Using participatory research, remote sensing and field surveys to build a state and transition model for the native pastures of northern Uruguay

Marcelo Pereira Machín

Instituto Plan Agropecuario, Br. Artigas 3802, Montevideo, Uruguay, www.planagropecuario.org.uy
Contact email: mpereira@planagropecuario.org.uy

Abstract. Native grasslands cover 55% of the agricultural lands of Uruguay. Balancing conservation, agricultural production and human well-being is a major management challenge. Adaptive management approaches have been developed for leased land, underpinned by a newly developed state and transition model (STM). The model was tested in northern Uruguay, in the Department of Paysandú, covering an area of 8300 ha. Floristic surveys were used to define five states, based on the relative cover of key plant species and functional types. Each state was characterized in terms of livestock density, sheep/cattle ratio and years since last ploughing. Aboveground Net Primary Production (ANPP) data were derived from MODIS NDVI data using the Monteith model. Total production and ANPP, including seasonal and inter-annual variability, were characterized for each state. Hypotheses on the drivers of the transitions between states of degradation were derived from local studies on the effect of grazing and cropping on grassland structure and function. A participatory engagement process with local stakeholders was used to develop actions that focused on managing the heterogeneity of forage resources and the desired transitions between states.

Keywords: Monitoring, NDVI, local knowledge.

Introduction

The extent of natural pastures in the Eastern Republic of Uruguay has decreased from 75% (SICA 2000) to 55% over a 12 year period (2000-2012) (Baeza *et al*. 2012), as a result of cropping intensification and the expansion of forestry. However, cropping expansion has declined from the 1950s to the end of the century (Saavedra 2010), resulting in abandonment of cropping in some areas. Plant species not commonly found in grazed pastures have established in the abandoned paddocks. This study reports on changes in native pasture composition and productivity located on public lands in the department of Paysandú (32^{o} 12.554' and 32^{o}7.530' South and longitude 57^{o}15.198' and 57^{o}26.308' West), which have been under cropping and grazing since 1939.

The aim of this work was to develop a state and transition model (STM) (Westoby *et al*. 1989, Briske *et al*. 2005) for the dominant soil unit in the study area and to describe each state in structural (physiognomy and floristic composition) and functional terms above ground net primary production (ANPP). Field and remotely sensed data were used to develop the model. The ranchers had input into developing and evaluating the model which was to be used by them to develop adaptive management strategies for the region.

Study site

The study was conducted on public land which is leased to private ranchers. The study area occupies 8348 ha, managed by 27 producers with an average area of 309 ha per farmer. 74% of farmers are tenants and 70% graze cattle and or sheep**.** Soil type is variable, with 15 types described for the region (CONEAT, 2013). The dominant Hapluderts soil type occupies 40% of the area. Hapluderts have an average organic matter content of 2.9%, a pH of 5.8 and show laminar erosion with an average loss of topsoil of 6-15 cm since 1939. Average annual rainfall is 1391 mm, and there may be deficits or excesses in any season.

About 50% of the area consists of original natural grassland or recolonizing native vegetation from land abandoned since 2008. 27% corresponds to recent cropping abandonment (less than 4 years), 12% corresponds to annual sown pastures and the balance (10%) is cropland. The average stocking rate in 2011 was 0.93 Livestock Units (requirements of 380 kg cow with calf at foot) per hectare, sheep 0.31 and a ratio of 2.63 of sheep to cows.

Methods

A total of 174 sites were surveyed in spring 2010. The selected paddocks had not been tilled for at least 4 years. The following variables were recorded: % ground cover, cover of weeds (foliar), and the cover and abundance of the 10 most abundant plant species (using Braun-Blanquet 1950). Sites included areas within paddocks on different soil types.

Principal components analysis (Di Rienzo *et al*. 2008) was used to identify variability in floristic diversity in the pastures. Cluster analysis was used to group paddocks with similar characteristics. These analyses were used to develop a STM for the dominant soil unit (Hapluderts). ANPP was estimated from Monteith's model (Monteith 1972) using NDVI images provided by the MODIS sensor following the protocol proposed by Piñeiro *et al*. (2006). The data were provided by the Laboratory of Regional Analysis and Remote Sensing IFEVA / FAUBA.

The STM was reviewed by academics for accuracy. It was then reviewed by the resource users (farmers and their families). In this way the development of the STM combined professional and local knowledge to deliver practical science outputs to end users. The communication of the model was made to the resource users in two ways. One way was a traditional graphic representation (see Figure 1). The second novel approach was particularly useful for farm field days. States were represented by real vegetation samples placed on a concrete floor. These states were linked by arrows using different coloured chalk to represent directions of change. This method allowed ranchers to become actively engaged with the model.

Results

States and transitions

The model has 5 states (Fig. 1) covering variable areas. The first "reference" state has high vegetation cover (90 to 100%) and plant species with relatively high productivity and nutritional value, *i.e. Paspalum notatum*, *Axonopus affinis*, *Mnesithea selloana*, *Paspalum dilatatum*, and *Nasella nessiana*. *Bromus auleticus* is also present in this group. Different ratios of sheep to cattle grazing modify shrub cover from the reference state. If the reference state is tilled or nonselective herbicide is applied, and then abandoned, then it will shift to the second state (IIa) "stubble." This state is characterized by recent tillage, lower vegetation cover and a dominance of exotic annuals which are soon colonized by the introduced perennial *Cynodon dactylon* and much later by other native perennial of low forage value (*i.e. Eragrostis lugens*, *Botriochloa laguroides*, *Schizachyrium microstachyum*, and *Sporobolus indicus*). Under tillage, the system will shift to substate b. The cessation of tillage and abandonment would shift the system to fourth state ("low forage value"), which is a stable state with little chance of returning back to the reference state, if management practices don't change. Shrubs may be present or absent depending on the ratio of sheep to cattle.

Recovery of a site post-tillage ("re-establishment paddocks") may result in one of four substates. These substates result from different management combinations including adjusting the stocking rate and the ratio of sheep to cattle. The substates differ in the amount of vegetation cover, the quality and productive value of the pasture (pastoral value) and the presence of weeds and shrubs. The transitions between the substates are also affected by the ratio of sheep to cattle and the selective control of weeds and shrubs.

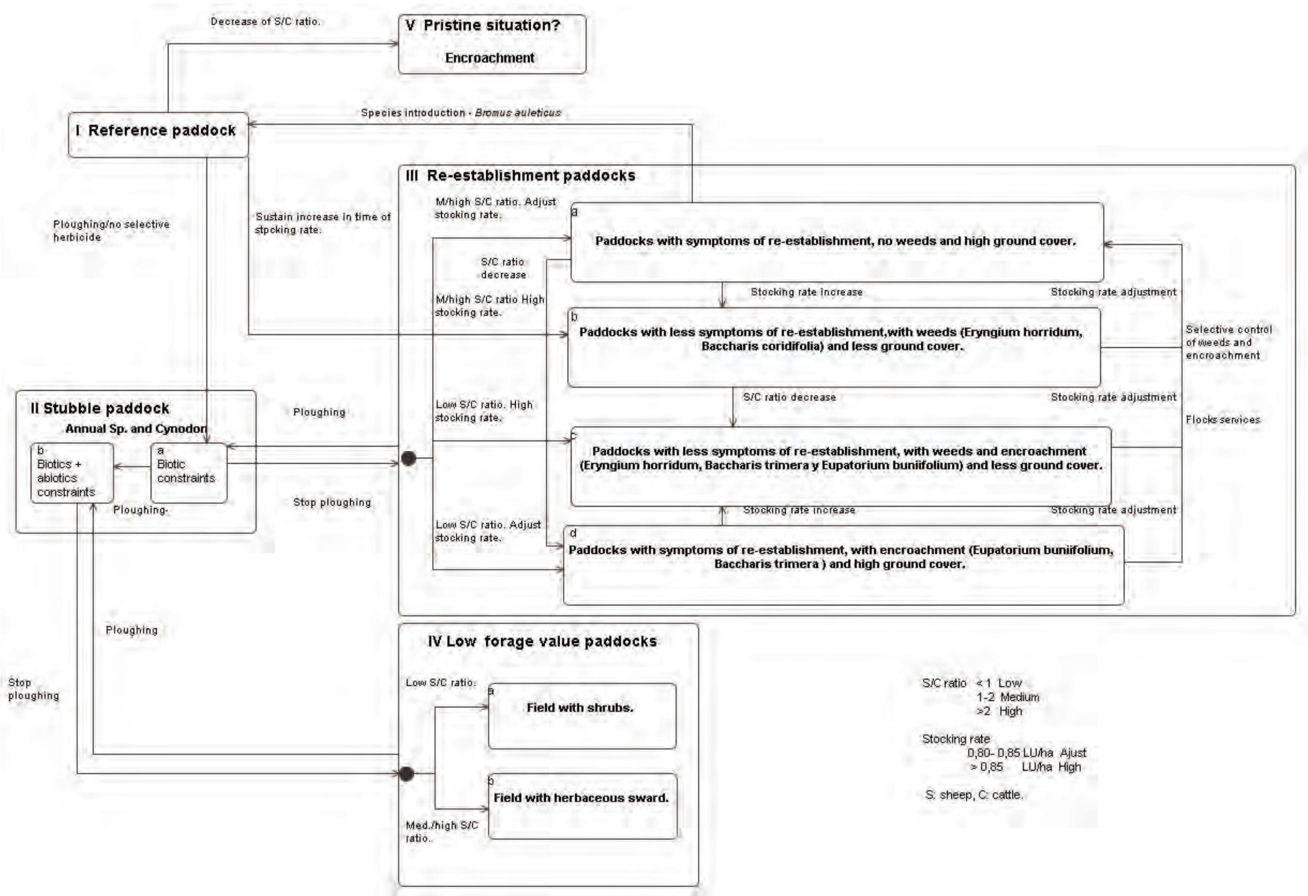

Figure 1. State and transition model for Hapluderts soils, Paysandu, Uruguay.

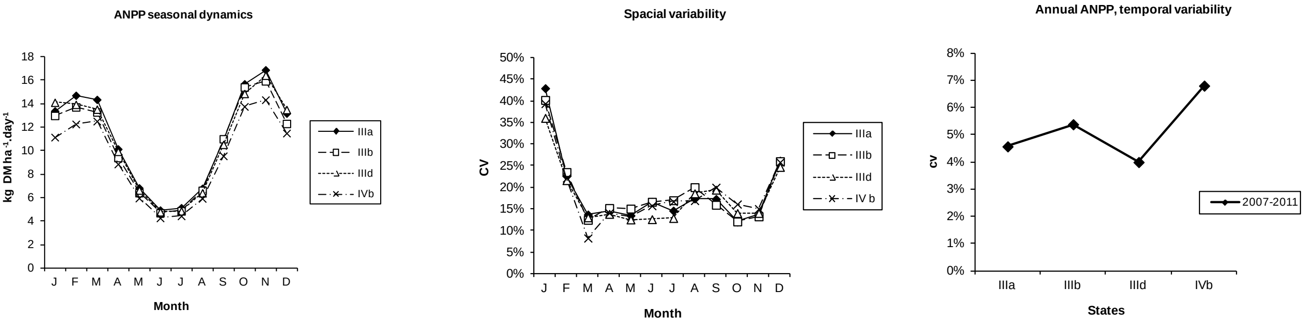

Figure 2. Seasonal dynamics of ANPP: (a) expressed in kg DM/ha/day, spatial variability; (b) expressed as a coefficient of variation (CV, %) and temporal variability; and (c) expressed as CV (%) in the analyzed time series (2007-2011).

Aboveground net primary production

For the period 2007-2011, ANPP ranged from 9.54 to 11.07 kg DM/ha/day. This equates to an annual amount of 3482-4040 kg DM/ha/year between states. Comparisons between the four states that were sampled more than once showed that only one (IVb) had significantly lower ANPP values than the others.

The seasonal dynamics of ANPP was similar for all states, with a peak in November and minimum in July (Fig. 2a). The highest spatial variability was recorded during the summer months (December to February) (Fig. 2b). Between years, state IVb was slightly more variable than the substates (IIIa, b, d) (Fig. 2c).

An experiential method was used with ranchers to validate the model. Ranchers provided information about the different states which was used to adjust the initial model.

Discussion

While STMs have not been developed previously for Uruguay, many of the transitions shown here have already been suggested by other authors (Rodriguez *et al*. 2003; Altesor *et al*. 2006). The information generated in this study, found no significant differences in ANPP between three substates, IIIa, IIIb and IIId. For substates IIIa and IIIb, the transition from the first to the second state is a result of overstocking which causes structural change, reduces the grazing area, the harvest index and, therefore, secondary production. The results from this work provides a scientific basis for us to objectively encourage a transition to substate a, which has similar ANPP but better structure than substate b.

The intensity of tillage, fertilization and duration of agricultural production alter soil properties, structure, organic matter content, nutrient levels, which differ substantially from the original state, in this case resulting in a significant ANPP difference in the substate IVb. These differences manifest themselves throughout the year, presenting pasture species of lower potential production. Differences were maximized in spring-summer, due to the dominance of C4 species (Berretta 1998; Lezama *et al.* 2006). Substate IVb is not only less productive but also more variable over time, which may result in a higher proportion of bare soil, and a greater proportion of opportunistic species such as annuals. Whether this state is reversible or not is currently under investigation.

All transitions, except the recovery of low forage value paddocks, are possible under different management regimes. However, time to recovery is important as recovery will be affected by drought and events of over-stocking which affects sward structure (Clarkson and Lee 1988).

The establishment of ANPP ranges for major substates allows us to set thresholds from which a transition may be triggered. The decrease of the sheep to cattle ratio in the reference state causes an increase in shrub cover. Small ruminant grazing may be an efficient tool to reduce shrub invasion and woody biomass accumulation (Jauregui *et al.* 2009).

The model performance assumes there to be a good supply of propagules (seed source). Increasing fragmentation of habitats, in this case mainly by land use change and the occurrence of adverse phiosferic effects, negatively affect the supply of propagules (Hobbs *et al*. 2008). Therefore additional measures are needed to ensure the availability of propagules for different existing plant communities (*e.g.* leave perimeter edges and strips ungrazed as a source of propagules).

Ranches in the region are small (*i.e.* average 309 ha) and ranchers face pressure to intensify land use. Therefore it is necessary to implement a strategy to reconcile conservation / restoration efforts with the economic needs of ranching families. The model indicates that resources will be in better condition under a cessation from tillage. Therefore we advise that ranchers intensify a small area that can foster products coming from natural grasslands, delivering a production and conservation outcome. While there are precedents whereby STMs are constructed from a combination of scientific and local knowledge (Ash *et al*. 1994; Knapp *et al*. 2011), this was a new challenge and was a highly enriching experience reaching far beyond expectations.

Acknowledgements

I want to thank all those who have made this work possible, especially Professor José Paruelo, Alice Altesor and Kerry Bridle for the constant support.

References

Altesor A, Piñeiro G, Lezama F, Jackson RB, Sarasola M, Paruelo JM (2006) Ecosystem changes associated with grazing in subhumid South American grasslands. *Journal of Vegetation Science* **17**, 323–332.

Ash AJ, Bellamy J A, Stockwell TGH (1994) State and transition models for rangelands.4.Application of state and transition models to rangelands in northern Australia. *Tropical Grasslands* **28**(4), 223–228.

Baeza S, Baldassini P, Arocena D, Pinto P, Paruelo JM (2012) Clasificación del uso/cobertura del suelo en Uruguay mediante series temporales de imágenes de satélites y árboles de decisión. *XXV Reunión Argentina de Ecología*. p. 130.

Berretta E (1998) Principales características climáticas y edáficas de la región de basalto en Uruguay. Serie técnica 102. INIA. Tacuarembó.

Briske DD, Fuhlendorf SD, Smeins FE (2005). Invited Synthesis Paper: State-and-transition models, thresholds andrRange-land health. In: *A Synthesis of Ecological Concepts and Perspectives*, **58**, 1–10.

Braun Blanquet J (1950) Sociología vegetal . ACME. Buenos Aires.

Clarkson NM, Lee GR (1988) Effects of grazing and severe drought on a native pasture in the traprock region of southern Queensland. *Tropical Grasslands* **22**(4), 177–183.

CONEAT (2013) CONEAT digital. http://www.prenader.gub.uy/coneat/viewer.htm?Title=CONEAT%20Digital. Accessed: 14 Jan 2013.

Di Rienzo JA, Casanoves F, Balzarini MG, Gonzalez L, Tablada M, Robledo CW (2008) InfoStat, versión 2008, Grupo InfoStat, FCA, Universidad Nacional de Córdoba, Argentina.

Hobbs NT, Galvin KA, Stokes CJ, Lackett JM, Ash AJ, Boone RB, Reid RS, Thornton PK (2008) Fragmentation of rangelands: Implications for humans, animals, and landscapes. *Global Environmental Change* **18**(4), 776–785.

Jauregui B, García U, Osoro K, Celaya R (2009) Sheep and Goat Grazing Effects on Three Atlantic Heathland Types. *Rangeland Ecology and Management* **62** (2), 119-126.

Knapp CN, Fernandez-Gimenez ME, Briske DD, Bestelmeyer BT, Wu, XB (2011) Using Participatory Workshops to Integrate State-and-Transition Models Created With Local Knowledge and Ecological Data. *Rangeland Ecology and Management* **64**(2), 158–170.

Lezama F, Altesor A, León R, Paruelo JM (2006) Heterogeneidad de la vegetación en pastizales naturales de la región basáltica de Uruguay. *Ecología Austral* **16**, 167–182.

Monteith JL (1972) Solar radiation and productivity in tropical ecosystems. *Journal of Applied Ecology* **9**, 747-766.

Piñeiro G, Oesterheld M, Paruelo JM (2006) Seasonal Variation in Aboveground Production and Radiation-use Efficiency of Temperate rangelands Estimated through Remote Sensing. *Ecosystems* **9**(3), 357–373.

Rodríguez C, Leoni E, Lezama F, Altesor A (2003) Temporal trends in species composition and plant traits in natural grasslands of Uruguay. *Journal of Vegetation Science* **14**, 433–440.

Saavedra C (2010) Un siglo de agricultura. Revista Plan Agropecuario. pp.46–49.

SICA (2000) Sistema de información Censo Agropecuario. DIEA, MGAP, ROU.

Westoby M Walker B, Noy-Meir I (1989) Opportunistic management for rangelands not at equilibrium. *Journal of Range Management* **42**, 266–274.