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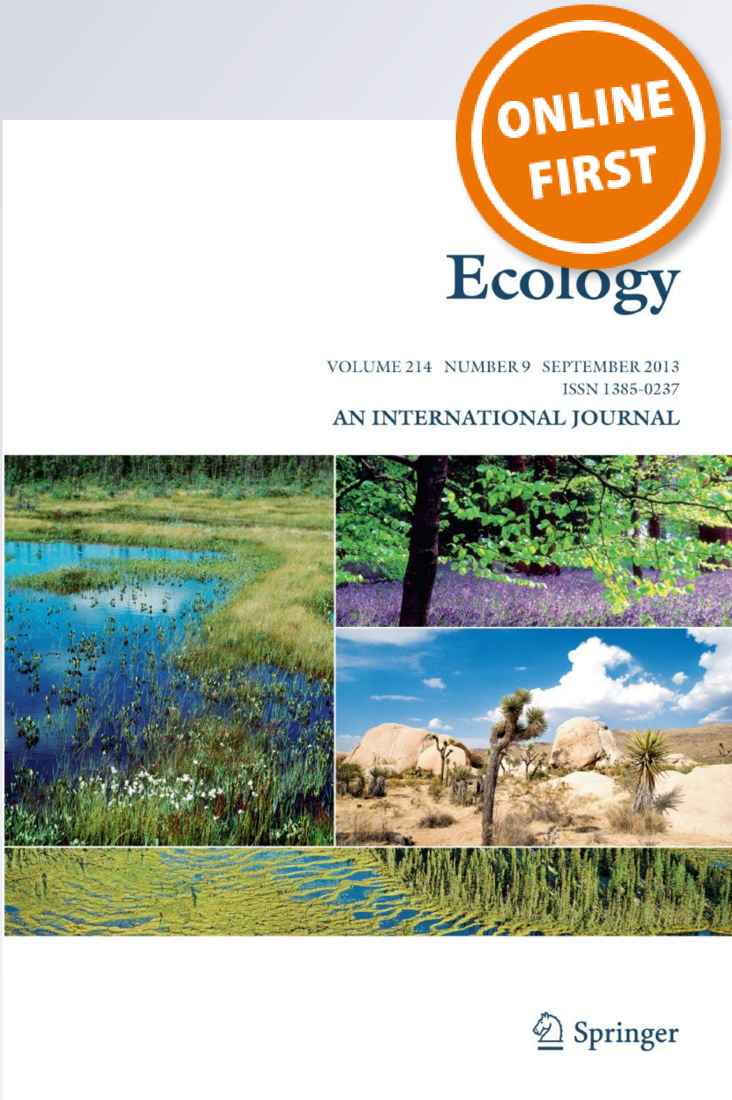

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Abstract There is a long lasting debate on the effects of domestic cattle grazing on natural ecosystems worldwide. Cattle are generally assumed to have negative effects on forest conservation; however, several studies also report positive and neutral effects. We aimed to investigate the available evidence for positive, negative and neutral effects of cattle grazing on forest and woody ecosystems of southern South America. We conducted a peer-review literature search using the ISI Web of Knowledge and Scopus databases to identify studies dealing with cattle impacts for nature conservation. We compiled a database of 211 cases from 126 original publications. A reduced number of forest ecosystems (Patagonian forest, Chaco and Monte) concentrated ~ 85% of the reported study cases. The hierarchical cluster analysis to group cases based on cattle effects, ecological variables and ecosystems reported that negative effects (~ 66% of cases) were mostly informed for vegetation variables and mainly occur in Patagonian forest and Chaco; positive effects (~ 16%) were mostly informed for Monte (no particular variable associated), while neutral effects (~ 18%) were mostly informed for fauna-related variables and Uruguayan savanna. Our study suggests that grazing effects by cattle on southern South America forests are not homogeneous and depend on the particular forest ecosystem considered as well as on the forest attribute measured. Different cattle effects found can be partially explained by differences in grazing history and different ecosystems productivity. It is vital to improve our understanding of cattle–forest interactions to guide synergies between sustainable management and forest conservation.

Keywords *Bos taurus* · Browsing · Domestic livestock effects · Forest structure composition and dynamics · Grazing · Native forests

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Introduction

Human-induced changes on large herbivores' distribution and abundance are important factors in global environmental change (Wardle and Bardgett 2004). Large herbivores, when introduced to a new habitat, imposed a new herbivory regime, mainly due to their different feeding patterns and body size (Hobbs and Huenneke 1992). Through selective herbivory and associated activities (e.g., trampling, fraying, bedding, urination and defecation), large herbivores have the potential to drastically modify composition, structure and dynamics of plant communities, facilitate plant invasions, alter water and nutrient cycles, and modify disturbance regimes, especially fire (Huntly 1991; Augustine et al. 1998; Hester et al. 2006; Hobbs 2006).

Livestock grazing is currently the most extended land use, occupying 25% of the global land surface (Asner et al. 2004). Livestock have been identified as one of the main causes of extinction of native plant and animal species resulting from habitat degradation caused by grazing and trampling (Gurevitch and Padilla 2004). Livestock-associated impacts currently constitute the third cause of reduction in native habitats and plant biomass after deforestation and fire (Díaz et al. 2006). However, there is opposite evidence showing that browsing and grazing by large herbivores can have positive or neutral effects (i.e., non-significant effects) on plant communities and ecosystems (Schieltz and Rubenstein 2016; Eldridge et al. 2016). For instance, it have been demonstrated that cattle, especially in rangelands and savannas, can reduce fuel biomass and fire temperatures (Kimuyu et al. 2014), or contribute to plant diversity conservation (Fensham et al. 2014). Considering forest regeneration, several studies indicate that livestock can facilitate native plant dispersal by seed transport, promote germination by opening new microsites through trampling and browsing, and promote tree regeneration by reducing fire frequency (Hester et al. 1996; Relva and Veblen 1998; Gill and Beardall 2001). Moreover, there is a long lasting debate on cattle conservation effects in forests worldwide, especially in western North America (Adams 1975; Belsky and Blumenthal 1997; Jones 2000; Wisdom et al. 2006; Foster et al. 2014; Pekin et al. 2015) and in African savannas (Goheen et al. 2010; Young et al. 2013). However, in southern South America this debate has not been approached with the necessary deepness and extent.

In southern South America, domestic cattle were introduced about 500 years ago, and stocking densities have increased substantially in many locations since early European settlement (Novillo and Ojeda 2008; Merino et al. 2009; Ballari et al. 2016). Extensive cattle ranching is the main economic activity in most mountainous regions in developing countries in Latin America, where it is difficult to cultivate (Steinfeld et al. 2006). In Argentina, domestic cattle have been historically most abundant in the humid pampas and savannas. However, in the last three decades, due to crop expansion, ranching has been relocated towards marginal areas for agriculture, mostly forested areas in the central-eastern and northeastern parts of the country (Guevara et al. 2009). In other forested areas, domestic cattle activity apparently has not increased (e.g., temperate forests) or has even decreased (e.g., subtropical montane forests, see Malizia et al. 2013). In Uruguay, livestock ranching is currently the main economic activity (Echávarri et al. 2014), while in Chile it constitutes one of the main activities in central and southern regions of the country. Besides its economic importance, cattle contribute to food security (Steinfeld et al. 2006) and have an important social and cultural value for rural populations inhabiting forest areas. Thus, the grazing landscape in southern South America is varied and complex.

Forest impacts by domestic cattle have been recognized as a conservation and management challenge, and several studies have been published on these topics in the region (Blackhall et al. 2008; Cingolani et al. 2008; Ballari et al. 2016). To promote compatible cattle management with forest conservation (i.e., damage limitation), it is necessary to have sound information on the main ecosystem processes and functions affected by cattle activities. Most knowledge of cattle effects comes from rangelands and temperate forests of the Northern Hemisphere, but the knowledge from temperate and subtropical forests of the Southern Hemisphere studies are more recent and relatively limited. To the best of our knowledge, there are no syntheses that show the overall effects of cattle grazing on the high diversity of forest ecosystems present in southern South America. In this review, we are interested on how cattle effects vary across forest and woody ecosystems in southern South America, considering a large array of ecological variables and their reported effects (positive, negative or neutral) in light of nature conservation and sustainable forest management. Second, we discuss our results with available information from other regions of the world. Finally, we provide insights to orient future research efforts.

Methods

Review protocol

We conducted a peer-review literature search in November 2017 using the ISI Web of Knowledge and Scopus databases to identify studies dealing with cattle impacts in forest and woody ecosystems of southern South America (search and studies were analyzed by one operator.). We used the following key words: TS = (forest*) AND TS = (cattle OR livestock) AND TS = (argentin* OR chile* OR urugua* OR pradera OR matorral OR espinal OR calden OR delta OR parana* OR monte OR misionera OR chaco OR yungas OR andean OR tucuma* OR andino patagonico OR andino-patagonico OR patagoni* OR nothofagus OR valdivian* OR magallan*). We did not refine the search by language, or include any restraining date. Only articles with original case studies were included (i.e., we did not consider reviews nor modeling studies). Studies that focused on cattle management for production were not included, neither were those that focused on human health. We employed a systematic review, a highly recommended method to provide an overview of the literature for a topic (Pullin and Gavin 2006; Lortie 2014). The inclusion criteria encompassed studies restricted to forest and woody ecosystems in Argentina, Chile and Uruguay. We included studies only considering domestic cattle (*Bos taurus*), because it is the largest and most abundant grazing ungulate (native or introduced) in these ecosystems (Price 1986).

Database construction

Studies were categorized according to their location into eight forest and woody ecosystems, following the Mercosur classification (PNUMA and CLAES 2008): Chaco (i.e., tropical seasonal dry forests), Chilean Matorral (i.e., temperate hygrophilous and sclerophyllous forests), Espinal (i.e., temperate shrublands and forests), Monte (i.e., temperate woodlands), Paranaense Rainforest (i.e., subtropical rain forests), Patagonian Forests (i.e., temperate humid sub Antarctic forests), Uruguayan savanna (i.e., subtropical savannas), and Yungas (i.e., subtropical montane forests).

For each publication, we also identified ecological response variables considered and we categorized them into seven broad categories of ecological variables: (i) conservation of vegetation structure, composition and dynamics (includes canopy and understory strata, regeneration and growth); (ii) conservation of faunal diversity (i.e., abundance, composition and diversity of fauna inhabiting forests); (iii) prevention of plant invasions (i.e., abundance and composition of invasive plants); (iv) reduction of fire frequency and probability; (v) conservation of soil features (i.e., water content, soil erosion and chemical properties); (vi) conservation of landscape features (i.e., land use and net primary productivity); and (vii) maintenance of abiotic conditions (i.e., microclimatic air temperature and humidity) (for details see Table 1, Online Appendix S1 and S2).

Since several studies reported multiple response variables, each response variable was accounted as a separate observation. Cattle effects were set as positive, negative or neutral whether the effect was considered beneficial, detrimental or neutral, respectively, to nature conservation and sustainability forest management, following the authors' analyses and interpretations.

Data analysis

We performed a multiple correspondence analysis (MCA) with R program (R Core Team 2018) using FactoMiner package (Lê et al. 2008) to determine groups from variables association. Studies were treated as individuals (rows) and variables (ecosystems, ecological response variables and cattle effects) as columns. In MCA, Chi square is used as a distance measure, which is a Euclidean distance among relative frequencies weighted by the inverse of weight. In addition, categories with frequencies lower than 2% were excluded from the analysis. Since the MCA explained low data variability ($\sim$ 18%), we applied Euclidean hierarchical cluster analyses based on the main factorial axes produced by the MCA. Cluster analyses were performed with R program (R Core Team 2018) using FactoMiner (Lê et al. 2008) and

Table 1 Number of cases with negative, positive, and neutral effects of cattle on the main ecological response variables studied along forest and woody ecosystems in southern South America

Ecosystem	Variable	Cattle effect		
		Positive	Negative	Neutral
Chaco	Conservation of faunal diversity	1	11	8
	Conservation of landscape features		2	
	Conservation of soil features		6	
	Conservation of vegetation structure, composition and dynamics	7	28	3
	Prevention of plant invasions	1		
Chilean Matorral	Conservation of vegetation structure, composition and dynamics	1	2	1
Espinal	Conservation of faunal diversity		1	
	Conservation of vegetation structure, composition and dynamics	1	4	1
Monte	Conservation of faunal diversity	1	2	2
	Conservation of soil features	5	2	1
	Conservation of vegetation structure, composition and dynamics	3	9	2
Patagonian forest	Conservation of faunal diversity	4	6	3
	Conservation of landscape features	1	1	
	Conservation of soil features		5	
	Conservation of vegetation structure, composition and dynamics	6	45	10
	Maintenance of abiotic conditions	1		1
	Prevention of plant invasions		1	
	Reduction of fire frequency and probability	1	3	2
Uruguayan savanna	Conservation of soil features		2	
	Conservation of vegetation structure, composition and dynamics		2	2
Paranaense rainforest	Conservation of faunal diversity		1	
Yungas	Conservation of faunal diversity		2	2
	Conservation of soil features		2	
	Conservation of vegetation structure, composition and dynamics		2	
	Reduction of fire frequency and probability	1		

cluster (Maechler et al. 2018) packages. We used the Ward's method to group cases by similarities of ecosystems, ecological response variables and cattle effects. Number of clusters or groups was defined considering the test-value scores of Ward's method.

Results

We identified 120 publications that matched the criteria for inclusion with 211 study cases that reported cattle impacts on forests in southern South America (Table 1, Table S1 in Online Appendix S2). Publications are not equally distributed across forest ecosystems present in the region (Fig. 1). Around 42% of the studies (90 of 211) reported information for Patagonian Forest (Fig. 2), ~ 31% (67) for Chaco, ~ 12% (27) for Monte, and the remaining ~ 13% (27) for all other ecosystems: Yungas (9), Espinal (7), Chilean Matorral (4), Uruguayan Savanna (6), and Paranaense Rainforest (1).

Considering all ecosystems together, negative effects were reported in ~ 65% of the studies (139 of 211), positive effects in ~ 16% (34) of the studies and neutral effects in ~ 18% (38) of the studies (Fig. 2).

Analyzing the ecological response variables considered, conservation of vegetation structure, composition and dynamics was by far the most studied response variable with ~ 61% of the reported cases

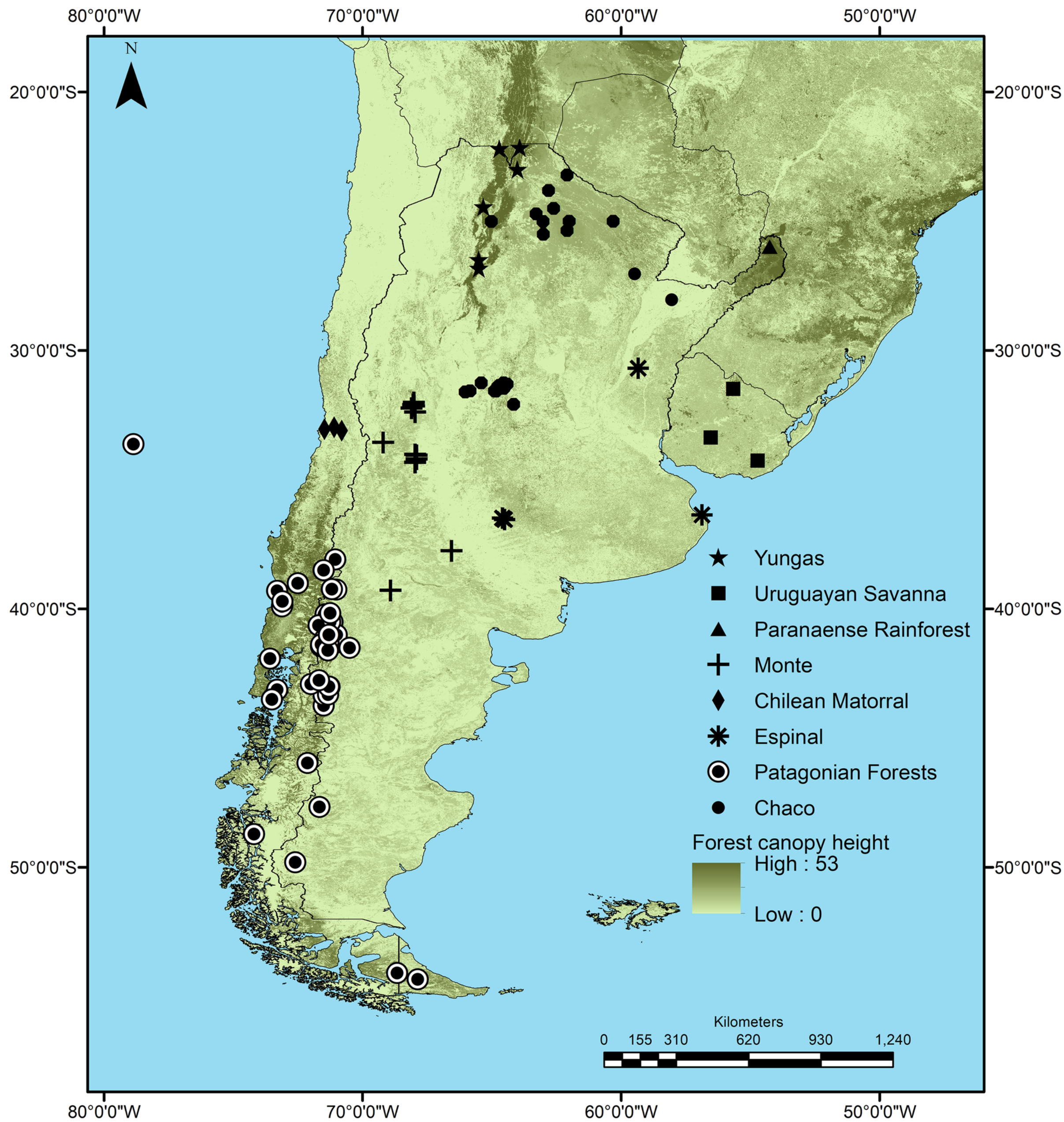
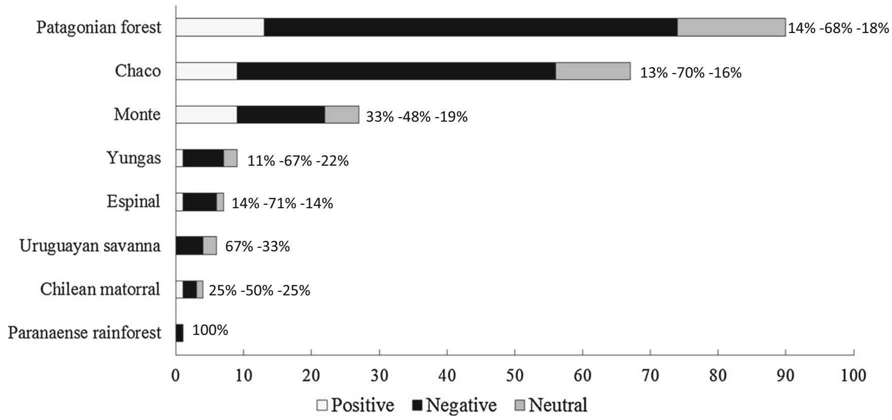


Fig. 1 Map showing locations of publications obtained from literature search on effects of domestic cattle on forest and woody ecosystems in southern South America (Argentina, Chile y Uruguay) (for details see Table S1). Symbols correspond to study sites. Forest height (m) shape (modified from Simard et al. 2011) is included in the map to show the distribution of the main forest and woody ecosystems present in the region

(129 of 211) (Table 1), followed by conservation of fauna diversity ~ 20% (44), and conservation of soil ~ 10% (23). The remaining variables totalized together ~ 7% of the reported cases: Reduction of fire frequency (7), conservation of landscape features (4), prevention of plant invasion (2), and maintenance of abiotic conditions (2).

Fig. 2 Number of study cases evaluating effects (positive, negative and neutral) of domestic cattle in eight forest and woody ecosystems in southern South America (Argentina, Chile and Uruguay). Numbers next to the bars represent percentage for positive, negative and neutral effects



Classification of study cases

The MCA yielded 5 factorial axes that together explain 69.9% of the total variance. Study cases excluded from the analyses due to their low frequencies were 13 in total (4 for Chilean matorral, 1 for Paranaense forest, 4 for Conservation of landscape features, 2 for Maintenance of abiotic conditions and 2 for Prevention of plant invasions). Cluster analysis separated study cases into five major groups (Fig. 3). The first group comprised seven cases dealing with Espinal ecosystem (test value (test v.) = 7.23; $P < 0.001$). The second group contained 101 cases characterized by negative cattle effects (test v. = 11.15; $P < 0.001$) related with Conservation of vegetation structure, composition and dynamics (test v. = 2.70; $P = 0.001$), predominantly located in Patagonian Forest (test v. = 3.61; $P < 0.001$) and Chaco (test v. = 3.75; $P < 0.001$). The third group comprised 15 cases mostly characterized by neutral cattle effects (test v. = 10.39; $P < 0.001$) related with Conservation of fauna diversity (test v. = 2.41; $P = 0.01$), manly located in Uruguayan Savanna (test v. = 4.30; $P < 0.001$). The fourth group contain 15 cases related with Reduction of fire frequency (test v. = 5.93; $P < 0.001$) at Yungas forests (test v. = 6.91; $P < 0.001$). The fifth group was represented by 41 cases mostly having positive effects (test v. = 9.12; $P < 0.001$), mainly located in Monte ecosystem (test v. = 7.87; $P < 0.001$).

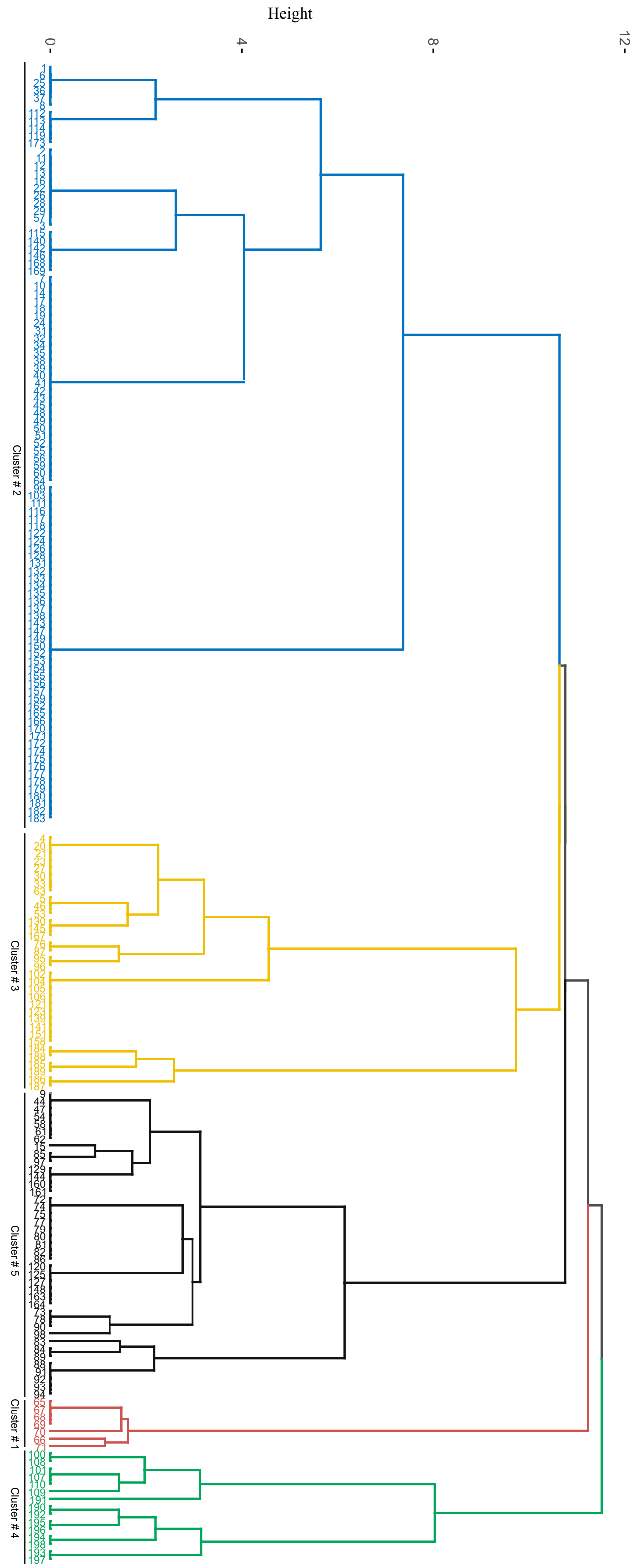
Discussion

Our results suggest that grazing effects by domestic cattle in southern South America forests are not homogeneous, but depend on forest ecosystems and forest attributes. However, there is a clear tendency that cattle mainly have negative effects for nature conservation and sustainability forest management for most ecoregions and ecological variables considered. Research efforts on cattle effects are concentrated in two (Patagonian forests and Chaco) out of eight forest and woody ecoregions of southern South America.

Cattle effects across ecoregions and studies cases

As the effect of grazing is determined, among other factors, by plant productivity (Hester et al. 2000), there is an increasing body of evidence supporting the notion that low productivity (arid) sites will be more sensitive to grazing (Proulx and Mazumder 1998; Cingolani et al. 2005); however, herbivory may also be influential in more productive systems (Milchunas and Lauenroth 1993). This is controversial, but can describe the pattern we found in Chaco (arid ecosystem) and Patagonian forest (humid) is where most negative effects were reported. Positive effects were associated with Monte, and neutral effects with Uruguayan savanna (Table 1). Two forest ecosystems (Espinal and Yungas) were not associated with any particular effect. It would be important to obtain information on forest productivity (e.g., from rainforests to savannas) to be able to compare plant responses to herbivory across a range of plant productivity of forest ecosystems. We strongly recommend increasing the number of studies on the

Fig. 3 Dendrogram resulting from a cluster analysis considering cattle effects, ecological variables and forest ecosystems. Numbers indicate study case (for details see Table S1)



forest–livestock interaction in these sites of contrasting productivity.

The two other forest ecosystems present in southern South America (Chilean matorral and Paranaense rainforest) report all the effect types (positive, negative and neutral), but as they resulted with very few publications, it is not possible to conclude exhaustively about them.

Cattle effects on main ecological response variables

Conservation of vegetation composition, structure and dynamics

Regarding vegetation attribute responses to cattle grazing, such as seedling and sapling recruitment, abundance and growth, they generally appeared as negatively affected by cattle grazing (e.g., Teich et al. 2005; Blackhall et al. 2008; Aschero and Garcia 2012; Zamorano-Elgueta et al. 2014). Similar effects were reported for several areas in North America (Belsky and Blumenthal 1997; Jones 2000; Kaufmann et al. 2014; Leopold and Hess 2017), and other places of Central and South America (Griscom et al. 2009; Marquardt et al. 2009). However, Vieira et al. (2006) in Brazil, no effects from cattle grazing were detected on seedling survival. In Buthan, the removal of herbaceous biomass by grazing enhanced regeneration of conifer species and reduced damage done by small rodents (Roder et al. 2002). Grazing, however, diminished number and density of broadleaved species (Roder et al. 2002). Conversely, positive cattle effects were reported favoring germination, seed dispersal, and flower and fruit production (Fuentes et al. 1989; Venier et al. 2012; de Paz and Raffaele 2013). Similar positive results were found in others forest and woody ecoregions worldwide, such as temperate broadleaf forests in Denmark (Bruun and Fritzbøger 2002), temperate mixed conifer forests in Bhutan Himalayas (Darabant et al. 2007) and African savannas (Goheen et al. 2010).

Conservation of faunal diversity

Conservation of faunal diversity, the second forest response variable most studied in the region, report mostly neutral effects. Cattle effects on fauna depended on the group (e.g., mammals, birds, arthropods) under study. Cattle have been reported as having neutral or positive effects on faunal abundance or diversity, with a shift on species composition towards more generalist species (Gill and Fuller 2007; Foster et al. 2014). We found that livestock changed vegetation structure and cover in ways that negatively affected small mammals, while ungulates were affected more by interference competition and changes in fodder quantity and quality. In Peru, cattle density positively affected raptor species richness that searched for food in open habitats, while presence of range restricted species that hunted from perches (Piana and Marsden 2014). Some of the articles reported that cattle presence did not have an effect on nest predation (De Santo et al. 2002; Mezquida et al. 2004).

Native species reduce habitat use when livestock are present (Côté et al. 2004), in particular we find this effect in relation to other herbivores. We found that cattle restrained habitat use as shown by native herbivores in Patagonian forest and Espinal (Frid 2001; Meier and Merino 2007; Vila et al. 2008; Soler Esteban et al. 2012). However, several native grazing species in Africa show positive responses to cattle presence, suggesting possible facilitation toward positive habitat use (Schieltz and Rubenstein 2016). We did not find any work describing facilitation like interaction between cattle and other mammals.

Invertebrates also showed mostly negative responses to grazing (Foster et al. 2014). However, it seems that ground beetles' diversity and abundance is favored by cattle presence (Sasal et al. 2017), without any consequence seen from the disturbances' history.

Conservation of soil features

Soil properties and functions were scarcely studied in southern South America and response patterns were variable (positive and negative effects). Stoking density is variable among ecosystems, thus this influences the effects. Light and moderate grazing have effects that are much less significant. Livestock is considered as important direct and indirect regulators of nutrient cycling; however, idiosyncratic results have been found in forests and other vegetation types (Binkley et al. 2003; Meglioli et al. 2013). Livestock enhance local soil nutrient availability when they gather food over a wide area and concentrate it in small spots in dung, urine and carcasses (Pastor et al.

2006). In riparian zones, grazing decreases resistance to erosion by reducing vegetation and exposing more vulnerable substrates.

Reduction of fire frequency and probability

Surprisingly, few publications in southern South America focused on the relationship between fire and cattle grazing. The relevant role played by large herbivores as regulators of spatial and temporal fire dynamics in forests, grasslands and savannas has been widely recognized (Hobbs 1996). Basically, cattle browsing alters fuel quality and quantity. We found that cattle can modify fire regime, throw selective browsing, increasing flammability of forest–shrubland systems (Blackhall et al. 2015b), mainly in Patagonian forests. For other ecosystems it was slightly reported. In USA, large herbivores have an important role in maintaining fire regime and its plant diversity associated in seasonally arid forest environment (Pekin et al. 2015). In north Australia, due to cattle impacts of fire regimes, savannas are being transformed into forests (Sharp and Whittaker 2003; Tasker and Bradstock 2006; Lehmann et al. 2014). We found that half of the studies analyzed reported negative effects. Further investigations are needed, considering native forests and the relation with other disturbances, such as fire, with different cattle abundances.

Prevention of plant invasions

There is contradictory evidence whether cattle grazing can hinder or promote invasion of introduced flora (Vavra et al. 2007). For our study region, evidence available on plant invasion–cattle relationship is scarce and limited to few ecosystems (Chaco, Chilean Matorral and Patagonian Forest). In Chaco, cattle apparently contributed to control tree invasion through browsing, relatively more intensively on exotic than on native trees (Capó et al. 2016), while in Patagonia overgrazing seemed to promote introduced plant species (Vidal et al. 2011). Other mechanism that was globally identified to contribute to plant invasion is seed dispersal by animal feces (Gill and Beardall 2001). In the only publication that we found reviewing this topic, apparently cattle and goat disperse (by consumption) relatively more *Acacia caven* than *Prosopis chilensis,* leading to a forest composition transformation (Fuentes et al. 1989). More studies are needed to elucidate the net effect of cattle as dispersers of native and introduced plants, especially because silvopastoral systems are encouraging as a forest management practice in the region (Peri et al. 2016).

Maintenance of abiotic conditions

Changes in air abiotic conditions due to cattle browsing were practically not reported according to our literature review. The only publication we identified on this topic showed no effect on air humidity and decrease in the air temperature due to cattle presence (Blackhall et al. 2015a). We did not find any literature on this issue. This is important due to the association of high temperatures and low humidity directly influences the conditions of the fuels present in an environment and therefore fire probability (ignition and propagation) (Blackhall et al. 2012, 2015a).

Conservation of landscape features

Changes in landscape structure due to cattle browsing were scarcely reported. Agricultural boundary is moving forward from productive areas to inferior ones pushing livestock to more unfavorable zones, like forests. Traditional models of vegetation transition in forested ecosystems have ignored the influences of ungulate herbivory, while research on effects of herbivory have typically excluded other disturbances (Wisdom et al. 2006). We contend that useful landscape research on herbivory must examine the interactions of ungulate grazing with other disturbance regimes at spatial extents of interest to forest and rangeland managers and under varying ungulate densities and species.

Conclusion

Most publications do not report data on cattle abundance or density, but rather, when reported, it is inferred from indirect indexes such as feces and trail counts, estimation of degree of browsing or interviews with cattle owners. Future research should include quantification of cattle stocking (i.e., rate and feeding behavior) associated with the effects found, to establish damage thresholds below which it is possible to maintain the values of forest conservation desired and make sure it is compatible with the productive levels of livestock. Different cattle effects found in this study on ecosystems and response variables can be partially explained by differences in grazing history and browsing pressures across different ecosystems. Despite the wide distribution of domestic cattle in southern South America as well as its relevance as economical resource and cultural value, publications resulting from our literature search of cattle impacts on forests of southern South America are largely restricted to few forest ecosystems and ecological variables. Although this may limit the generalizations we can make on cattle grazing effects in this region, clear patterns emerge from the information gathered and analyzed here. We strongly recommend additional studies at wide regional scales establishing common standard experimental methods and metrics, controlled by cattle density. These will allow to substantially improve our understanding on the interactions among domestic cattle and different biotic and abiotic components of forests ecosystems, and to guide synergies between sustainable management and forest conservation.

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