Climate change impacts on South American Rangelands

Laura Yahdjian[1] *and Osvaldo E. Sala*[2]

Authors are [1] Research Scientist from Instituto de Investigaciones Fisiológicas y Ecológicas Vinculadas a la Agricultura (IFEVA) and Department of Ecology, School of Agronomy, University of Buenos Aires, CONICET, Av. San Martín 4453, C1417DSE, Buenos Aires, ARGENTINA. [2] Professor Department of Ecology and Evolutionary Biology and Director of the Environmental Change Initiative, Brown University, Box 1951, Providence, RI 02912, USA, e-mail: Osvaldo_Sala@Brown.edu.

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Correspondence: Laura Yahdjian, IFEVA, Faculty of Agronomy, Av. San Martín 4453, Buenos Aires, C1417DSE, ARGENTINA. Phone: (5411) 4524-8070 ext 8134, Fax: (5411) 4514-8730, e-mail yahdjian@ifeva.edu.ar.

Abstract

South American Rangelands cover 33% of the area of the subcontinent. Rangeland productivity and species composition are directly related to the highly variable amounts and seasonal distribution of precipitation and only secondarily controlled by other climatic variables. Primary production increases linearly with annual precipitation and livestock biomass increases linearly with primary productivity, resulting in a direct relationship between annual precipitation and livestock biomass. South American Rangelands sustain pastoralist activities, subsistence farming, and commercial ranching and are a key factor in the economy of many countries. As predicted by current climate-change models, all of South America is very likely to warm during this century and mean temperature may arise 2° C by 2020. Annual precipitation is likely to decrease in the southern Andes, to increase in Tierra del Fuego during winter and to increase in the Pampas region during summer. The frequency of occurrence of weather and climate extremes in South America is likely to increase in the future, which, in turn, will affect current and future primary production. Whereas livestock production may increase in the pampas region as a consequence of precipitation increases, livestock production could be negatively affected by higher temperatures or increased evapotranspiration rates. We propose development of Rangeland Alarm Systems (RAS) to alert land managers of impending droughts and the consequent forage shortage that may lead to short-term economic losses and long-term ecosystem deterioration.

Keywords

South American grasslands, Herbivore biomass, Primary productivity, Temperature changes, precipitation changes

Resumen

Las regiones de pastoreo de Sudamérica cubren un 33% del área del subcontinente. La productividad y la composición de especies de las áreas de pastoreo están directamente relacionadas con la distribución estacional y las cantidades anuales de las precipitaciones, que son variables entre años. Sólo en segundo lugar la productividad puede estar controlada por otras variables climáticas. La productividad primaria aumenta linealmente con la precipitación anual y la biomasa de herbívoros, a su vez, aumenta linealmente con la productividad primaria neta, dando por lo tanto una relación directa entre la precipitación anual y la biomasa de herbívoros. Los pastizales de Sudamérica mantienen actividades de pastoreo de subsistencia y comerciales y son un factor clave en la economía de muchos países. Según predicen los modelos de cambio climáticos actuales, muy probablemente todo Sudamérica se calentará durante este siglo y la temperatura promedio puede llegar a subir 2° C en el año 2020. Los pronósticos de cambios en las precipitaciones consideran que la precipitación anual disminuirá en el sur de los Andes, aumentará en Tierra del Fuego durante el invierno y aumentará en la región pampeana durante el verano. La frecuencia de ocurrencia de eventos climáticos extremos en Sudamérica seguramente aumentará en el futuro, lo que, a su vez, afectará la producción primaria actual y futura. Mientras que la producción ganadera puede aumentar en la región pampeana como consecuencia del aumento en las precipitaciones, la producción puede verse afectada negativamente por el aumento en la temperatura y los incrementos en las tasas de evapotranspiración. En este trabajo proponemos desarrollar un Sistema de Alarma Ganadero (RAS, de su sigla en ingles) para alertar a los productores sobre las sequías inminentes y sus consecuencias sobre la disponibilidad de forraje a fin de mitigar las pérdidas económicas a corto plazo y el deterioro de los ecosistemas en el largo plazo.

INTRODUCTION

1. Overview of South American rangeland resources and their use

South America is highly heterogeneous in terms of climate, ecosystems, human population distribution and cultural traditions. Rangelands are placed in regions with climate spread from arid to subhumid, in which mean annual precipitation ranges from approximately 150 to 1500 mm, although these boundaries are subject to modification by local edaphic conditions, evaporative demands, altitude and topography. Within South America, rangelands cover 33% of the area (Figure 1), including grasslands, shrublands, savannahs, and hot and cold deserts, excluding hyper-arid deserts (IPCC, 1996). In terms of vegetation physiognomy, ecosystems have an important herbaceous layer and woody vegetation can range from scattered dwarf shrubs to an almost continuous canopy of small stature trees. A vertical partitioning of soil resources, comparable to the two-phase aboveground structure composed by the herbaceous and the shrub and tree layers, have been described for several ecosystems. Fire and flooding play an important role in maintaining the balance between herbaceous and woody vegetation. Frequent flooding leads to open grasslands, whereas better drained areas support savanna or woodland. Finally, large grazing mammals, mainly livestock in South America, have pronounced effect upon vertical structure of savanna grasslands. The herbaceous layer is composed of C_3 and C_4 species, which typically have different phenology with C_3 species maximum productivity occurring in early spring, whereas C4 species have maximum productivity in late spring or early summer (McNaughton et al., 1993).

South American Rangelands include the Patagonian Steppe, the Monte, the Pampas, grass and savanna woodland known as “Llanos” or “Cerrado”, the open dry thorny woodlands called “Chaco”, and the dry thorn scrub named “Caatinga” (McNaughton et al., 1993) (Figure 1). Rangelands are associated with climates with pronounced dry seasons, high fire frequencies, and highly variable, but often anomalous, soil properties. Over much of South America, changes in the intensity and location of tropical convection are the fundamental driver of climate, but extratropical disturbances also play a role through the year in southern South America. A continental barrier along the Pacific coast in South America and the world' largest rainforest are unique geographical features that shape the climate in the area. A warm season precipitation maximum, associated with the South American Monsoon System dominates the mean seasonal cycle of precipitation in tropical and subtropical latitudes. In temperate latitudes, precipitation is uniform along the year, whereas in the Patagonian region, Mediterranean climate is characteristic with a cool-season precipitation maximum.

Productivity and controls

Rangeland productivity and species composition are directly related to the highly variable amounts and seasonal distribution of precipitation and only secondarily controlled by other climatic variables. Primary productivity, the rate at which plants accumulate biomass, varies linearly along the arid-subhumid range (150-1500 mm mean annual rainfall), according to a model constructed with 14 South American ecosystems (McNaughton et al., 1993). This relationship between primary productivity and precipitation in arid to subhumid ecosystems is widely similar across any different geographic regions with an increment of between one-half and three-fourths of a gram of production per square meter annually for each millimeter of precipitation (McNaughton et al., 1993).

Also, a number of ecosystem properties of the herbivore trophic level (biomass, consumption, and productivity) are significantly correlated with primary productivity in terrestrial ecosystems ranging from desert to tropical forest (McNaughton et al., 1989). In accordance with this pattern, livestock biomass increases linearly with primary productivity across 67 agricultural sites in Argentina (Oesterheld et al., 1992). However, the biomass of livestock supported per unit of primary production is about and order of magnitude above the level of natural herbivores, which indicates that agricultural management practices like dietary supplementation, veterinary practices or elimination of predators significantly increase the carrying capacity of ecosystems (Oesterheld et al., 1992).

Nutrient availability can also constrain primary production and livestock biomass in South American rangelands. Savannah vegetation of the Neotropics is often associated with extraordinary infertile soils, whereas in the other extreme, Argentinean Pampas occur on soils that are among Earth's most fertile. Experimental fertilization with N and P in Venezuelan llanos produced aboveground yield increases. Grassland fertilization experiments throughout Argentina encompassing climates from subtropical to temperate also showed increases in primary productivity and higher responses to P fertilization than N fertilization. Also, in the arid Patagonian steppe (mean annual precipitation less than 200 mm), nitrogen addition produced significant grass aboveground production increases (Yahdjian and Sala submitted). Even when for each site there was a linear increase in yield that corresponded to the level of N or P fertilization, when all sites were pooled together the large variability in soils and climates masked a clear relationship between yield and fertilization dose highlighting that soil features vary at a scale finer than the regional patterns (McNaughton et al., 1993).

Human use: rangeland activities and importance in the economy

South American rangelands sustain pastoralist activities, subsistence farming, and commercial ranching and are a key factor in the economy of many countries (e.g., Brazil, Argentina and Uruguay). There are approximately 570 million animal units in the subcontinent, and over 80% of them are fed from rangelands (Christensen et al., 2007).

The described relationship between primary productivity and livestock biomass was accompanied by a pattern of change in average body size of major herbivores, which in South America are represented by livestock. A reduction in the proportion of sheep, compared to cattle, present in livestock herds with increasing ANPP was evident across 67 locations in Argentina (Oesterheld et al., 1992). The proportion of sheep varies from near 100% at the lowest productivity levels in Patagonian areas receiving less than 200 mm of precipitation annually to near zero at the highest productivities in subtropical regions with annual precipitation levels near 1500 mm (Oesterheld et al., 1992). Sheep production is the main economic activity in the Patagonian steppe and is based on rangeland grazing. There are approximately 15 million sheep, with a production of 50.000 ton of wool per year. In 2002, meat and wool sheep exports from the Patagonian region were worth US$607 million.

2. Review of projected climate change for South and Central American

Projected temperature changes

The annual mean warming for South American rangelands is likely to be similar to the global mean warming in southern South America, and higher to the global mean warming in Northern South America (Christensen et al., 2007). The projected mean warming for South America to the end of the century, according to different climate models, ranges from 1 to 4°C or 2 to 6°C, depending on the scenario of change involved in the model (Christensen et al., 2007). For 2020, temperature changes range from a warming of 0.4°C to 1.8°C, and for 2080 of 1.0°C to 4.5°C. The highest values of warming are projected to occur over tropical South America and, generally, in the most continental regions such as inner Amazonia (Figure 2). However, all South America is very likely to warm during this century. Seasonal variations in warming are relatively modest. The projected warming tends to be larger in the summer period, December-February (DJF) than during winter, July-August period (JJA), except for central Amazonia (Figure 2).

Projected precipitation changes

Most general circulation model projections highlight the complexity of precipitation patterns (Christensen et al., 2007). For tropical South America, projections range from a reduction of 20 to 40% to an increase of 5 to 10% for 2080. Uncertainty is even larger for southern South America in both, winter and summer seasons although the percentage change in precipitation is somewhat smaller than that for tropical South America (Figure 2). Annual precipitation is likely to decrease in the southern Andes, with relative precipitation changes being largest in summer (DJF, Figure 2). Changes in atmospheric circulation may induce large local variability in precipitation changes in mountain areas. Precipitation is likely to increase in Tierra del Fuego during winter and in the Pampas region during summer. It is uncertain how annual and seasonal mean rainfall will change over Northern South America. In some regions, there is qualitative consistency among the simulations resulting in rainfall increasing in Ecuador and Northern Peru, and decreasing at the northern tip of the continent and in southern Northeast Brazil (Figure 2). The seasonal cycle modulates this mean change, especially over the Amazon Basin where monsoon precipitation increases in DJF and decreases in JJA (Figure 2). In other regions like Pacific coasts of northern South America and a region centered over Uruguay and in Patagonia, the sign of the response is preserved throughout the seasonal cycle.

During the 20th century, significant increases in precipitation were observed in southern Brazil, Paraguay, Uruguay North-east Argentina and North-west Peru and Ecuador.

Conversely, a declining trend in precipitation was observed in Southern Chile, south-west Argentina and Southern Peru (Christensen et al., 2007).

Extremes

Over the past three decades, South America has been subjected to climate-related impacts of increased El Niño occurrences. Two extremely intense episodes of the El Niño phenomenon (1982/83 and 1997/98) and other severe climate extremes have happened during this period, contributing greatly to the heightened vulnerability of human systems to natural disasters (floods, drought, landslides, etc.). The frequency of occurrence of weather and climatic extremes in South America is likely to increase in the future (Christensen et al., 2007). Some models anticipate extremely wet seasons while others show the opposite tendency. However, models agree with the projections of more intense wet days per year over large parts of South-eastern South America and weaker precipitation extremes over the coasts of Northeast Brazil.

Climate change interactions with other global change drivers: land-use change

The area planted to soybeans in South America, projected to be one of the main drivers of future land-use change, is expected to almost duplicate by the year 2020 at the expense of forests. This massive deforestation will have negative impacts on the biological diversity and ecosystem composition of South America, as well as having important implications for regional and local climate conditions.

Rangeland intensification is also a land-use change expected in future with environmental implications. In Patagonia, for example, the introduction of unsustainable sheep stocking rates along with inappropriate management have already resulted in major changes in rangeland composition and even desertification. This process is causing the loss of approximately 1,000 km^2 per year. Overall, 35% of the area of rangelands has been transformed into desert. As a result, the number of sheep decreased by 30% between 1960 and 1988-representing a loss of about US$ 260 million (Sala and Paruelo, 1997).

3. Implications of climate change for rangeland resources

Impacts of climate change on rangelands resources

Changes in climate are already affecting several sectors. Some reported impacts associated with heavy precipitation are increase in flood frequency, stream flow, landslides, and storms, which can in turn affect rangeland resources. The linear relationship between precipitation and primary production leads to increases in forage production with precipitation increases. For the Argentinean Pampa, precipitation increases led to increases in pasture productivity by 7 % in Argentina and Uruguay during the past decade (Gimenez, 2006), along with increases in soybean, maize, wheat and sunflower production. Pasture increases could, in turn, have a positive effect on livestock production due to the linear relationship between primary production and herbivore biomass (Oesterheld et al., 1992) that results in linear relationships between mean annual precipitation and livestock biomass (Figure 3). However, precipitation decreases are expected for several of the South American Rangelands, with opposite results. With direct relationship between annual precipitation and aboveground primary production reported by (McNaughton et al., 1993) and direct relationship between primary production and herbivore biomass reported by (Oesterheld et al., 1992), we constructed a model which directly relates annual precipitation with herbivore biomass. The equation is:

$$B = [(0.48 \text{ mm} - 30) \exp 1.602] / 9590$$

where B is herbivore biomass (livestock) and annual precipitation is expressed in mm per year.

The predicted increase in the frequency and intensity of extreme events is expected to affect future primary production. The inter-annual variation in precipitation leads to time lags in the recovery of production from dry conditions, even when the subsequent year has above-average precipitation. These time lags experienced after drought are proportional to the intensity of drought, leading to more pronounced production legacies when the drought intensity is high. As a consequence, the predicted increase in the frequency and intensity of extremes events, where dry years may be more common and even more pronounced, are expected to cause higher production variability between years, with negative consequences in forage production and the stability of livestock production. Field manipulative experiments help to understand the ecological consequences of climate changes. For example, in the Patagonian steppe, manipulative experiments showed that a past high intensity drought (80% average-rainfall reduction) caused a 40 % aboveground production reduction (comparing with the case that had not experienced drought) during next year, even when that year had higher-than-average annual precipitation.

Direct impacts on animal production

Temperature can impact directly animal production. Heat waves in central Argentina have led to reductions in milk production in Holando Argentino (Argentine Holstein) dairy cattle, and the animals were not able to completely recover after these events. As a consequence, cattle and dairy productivity is expected to decline in response to increasing temperature. In addition, temperate grasslands and the animal production depending on them are vulnerable to drought. Therefore, livestock production could be negatively affected by higher temperatures or increased evapotranspiration rates. However, the experience has shown that extreme events, such as large-scale floods or drought-erosion cycles, may pose the highest risks (Soriano, 1992).

In South America overall, consumption of animal products (meat) has historically been higher than in other developing countries and is predicted to increase further. The annual per capita demand for meat products is projected to rise to 64.3 kg in 2020. Demand is very close to supply and this is also true for milk. In the next 20 years, the intake of calories per capita is predicted to grow.

4. Response management of South American rangelands to climate change

As we described above, climate change will negatively affect rangelands in two ways; reducing average water availability and increasing its variability. In general it would be easier to manage for lower water availability than for extreme drought because the difficulty in predicting these infrequent events and the cost of deploying response mechanisms that only enters into effect rarely. Extreme droughts have short-term consequences resulting from reduced production and the long-term effect of overgrazing. In some cases, the combination of drought and overgrazing has resulted in irreversible damage when ecosystems flipped into another state.

We suggest that a good management tool would be the development of region-specific Rangeland Alarm Systems (RAS). These systems would alert ranchers, land managers, and policy makers of impending droughts and would encourage them to act promptly to protect animals and rangelands. RASs are conceptually related to alarm systems developed for fruit growers alerting them about insect plagues and informing farmers about type and timing of the use pesticide. Climatic conditions, mathematical models and insect counts are the basis for plague alarm systems. Rangelands alarm systems should be a combination of an ecological model with medium-term meteorological forecast. Currently, medium-term weather forecasts are available and certainly they will improve with time, making forecasts further ahead and more precise. Ecological models would combine medium-term forecasts of rainfall amount and seasonality to forecast forage production. These models would be easier to develop in regions where the rainy season and the growing season are out of synchrony, such as the annual grasslands of California or the steppes of Patagonia. The occurrence of the bulk of precipitation a few months before the growing season starts provides the opportunity to forecast forage shortage a few months ahead of their occurrence. The lead time that the alarm system provides would allow ranchers and land managers to get ready and implement a series of response options.

Major response options to drought are associated with alleviating forage and water shortage. Basically, there are two types of approaches to the problem, reduce stocking rates or increase forage and water supplies. Managers that have to reduce stocking rates would benefit from the use of RAS because they will be able to sell their animals before prices drop as a result of the drought. RAS would smooth the economic ups and downs of farm's incomes by providing lead time to reduce stocking rates. The alternative approach to reduce stocking rates is to secure additional forage. Specifics as to where to obtain additional forage depends on the region and the ranch. In some cases, managers may need to buy forage or grain from other ranches or from other regions. In another case, they can save paddocks to be consumed during the drought.

Governments can contribute at different scales and in different ways. First, they could support the development of region-specific RAS. Second, they could contribute to the communication of RAS results so alarms reach land managers at all levels. Communication of RAS results may use different tools depending on the region from television and radio, to extension services and local leaders. Third, government may facilitate the implementation of response option by providing loans for ranchers to purchase additional forage or grain. In some regions, government may reduce tax burden during drought periods to alleviate the economic consequences of reduced production.

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Figure legends

Figure 1. Map of South America Rangelands distributions and extension. Regions occupied by extensive arid to subhumid ecosystems where rangeland is one of the main productivity activities are shown with colors. Redrawn from (Olson et al., 2001) and from (Eva et al., 2002).

Figure 2. Temperature and precipitation changes over Central and South America from the MMD-A1B simulations. Top row: Annual mean, DJF and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Middle row: same as top, but for fractional change in precipitation. Bottom row: number of models out of 21 that project increases in precipitation. Reproduced with permission from (Christensen et al., 2007).

Figure 3.Relationship between large herbivores (livestock) biomass and annual precipitation for South American arid to subhumid ecosystems. Model equation is B = [(0.48 mm – 30) exp 1.602] / 9590. Modified from (Oesterheld et al., 1992) and from (McNaughton et al., 1993).