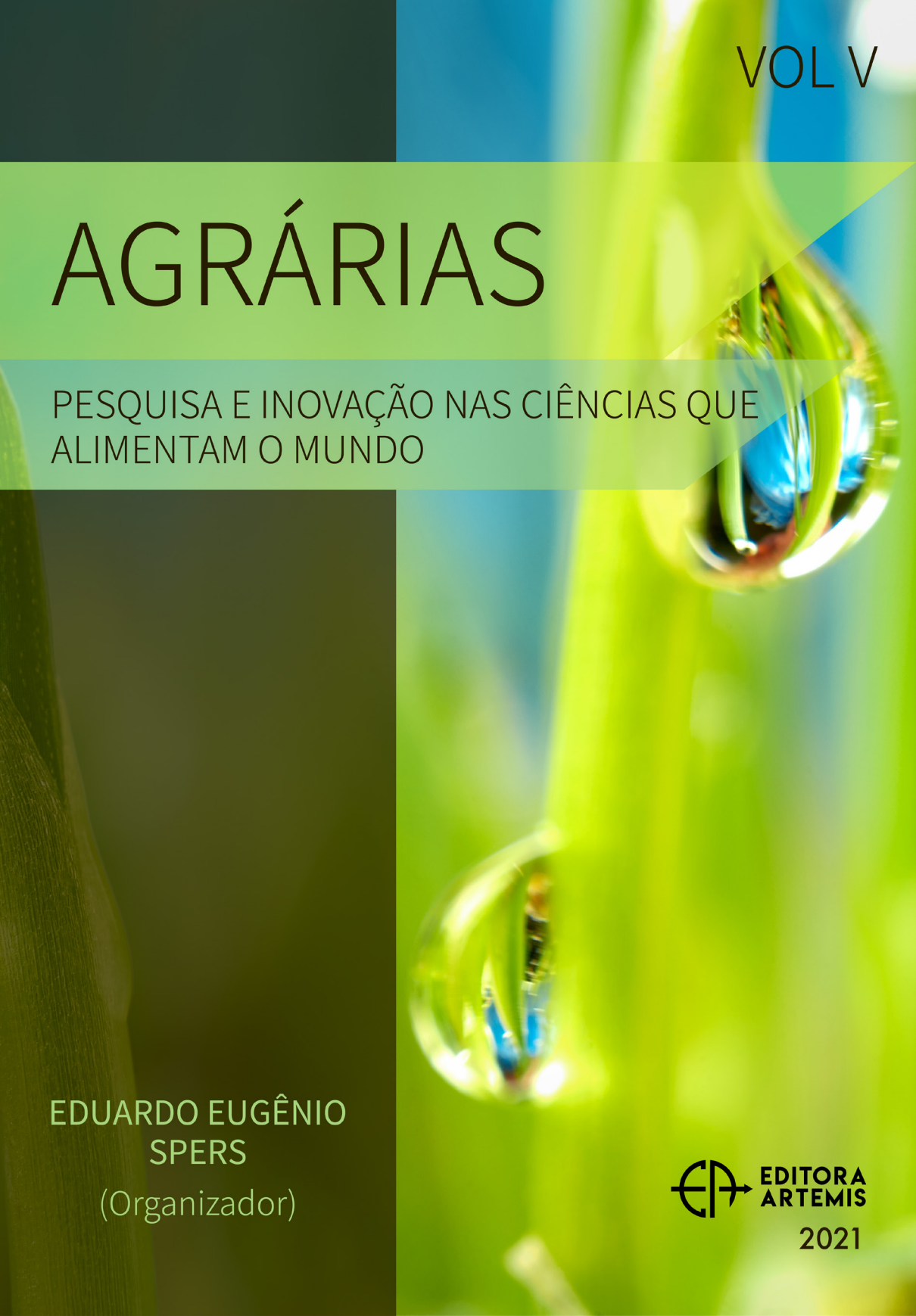
VOL V

AGRÁRIAS

PESQUISA E INOVAÇÃO NAS CIÊNCIAS QUE ALIMENTAM O MUNDO



EDUARDO EUGÊNIO SPERS
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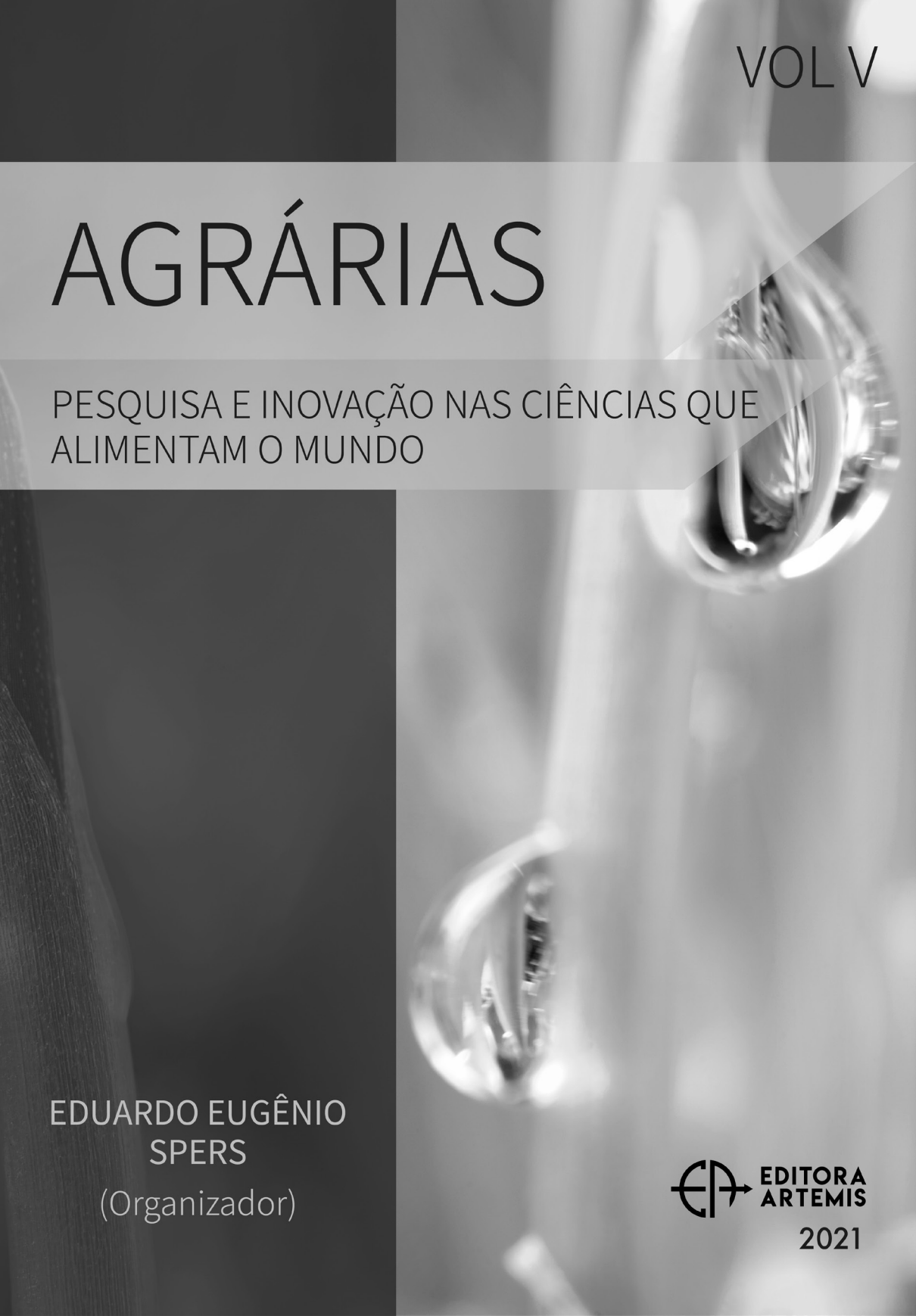

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APRESENTAÇÃO

As Ciências Agrárias são um campo de estudo multidisciplinar por excelência, e um dos mais profícuos em termos de pesquisas e aprimoramento técnico. A demanda mundial por alimentos e a crescente degradação ambiental impulsionam a busca constante por soluções sustentáveis de produção e por medidas visando à preservação e recuperação dos recursos naturais.

A obra **Agrárias: Pesquisa e Inovação nas Ciências que Alimentam o Mundo** compila pesquisas atuais e extremamente relevantes, apresentadas em linguagem científica de fácil entendimento. Na coletânea, o leitor encontrará textos que tratam dos sistemas produtivos em seus diversos aspectos, além de estudos que exploram diferentes perspectivas ou abordagens sobre a planta, o meio ambiente, o animal, o homem, o social e sobre a gestão.

Este Volume V traz 28 artigos de estudiosos de diversos países: são 18 trabalhos de autores da Argentina, Canadá, Colômbia, Cuba, Espanha, México e Portugal e dez trabalhos de pesquisadores brasileiros, divididos em três eixos temáticos.

Os dez trabalhos organizados sob o eixo temático **Clima, Solo e Água** desenvolvem temas relativos à importância desses elementos para a manutenção dos ecossistemas. Os 14 títulos que compõem o eixo temático **Agroecologia e Desenvolvimento Sustentável**, por outro lado, apresentam estudos sobre diferentes formas de se diminuir, reverter ou harmonizar as consequências da atividade humana sobre o meio ambiente. Seguindo a mesma linha, o eixo **Resíduos Agrícolas e Logística Reversa** traz quatro trabalhos que finalizam este importante volume.

Desejo a todos uma proveitosa leitura!

Eduardo Eugênio Spers

SUMÁRIO

CLIMA, SOLO E ÁGUA

CAPÍTULO 10

CHANGES IN SHRUB INVASION IN SOUTH AMERICA PROTECTED TEMPERATE NATIVE FORESTS

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ABSTRACT: Detecting invaded areas and mapping the extent and spatial pattern of invasive plants are important. The aim of this work was: a) to know the spatial changes in the invasion of shrub species protected by temperate native forests of the Mesopotamian Spinal using state-transition models, and b) to establish a future prediction model on the level of shrub invasion depending on the intensity of the current cattle grazing system. The study was carried in Protected Area 'El Caraya' (Argentina), hereinafter, PA 'El Caraya'. Field sampling was carried out with 85 sites in 2011 and 82 sites in 2018 both located randomly and geo-referenced with GPS. At each sampling point, the level of shrub invasion was recorded. To map the distribution of shrub invasive classes, we obtained two Landsat images recorded on 2011 and 2017. Changes in the level of shrub invasion were evaluated with the change analysis model and the future trend using the Markov model. More than 30% of the PA 'El Caraya' territory did not present changes in the levels of shrub invasion, which indicates that the structural components such as herbaceous, shrub and tree are balanced. The results of this research have shown that remote sensors are a simple and useful tool that allow us to know what the spatial changes in the levels of invasion of shrub species in protected temperate native forests of southern South America, as was also possible to predict the future state under the same conditions of the study period.

KEYWORDS: Remote sensing. Landsat. Land change modeler. *Baccharis* spp. Protected area.

1 INTRODUCTION

Changes in land cover and use in terrestrial ecosystems are the result of anthropogenic intervention (Weng and Wie, 2003). Richards (1990) summarized different calculations to estimate that over the last 300 years, we have lost roughly 20% of our forests and woodlands, 1% of grasslands and pastures (most pastures came from grasslands), while cropland areas increased by 466%. All these changes have caused modifications in the remaining ecosystems, such as favoring the introduction of shrubs in temperate native forests in South America (Sabattini, 2015). Natural grasslands are among the ecosystems that have been most disturbed by humans (Hannah et al. 1995). However, temperate native forests in South America have been heavily invaded by human intervention (Wilson and Sabattini, 2001) causing a shrub invasion that reduces the livestock potential of these ecosystems (Sabattini et al, 1999; 2002). Shrub increase is occurring in rangelands in North and South America, Africa, India, Scandinavia and Australia (Archer et al., 2017).

Invasions by exotic and native plants are one of the main causes of the degradation of ecosystems and biodiversity globally (Theoharides and Dukes, 2007). Trends toward increasing woody or shrub plant abundance in temperate and tropical grasslands and savannas in recent history have been reported worldwide (McPherson 1997).

Proximate causes for the increase in shrubs (both native and exotic) have been grouped into three general areas (Brown and Archer, 1999): (1) atmospheric CO_2 enrichment favoring C3 shrubs over C4 grasses; (2) suppression of burning allowing fire sensitive shrubs to increase and (3) domestic livestock grazing altering competitive relationships between grasses and shrubs. The shrubs present in native forests of the Mesopotamian Spinal (Argentina) are of the genus *Baccharis* (mainly), *Eupatorium* or *Aloysia* (Sabattini et al., 2018; Sabattini et al., 2019). These present high vegetation cover, reducing the entrance of light, water and nutrients for the species foraged by cattle in a large part of the Argentine territory (Sabattini et al., 1999). The genus *Baccharis* was native area is entirely confined to the New World and ranges from the warmest regions of the USA to Patagonia and Tierra del Fuego in Argentina and Chile (Mabberley, 2008). Species of *Baccharis* are of limited economic importance.

Several studies used remote sensing images to map distributions of terrestrial native and non-native invasive plants, relying either on aerial photographs, satellite imagery or high-resolution satellite imagery (Lass et al., 2005). Landsat satellite images provide an excellent alternative for mapping the spread of non-native invasive plants at broad scales and at low cost, especially given the increasing availability of the global Landsat archives (Woodcock et al., 2008). Land-use and land-cover change (LUCC) also known as land change is a term for the human modification of Earth's terrestrial surface. It is widely

accepted that LULC have an important on majority of ecosystems. Currently models are based on the spatial transition, called the method of Markov Chains (Pontius and Malanson, 2005), they assume explicitly that neighboring areas influence the probability of transition from the area or central cell study.

The aim of this work was: a) to know the spatial changes in the invasion of shrub species protected by temperate native forests of the Mesopotamian Spinal using state-transition models, and b) to establish a future prediction model on the level of shrub invasion depending on the intensity of the current cattle grazing system. These results would make it possible to establish whether the management plans carried out in protected native forests are correct based on sustainable ecological principles.

2 MATERIAL AND METHODS

2.1 STUDY AREA

The study was carried in Protected Area Estancia 'El Caraya' (hereinafter, PA 'El Caraya') located in the center-north of the province of Entre Ríos, Argentina (30° 38' S, 48° 47' W) and has 10,609 ha. According to the Köppen classification, the area corresponds to a humid subtropical climate, characterized by hot and humid summers and cool winters. Average annual rainfall is 1300 mm, rains being concentrated between October and March. However, in the last decade there have been notable changes in the distribution of seasonal and annual rainfall. Changes in the distribution of seasonal and annual rainfall were recorded in the evaluation period. In the period 2011-2017, an increase of 32% was observed with respect to the average annual rainfall of the last 30 years (1982-2011) in the PA 'El Caraya'. However, during the autumn-winter period of 2013, rainfall was lower than normal, registering an annual decrease of 9.5% compared to the historical average. Seasonally precipitation changed over the years, watching over the first five years a significant decline from the historical average, while in the spring and summer an opposite trend (Table 1).

Table 1. Percentage variation of seasonal rainfall and its relationship with the historical mean (1982-2011) of the ANP 'El Caraya'

Year	Summer	Autumn	Winter	Spring
2011	-15%	-36%	-7%	+85%
2012	+46%	-25%	+62%	+103%
2013	+1%	-46%	-67%	+57%
2014	+91%	-8%	+5%	+44%
2015	+127%	-27%	+147%	+49%
2016	+21%	+133%	+34%	+10%
2017	+35%	+46%	+80%	+8%
Average (mm)	**416**	**437**	**150**	**325**

According to Oyarzabal et al. (2018), the study area corresponds to the Spinal Phytogeographic province, which is characterized by xerophilous forests dominated by *Prosopis nigra* Griseb., *P. affinis* Spreng. and *Vachellia caven* Molina (Sabattini et al., 1999). Studies in PA 'El Caraya' indicate the presence of *Celtis ehrenbergiana* Gillies ex Planch., *Geofroea decorticans* (Gill. Ex Hook. & Arn.) Burkart, *Eugenia cisplatensis* Cambess. and *Parkinsonia aculeata* L. In addition, there are other areas represented by closed forests with shrub cover between 32.5% and 62.5%, the dominant species being *Baccharis punctulata* L., accompanied by *Eupatorium buniifolium* Hook. & Arn., *E. laevigatum* Lam. and *Aloysa grattisima* (Gillies & Hook. ex Hook.) Tronc. The condition of the natural grassland responds to a very good condition for livestock production, being very palatable, of good size and vigor (Sabattini et al., 2002), and also species of the genera *Nassella* E.Desv., *Bothriochloa* Kuntze, *Chloris* Sw. and *Paspalum* L. dominate (Sabattini et al., 2015).

Land use, predominantly cattle grazing and extensive logging, have substantially altered natural vegetation communities. Current deforestation rates between 1990 and 2010 are high (1.1% per year) and forest fragmentation is increasing while the remaining forests are under pressure from grazing, selective logging, fire, and non-native invasive plants (Sabattini, 2015).

2.2 REMOTE SENSING DATA AND PROCESSING

Field sampling was carried out with 85 sites in 2012 and 82 sites in 2018, both located randomly by the preferential sampling method (Matteuci and Colma, 1982) and geo-referenced with GPS. At each sampling point, the level of shrub invasion was recorded according to the vegetation cover (Sabattini et al., 2014): Class + (5%); Class 1 (15%); Class 2 (25%); Class 3 (50%) and Class 4 (75%).

To map the distribution of shrub invasive classes in the study area, we obtained two Landsat images recorded on January 16th 2011 (Landsat 5TM), and December 24th 2017 (Landsat 8OLI) from the United States Geological Survey Earth Resources Observation and Science data center (USGS EROS) (http://edc.usgs.gov). Satellite images were selected for their availability with low cloud cover, same season, and according to the previous accumulated soil moisture content. A maximum likelihood supervised classification was performed using Landsat 5-TM bands 3, 4 and 5, and Landsat 8-OLI 4, 5 and 6. In addition, the training sites for each level of shrub invasion were established using the sampling sites as a base and field photographs taken in other available surveys. As a result, the classification of the five levels of shrub invasion was obtained, evaluating the success with the global reliability index (0-100%) and the Kappa index (Chuvieco, 1990) for each year.

Changes in the level of shrub invasion between 2011 and 2017 were evaluated with the Change Analysis module of Land Change Modeler (LCM) software IDRISI Selva (Eastman, 2009). Maps were obtained with the changes that occurred in all the classes, as well as losses, gains and persistence for each class, establishing the state-transition matrix between the years. The future trend was quantified using the Markov model. Markov chain analysis is a stochastic modelling approach which has been used extensively for land cover change modelling (Fathizad et al., 2015). It assumes that the probability of a system being in a certain state at a certain time can be determined if its state at a prior time is known with the assumption that rates of change observed during the calibration period (t_1 to t_2), will remain the same during the simulation period (t_2 to t_3).

3 RESULTS

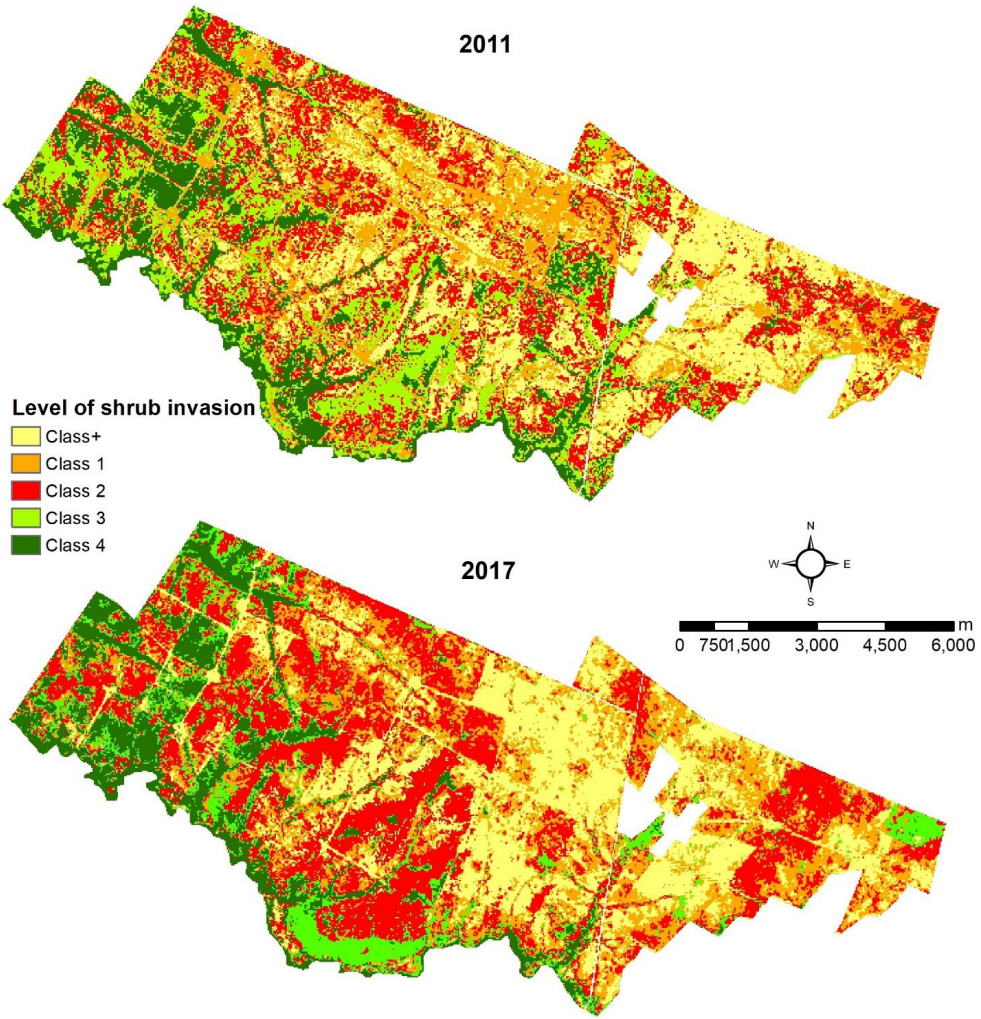
In general terms, 36% (3,775 ha) of the surface of the temperate native forests of the PA 'El Caraya' remained stable in relation to the level of shrub invasion in the period evaluated, of which 1,632 ha corresponded to forests with high conservation level (Class + and Class 1), 987 ha at medium conservation level (Class 2) and 1,156 ha to those forests with high shrub cover (Fig 2, Table 2). 64% of the total presented notable changes due to the intrinsic successional dynamics characteristic of these ecosystems. Class + in 2011 was represented by 2,407 ha, while in 2017 coverage increased by 17.4% (2,826 ha). The dynamics indicate that 1,368 ha were lost during the analyzed period, of which 70.5% were converted to Class 1 where the level of shrub invasion is significantly low, while the remaining percentage were native forests that presented a level of degradation. elevated by the constant invasion of the bushes (403 ha). However, it is important to mention that 1,787 ha were transformed to Class + from other levels of shrubs, of which 54.7% corresponded to Class 1 and 27.1% to Class 2 (Table 2)

Table 2. Transition matrix between shrub invasion levels between 2011 and 2017 (ha). The main diagonal represents areas of each class that persisted, and in the sense of rows and columns, areas that lost and won in 2017 for each class, respectively. Values expressed in hectares.

Shrub invasion levels	Class +	Class 1	Class 2	Class 3	Class 4	2011
Class +	**1,039**	965	363	37	3	2,407
Class 1	977	**593**	344	118	23	2,055
Class 2	483	723	**987**	298	67	2,558
Class 3	233	232	1,030	**419**	212	2,126
Class 4	94	63	222	347	**737**	1,463
2017	2,826	2,576	2,946	1,219	1,042	10,609
Loss	1,368	1,462	1,571	1,707	726	
Gains	1,787	1,983	1,959	800	305	

Relatively, Class 1 registered an increase of 521 ha in 2017 compared to 2011. Only 6.8% of the surface registered in 2011 were transformed into temperate native forests of medium to low level of conservation (Class 3 and 4), while 76.4% found a high conservation value (Class + and 1) because they respond to forests with a low level of shrub invasion. It is important to mention that 723 ha of Class 2 corresponds to 36.5% of the increased surface area of Class 1, while only 295 ha were recovered from Class 3 and 4 (Table 2).

Fig. 2. Shrub invasion levels in the PA 'El Caraya' for 2011 and 2017. Kappa index 0.892 and 0.767; Global reliability index 85.8% and 80.3% (2011 and 2017, respectively).



Class 2 presented a net increase of 388 ha in 2017, increased by the conversion of Class 3 (1,030 ha). On the other hand, 707 ha of Class 2 were transformed into Class + and 1 allowing their conservation level to be increased. The native forest classes with a

low conservation level (Classes 3 and 4) decreased significantly, obtaining a net loss of 1,328 ha, representing 12.5% of the surface of the natural area. In this sense, 21.30% of the surface of Class 3 (453 ha) became Class 2 (298 ha), Class 1 (118 ha) and Class + (37 ha). However, in 16.3% the degradation processes continued due to the advance of the shrubs and semi-woody plants. Regarding Class 4, it did not undergo substantial changes, obtaining a conversion of 212 ha to Class 3, while only 93 ha to Classes of medium to high level of conservation.

Table 2 shows the probability matrix of the change in the classes of shrub invasion for the year 2027. According to the period analyzed, in the next 10 years the surface of Class + will maintain 42% of the surface, 33 % of Class 1, 30% of Class 2, 14% of Class 3 and 33% of Class 4. Low shrub invasion levels (eg Class + and 1) would increase their share of the total ANP area 'El Caraya', presenting significant changes between classes. In addition, 60% of the surface of Class 2 in 2027 that presents medium conservation value, will be shaped by the transformation of areas with high shrub cover (Class 3 and 4).

Table 3. Status-transition matrix to the year 2027 for the ANP 'El Caraya' shrub invasion classes

	Class +	**Class 1**	**Class 2**	**Class 3**	**Class 4**
Class +	0,4204	0,3380	0,1879	0,0461	0,0076
Class 1	0,3861	0,3340	0,2089	0,0536	0,0173
Class 2	0,2906	0,2733	0,3000	0,0989	0,0372
Class 3	0,1860	0,2255	0,3590	0,1386	0,0908
Class 4	0,1071	0,0994	0,2578	0,2049	0,3308

In 2027, 3,563 ha are expected to show no changes in the levels of shrub invasion, representing 33.5% of the total area of the PA 'El Caraya'. The areas of high conservation value increase by 11.8% (6,383 ha) compared to the year 2017. On the other hand, the areas with high shrub cover will show a decrease of 29.9%, obtaining 943 ha of Class 3 and 631 ha in Class 4. Those areas where there is an average level of shrub invasion will be stable with an area of 2,662 ha (Class 2), which means a decrease of 9.6%.

4 DISCUSSION

The change in the levels of shrub invasion was determined using techniques of land change models. The objective of this research is to evaluate how livestock management is in a protected area under the multiple-use reserve modality, using shrub invasion as an indicator.

The complex processes of land cover change are difficult to capture in variables, and model in algorithms, since they are often shaped by dynamic, non-linear human-

nature interactions (Camacho Olmedo et al., 2015). For this reason, the discussion will firstly focus on potential sources of error in the LCM and potential limitations (Pontius and Malanson 2005). The accuracy of an inductive model's output is a function of both the model itself i.e. suitability of algorithms within the model to fulfil the intended purpose, and the accuracy of the input data. In our study, very good indices of certainty in the classifications have been obtained in each year, which is good from the LCM point of view. In addition, there are many sampling sites that provide information on the reality of the territory as the great extension of the PA 'El Caraya'. For this reason, it is possible to affirm that the combination of randomly distributed field samplings throughout the study area, with the use of LCM, allows to estimate not only the change in the types of shrub invasion but also to predict in the future.

More than 30% of the PA 'El Caraya' territory did not present changes in the levels of shrub invasion, which indicates that the structural components such as herbaceous, shrub and tree are balanced. This balance would be fundamentally associated with the position within the ecological plant succession, being the case of more mature natural ecosystems. However, much of the territory presented important changes in the levels of shrub invasion. It has been widely documented that the introduction of invasive species has negative implications on the dynamics of ecosystems through the modification of the composition and decrease in species richness with effects on ecological interactions (intra and interspecific), and effects on competition and facilitation, among others (Pywel et al., 2003; Hejda et al., 2009). Through the process of secondary succession, attributes of structure and composition can be recovered after disturbances at different spatio-temporal scales, such as hurricanes, fires, felling, agricultural agriculture or livestock (Chazdon, 2003). However, it has been observed that secondary succession is one of the processes that is mainly affected by the introduction of shrub species. It has been observed that the introduction of invasive species can modify the patterns of dominance and establishment of species from the initial phase of succession (Fine, 2002). Moreover, the introduction of native and non-native species generates a new *status quo* inside of the plant community that lead to the establishment of an alternative state which affects the feedback processes returning to the original state (Faist and Beals, 2018). These results are similar to those obtained in Jean-Baptiste et al (2018) where they have demonstrated that invasive species disrupt the ecological mechanisms that drive secondary succession, but through recovery strategies it is possible to foster secondary succession. Other research shows the negative ecological consequences of conversion of native forest stands into non-native tree forest stands, where the biodiversity of native trees declines, and that vertical structure is much less complex (Hoyos et al., 2010).

Furthermore, the spatial distribution of the types of shrub invasion was highly heterogeneous and linked to abiotic (variation in rainfall) and biotic (cattle grazing) factors. Climate change has many facets, some of which can have potentially important bearing on shrub encroachment. This led to considerations of a possible link between the encroachment of the C3 shrub into the C4 grass dominated communities. Changes in temporal rainfall regimes severely affect growth peaks of grasslands and shrubs. The shrub canopy develops rapidly and greatly reduces the amount of light reaching the ground, and presumably completely alters most microclimatic features. In addition, before Autumn and Winter, the rainfall in the study area was lower between 2011 and 2015. This would affect the sexual and asexual reproduction of plant species, especially shrubs of the *Baccharis* genus. Successful establishment of seedlings is likely to be the critical process determining the invasion rate. *Baccharis* seeds are released during the wet winter months.

The intensity of livestock grazing influences shrub cover. The PA 'El Caraya' presented a moderate intensity during the study period, varying seasonally depending on the primary productivity of the natural grassland, as well as the cultural tasks of livestock farming. The moment, intensity and grazing pressure establish the competition relationship between the physiognomic and floristic components of the native forest (Sabattini et al., 2002). In temperate native forests where grazing intensity is moderate to high, the level of shrub invasion is reduced due to the increased grazing pressure (Sabattini et al., 2018). These mechanisms, although not easily attributable and verifiable due to the high heterogeneity in such a large area, may be one of the factors of relative weight that has contributed to the decrease in the level of shrub invasion in the PA 'El Caraya' in the year 2017 (Table 2). Maintaining the current biotic and abiotic conditions, it is expected that the level of shrub invasion will be reduced as explained by the state-transition matrix (Table 3), considering the aforementioned restrictions.

5 CONCLUSION

The results of this research have shown that remote sensors are a strategic, simple and useful tool to know what the spatial changes in the levels of invasion of shrub species in protected temperate native forests of southern South America. Furthermore, by using simulation models, it was possible to predict the future state under the same conditions of the study period. On the other hand, the design and execution of the management plan carried out in the PA 'El Caraya' has decreased the level of shrub invasion in much of its territory due to numerous abiotic and biotic factors, but which a priori is possible attribute with greater relative weight to the moderate cattle grazing intensity used in the last 10 years.

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