far from what has been internationally agreed.

## 7. Conclusions

Land use change is driving intensification of livestock systems in the *Río de la Plata grasslands* region, thereby decreasing the area of native grassland and the ecosystem services they provide. Without intervention, these developments are likely to lead to the disappearance of native grassland-based livestock production systems and the associated ecosystem services provided, either by the replacement of native grasslands by crops or leys, or by their degradation through overgrazing.

We identified the need for more knowledge of ecosystem services provided by native grasslands and on livestock production strategies that support these services. The evidence presented in this paper suggests that it is possible to combine high levels of ecosystem service provisioning and meat production. Working with farmers on changing their management strategies and designing policies to enable economic conditions for this to happen, appear promising avenues to combine production and conservation in this neglected biome.

## Acknowledgments

We thank Marcos Angelini and Mario Michelazzo for their support in building the maps of the regions. We also thank Tanice Andreatta, Santiago Baeza, Pablo Barbera, Mariana Calvi, Pablo Cañada, Cristian Feldkamp, Martín Jaurena, Esteban Melani, Gustavo Melani, Carlos Nabinger, José Otondo, Ignacio Paparamborda, Gervasio Piñeiro, Andrea Ruggia and

Santiago Scarlato for giving access to grey and locally published literature. The comments of the ERL editorial board members on our first submission were very helpful in improving the quality of the paper. This work has been conducted as part of a PhD thesis project supported by the Agricultural Transformation by Innovation (AGTRAIN) Erasmus Mundus Joint Doctorate Program, funded by the EACEA (Education, Audiovisual and Culture Executive Agency) of the European Commission and Comisión Sectorial de Investigación Científica—Uruguay (CSIC).

## References

- Abba A M, Zufiaurre E, Codesido M and Bilenca D N 2015 Burrowing activity by armadillos in agroecosystems of central Argentina: biogeography, land use, and rainfall effects *Agric. Ecosyst. Environ.* **200** 54–61
- AIACC 2006 Climate change and variability in the mixed crop/livestock production systems of the Argentinean, Brazilian and Uruguayan Pampas 54 *Final report project LA 27*
- Alianza del Pastizal 2015 Alianza del Pastizal *Alianza del Pastizal* (<http://alianzadelpastizal.org/>)
- Allen V G et al 2011 An international terminology for grazing lands and grazing animals *Grass Forage Sci.* **66** 2–28
- Alkemade R et al 2013 Assessing the impacts of livestock production on biodiversity in rangeland ecosystems *Proc. Natl Acad. Sci. USA* **110** 20900–5
- Altesor A, Di Landro E, May H and Ezcurra E 1998 Long-term species change in a Uruguayan grassland *J. Veg. Sci.* **9** 173–80
- Altesor A, Oesterheld M, Leoni E, Lezama F and Rodriguez C 2005 Effect of grazing on community structure and productivity of a Uruguayan grassland *Plant Ecol.* **179** 83–91
- Altieri M and Pengue W 2006 GM soybean: Latin America's new coloniser *Seedling* **1** 13–7 ([www.grain.org/article/entries/588-gm-soybean-latin-america-s-new-colonizer](http://www.grain.org/article/entries/588-gm-soybean-latin-america-s-new-colonizer))
- Alvarez R 2001 Estimation of carbon losses by cultivation from soils of the Argentine Pampa using the Century Model *Soil Use Manag.* **17** 62–6
- Antuña J C, Rossanigo C, Arano A and Bartel M 2010 *Análisis de la actividad ganadera bovina por estratos de productores y composición del stock Años 2008 a 2010, Región Pampeana* (Buenos Aires)
- Arballo E, Cravino J L and Lyons J A 1999 *Aves del Uruguay: Manual Ornitológico* (Montevideo: Hemisferio Sur)
- Arzubi A, Vidal R and Moraes J 2013 *Boletín trimestral bovinos* (Buenos Aires, Septiembre 2013)
- Assad E D et al 2013 Changes in soil carbon stocks in Brazil due to land use: paired site comparisons and a regional pasture soil survey *Biogeosciences* **10** 6141–60
- Azpiroz A B, Isacch J P, Dias R A, Di Giacomo A S, Fontana C S and Palarea C M 2012 Ecology and conservation of grassland birds in southeastern South America: a review *J. Ornithol.* **83** 217–46
- Baladrón A V, Malizia A I, Bó M S, Liébana M S and Bechard M J 2012 Population dynamics of the southern short-tailed opossum (*Monodelphis dimidiata*) in the Pampas of Argentina *Aust. J. Zool.* **60** 238–45
- Baldi G and Paruelo J M 2008 Land-use and land cover dynamics in South American temperate grasslands *Ecol. Soc.* **13** 6 ([www.ecologyandsociety.org/vol13/iss2/art6/](http://www.ecologyandsociety.org/vol13/iss2/art6/))
- Balvanera P et al 2012 Ecosystem services research in Latin America: the state of the art *Ecosyst. Serv.* **2** 56–70
- Barral M P and Maceira N O 2012 Land-use planning based on ecosystem service assessment: a case study in the Southeast Pampas of Argentina *Agric. Ecosyst. Environ.* **154** 34–43
- Beauchemin K A, Henry Janzen H, Little S M, McAllister T A and McGinn S M 2010 Life cycle assessment of greenhouse gas emissions from beef production in western Canada: a case study *Agric. Syst.* **103** 371–9

- Beçoña G, Astigarraga L and Picasso V D 2014 Greenhouse gas emissions of beef cow-calf grazing systems in Uruguay *Sustain. Agric. Res.* **3**
- Behling H, DePatta Pillar V and Girardi Bauermann S 2005 Late Quaternary grassland (Campos), gallery forest, fire and climate dynamics, studied by pollen, charcoal and multivariate analysis of the São Francisco de Assis core in western Rio Grande do Sul (southern Brazil) *Rev. Palaeobot. Palynol.* **133** 235–48
- Behling H, Jeske-Pieruschka V, Schüler L and Pillar V D P 2009 Dinâmica dos campos no sul do Brasil durante o Quaternário Tardio *Campos sulinos: conservação e uso sustentável da biodiversidade* ed V D P Pillar et al (Brasília/DF: Ministério do Meio Ambiente—MMA) pp 13–25
- Bencke G A 2001 *Lista de referência das aves do Rio Grande do Sul ed Fundação Zoobotânica do Rio Grande do Sul* (Porto Alegre: Publicações Avulsas FZB)
- Bernardi R E, Holmgren M, Arim M and Scheffer M 2016 Why are forests so scarce in subtropical South America? The shaping roles of climate, fire and livestock *For. Ecol. Manage.* **363** 212–7
- Bernoux M, da Conceição Santana Carvalho M, Volkoff B and Cerri C C 2002 Brazil's soil carbon stocks *Soil Sci. Soc. Am. J.* **66** 888
- Bernoux M and Volkoff B 2006 Soil carbon stocks in soil ecoregions of Latin America *Carbon sequestration in soils of L ed R Lal et al* (New York, London, Oxford: Food Products) pp 65–78
- Berretta E 2003 *Perfiles por País del Recurso Pastura/Forraje* (Roma)
- Berretta E J, Risso D F, Montossi F and Pigurina G 2000 *Campos in Uruguay Grassland Ecophysiology and Grazing Ecology* ed G Lemaire et al (Cambridge: CAB) pp 377–94
- Bidegain M, Crisci C, del Puerto L, Inda H, Mazzeo N, Taks J and Terra R 2012 *Clima de cambios: Nuevos desafíos de adaptación en Uruguay* (Montevideo)
- Bilenca D, Codesio M, González Fischer C and Pérez Carusi L 2009 Biodiversidad en la ecorregión pampeana 43
- Bilenca D and Miñarro F 2004 *Identificación de Áreas Valiosas de Pastizal (AVPs) en las Pampas y Campos de Argentina, Uruguay y sur de Brasil* ed D Bilenca and F Miñarro (Buenos Aires: Fundación Vida Silvestre Argentina)
- Bindraban P S, Franke A C, Ferraro D O, Ghersa C M, Lotz L A P, Nepomuceno A, Smulders M J M and van de Wiel C C M 2009 GM-related sustainability: agro-ecological impacts, risks, and opportunities of soy production in Argentina and Brazil (Wageningen)
- Blanco D E, Lanctot R B, Isacch J P and Gill V A 2004 Temperate grasslands of southern South America as habitat for migratory shorebirds *Ornitol. Neotrop.* **15** 159–67
- Boldrini I I 1997 *Campos no Rio Grande do Sul: Caracterização Fisionômica e Problemática Ocupacional* (Porto Alegre: Universidade Federal do Rio Grande do Sul)
- Boldrini I I 2007 Formação campestres no sul do Brasil: origem, histórico e modificadores *II Simposio de forrageiras e produção animal* ed M Dall'Agnol et al (Porto Alegre: Gráfica Metrópole LTDA) pp 7–13
- Boldrini I I 2009 A flora dos campos do Rio Grande do Sul *Campos sulinos: conservação e uso sustentável da biodiversidade* ed V D P Pillar et al (Brasília: MMA) pp 63–77
- Bommarco R, Kleijn D and Potts S G 2012 Ecological intensification: harnessing ecosystem services for food security *Trends Ecol. Evol.* **28** 230–8
- Booman G C, Calandrini M, Laterra P, Cabria F, Iribarne O and Vázquez P 2012 Areal changes of lentic water bodies within an agricultural basin of the Argentinean Pampas. Disentangling land management from climatic causes *Environ. Manage.* **50** 1058–67
- Brazeiro A, Panario D, Soutullo A, Gutierrez O, Segura A and Mai P 2012 *Clasificación y delimitación de las eco-regiones del Uruguay* (Montevideo, Uruguay)
- Burkart A 1975 Evolution of grasses and grasslands in South America *Taxon* **24** 53–66
- Calvi M 2010 *Evolución de la ganadería correntina* (Mercedes, Argentina)
- Cardoni D A, Isacch J P and Iribarne O 2012 Effects of cattle grazing and fire on the abundance, habitat selection, and nesting success of the bay-capped wren-spinetail (*Spartonicoa maluroides*) in coastal saltmarshes of the Pampas region *Condor* **114** 803–11
- Cardozo G, Jaurena M and Do Carmo M 2015 Herbage allowance a management tool for re-design livestock grazing systems: four cases of studies *5th Int. Symp. for Farming Systems Design 'Multi-Functional Farming Systems in a Changing World' (Montpellier, France)* pp 347–8
- Caride C, Piñeiro G and Paruelo J M 2012 How does agricultural management modify ecosystem services in the Argentine Pampas? The effects on soil C dynamics *Agric. Ecosyst. Environ.* **154** 23–33
- Carriquiry M et al 2012 La cría vacuna sobre campo nativo: Un enfoque de investigación jerárquico para mejorar su productividad y sostenibilidad *Veterinaria* **48** 41–8
- Carvalho P C F D F, Batello C and de Faccio Carvalho P C 2009a Access to land, livestock production and ecosystem conservation in the Brazilian Campos biome: the natural grasslands dilemma *Livest. Sci.* **120** 158–62
- Carvalho P C F, Nabinger C, Lemaire G and Genro T C M C M 2009b Challenges and opportunities for livestock production in natural pastures: the case of Brazilian Pampa Biome *Proc. 9th Int. Rangel. Congr. Divers. Rangelands a Sustain. Soc. ed R Feldman et al* pp 9–15
- Castillo D F, Lucherini M and Casanave E B 2011 Denning ecology of Molina's hog-nosed skunk in a farmland area in the Pampas grassland of Argentina *Ecol. Res.* **26** 845–50
- Castillo D F, Vidal E M L, Casanave E B and Lucherini M 2012 Habitat selection of Molina's hog-nosed skunks in relation to prey abundance in the Pampas grassland of Argentina *J. Mammal.* **93** 716–21
- Cerezo A, Conde M C and Poggio S L 2011 Pasture area and landscape heterogeneity are key determinants of bird diversity in intensively managed farmland *Biodivers. Conserv.* **20** 2649–67
- Chagas C I I et al 2007 Water quality of superficial runoffs in extensive and intensive farming systems in Argentina *Agrochimica* **51** 130–6
- Chaneton E J and Facelli J M 1991 Disturbance effects on plant community diversity: spatial scales and dominance hierarchies *Vegetatio* **93** 143–55
- Chaneton E J and Lavado R S 1996 Soil nutrients and salinity after long-term grazing exclusion in a Flooding Pampa grassland *J. Range Manage.* **49** 182–7
- Cléricali C and García Préchac F 2001 Aplicaciones del modelo USLE/RUSLE para estimar pérdidas de suelo por erosión en Uruguay y la región sur de la cuenca del Río de la Plata *Agrociencia* **5** 92–103
- Codesido M, Fischer C G and Bilenca D 2008 Land use patterns and bird assemblages in agroecosystems of the Pampean Region, Argentina *Ornitol. Neotrop.* **19** 575–85
- Codesido M, González-Fischer C and Bilenca D 2011 Distributional changes of landbird species in agroecosystems of Central Argentina *Condor* **113** 266–73
- Codesido M, González-Fischer C and Bilenca D 2012 Agricultural land-use, avian nesting and rarity in the Pampas of central Argentina *Emu* **112** 46–54
- Codesido M, González-Fischer C M and Bilenca D N 2013 Landbird assemblages in different agricultural landscapes: a case study in the Pampas of Central Argentina *Condor* **115** 8–16
- Da Trindade J K, Pinto C E, Neves F P, Mezzalana J C, Bremm C, Genro T C M, Tischler M R, Nabinger C, Gonda H L and Carvalho P C F 2012 Forage allowance as a target of grazing management: implications on grazing time and forage searching *Rangel. Ecol. Manage.* **65** 382–93
- de Groot R et al 2012 Global estimates of the value of ecosystems and their services in monetary units *Ecosyst. Serv.* **1** 50–61
- Develey P F, Setubal R B, Dias R A and Bencke G A 2008 Grasslands bird and biodiversity conservation aligned with livestock production *Rev. Bras. Ornitol.* **16** 308–15

- de Vries M and de Boer I J M 2010 Comparing environmental impacts for livestock products: A review of life cycle assessments *Livest. Sci.* **128** 1–11
- Di Giacomo A S, Vickery P D, Casañas H, Spitznagel O A, Ostrosky C, Krapovickas S and Bosso A J 2010 Landscape associations of globally threatened grassland birds in the Aguapey river Important Bird Area, Corrientes, Argentina *Bird Conserv. Int.* **20** 62
- Díaz R, Jaurena M and Ayala W 2006 Impacto de la intensificación productiva sobre el campo natural en Uruguay XXI Reunión do Grupo Técnico em Forrageiras do Cone Sul-Grupo Campos. *Palestras e Resumos* vol 1 (Pelotas) pp 49–67
- Díaz-Zorita M, Duarte G and Grove J H 2002 A review of no-till systems and soil management for sustainable crop production in the subhumid and semiarid Pampas of Argentina *Soil Tillage Res.* **65** 1–18
- Dick M, Abreu da Silva M and Dewes H 2015 Mitigation of environmental impacts of beef cattle production in southern Brazil e Evaluation using farm-based life cycle assessment *J. Clean. Prod.* **87** 58–67
- Doré T, Makowski D, Malézieux E, Munier-Jolain N, Tchamitchian M and Titttonell P 2011 Facing up to the paradigm of ecological intensification in agronomy: revisiting methods, concepts and knowledge *Eur. J. Agron.* **34** 197–210
- Dotta G, Phalan B, Silva T, Green R E and Balmford A 2015 Assessing strategies to reconcile agriculture and bird conservation in the temperate grasslands of South America *Conserv. Biol.* **30** 618–27
- Durán A 1991 *Los suelos del Uruguay* (Montevideo: Hemisferio sur)
- Durán A 1998 Contenido y distribución geográfica de carbono orgánico en suelos del Uruguay *Agrociencia Uruguay* **2** 37–47
- Engel V, Jobbágy E G, Stieglitz M, Williams M and Jackson R B 2005 Hydrological consequences of Eucalyptus afforestation in the Argentine Pampas *Water Resour. Res.* **41** 1–14
- FAO 2007 *Future Expansion of Soybean 2005–2014* (Santiago)
- FAO 2013 FAOSTAT (<http://faostat3.fao.org/faostat-gateway/go/to/home/E>)
- Fernández G J, Posse G, Ferretti V, Gabelli F M and Fernandez G 2004 Bird-habitat relationship for the declining Pampas meadowlark populations in the southern Pampas grasslands *Biol. Conserv.* **115** 139–48
- Ferreira P M A and Boldrini I I 2011 Potential reflection of distinct ecological units in plant endemism categories *Conserv. Biol.* **25** 672–9
- Frangi J L and Barrera M D 1996 Biodiversidad y dinámica de pastizales en la Sierra de la Ventana, Provincia de Buenos Aires, Argentina *Biodiversidad y funcionamiento de pastizales y sabanas en América Latina* ed G Sarmiento and M Cabido (Mérida: CYTED Y CIELAT) pp 133–64
- Gabelli F M, Fernández G J, Ferretti V, Posse G, Coconier E, Gavieiro H J, Llambías P E, Peláez P I, Vallés M L and Tubaro P L 2004 Range contraction in the pampas meadowlark *Sturnella defilippii* in the southern pampas grasslands of Argentina *Oryx* **38** 164–70
- Galantini J A and Rosell R A 2006 The potential for soil carbon sequestration in the Pampas *Carbon sequestration in Soils of Latin America* ed R Lal (New York, USA: Food Products Press) pp 383–403
- García Préchac F 1992 *Conservación de suelos* (Montevideo, Uruguay)
- García Préchac F, Ernst O, Siri-Prieto G and Terra J A 2004 Integrating no-till into crop–pasture rotations in Uruguay *Soil Tillage Res.* **77** 1–13
- Garibaldi L A, Semmartin M and Chaneton E J 2007 Grazing-induced changes in plant composition affect litter quality and nutrient cycling in flooding Pampa grasslands *Oecologia* **151** 650–62
- Gavier-Pizarro G I, Calamari N C, Thompson J J, Canavelli S B, Solari L M, Decarre J, Góijman A P, Suarez R P, Bernardos J N and Zaccagnini M E 2012 Expansion and intensification of row crop agriculture in the Pampas and Espinal of Argentina can reduce ecosystem service provision by changing avian density *Agric. Ecosyst. Environ.* **154** 44–55
- Gerber P J et al 2013 *Tackling climate change through livestock – a global assessment of emissions and mitigation opportunities* Food and Agriculture Organization of the United Nations (FAO), Rome
- Ghersa C M and Leon R J C 1999 Successional changes in agroecosystems of Pampa of the rolling pampa *Ecosystems of Disturbed Ground* ed L Walker (Amsterdam: Elsevier) pp 487–502
- Goyenola G et al 2015 Phosphorus dynamics in lowland streams as a response to climatic, hydrological and agricultural land use gradients *Hydrol. Earth Syst. Sci. Discuss.* **12** 3349–90
- Grau H R, Aide T M and Gasparri N I 2005 Globalization and soybean expansion into semiarid ecosystems of Argentina *Ambio* **34** 265–6
- Guichon M L and Cassini M H 1999 Local determinants of coypu distribution along the Luján River, East central Argentina *J. Wildl. Manage.* **63** 895–900
- Hasenack H, Weber E J, Boldrini I I and Trevisan R 2010 Mapa de sistemas ecológicos da ecorregião das savanas uruguaias em escala 1:500.000 ou superior e relatório técnico descrevendo insumos utilizados e metodologia de elaboração do mapa de sistemas ecológicos (Porto Alegre)
- Herrero M and Gil S B 2008 Consideraciones ambientales de la intensificación en producción animal *Ecol. Austral* **18** 273–89
- IBGE 2006 *Censo Agropecuario 2006, Brasil, Grandes Regiões e Unidades da Federação* (Brasília/DF: Instituto Brasileiro de Geografia e Estatística)
- IBGE 2014 Series estadísticas IBGE (<http://seriesestadisticas.ibge.gov.br/>)
- INAC 2012 Series estadísticas Dirección Nacional de Carnes
- INDEC 2002 *Censo Nacional Agropecuario 2002. Argentina* (Buenos Aires: Instituto Nacional de Estadística y Censos)
- Indec 2009 Censo nacional agropecuario 2008, Resultados provisionarios 11
- INIA 2013 Banco de Datos Agroclimático (<http://inia.org.uy/online/site/gras.php>)
- INTA 2015 Sistema de información clima y agua (<http://climayagua.inta.gob.ar/>)
- Isacch J P, Bo M S, Maceira N O, Demaría M R and Peluc S 2003 Composition and seasonal changes of the bird community in the west pampa grasslands of Argentina *J. Ornithol.* **74** 59–65
- Isacch J P and Cardoni D A 2011 Different grazing strategies are necessary to conserve endangered grassland birds in short and tall salty grasslands of the flooding pampas *Condor* **113** 724–34
- Isacch J P, Cardoni D A and Iribarne O O 2014 Diversity and habitat distribution of birds in coastal marshes and comparisons with surrounding upland habitats in Southeastern South America *Estuaries Coasts* **37** 229–39
- Isacch J P, Maceira N O, Bo M S, Demaría M R and Peluc S 2005 Bird-habitat relationship in semi-arid natural grasslands and exotic pastures in the west pampas of Argentina *J. Arid Environ.* **62** 267–83
- Isacch J P and Martínez M M 2003 Habitat use by non-breeding shorebirds in flooding pampas grasslands of Argentina *Waterbirds* **26** 494
- Janzen H H 2011 What place for livestock on a re-greening earth? *Anim. Feed Sci. Technol.* **166–167** 783–96
- Jorge G, Pérez Bidegain M, Terra J and Sawchik J 2012 WEPP as a tool for enabling a more comprehensive analysis of the environmental impacts of soil erosion *Agrociencia Uruguay* **16** 268–73
- Krapovickas S and Di Giacomo A S D 1998 Conservation of pampas and campos grasslands in Argentina *Parks* **8** 47–53
- LART 2013 Sistema de seguimiento forrajero (<http://larfile.agro.uba.ar/lab-sw/sw/gui/Inicial.page>)
- Lavado R S, Sierra J O and Hashimoto P N 1996 Impact of grazing on soil nutrients in a pampean grassland *J. Range Manage.* **49** 452–7
- León R J C, Rusch G M and Oesterheld M 1984 Pastizales pampeanos—impacto agropecuario *Phytocoenologia* **12** 201–18

- Lewis J P 1996 Pastizales y sabanas de la provincia de Santa Fe, Argentina *Biodiversidad y funcionamiento de pastizales y sabanas en América Latina* ed G Cabido and M Sarmiento (Mérida: CYTED Y CIELAT) pp 77–100
- Loydi A 2012 Vegetation change in response to grazing exclusion in montane grasslands, Argentina *Plant Ecol. Evol.* **145** 313–22
- Machado I 2015 Emissão de metano por bovinos sob níveis de oferta de forragem em pastagem nativa do Bioma Pampa *PhD Thesis* Universidade federal do Rio Grande do Sul, Brazil
- MAGyP 2014 Sistema Integrado de Información Agropecuaria (<http://siia.gov.ar/>)
- Manfredi C, Soler L, Lucherini M and Casanave E B 2006 Home range and habitat use by Geoffroy's cat (*Oncifelis geoffroyi*) in a wet grassland in Argentina *J. Zool.* **268** 381–7
- Manfredi C, Vidal E L, Castillo D F, Lucherini M and Casanave E B 2012 Home range size and habitat selection of Geoffroy's cat (*Leopardus geoffroyi*, Felidae, Carnivora) in the pampas grassland *Mammalia* **76** 105–8
- Maraschin G E, Moojen E L, Escosteguy C M D, Correa F L, Apezteguia E S, Boldrini I I and Riboldi J 1997 Native pasture, forage on offer and animal response *18th Int. Grassl. Congr.* pp 27–8
- Medan D, Torretta J P, Hodara K, Fuente E B and Montaldo N H 2011 Effects of agriculture expansion and intensification on the vertebrate and invertebrate diversity in the Pampas of Argentina *Biodivers. Conserv.* **20** 3077–100
- MGAP 2002 *Censo General Agropecuario 2000* (Montevideo: MGAP, Dirección Estadísticas Agropecuarias)
- MGAP 2005 *Anuario estadístico agropecuario 2005* (Montevideo)
- MGAP 2012a *Anuario estadístico agropecuario 2012* (Montevideo)
- MGAP 2012b DICOSE *Declar. jurada semovientes* (<http://mgap.gub.uy/DGSG/DICOSE/dicose.htm>)
- MGAP 2013a *Anuario Estadístico Agropecuario 2013* (Montevideo)
- MGAP 2013b *Censo General Agropecuario 2011* (Montevideo)
- Ministerio da Agricultura; Pecuária e abastecimento 2015 Instituto nacional de meteorologia: (<http://inmet.gov.br/portal/>)
- Ministério Do Meio Ambiente 2015 Instituto Chico Mendes de Conservação da Biodiversidade *UNIDADES Conserv.:* (<http://icmbio.gov.br/portal/biodiversidade/unidades-de-conservacao/biomas-brasileiros.html>)
- Modernel P, Astigarraga L and Picasso V 2013 Global versus local environmental impacts of grazing and confined beef production systems *Environ. Res. Lett.* **8** 35052
- Moher D, Liberati A, Tetzlaff J and Altman D G 2009 Preferred reporting items for systematic reviews and meta-analyses *Acad. Clin. Ann. Intern. Med.* **151** 264–9
- Muscat B 2015 Emissão de metano e comportamento ingestivo de bovinos de corte em pastagem natural com diferentes níveis de intensificação *PhD Thesis* Universidade Federal do Rio Grande do Sul, Brazil
- Nabinger C, Carvalho P C D F, Pinto E C, Mezzalira J C, Brambilla D M and Boggiano P 2011 Servicios ecosistémicos de las praderas naturales : ¿es posible mejorarlos con más productividad? *Arch. Latinoam. Prod. Anim.* **19** 27–34
- Nabinger C, de Moraes A and Maraschin G E 2000 Campos in Southern Brazil *Grassland Ecophysiology and Grazing Ecology* ed G Lemaire et al vol 1996 (Wallingford: CAB) pp 355–76
- Naylor R, Steinfeld H, Falcon W, Galloway J, Smil V, Bradford E, Alder J and Mooney H 2005 Losing the links between livestock and land *Science* **310** 1621–2
- Noellemeyer E, Frank F, Alvarez C, Morazzo G and Quiroga A 2008 Carbon contents and aggregation related to soil physical and biological properties under a land-use sequence in the semiarid region of central Argentina *Soil Tillage Res.* **99** 179–90
- OECD 2007 *OECD-FAO Agricultural Outlook 2007–2016*
- Overbeck G E et al 2007 Brazil's neglected biome : the South Brazilian Campos *Perspect. Plant Ecol. Evol. Syst.* **9** 101–16
- Overbeck G E, Müller S C, Pillar V D and Pfadenhauer J 2006 Floristic composition, environmental variation and species distribution patterns in burned grassland in southern Brazil *Braz. J. Biol.* **66** 1073–90
- Pacheco J F and Bauer C 2000 *Biogeografia e Conservação da Avifauna na Mata Atlântica e Campos Sulinos—construção e nível atual do conhecimento* (Brasília)
- Parera A and Kesselman D 2000 Diagnóstico sumario de la fauna de mamíferos de la eco- región pampeana: caracterización y estado del conocimiento *Situación Ambiental Argentina 2000* ed C Bertonatti et al (Buenos Aires: Fundación Vida Silvestre Argentina) pp 181–4
- Paruelo J M, Guerschman J P, Verón S R, Piñeiro G, Baldi G, Jobbágy E G and Baeza S 2006 Cambios en el uso de la tierra en Argentina y Uruguay: marcos conceptuales para su análisis *Agrociencia* **10** 47–61
- Paruelo J M, Pineiro G, Baldi G, Baeza S, Lezama F, Altesor A and Oesterheld M 2010 Carbon Stocks and Fluxes in Rangelands of the Rio de la Plata Basin *Rangel. Ecol. Manage.* **63** 94–108
- Payret C C, Pineiro G, Achkar M, Gutiérrez O and Panario D 2009 The irruption of new agro-industrial technologies in Uruguay and their environmental impacts on soil, water supply and biodiversity: a review *Int. J. Environ. Health* **3** 175
- Perdomo C, Irisarri P, Ernst O, del Pino A and Rovira P 2012 Emisiones de óxido nitroso de suelos bajo cultivos anuales, pasturas y plantaciones forestales en Uruguay 'Latinoamérica unida protegiendo sus suelos' *XIX Congreso latinoamericano de la ciencia del suelo. XXIII Congreso argentino de la ciencia del suelo* (Mar del Plata, Argentina)
- Petz K et al 2014 Mapping and modelling trade-offs and synergies between grazing intensity and ecosystem services in rangelands using global-scale datasets and models *Glob. Environ. Change* **29** 223–34
- Peyraud J-L, Taboada M and Delaby L 2014 Integrated crop and livestock systems in Western Europe and South America: a review *Eur. J. Agron.* **57** 31–42
- Picasso V D, Modernel P D, Becoña G, Salvo L, Gutiérrez L and Astigarraga L 2014 Sustainability of meat production beyond carbon footprint: a synthesis of case studies from grazing systems in Uruguay *Meat Sci.* **98** 346–54
- Pillar V D, Tornquist C G and Bayer C 2012 The southern Brazilian grassland biome: soil carbon stocks, fluxes of greenhouse gases and some options for mitigation *Brazilian J. Biol.* **72** 673–81
- Presidência da República 2012 Código florestal brasileiro ([http://planalto.gov.br/ccivil\\_03/\\_Ato2011-2014/2012/Lei/L12727.htm](http://planalto.gov.br/ccivil_03/_Ato2011-2014/2012/Lei/L12727.htm))
- Pretelli M G, Isacch J P and Cardoni D A 2013 Year-round abundance, richness and nesting of the bird assemblage of tall grasslands in the south-east pampas region, Argentina *Ardeola* **60** 327–43
- QGIS 2014 QGIS geographic information system *Open Source Geospatial Found. Proj.* (<http://qgis.osgeo.org/>)
- Quintans G, Scarsi A, Velazco J I, López-Mazz C, Viñoles C and Bancho G 2012 Recientes avances en el conocimiento del manejo de los rodeos de cría: Aportes desde INIA *Veterinaria* **1** 87–90
- Ran Y, Deutsch L, Lannerstad M and Heinke J 2013 Rapidly intensified beef production in Uruguay : impacts on water related ecosystem services *Aquat. Proc.* **1** 77–87
- Rapoport E 1996 The flora of Buenos Aires: low richness or mass extinction *Int. J. Environ. Sci.* **22** 217–42
- Redo D J, Aide T M, Clark M L and Andrade-Núñez M J 2012 Impacts of internal and external policies on land change in Uruguay, 2001–2009 *Environ. Conserv.* **39** 122–31
- Rossanigo C, Arano A and Rodríguez Vázquez G 2012 Stock 2012 del ganado bovino Mapas de Existencias e indicadores ganaderos 17
- Royo Pallarés O, Berretta E J and Maraschin G E 2005 The South American Campos ecosystem *Grasslands of the World* ed J M Suttie et al (Rome: FAO) pp 171–219
- Ruggia A, Scarlato S, Cardozo G, Aguerre V, Dogliotti S, Rossing W and Tittone P 2015 Managing pasture-herd interactions in livestock family farm systems based on natural grasslands in Uruguay *5th Int. Symp. for Farming Systems Design 'Multi-Functional Farming Systems in a Changing*

- World'ed G Emmanuel and J Wery (Montpellier, France) pp 267–8
- Ruviaro C F, de Léis C M, Lampert V D N, Barcellos J O J and Dewes H 2014 Carbon footprint in different beef production systems on a southern Brazilian farm: a case study *J. Clean. Prod.* **96** 435–43
- SAGyP and INTA 2013 GeoINTA (<http://geointa.inta.gov.ar/visor/>)
- Sala O E, Oesterheld M, León R J C and Soriano A 1984 Grazing effects upon plant community structure in subhumid grasslands of Argentina *Vegetatio* **67** 27–32
- Sala O E and Paruelo J M 1997 Ecosystem services in grasslands *Nature's services: Societal dependence on natural ecosystems* ed G C Daily (Washington, DC: Island) pp 237–51
- Scarlatto S, Albicette M M, Bortagaray I, Ruggia A, Scarlatto M and Aguerre V 2015 Co-innovation as an effective approach to promote changes in farm management in livestock systems in Uruguay *5th Int. Symp. for Farming Systems Design 'Multi-Functional Farming Systems in a Changing World'* ed G Emmanuel (Montpellier, France) pp 281–2
- Scobie J R 1964 *Revolution on the Pampas: A Social History of Argentine Wheat, 1860–1910* (Berkeley: Institute of Latin American Studies)
- SEBRAE, SENAR and FARSUL 2005 *Diagnóstico de Sistemas de Produção de Bovinocultura de corte do Estado do Rio Grande do Sul. Relatório de Pesquisa (Porto Alegre)*
- Soca P, Carriquiry M, Do Carmo M, Scarlatto S, Astessiano A L, Genro C, Claramunt M and Espasandín A 2013a Oferta de forraje del campo natural y resultado productivo de los sistemas de cría vacuna del Uruguay: I Producción, uso y conversión del forraje por campo natural *Seminario de actualización técnica: Cría Vacuna* ed G Quintans and A Scarsi (Treinta y Tres: INIA) pp 97–117
- Soca P, Espasandín A and Carriquiry M 2013b *Efecto de la oferta de forraje y grupo genético de las vacas sobre la productividad y sostenibilidad de la cría vacuna en campo natural* (Montevideo, Uruguay: INIA)
- Soca P and Orcasberro R 1992 Propuesta de Manejo del Rodeo de Cría en base a estado corporal, altura del pasto y aplicación del destete temporario *Evaluación Física y Económica de Alternativas Tecnológicas en Predios Ganaderos* (Paysandú: Facultad de Agronomía, Universidad de la República)
- Sollenberger L E, Moore J E, Allen V G and Pedreira C G S 2005 Reporting forage allowance in grazing experiments *Crop Sci.* **48** 896–900
- Soriano A 1992 *Río de la Plata Grasslands Ecosystems of the world* ed R T Coupland (Amsterdam: Elsevier) pp 367–407
- Steinfeld H, Mooney H A, Schneider F and Neville L E 2010 *Livestock in a changing landscape Drivers, Consequences, and Responses* vol 1 (Washington, DC: Island)
- Strassburg B B N, Latawiec A E, Barioni L G, Nobre C A, da Silva V P, Valentim J F, Vianna M and Assad E D 2014 When enough should be enough: improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil *Glob. Environ. Change* **28** 84–97
- Straumann J M, Ayala W, Vázquez A I and Quintans G 2008 Efecto del manejo nutricional en el primer invierno sobre la aparición de la pubertad en terneras de raza carnífera (primer año de evaluación) *Seminario de actualización técnica: Cría Vacuna (parte I)* ed G Quintans et al (Montevideo, Uruguay: INIA) pp 59–63
- Tessema W K, Ingenbleek P T M and van Trijp H C M 2013 Pastoralism, sustainability, and marketing. a review *Agron. Sustain. Dev.* **34** 75–92
- Tittonell P 2014 Ecological intensification of agriculture—sustainable by nature *Curr. Opin. Environ. Sustain.* **8** 53–61
- Tonello M S and Prieto A R 2008 Modern vegetation–pollen–climate relationships for the Pampa grasslands of Argentina *J. Biogeogr.* **35** 926–38
- Tornquist C G, Giasson E, Mielniczuk J, Cerri C E P and Bernoux M 2009 Soil Organic Carbon Stocks of Rio Grande do Sul, Brazil *Soil Sci. Soc. Am. J.* **73** 975
- Trigo E J and Cap E J 2004 The impact of the introduction of transgenic crops in argentinean agriculture *Agrobioforum* **6** 87–94
- UNEP, CIUP, ACTO and CIUP 2009 *GEO Amazonia, Environment Outlook in Amazonia*
- Valls J F M 1986 Principais gramíneas forrageiras nativas das diferentes regiões do Brasil *Proc. 3rd Simpósio sobre Produção Animal* (Campinas: Fundação Cargill)
- Vega E, Baldi G, Jobbágy E G, Paruelo J, Jobbágy E G and Paruelo J 2009 Land use change patterns in the Río de la Plata grasslands: the influence of phytogeographic and political boundaries *Agric. Ecosyst. Environ.* **134** 287–92
- Vervoort F B 1967 *La vegetación de la República Argentina. VII Las comunidades vegetales de la depresión del salado* (Buenos Aires, Argentina: Instituto Nacional de Tecnología Agropecuaria)
- Viglizzo E F and Jobbágy E G 2010 *Expansión de la Frontera Agropecuaria en Argentina y su Impacto Ecológico-Ambiental* 106
- Viglizzo E F, Lertora F, Pordomingo A J, Bernardos J N, Roberto Z E and Del Valle H 2001 Ecological lessons and applications from one century of low external-input farming in the pampas of Argentina *Agric. Ecosyst. Environ.* **83** 65–81
- Wingeyer A B, Amado T J C, Pérez-Bidegain M, Studdert G A, Varela C H P, García F O and Karlen D L 2015 Soil quality impacts of current South American agricultural practices *Sustainability* **7** 2213–42
- Zalba S M and Cozzani N C 2004 The impact of feral horses on grassland bird communities in Argentina *Anim. Conserv.* **7** 35–44
- Zalba S M, Sánchez R and Cozzani N C 2008 Priorities for the conservation of an endangered grassland bird : clues from its nesting biology *Ornitol. Neotrop.* **20** 35–46