Changes in vegetation seasonality and livestock stocking rate in La Pampa Province (Argentina)

Cambios en la estacionalidad de la vegetación y la carga animal en la provincia de La Pampa (Argentina)

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Originales: *Recepción:* 27/09/2017 - *Aceptación:* 28/07/2018

Abstract

Crop production is traversing expansion and intensification processes all over the planet and in consequence the large scale cattle production is being displaced to marginal lands with lower stocking capacity. The objective of this work was to assess the seasonality of vegetation in La Pampa province located in a semiarid region in Argentina and to explore if the variations in seasonality are related to the stocking rate. The hypothesis is the changes in stocking rate of rangelands and its grazing pressure alter the proportion of different vegetation functional groups and so the vegetation seasonality. It is predicted that overgrazing of seasonal grasses will alter the proportion of woody species having consequences over spectral indices. It was analyzed satellite data, particularly the MODIS Enhanced Vegetation Index (EVI) and related it to stocking rate records from SENASA. This work evidences the relationship between the stocking rate and the spectral index EVI, indicator of the primary productivity of vegetation, at departmental scale in the natural areas of Monte and Espinal of La Pampa. Results indicate that in western region (Monte) there was an increment in the stocking rate at department level and a decrease in vegetation seasonality. It is posed that the higher grazing pressure led to the overgrazing of the most palatable herbaceous species, increasing the shrub proportion in landscape.

Keywords

MODIS • EVI • vegetation indices • shrub proportion

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Resumen

La producción de cultivos está atravesando procesos de expansión e intensificación alrededor de todo el planeta. En consecuencia, la producción ganadera está siendo desplazada hacia tierras marginales de menor capacidad de carga. El objetivo de este trabajo es evaluar la estacionalidad de la vegetación en la provincia de La Pampa, ubicada en la región semiárida argentina; y explorar si las variaciones en la estacionalidad están relacionadas con la carga de ganado vacuno. Se plantea como hipótesis que los cambios en la carga animal y la presión de pastoreo alteran la proporción de diferentes grupos funcionales de vegetación, y de esta manera, su estacionalidad. Se predice que el sobrepastoreo de los pastos más estacionales alterará la proporción de especies leñosas, y ello repercutirá sobre los índices espectrales. Se analizó la información satelital, particularmente el Índice de Vegetación Mejorado (EVI) de MODIS y se lo relacionó con los registros de carga animal de SENASA. Este trabajo evidencia la relación entre la carga animal y el EVI, indicador de la productividad primaria de la vegetación, a la escala de departamento en las áreas naturales del Monte y el Espinal de La Pampa. Los resultados indican que al oeste de la provincia (Monte) hubo un aumento de la carga animal y una disminución de la estacionalidad de la vegetación a escala de departamento. La mayor presión de pastoreo habría conducido al sobrepastoreo de las especies herbáceas más palatables aumentando la proporción de arbustos en el paisaje.

Palabras clave
MODIS • EVI • índices espectrales • proporción de arbustos

Introduction

The rapid growth in the global demand for primary products, together with regional changes in rainfall levels, rural activities and rural population distribution present a complex picture of change in land use and land cover all around the world. These scenarios gain particular importance in the semiarid regions of Latin America. These are fragile ecosystems that are being affected by changes in cattle production (12, 35) with the consequence of various factors that limit the transformation of primary into secondary production: i) high non-edible woody fraction; ii) poor quality of many grassland species; iii) temporary fluctuations in primary productivity that cannot be linked to cattle consumption and result in lower stocking rates, iv) growing difficulties to access foraging lands, and/or v) insufficient water through distribution.

Particularly, in Argentine the expansion and intensification of agriculture in the most productive areas of the country (*e.g.* Pampas Region) has caused large-scale displacement of cattle to the western semiarid and arid drylands, a vast rangeland that shows a decreasing stocking capacity from east to west (*e.g.* 9, 37, 38). The expansion process encouraged a rethinking of Argentina's livestock areas (32), which led to the displacement of animals from the most productive areas of the Pampas Region to neighboring semi-arid areas (*e.g.* La Pampa Province).

Changes in land use, like the ones arising from the greater cattle presence in former marginal lands, can lead to the overgrazing of the most palatable species, favoring those that are less palatable and often more tolerant to water stress. Moreover, it can give way to changes in the relative abundance of functional groups, such as grasses and shrubs (19, 25, 31, 39). It has also been well-documented that the conversion of herbaceous systems to shrublands as a result of overgrazing can reduce forage availability in some semiarid regions of the world subjected to high and long-term grazing pressure (3, 18, 25).

Remote sensing provides valuable information for estimating vegetation attributes, and many spectral indices based on data from satellite borne sensors have proved to be very useful for estimating the photosynthetically active radiation absorbed by the canopy (fAPAR), or the leaf area index (LAI) (*e.g.* 10, 11, 13, 21, 22, 23, 27, 34), among others. Considering various indices, the Normalized Difference Vegetation Index (NDVI) has been widely used to detect seasonal patterns and interannual trends in vegetation phenology. NDVI time series from AVHRR/NOAA sensors have made it possible to describe functional diversity in the ecosystems of South America (*e.g.* Pettorelli *et al.*, 2005) and the Iberian Peninsula (*e.g.* Alcaráz-Segura *et al.*, 2009), and to identify temporal trends in vegetation carbon gain and loss (4, 14, 22, 26, 29). Oesterheld *et al.* (1998) have also shown a strong relationship between livestock biomass and the annually integrated NDVI.

Enhanced Vegetation Index (EVI) improve NDVI by reducing atmospheric and background effects over vegetation signal, improving vegetation monitoring (15). By calculating the seasonal curve of the EVI, different attributes, such as the start, end and duration of the growing season, among others, can be estimated in order to characterize certain ecosystem functions (2, 7, 16, 30). This vegetation index is one of the most widely recommended for studying semiarid ecosystems, since it reduces the influence of bare soils on the visible and near infrared reflectances (15, 17). Climate conditions could have consequences on the Aboveground Net Primary Productivity (ANPP) in rangelands, and therefore on the annual livestock stocking rate. In this context, the use of integrated EVI could be an indicator of the carrying capacity of ecosystems, since the annual integrated NDVI is strongly associated to the aboveground net primary productivity (ANPP) of grasslands (26).

The main objective of this work was to assess the seasonality of vegetation in La Pampa province located in a semiarid region in Argentine and to explore if the variations in seasonality are related to the stocking rate. The hypothesis is that changes in stocking rate of rangelands and its grazing pressure alter the proportion of different vegetation functional groups and so the vegetation seasonality. It is predicted that overgrazing of seasonal grasses will alter the proportion of woody species having consequences over spectral indices.

Materials and methods

Study area

Within the semiarid region of Argentine, this work assessed the province of La Pampa (figure 1, page XXX), covering a total surface of approximately 143440 km^2.

Source: IGN (National Geographic Institute - Argentina). / Fuente: IGN (Instituto Geográfico Nacional - Argentina).

Figure 1. Region of interest: La Pampa (in dark blue); Departments of La Pampa. Red tones in La Pampa province are related to Ecoregion: Monte, Espinal and Pampas, in west-east sense.

Figura 1. Área de interés: La Pampa (en azul oscuro); Departamentos de La Pampa. Los tonos de rojos en la provincia de La Pampa representan las Ecorregiones: Monte, Espinal y Pampas, en sentido oeste-este.

Rainfall in the province is concentrated during the summer months, with interannual fluctuations ranging between 200 and 700 mm.year^{-1}, with an east-west decreasing gradient. Mean annual temperatures vary between 15 and 17° (INTA Agrometeorological Database).

In north-east corner of La Pampa, corresponding to Pampa medanosa complex of Pampa ecoregion, psamophile steppes originally prevailed. Nowadays is occupied by annual or perennial crops (20). Espinal ecoregion, cuts across diagonally in a NW-SE direction the central region. Pampas arenosas complexes are dominated by a tree stratum of Calden (*Prosopis caldenia*) and psamophile grasslands covering the herbaceous stratum.

Other tree species as *Prosopis flexuosa* var. Depressa, *Geoffroea decorticans, Schinus fasciculata* and *Jodinia rhombifolia* and shrubs as *Hyalis argentea* conform the espinal landscape (5, 6, 20).

The western ecoregion; Monte de llanuras y mesetas, hereafter Monte, is dominated by shrub species of *Larrea* ssp and *Atriplex lampa* (20).

Data sets

Estimating stocking rate

Annual cattle stocking rates were estimated based on annual reports by SENASA (National Animal Health and Agri-food Quality Service-Argentine) (36), a government agency that keeps long-term records on the number of cattle vaccinated against foot and mouth disease at a departmental level in all provinces of Argentina. This study was based on SENASA's records for the 2003 to 2009 period, including different cattle categories (*e.g.* cows, heifers). These categories were then converted into Animal Unit Equivalents (AUE) using the following coefficients: cows 1; heifers, steers and yearlings 0.8; calves 0.6; and bulls 1.3 (8). For each studied year, the stocking rate (expressed in AUE ha^{-1}) was estimated based on AUE data and the area of each department.

Satellite monitoring of vegetation

Vegetation monitoring was performed using the Enhanced Vegetation Index (EVI) calculated as:

$$EVI = 2.5 \frac{\rho nir - \rho red}{\rho nir + 6 \cdot \rho red - 7.5 \cdot \rho blue}$$

where:

ρnir, ρred, and ρblue = apparent reflectances in the near infrared, red and blue spectral bands of the electromagnetic spectrum, respectively.

MODIS Terra satellite provides 16-day composite EVI data (MOD13Q1) at a spatial resolution of 250 m (16). In this case, MOD13Q1 images corresponding to tiles h12/v12 and h13/v12 were downloaded for the July 2003-June 2010 period (https://lpdaac.usgs.gov/data_access/data_pool). This time series-more extensive than SENASA's-allowed us to integrate data regarding vegetation function during the stage of the growing season when livestock is estimated.

Meteorological data

Precipitation data was gathered from different sources: INTA (National Institute of Agricultural Technology), APA (annual data, Water Administration of La Pampa Government, http://www.apa.lapampa.gov.ar/index.php), Police Department of La Pampa (monthly data, http://www.policia.lapampa.gov.ar/contenidos/ver/lluvias), and GPCC (Rudolf *et al.*, 2005, Global Precipitation Climatology Center, annual data, https://climatedataguide.ucar.edu/climate-data/gpcc-global-precipitation-climatology-centre). GCPP gridded data at 50 km resolution were averaged per department. GCPP data fitted to APA data (R^2=0.83) (37). Annual records were calculated summing monthly records, except for those provided annually. Depending on the availability of data for each year, department records from different data sources were averaged.

Estimating vegetation seasonality

With the aim of analyzing seasonal dynamics pixel by pixel, MODIS EVI composite images were stacked into nine-year sets (2003-2010); each one comprising a complete growing season in the southern hemisphere (from July_{year} to June_{year+1}). In order to get a description of the seasonal variation, every pixel from each set of images was used to calculate maximum, minimum and mean values for the corresponding season (figure 2A).

To get an indicator of vegetation seasonality, an annual range relative ratio (RREL) was later calculated as the ratio between the amplitude ($Maximum_{year}$ minus $Minimum_{year}$) and the mean value of the season based on the EVI. The resulting data was used to create a new time series consisting of $RREL_{year}$ per pixel, and was considered as an indicator of vegetation seasonality throughout the entire period (28). With the new $RREL_{year}$ series, a linear regression was calculated and the slope was analyzed to provide temporal trend data for every pixel of the study area (figure 2B). Goodness of fit was not taken into consideration, since the aim was not to linearize changes, but to study their trend over time.

In this regard, the strategy is based on the evidence showing that shrubs make more efficient use of water throughout the year (24), which in turn results in a lower intra-annual vegetation indices variability as opposed to the greater seasonality of grasses (37). Since it is not possible to separate Calden tree renewals from grasses, the methodology presents some limitations in this sense, particularly in Espinal departments.

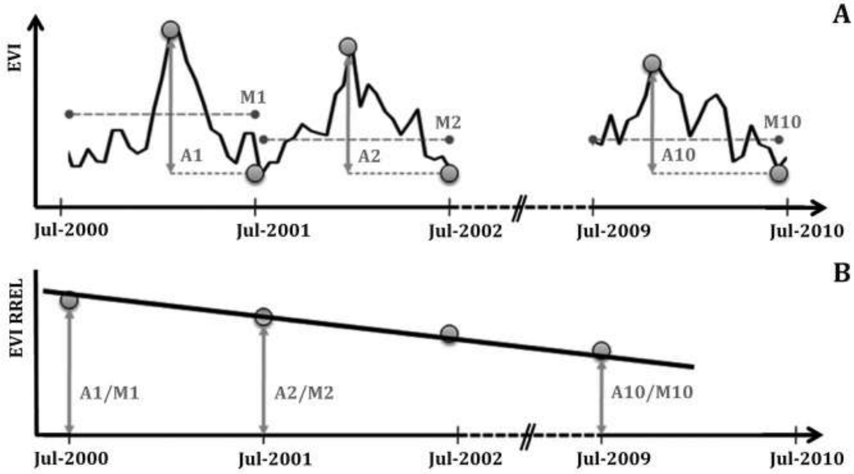


Figure 2. Assessment of EVI variability over time. A) Curve amplitude (An) calculated from the maximum and minimum values for each period (grey circles) and mean values (Mn) for each growing season (Jul 2000-Jul 2001); B) Trend in EVI RREL, calculated as the ratio of An the Mn for each period.

Figura 2. Variabilidad del EVI a lo largo del tiempo. A) Amplitud (An) calculada a partir de los valores máximo y mínimo para cada periodo (círculos grises) y los valores medios (Mn) para cada estación de crecimiento (Jul 2000-Jul 2001); B) Tendencia del rango relativo del EVI (RREL), calculado como la relación entre An y Mn para cada periodo.

In order to have an indicator of seasonality of vegetation for each pixel, it was analyzed the EVI RREL. At department level, mean RREL was related to changes in stocking rate (2010 *vs.* 2003) and to mean annual precipitation. Significance of regressions were test considering α=5%. To analyze trending in RREL it was calculated the slope of regression between RREL-time at pixel level and averaging pixel values per department.

Results and discussion

At a provincial level, cattle stock fell by 24% between 2003 and 2009 (table 1). However, at a departmental level, changes on cattle stocks depended on the type of dominant vegetation. Negative trend showed a decrease of about 100800 number of cattle heads by year ($y = -100779x + 4\ 10^6$; $R^2 = 0.5876$). While the departments belonging to Espinal, experienced an average decrease of 28%, the western departments dominated by Monte registered an approximate rise of 84%, considering differences in department stock between 2003 and 2009, and then averaging by department categories. Departments located in the limits of both ecoregions and have half and a half of area in each one, are linked to one ecoregion or the other one, depending on the stock value. Chalileo and Limay Mahuida are considered Monte because they had low cattle stock in average, but Lihuel Calel is considered Espinal because it showed greater cattle stock in average.

The stocking rate at province level decreased during the studied period, decreasing also the inter-department variability (table 1). At department level, for Monte ecoregion, stocking rate went up during the first period, 2003 to 2008, and was followed by a marked drop in 2009 and 2010 (polynomial regressions illustrate trends, figure 3, page XXX). One of the possible causes that could contribute to this particular behavior is the severe drought that affected the region in 2008-2009 (37). That same year, rainfall was 26% lower than the mean levels recorded for the 2003 to 2010 period. This was also the driest season except for 2003, for the same period.

Table 1. Stocking rate (AUE ha^{-1} $year^{-1}$) and cattle stock (Number of heads) evolution in La Pampa. The values are expressed as mean ± standard deviation.

Tabla 1. Carga animal (EV ha^{-1} $año^{-1}$) y existencia (número de cabezas) a lo largo de los años estudiados. Los valores se expresan como valor promedio ± desvío estándar.

	La Pampa	
Period	**Stocking rate**	**Cattle stock**
2003-2004	0.387 ± 0.266	3510752 ± 76307
2004-2005	0.378 ± 0.269	3357299 ± 73462
2005-2006	0.370 ± 0.251	3402373 ± 69853
2006-2007	0.366 ± 0.238	3437193 ± 65390
2007-2008	0.357 ± 0.230	3371836 ± 64093
2008-2009	0.333 ± 0.202	3224575 ± 61400
2009-2010	0.293 ± 0.199	2668809 ± 52038

When relating animal stocking rates in each department to the mean inter-annually integrated EVI for the growing season (from $July_{year}$ to $June_{year+1}$), as a proxy of ANPP, it was founded a positive correlation and a significant adjustment. The relationship between annual EVI and stocking rate for the 22 departments points to a sigmoid distribution ($y = -97.252x^3 + 68.189x^2 - 11.699x + 0.6379$; $R^2 = 0.8898$; n=154). Relationship between EVI and Stocking rate can be divided into three sections (figure 4A, page XXX): a) mean EVI values above 0.3; b) mean EVI values between 0.15 and 0.3; c) mean EVI values bellow 0.15.

Above the mean EVI value of 0.3, there were no variations in stocking rates. In this case, rises in the mean EVI could respond to higher primary productivity from the tree component, which would have no effect in forage offer; or maybe they could stem from a greater offer of lower quality forage, thus limiting the stocking rate.

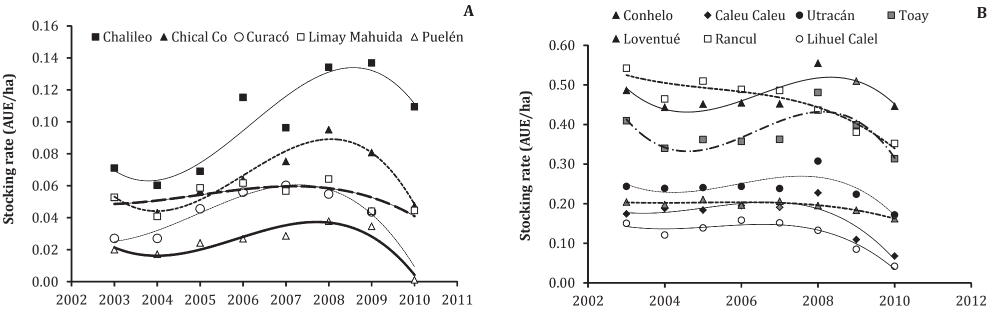


Figure 3. Stocking rate in the departments of La Pampa for the 2003-2010 period according to land vegetation types (A) monte and (B) espinal. The lines show the polynomial regression at departmental level.

Figura 3. Carga animal en los departamentos de La Pampa para el periodo 2003-2010 para los tipos de vegetación (A) monte y (B) espinal. Las líneas muestran la regresión polinómica a escala de departamento.

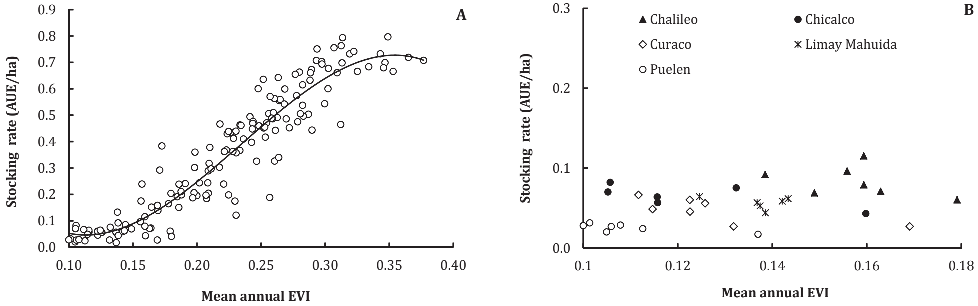


Figure 4. (A) Stocking rate as a function of mean annual EVI for La Pampa for the 2003-2010 period. The solid line shows the polynomial regression for the province; (B) Stocking rate as a function of mean annual EVI for Monte departments for the 2003 to 2010 period.

Figura 4. (A) Carga animal en función del EVI anual promedio para La Pampa para el periodo 2003-2010. La línea sólida muestra la regresión polinómica para la provincia; (B) Carga animal en función del EVI anual promedio para los departamentos del Monte para el periodo 2003-2010.

Vázquez *et al.* (2013) attributed the increment in NDVI from 1982 to 2006 in west La Pampa to the increasing shrub proportion. Shrubs and tree renewals could affect water and light interception, having consequences on grasses and receptivity.

For mean EVI values between 0.15 and 0.30, there was a positive linear trend with stocking rates ($y = 3.2401x - 0.3659$; $R^2 = 0.8675$; n=109). This narrow linear portion of the relationship would be associated with a strong correlation between EVI and the photosynthetic activity of grasslands and therefore to the ANPP of grasslands. As to mean EVI values between 0.1 and 0.15, there were no variations in departmental stocking rates.

Finally, considering the lower EVI range, departmental increases did not reflect a rise in the stocking rate of rangelands (figure 4B, page XXX). Only Monte departments where situated in this first section of EVI-Stocking rate relationship. In coincidence with previous findings this results insinuate the increasing stocking rate in these marginal ecosystems can lead to the overgrazing of the most palatable herbaceous species, and as a result reduces the availability of these species in contrast to shrub species (37). The higher mean annually integrated EVI corresponds to a greater shrub proportion replacing grasses, which is in turn linked to a drop in the annual seasonality. Although mean EVI values did not differ significantly between years at a departmental level (figure 4B, page XXX; $y = 0.302x + 0.0147$; $R^2 = 0.0905$; $p=0.25$), RREL decreased significantly ($\alpha=10\%$) between 2000 and 2010 in those Monte departments (figure 5A, page XXX; $y= -0.0183x + 37.2$; $R^2 = 0.3756$; $p=0.057$), supporting the hypothesis. Those departments most affected by increases in the stocking rate also experienced sharper declines in vegetation seasonality. This functional change in the landscape could be considered as indirect evidence of a higher proportion of shrub species, leading to a drop-in cattle receptivity during the final period. On the other hand, the increment of tree renewals has been described as a grassland degradation indicator and could be a source of noise in the association of the receptivity to seasonality of vegetation.

Mean RREL is related to mean annual precipitation (figure 5B, page XXX; $y = 0.001x + 0.1389R^2 = 0.8218$; $p<0.0001$) and more weakly to changes in stocking rate ($y = 0.0014x + 0.3544$; $R^2 = 0.5932$; $p<0.01$). It is possible that both variables are acting together to generate nonlinearities in the vegetation index's response to stocking rates changes in rangelands. The reduction in the inter-annual RREL could be associated with higher stocking rates over the years (18) and/or a decrease in inter-annual precipitation that could favor the competitive ability of shrubs against grasses for water resources (17).

At pixel level RREL evolution over the years for the entire province of La Pampa and found a marked difference between the northeastern and southwestern regions (figure 6, page XXX). The southwest became less seasonal (negative slope of RREL over the years), while the northeast became more seasonal. These differences are closely linked to the results found in figure 4 (page XXX). It holds the idea that during the last few years, the less productive areas have been subjected to increases in stocking rates, which result in a higher shrub proportion and lower seasonality in these ecosystems. In contrast, the more productive areas have seen a rise in cropping as opposed to livestock production. Thus departments located in Pampas ecoregion became more seasonal as consequence of displacing in croplands frontier.

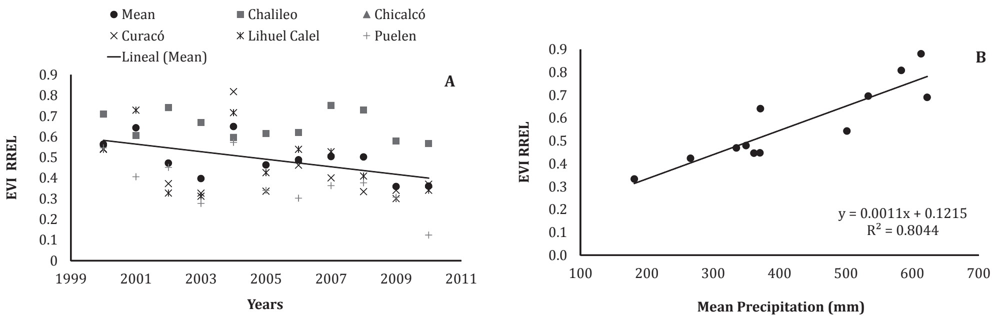


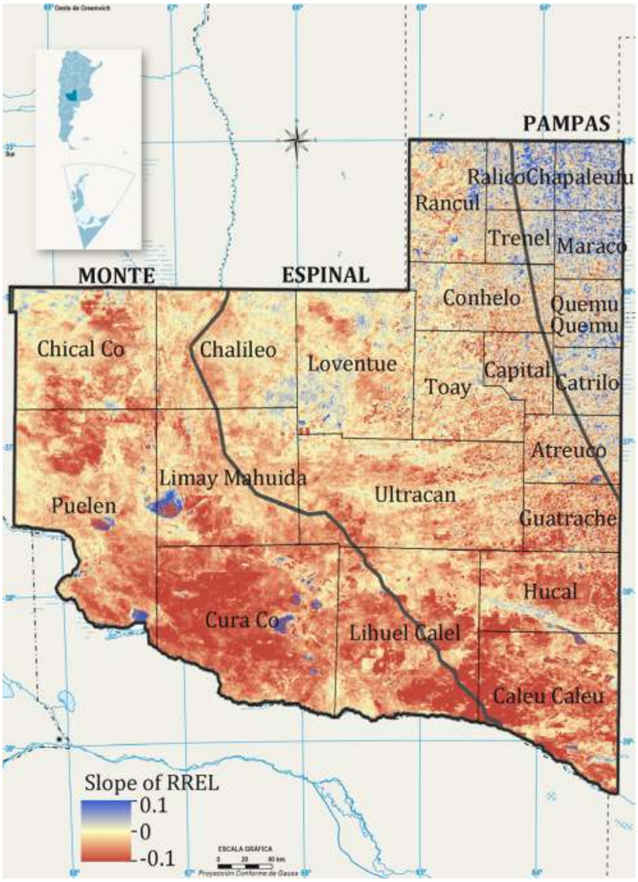
Figure 5. (A) Mean EVI RREL for Monte departments for the 2003 to 2010 period. The line represents the linear trend for the department's average. (B) Mean EVI RREL as a function of mean precipitation for Monte departments.

Figura 5. (A) EVI RREL promedio para los departamentos del Monte para el periodo 2003-2010. La línea representa la tendencia lineal para el promedio de los departamentos. (B) EVI RREL promedio en función de la precipitación promedio para los departamentos del Monte.

This work evidences the relationship between the stocking rate and the spectral index EVI, indicator of the ANPP, at departmental scale in the natural areas of Monte and espinal of La Pampa. The direction of changes in stocking rate at this scale during the studied period depended on the predominant type of vegetation. The departments of Monte, with a lower average of EVI, increased the stocking rate between 2003 and 2008, and those of the Espinal showed, on average, decreasing values.

The temporal pattern of EVI, studied through its relative range, suggests a loss of vegetation seasonality. The decrease in seasonality was related to increasing stocking rate in Monte departments, which in turn were those that experienced greater increases in stocking rate. This analysis is consistent with the hypothesis that increases in stocking rate, and hence in grazing pressure on grasslands species, produced changes in seasonality. Seasonality changes could be originated by increasing relative proportion of shrub species, to the detriment of grasslands, contributing to lower stocking capacity. It could be clearer in case of Monte departments, but in Espinal where Calden renewals could play an important role in the determination of seasonality the cause-effect relation should be particularly analyzed. Because of that, in the terms presented in this paper, the decrease, derived from temporary EVI attributes, could be associated, indirectly and at the departmental level, with increases in stocking rate especially in the western area of the province of La Pampa.

Finally, this work opens the doors to analyze in more detail the changes vegetation seasonality and its prevailing causes. The idea of a possible relative increase of shrub species requires a study of vegetation on a more detailed scale and from field data. Therefore, it is necessary the availability of vegetation monitoring sites that serve as a basis for the validation of indices, such as the proposed here, and the generation of empirical models based on satellite information.



Source: IGN (National Geographic Institute - Argentina). / Fuente: IGN (Instituto Geográfico Nacional - Argentina).

Figure 6. Representation of the slope of trend in EVI RREL per year for La Pampa.

Figura 6. Mapa de la pendiente de la tendencia del EVI RREL anual para La Pampa.

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Aknowledgements

We thank both anonymous reviewers who helped to improve this article. This work was financed by INTA (PNNAT 1128024) and a grant from the InterAmerican Institute for Global Change Research (IAI) CRN2031, supported by the US National Science Foundation (Grant GEO0452325).