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IMPACT OF GRAZING MANAGEMENT ON THE PRODUCTIVITY OF COLD TEMPERATE GRASSLANDS OF SOUTHERN PATAGONIA- A CRITICAL ASSESSMENT

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Abstract

The contention that productivity of cold temperate grasslands of southern Patagonia have been greatly affected by domestic herbivore grazing in the past is fairly widespread. The consequences of spatiotemporal interactions between grazing and abiotic factors on the overall productivity of such systems, however, are still poorly understood. Predictions of both short- and long-term impacts of grazing management strategies on grassland productivity require a better understanding of these interactions. In this paper we make a critical assessment of the impact of grazing management on long-term sustainability of the grass steppes of southern Patagonia (Argentina). We discuss this issue in the context of current understanding of structure and function of these grass steppes, and of present-day global change concerns. We explore the capabilities of present-day tools to integrate biotic and abiotic factors at the landscape level to improve grazing management decisions.

Introduction

Grazing management on rangeland ecosystems has historically sought to obtain “maximum sustained use of forage crop without jeopardy to other resources or uses of the land” (Sampson 1953, p 5). Extensive grazing management strategies (*sensu* Briske and Heitschmidt 1991) such as the manipulation of either animal numbers and types, or the timing of grazing events, and (to a lesser degree) the manipulation of spatial distribution of livestock, have been used to achieve such goals with varying degrees of success (Hart and Norton 1988; Heitschmidt and Taylor 1991). The use of traditional grazing management strategies has not always been effective in attaining ecological and socio-economic sustainability because, in a number of grazed ecosystems, unpredictable abiotic factors (such as droughts) can strongly constrain their success (Ellis and Swift 1988).

Improper grazing management, on semiarid grasslands, can trigger species and/or life-form replacements that often involve the loss of forage (palatable) species and can result in situations of reduced livestock productivity and/or in increased vulnerability to invasion by weeds (Briske 1996, and references therein). The magnitude of species and/or life-form replacement processes depends on the primary productivity of the system considered, its evolutionary history of grazing, and the level of plant biomass consumption by grazers (Milchunas and Lauenroth 1991); the latter being significantly higher in managed systems than in grasslands grazed only by native ungulates (Oesterheld *et al.* 1992). Whereas grazing-induced species replacement does not necessarily imply a decrease in primary productivity (Milchunas and Lauenroth 1991), when shifts in species composition are coupled with soil fertility loss, the

system can become permanently impoverished through a process known as desertification (Schlesinger *et al.* 1990).

This paper focuses mostly on extensive grazing management and productivity of the cold temperate grass steppes of southern Patagonia (the Magellanic steppe). Unherded sheep flocks raised in very large paddocks have grazed these grass steppes for the last 100 years. Sheep numbers have been shrinking since the mid 20th century as a consequence of what has been described as improper grazing management (Borrelli and Oliva 1999). Golluscio *et al.* (1998) recently suggested three grazing-related factors that could have favored ecosystem degradation of Patagonian steppes in general, namely: "1) overestimation of carrying capacity; 2) inadequate distribution of animals in very large, heterogeneous paddocks; and 3) year-long continuous grazing" (p.265). All three of these factors are in some way related to the (lack of proper) use of the extensive grazing management strategies mentioned above (Heitschmidt and Taylor 1991), and are totally applicable to the situation of the Magellanic steppe.

The objective of this paper is to make a critical assessment of the impact of grazing management on long-term sustainability of the grass steppes of southern Patagonia. To achieve this we will: a) briefly describe our target area; b) discuss impacts of grazing management in relation to the diagnosis made by Golluscio *et al.* (1998); and c) single out challenges for the future and the suitability of present-day tools to take on such challenges.

The grass steppes surrounding the Straits of Magellan

The Magellanic steppe is one of the southernmost grazed terrestrial ecosystems of the Earth. Its grass-dominated steppes cover approximately 3 million hectares of southern Argentine Patagonia (Fig.1). A pronounced decrease in the altitude of the Cordillera de los Andes at approximately 52° latitude South allows westerlies from the Pacific Ocean to carry moisture past the western mountain slopes into the continent, giving way to the formation of this grass-dominated ecosystem (Burgos 1985). Annual rainfall ranges from about 200 to 400 mm decreasing from West to East, and from South to North. Precipitation tends to be evenly distributed throughout the year as opposed to the generalized winter precipitation pattern of most of the Patagonian steppe (Soriano 1983). Mean annual temperatures fall within the range of 6.5 to 7.5 °C (De Fina and Ravello 1972). Very strong constant westerlies that occur especially in the spring and summer (500 to 620 km/day) are an outstanding climatic feature of this ecosystem (De Fina and Ravello 1972). *Festuca gracillima* (Hook), a tussock-forming bunchgrass, is the dominant plant species; it occurs along with a number of associated cool season short grasses, forbs, and dwarf shrubs that can cover more than 80% of the soil surface (Roig *et al.* 1985). In the moister areas of the Magellanic steppe, the tussock grasslands intermingle with *Empetrum rubrum* heathlands (on soils originated from of quaternary deposits) or with *Chilotrimum diffusum* shrublands (Collantes *et al.* 1989). Riparian-type meadows are also common and occur either associated with river- floodplains (mostly in the northern drier areas of the steppe), or as a patchwork of lowland swales mingled with the upland *Festuca* grasslands in the more humid grass steppes, especially on the island of Tierra del Fuego (Collantes and Anchorena, *in press*). Hence, landscape heterogeneity tends to increase along rainfall gradients on the steppe.

The Magellanic steppe, as the rest of Patagonia, is thought to have evolved without heavy grazing pressure by large herbivores (Markgraff 1985). With the beginning of the sheep-farming era in the late 1880's, these grass steppes were subjected to a dramatic increase in grazing pressure by domestic herbivores over a relatively short period of time (Oliva *et al* 1995). Since the early days of land occupation by European settlers, sheep population increased steadily

reaching the unprecedented number of 1.3 million head on the Island of Tierra del Fuego in 1905 and 1.8 million head on the continental area of the Magellanic Steppe in 1937. Sheep numbers remained fairly stable until the mid 1970's, and since then, flocks have been shrinking steadily, falling to approximately 0.31 million head on the Island of Tierra del Fuego and 0.57 million head on the continental area of the steppe in 1996 (Oliva *et al.* 1995; Borrelli *et al.* 1997; Provipa 1999).

Sheep farms on the Magellanic steppe typically raise unherded flocks in very large paddocks (ranging between 2,000 to 5,000 hectares) on a year-round basis (Barbería 1995). Land is privately owned and there are presently no government-enforced land conservation guidelines to regulate grazing practices (Borrelli and Oliva 1999). Although winter shortage of forage can be severe, feed supplements are rarely used. Sheep stocking rates range from 0.35 to 0.50 head ha⁻¹ year⁻¹ on the continent, and up to 1 head ha⁻¹ year⁻¹ on the island of Tierra del Fuego (Oliva and Borrelli 1993; Cingolani *et al.* 1998). The single most important factor affecting long-term productivity of the Magellanic grass steppes (as well as other Patagonian steppes) is possibly the occurrence of life-form shifts in the plant communities, driven in part by improper grazing (León and Aguiar 1985; Borrelli *et al.* 1988). The reason for this being that shifts in vegetation life-form are close-to-irreversible (Oliva *et al.* 1998, and references therein), and are thought to involve not only a reduction in forage biomass but also a decrease in water-use efficiency that leads to an overall decline of aboveground net primary productivity (ANPP), particularly in the cases where grasses are replaced by woody plants (Aguiar *et al.* 1996). On the moister Magellanic steppe of the island of Tierra del Fuego, vegetation replacement processes are possibly not as dramatic since they often only involve shifts from tussocks to short grasses (Baetti *et al.* 1993). Therefore, the consequences of plant species replacement on livestock carrying capacity and overall ecosystem function in Tierra del Fuego may not be as severe as on the drier steppes; although this matter has not been fully investigated.

Livestock carrying capacity of the Magellanic grass steppes

The calculation of livestock carrying capacity is central to any sustainable grazing management scheme. Unfortunately, locally developed guidelines to help regulate animal numbers on the Magellanic steppe, came on the scene more than 80 years after livestock were introduced (Borrelli and Oliva 1999). As in other areas of Patagonia, most farmers assigned sheep numbers on a “trial-and error” basis using wool production or lamb-marking rates as the criteria to adjust animal numbers; others established stocking rates based entirely on economic profit expectations (Soriano and Paruelo 1990; Barbería 1994). A preliminary examination of the relations between historic rainfall records and the evolution of sheep numbers of the continental area of the Magellanic steppe, shows two distinct periods in the sheep farming era (Fig 2a,b,c). During the first 30 years most of the variability in sheep numbers can be explained by the variation in precipitation, a variable that has been shown to relate linearly to ANPP (Sala *et al.* 1988, Paruelo and Sala 1995). After the 1970's this relation disappears, and a second period begins where sheep numbers decrease despite an apparent phase of overall increase in annual precipitation. Whereas the data used to construct these relations are scarce, and therefore require cautious interpretation, they do suggest the probable occurrence of a breaking point in the system somewhere around the 1960's or 1970's. It is interesting to note that the change in the precipitation-sheep number relation on the continental area of the Magellanic steppe occurred after a 30-year period of decreasing annual rainfall, and following the driest decade of the century (Fig. 3). Were original sheep numbers a gross overestimation of the Magellanic steppe's livestock

carrying capacity? If so, did 30 to 40 years of overgrazing produce species and or life/form replacements that reduced the productivity of the steppe? How did extreme drought conditions interact with sheep numbers in the triggering of such species replacement?

It was not until the late 1980's and early 1990's that government concern about what was perceived as rangeland desertification lead to serious investment in grazing research. These efforts resulted in the development of several rangeland survey methods that were basically designed to aid sheep farmers in decisions involving stocking rate adjustments (Golluscio *et al.* 1998). Among these, INTA (Instituto Nacional de Tecnología Agropecuaria) developed the Santa Cruz method (described in detail by Borrelli and Oliva 1999) that estimates livestock carrying capacity by sampling biomass of short grasses and forbs and stubble heights of preferred grasses at the level of individual paddocks. Close to 6% of the entire area of the Magellanic steppe has been surveyed using this method. Local validation and adjustment of the method was done using a long-term grazing experiment conducted at a site on the drier area of the steppe (Oliva *et al.* 1998). The implementation of the Santa Cruz method basically involves a year to year adjustment of sheep numbers and a planned distribution of flock categories (ewes, rams, wethers, etc) among paddocks on the basis of forage availability and range site quality (Borrelli and Oliva 1999). Adjustment of animal numbers is complemented by a series of accepted sheep raising practices (such as pre-lambing shearing, strategic use of riparian areas, genetic improvement) and has produced an overall stabilization and improvement of sheep production and (in many cases) an improvement in economic returns (Borrelli and Oliva 1999). On the basis of on-farm data collected from those surveys Borrelli *et al.* (1997) developed a regional decision support system suggesting regional livestock carrying capacities for the different rangeland types that make up the Magellanic grass steppes. While we know that stocking rates adjusted following INTA's methods did not produce unfavorable plant replacements in a 10-year experiment on the drier grass steppes (Oliva *et al.* 1998), can we be sure that these grazing guidelines will ensure long-term sustainability?

To address both this and the previous question (regarding possible historical overgrazing of the Magellanic steppe) we plotted: a) INTA's livestock carrying capacity estimates; b) latest livestock census figures; c) historic peak sheep-population numbers; and d) an estimate of guanaco (*Lama guanicoe*) numbers previous to European colonization of Tierra del Fuego (Lauenroth 1998), on a regional-scale herbivore carrying capacity relationship developed by Oesterheld *et al.* (1992) for all South America (Fig. 4). Using a very large livestock census data set, and calculating ANPP as a linear transformation of annual precipitation Oesterheld *et al.* (1992) found that whereas the rate of increase of herbivore biomass with increasing ANPP was the same in managed and natural grazed ecosystems, the former exhibited significantly higher herbivore biomass than the latter. We used the same transformations as those published by Oesterheld *et al.* (1992) and plotted our data together with the predicted values of herbivore biomass (the 2 regression curves on Fig. 4) of both managed and natural systems, for levels of ANPP (linearly transformed precipitation data) of the Magellanic steppe. This allowed us to compare our data (qualitatively) to regional independent estimates of herbivore carrying capacity.

Historic peaks in sheep numbers, both on the continent and on the island of Tierra del Fuego, were clearly well above the predicted value of livestock biomass for managed systems. Present day numbers have fallen to levels that are much closer to the regional carrying capacity relations, except for the drier Magellanic steppe where present numbers are somewhat below the expected level. It seems reasonable to speculate that grazing-driven life-form replacement processes on the drier areas of the grass steppes (involving shifts from grass to woody-plant-dominated communities) may have impacted livestock carrying capacity more negatively than on

the moister areas of the steppe, where vegetation replacement involves less dramatic species shifts. INTA's calculations of livestock carrying capacity appear to be somewhat excessive for the moister areas (with higher levels of ANPP) of the steppe. At the drier end of the gradient (with lower levels of ANPP), where the actual Santa Cruz rangeland survey method was developed and validated, INTA's suggested carrying capacity appears to fall well in line with the regional equation. Finally, pre-European guanaco numbers in Tierra del Fuego appear to be well above the expected herbivore biomass value for natural systems. It is hard to tell, however, whether this is a product of possible overestimation of Lauenroth's (1998) calculations or if, in fact, the moister areas of the Magellanic grass steppes were subjected to unusually high densities of herbivores prior to European occupation.

Spatial heterogeneity of sheep grazing

The management of large grazing units such as Magellanic steppe-type paddocks requires taking into consideration the consequences of heterogeneous spatial distribution of herbivores at the landscape level (Coughenour 1991). This is a problem common to most of the Magellanic steppe (as well as other areas of Patagonia [Golluscio *et al.* 1998]), but it is thought to affect sheep farms of the moister areas of the steppe the most. On the island of Tierra del Fuego Cingolani *et al.* (1998) have recently reported that sheep productivity is significantly affected by landscape-level heterogeneity in vegetation and soil fertility. The opposite (*i.e.* the influence of spatial variability of sheep grazing on plant community composition and productivity) is still poorly understood, although there is widespread evidence of its effects across the Magellanic grass steppes. For example, abrupt fence-line vegetation contrasts along North-South fences are common (Borrelli *et al.* 1988). Since sheep tend both to walk and to graze against the wind, and given the prevailing strong westerlies in this area, grazing activity tends to concentrate along the western portions of paddocks on most of the Magellanic steppe, producing characteristic fence-line contrasts that can be easily identified on aerial photographs and on medium-resolution satellite images.

The Santa Cruz rangeland survey method calculates the coefficient of variation of stubble height measurements of the key species as a means of inferring unevenness of sheep grazing distribution (Borrelli and Oliva 1999). However, since the sampling scheme used by this method deliberately avoids areas of high sheep density such as watering points, sheep camps, and fence lines (Borrelli *et al.* 1990), calculation of overall spatial heterogeneity of grazing is likely to be considerably underestimated. Hence, our ability to quantify the extent of heterogeneity of sheep grazing across the landscape on the Magellanic steppe with the data available to date is somewhat limited.

Factors not related to vegetation, such as topography, can also influence spatial distribution patterns of herbivores considerably (Coughenour 1991). On the Magellanic steppe this is clearly the case with North (and some East) -facing slopes. The increased exposure to solar radiation causes these sites to be "warmer" and is therefore thought to induce high sheep concentration. North-facing slopes tend to exhibit more dramatic shifts in plant species and/or life-form composition compared to the rest of the landscape and are often considered by farmers and range managers as necessary "sacrifice areas". Interestingly, however, changes in the plant community on these sites are likely to be triggered by an interaction of abiotic factors (higher temperatures and, presumably, more negative water balances than sites with average exposure to incoming radiation) and grazing, rather than by the effects of heavy sheep grazing alone. Another example of topographically-driven distribution patterns are the low, moister riparian areas that

are usually subject to higher sheep densities than the surrounding dryland (Golluscio *et al.* 1998). Even though riparian areas have mesophytic vegetation that is somewhat more resilient under heavy grazing, shifts toward low growing dicotyledons that are able to avoid grazing are common (Borrelli and Oliva 1999). The focus of efforts aimed at reducing the negative impacts of grazing heterogeneity on the Magellanic steppe have concentrated mostly on the management of riparian areas. Generally, emphasis has been placed on trying to convince farmers to manage these habitats as separate grazing units (Paz and Buffoni 1982)

Many questions in the area of spatial heterogeneity of sheep grazing require urgent answers in order to allow for improved grazing management strategies on the Magellanic steppe. For example, what is the range of effective stocking rates created in large (Magellanic steppe-type) paddocks when animal numbers are adjusted using mean forage availability values?, Or, how is this range of stocking rates affected by paddock size, landscape heterogeneity, and overall animal numbers? And finally, how do the interaction of abiotic factors and sheep distribution patterns interact to produce “unfavorable” species and/or life form-replacements? Undoubtedly, the use of more sophisticated tools (that will be discussed below) than those that have been used so far will be needed to address these questions.

Continuous grazing vs grazing systems

Because sheep are highly selective herbivores, continuous year-long grazing (the most common method used by ranchers on the Magellanic steppe) tends to exacerbate patterns of uneven use of plant species (Paruelo *et al.* 1992). On the drier areas of the Magellanic steppe, stabilization of plant species composition (both in terms of richness and relative abundance) appears to be possible under conditions of moderate continuous grazing (Oliva *et al.* 1998), although structural differences between grass species (tussocks vs. inter tussock vegetation) persist. Tussocks may, in fact, function as a structural matrix of this grass steppe playing an important role in the stability of the system (Oliva 1996); however, the relations between structure and function of the Magellanic grass steppes are largely ignored. Mixed-grazing by cattle and sheep is presently being tested as a tool to control structural heterogeneity but its impact on long-term sustainability of the steppe is unclear (Cibils *et al.* 2000).

Lack of rest and reduced windows of opportunity for adequate reproduction of preferred plant species are the most important consequences of year-round continuous grazing (Briske and Richards 1995). A number of rotation systems have been designed to provide periodic rest and thus counteract the detrimental impact of grazing at the level of plant species or patches (Heitschmidt and Taylor 1991). The success of many such systems applied on semi-arid grasslands compared to season-long moderate grazing has been questioned repeatedly (Coughenour 1991, and references therein). Results of an unreplicated rest-rotation grazing study conducted on the Magellanic steppe reaffirm previous questions on the benefits of grazing systems when compared to continuous moderate grazing (Borrelli 1999). However, in the moister Magellanic steppe the application of rest rotation methods appears to be the only feasible way of providing rest to the highly utilized riparian swales (Borrelli and Oliva 1999). Other experiences in north-western Patagonian pre-Andean grass steppes (where a combination of continuous and short duration grazing was applied) produced positive results both in terms of vegetation and secondary production (Paruelo *et al.* 1992). Reduction in defoliation heterogeneity of individuals of the same grass species, and increases in cover of palatable grasses are some of the (short term) results reported (Paruelo *et al.* 1992).

The implementation of grazing systems requires a good deal of management flexibility to

make necessary adjustments in “unusually” dry or wet years which, unfortunately, are the rule rather than the exception in semiarid environments. For this reason it is often difficult, when analyzing studies reported in the literature, to isolate the effects of climate and grazing on the success or failure of a given grazing system (Coughenour 1991). What is currently called for on the Magellanic steppes is possibly the development of systems tailored to the needs and problems of specific farms. However, a better understanding of the climate-grazing interactions will be needed to develop such systems.

Old problems, new challenges, and tools to address them

Quantification of spatial heterogeneity of sheep distribution will be needed to study the impact of grazing in a spatially-explicit manner. Geo Positioning Systems (GPS) have been recently used with sheep in Britain to conduct these studies by Rutter *et al.* (1997). These authors were able to successfully map sheep distribution across the landscape. The use of GPS collars (commonly applied in wildlife migration studies) on domestic livestock is becoming more widespread. The superimposing of GPS readings on a GIS system containing soils, vegetation, and topography information for the target area, together with the use of spatial statistical techniques, should allow important breakthroughs in this area.

An issue that emerges repeatedly in our analysis, is the paucity of information on how abiotic (mostly climatic) and grazing factors interact to produce unwanted changes in the vegetation of the Magellanic grass steppes. The relevance of this issue is heightened by recent concerns regarding the impact that global climatic change could have on semiarid grassland ecosystems. For example, Alward *et al.* (1999) showed that warmer night temperatures are associated with (and could probably induce) shifts in species composition on a semiarid grassland with a mixture of C₃ and C₄ species, a process that could have an important impact on the livestock production industry.

Mean annual temperatures in Argentina have increased on average 1°C over the last century; annual precipitation has increased on average 10% over the same period (Hulme and Sheard 1999). An analysis of historic records of surface mean annual temperatures for Río Gallegos, (the main city with meteorological records on the continental area of the Magellanic steppe) shows a significant increase over the last 70 years (Fig. 5). The hottest year on record was 1998. Records of annual precipitation, on the other hand, do not show a clear trend for the 1930-1990 period (Fig. 3). Climate change predictions for southern Patagonia from several Global Circulation Models simulating a scenario of doubling of atmospheric CO₂ concentration, include a mean annual temperature increase of about 0.7 °C over the next 30 years, and an increase in winter precipitation of about 8% over the same time period (Lábraga 1998). It seems reasonable to speculate that higher temperatures with close-to-equal precipitations observed over the 60/70 year records for Río Gallegos, could have led to present-day drier environmental conditions relative to the pre-European situation. Changes predicted for patterns of annual distribution of rainfall by GCMs could eventually enhance the susceptibility of Magellanic grass steppes to undergo further unwanted replacements from grass to woody life-forms, according to a conceptual model proposed by Sala *et al.* (1997).

Predicting the long-term sustainability of the Magellanic grass steppes under grazing within the context of a changing climate, is possibly the most important challenge we face today. In order to address this issue we will need to increase our understanding of animal-plant-environment interactions at several spatial and temporal scales. Ecological models have been used successfully in the past to integrate biotic and abiotic factors into a system in order to study

their interactions. A new generation of these models, that uses GIS technology, can simulate ecosystem dynamics taking spatial heterogeneity into account. A good example of this is the SAVANNA landscape model developed by Coughenour (1993) at the Natural Resource Ecology Laboratory of Colorado State University. SAVANNA is a spatially explicit, process-oriented model that can simulate long-term dynamics in the plant community under an array of disturbance events and of climatic and management scenarios. It has proven to be an excellent tool to simulate processes occurring at different spatial scales, and to address questions involving spatial heterogeneity of sheep distribution and its expected impacts on plant functional type replacement processes. SAVANNA has been used successfully to simulate cold temperate steppes in western United States, and the dynamics of African savannas and Australian shrublands. The use of this generation of simulation models would allow an assessment of present understanding of structure and functioning of the Magellanic grass steppes, a prioritization of future field research, and would help generate longer-term predictions of system sustainability under grazing.

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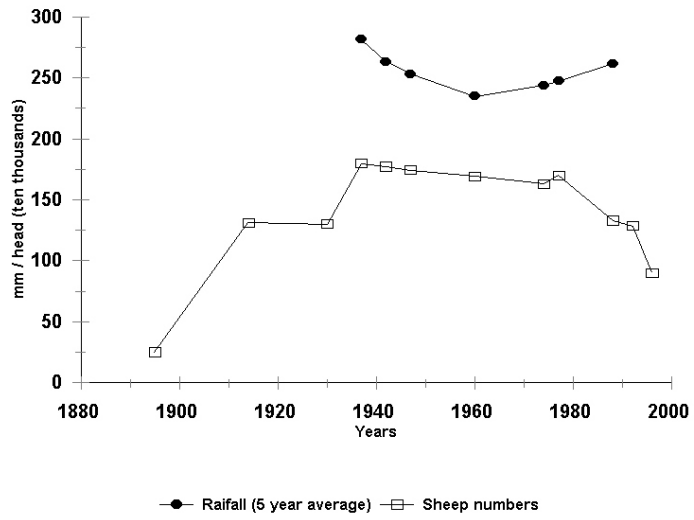
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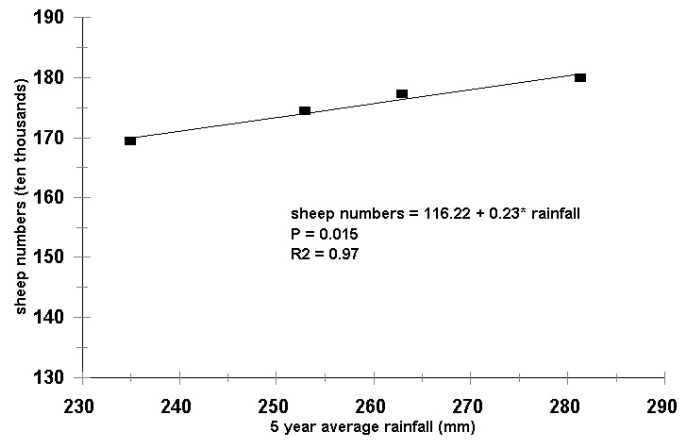


Figure 1 A map of the Magellanic grass steppes

a)



b)



c)

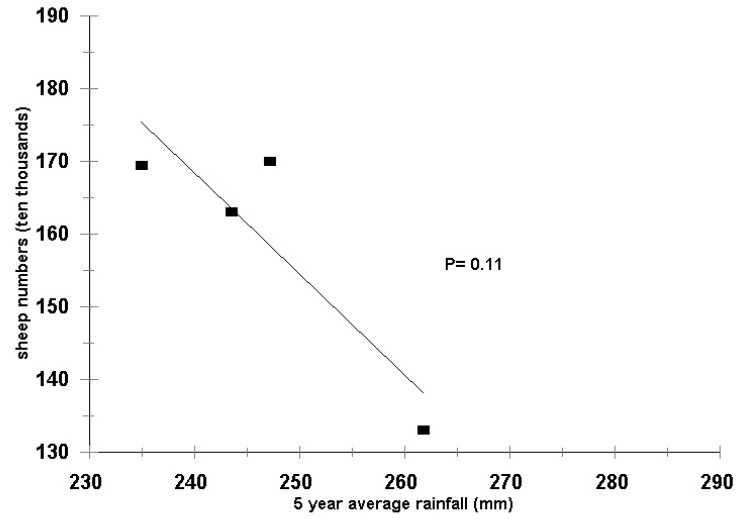


Figure 2: a) Sheep numbers for Güer Aike county (continental area of the Magellanic steppe) and 5-year average precipitation data for Río Gallegos. b) Relation between Güer Aike county sheep population and 5-year average precipitation for Río Gallegos for the period 1930-1960.c) same as b) for the period 1960-1990.

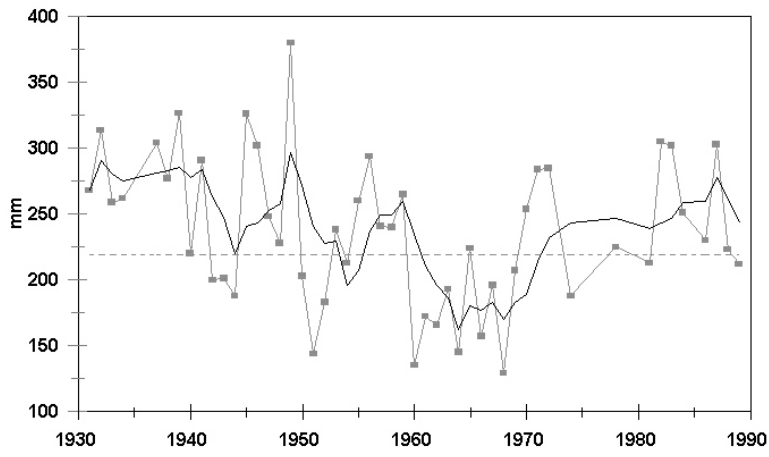


Figure 3: Historic annual precipitation data for Río Gallegos

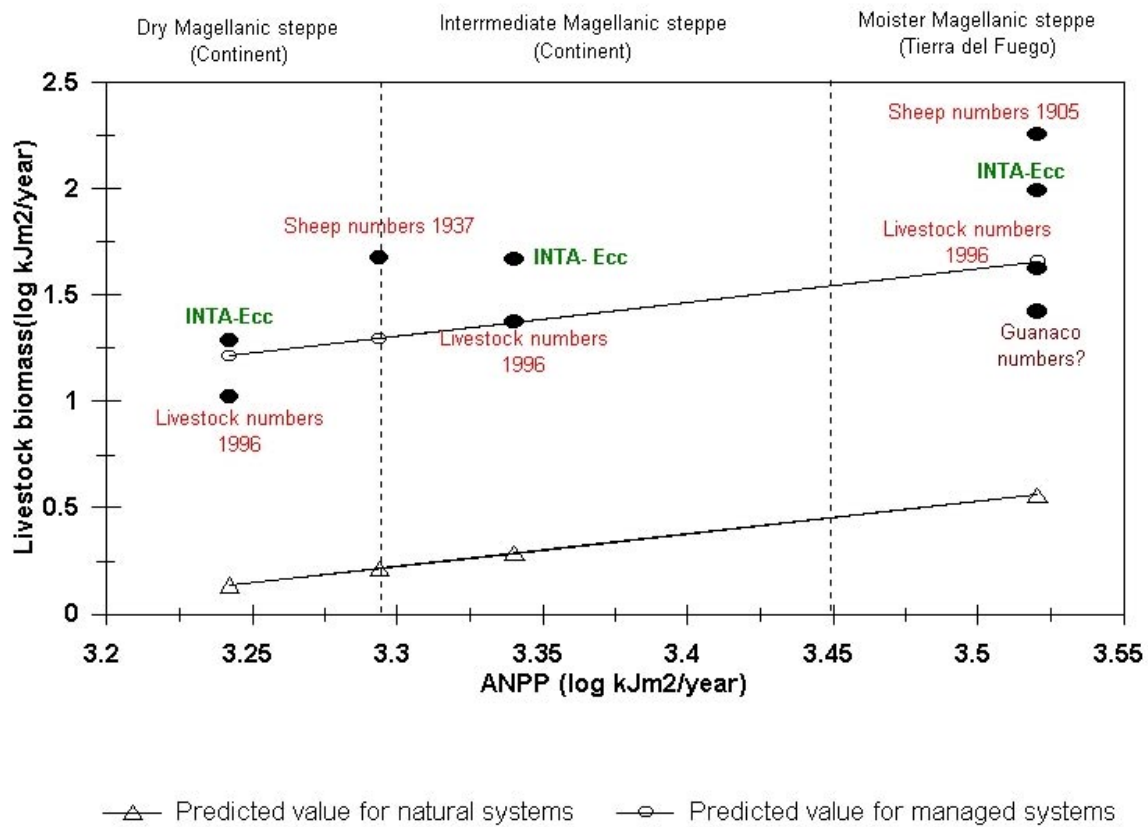


Figure 4: Relation between log ANPP (calculated as $[(0.6 * \text{precipitation}) - 29] * 16.76 \text{ kJ}$) and log livestock biomass (using 9,900 kJ per kg of fresh live weight) for different sites on the Magellanic steppe in relation to regional herbivore carrying capacity equations developed by Oesterheld *et al.* (1992). The linear fit lines correspond to predicted values of herbivore biomass according to Oesterheld *et al.* (1992) for managed systems (open circles) calculated as: $\log \text{ herbivore biomass} = 1.602 * \log \text{ ANPP} - 3.98$; and for natural habitats (open triangles) calculated as: $\log \text{ herbivore biomass} = 1.52 * \log \text{ ANPP} - 4.79$. The solid circles correspond to: a) peak sheep population census numbers; b) INTA's estimation of livestock carrying capacity; c) Livestock numbers (mostly sheep) in 1996 from state census figures; d) an estimation of guanaco biomass.

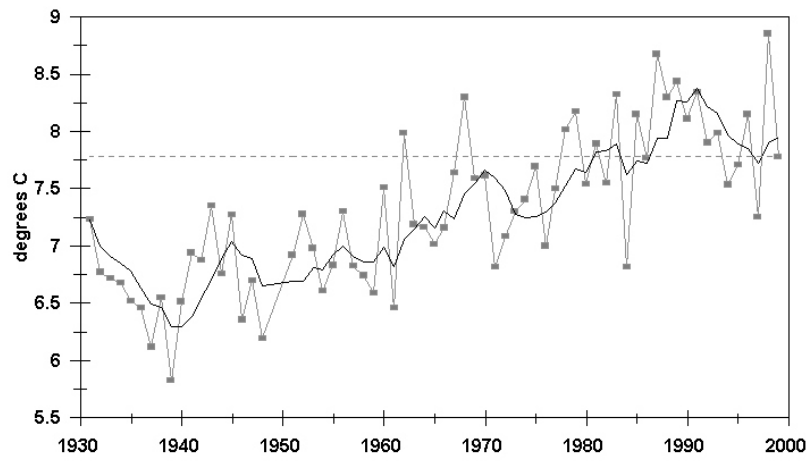


Figure 5: Historic mean annual temperature data for Río Gallegos.