The power of long-term observation: What can reveal 19 years of grassland monitoring without experimental manipulation?

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Introduction

Long-term ecological monitoring is required for understanding population dynamics. Vegetation changes in arid and semi-arid ecosystems generally occur in the short- term in response to rainfalls and in the long-term in response to rare events (fires, volcanic eruptions). For developing management strategies for sustainable animal production and species conservation it is necessary to know how resilient arid and semi-arid ecosystems are.

Methods

We acquired three long-term plant community data sets for three sites in grasslands of the northwestern Patagonia region (San Ramon ranch, 41º 03' S, 71º 01' W; Argentina) (Fig. 1). The grasslands are co-dominated by *Pappostipa speciosa* (Trin. & Rupr.) Romasch and Festuca *pallescens* (St. Yves) Parodi tussock grasses with presence of *Mulinum* spinosum (Cav.) Persoon and *Senecio* bracteolatus Hook. & Arn. scattered shrubs and *Fabiana* imbricata Ruiz & Pav. shrublands.

Two of these sites were postfire (North and South sites) and the third (Control site) was an unburned grassland similar in vegetation, soil, and topography to the postfire sites. The South site is influenced by the nearness of a road, which constitutes a corridor for exotic species.

The peak-season foliar cover was measured by species in individual plots (18 by site) located in fixed transects (3 by site) from 1999 to 2007 (9 years) in the postfire sites and from 1999 to 2017 (18 years) in the control site. From these data we calculated richness, diversity and evenness of the three communities.

Natural disturbances: drought, fire and volcanic eruption

Before the 1999 first vegetation measuring a severe drought affected the region. Then a severe wildfire occurred in 1999 January affecting a big area (21477 ha, see Ghermandi *et al.* 2004) and in 2011 a volcanic eruption deposited between 30 and 0,2 mm of tephra on a very huge area (19700000 ha in Río Negro Province; Gaitán 2011, Ghermandi& Gonzalez 2012, Ghermandi *et al.,* 2015).

Climate and soil

The climate is Mediterranean and temperate with the 60% of precipitations concentrated in autumn and winter. The mean annual precipitation is 578 mm, and the mean annual temperature is 8.7º C. Strong W-NW winds blow frequently throughout the year, accentuating water stress in summer (meteorological station of the San Ramón ranch, unpublished data). Soils are Haploxerolls with sandy-loam texture and superficial horizons containing organic matter (Gaitán *et al.,* 2004).

Weather data sets

We calculated seasonal weather from the data base of San Ramon meteorological station because we assumed that population dynamics of individual plant species, which underlie richness and diversity fluctuations, are affected by weather on a finer temporal scale than captured by annual values (Adler and HilleRisLambers 2008).

Data analysis

Vegetation monitoring began in 1999. Two recently burned sites and an unburned site were evaluated. Burned sites (North and South sites) were monitored until 2007 and unburned (Control) until the year 2017. In July 2011 a volcanic eruption occurred and from that year the unburned site represents a post-eruption site. Therefore, the data collection allowed to monitor the dynamics of the vegetation in three situations, control, post-fire (two sites), and post-eruption, where the Control and post-eruption sites are the same site in different periods.

The experimental design generated data with a hierarchical structure: observations nested in points (repeated measures) nested in sites. Thus, both the cover and the richness were analyzed with linear mixed-effects models considering the point as a random effect (random intercept model). The models included variance functions and the temporal correlation was modeled with an auto-regressive structure of mobile windows (ARMA). The fixed-effects of the models included time, disturbance condition, precipitation and temperature occurred during winter and spring, and interactions. Interactions analyzed were disturbance x time (to evaluate if temporal patterns differ among disturbance conditions) and the double-interactions between precipitation and temperature (to evaluate, for example, if the effect of spring temperature depends on whether winter was rainy).

Results

Cover

- Control
  The study began (1999) with an average coverage of 55%, which, on average and discounting the effects of climate, grew at an annual rate of 1.5% until 2010.
- Post fire
  After the fire both sites burned had a cover of ≈ 33% (between 20 and 25% less than the control), which, discounting the effect of the climate, increased in both sites at average rates close to 2% per year. However, the trends of temporal change were not significantly different from that of control.
- Post eruption
  Immediately after the eruption the control site had 57% cover. This represented a reduction of 10%, since the previous year the cover was 67%. Unlike control and burned sites, coverage remained almost constant after the eruption (0.3% / year increase).

– Weather
The winter and spring rains had a positive effect on vegetation cover (0.04 and 0.07% per mm, respectively). Positive interaction between spring and winter temperatures was found. This means that the coverage was higher in warm springs preceded by warm winters. In particular, when the winters were cold the spring temperature affected the cover. The spring temperature also benefited the cover when it was preceded by wet winters.

Richness
– Control
The study began (1999) with an average richness of 8 species. Eleven years later (year 2010), that is, before the eruption, it was 10 species. This implied that, discounting the effects of the weather, richness increased significantly during this period at an average annual rate of 0.3 species.
– Post fire
After the fire, the number of species of the burned sites was significantly higher than that of the control (9 and 11 species in each site). In addition, unlike the control, between 1999 and 2007 both sites decreased their richness at an average rate of between 0.05 and 0.25 species per year.
– Post eruption
After the eruption, the control site had, on average, 6 species. This means that the disturbance eliminated almost 3 species (the previous year the average richness was almost 9 species). After the volcanic event, the richness increased to an average rim of 0.7, differentiating significantly from the pre-eruption trend and from the post-fire sites.
– Weather
Precipitation benefited richness. In the winter, on average, richness increased by 0.01 species per mm of rain, and in the spring by 0.03 species per mm. The temperature of spring increased the richness and this effect was higher when the temperatures of winters were higher (positive interaction).

Preliminary conclusions
The climate affected similarly the cover and richness. Both the rains and the temperature had a positive effect, and the effect of the spring temperature depended on the winter temperature. In contrast, the cover and richness were affected differently by the type of disturbance. After the fire the cover was increasing in time and the richness was decreasing. In contrast, while the cover remained relatively constant post-eruption, the richness increased.