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Effects of volcanic ash deposition on the early recovery of gap vegetation in Northwestern Patagonian steppes

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ABSTRACT

Volcanic eruptions can cause changes in plant communities through the effects of ash fall. We studied the effect of ash deposition on vegetation recovery in inter-plant patches (gaps) following the eruption of the Puyehue-Cordón Caulle volcano (June 2011) in the Northwestern Patagonian steppe of Argentina. We estimated the aboveground vegetation cover and the seed bank abundance (April 2012) in gaps with and without ash (November 2011 and December 2012). We compared the sampled data with studies performed in the area before the eruption. Total plant cover was greater in gaps with ash compared to gaps without ash. Ash deposition suppressed cover of therophyte exotic species, but augmented total cover due to the increase of geophyte cover. Pre- and post-eruption soil seed bank was dominated by therophytes, mostly exotic species. However, ash deposition decreased the abundance of the total seed bank, including therophyte species. The position of buds and plant size in relation to ash layer thickness were important in determining plant recovery. Our results indicate that ash derived from volcanic activity can change species abundance and composition of steppe gaps that are important for the regeneration of matrix species.

1. Introduction

Global volcanic activity is an important hazard affecting almost all world biomes. There are 1551 active volcanoes (i.e. Holocene volcanoes), which 868 of them have erupted in historical times (Smithsonian Institution, National Museum Natural History, Global Volcanism Program, 2013). Despite the impacts of volcanic eruptions on many different ecosystems, studies on post-eruption recovery are relatively scarce in steppes (Mack, 1981, 1987; Black and Mack, 1986; Martin et al., 2009; Wilson et al., 2012; Ghermandi and Gonzalez, 2012). However, a high number of active volcanoes impact the arid lands that cover approximately 1/3 of the earth surface. Tephra deposits may cover large regions and their depth varies depending on distance to volcanic source (lower depth at greater distance), but they usually spread homogeneously at a landscape scale (del Moral and Grishin, 1999).

The effects of ash deposition on ecosystems are complex and depend on chemical composition of the ash, size and shape of particles, season of eruption occurrence, depth of ash deposits, type of vegetation and fauna, climate, topography and land use (Dale et al., 2005). Ash alters water use due to plant death and changes water availability because ash texture is different from that of soil particles and produces a mulching effect by retarding water evaporation from soil surface (Black and Mack, 1986), and by increasing water retention because of ash's high porosity (Wilson et al., 2012). Volcanic ash can change the albedo in grasslands (Black and Mack, 1986). An inverse relation exists between soil temperature and albedo, and the gray ash surface has a higher albedo than the darker soil. In open habitats, like the steppe, where seed germination responds positively to soil temperature increases during the growing season (Ferrari and Parera, 2015), the increase of soil albedo can decrease seedling emergence. Ash fall is more detrimental at the start of the growing season (spring) and less severe in autumn, when plants are dormant (Mack, 1981; Hotes et al., 2004).

Initial changes in vegetation cover are greatly influenced by pre-eruption species composition, thus description and monitoring of post-disturbance effects on vegetation soon as eruption is critical (Zobel and Antos, 1997). Complete burial by ash kills small annual species (Smith, 1913; Galán de Mera et al., 1999; Tsuyuzaki and Hase, 2005), but, if the tephra layer is not too deep, plants with buds localized near volcanic ash surface can recover more easily than annual species (Kent et al., 2001; Voronkova et al., 2008). Persistent seed banks can survive under tephra. Mack (1981)

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recorded the seed production of annual species *Draba verna, Holosteum umbellatum* and *Erodium cicutarium* buried after Mount St. Helens eruption and he suggested that these species' recruitment would depend on gaps without ash and that their abundance may be diminished. Ash fall can also have beneficial effects on vegetation, such as reduced seed predation and herbivory by insects due to the insecticide effects of the ash (Buteler et al., 2011; Masciocchi et al., 2012).

Argentinean Patagonia is a vast territory that extends from 37° to 55° S and covers 786,595 km^2 (del Valle, 1998). Most of this region is impacted by eruptions from the Chilean Southern Volcanic Zone (33°–46° S) (Lara et al., 2006; Wilson et al., 2012) which has 500 active volcanoes, 60 of which have historical records during the last 450 years (300 eruptions in total, Servicio Nacional de Geología y Minería de Chile). Dominant winds are westerly and ash fall impacts the steppe that occupies most of Argentinean Patagonia. Recently (1991, 2008) two Chilean volcanoes erupted explosively affecting the Argentinean steppe (Besoain et al., 1997; Lara et al., 2006; Martin et al., 2009). Also the Puyehue-Cordón Caulle volcanic complex erupted on 24 May 1960 following an earthquake (magnitude 9.5, the largest measured earthquake in history) on 22 May. This eruption started with a powerful explosive phase, which formed an ash column 8 km in height (Barrientos, 1994).

In Patagonian steppe, gaps (areas between tussock grasses and shrubs) are the recruitment microsites for dominant plant species (Defossé et al., 1997; Franzese et al., 2009; Franzese and Ghermandi, 2012a,b), and also preserve herbaceous richness (Ghermandi and Gonzalez, 2009). For this reason we studied the early vegetation dynamics of gap microsites after the most recent eruption of the Puyehue-Cordón Caulle volcanic complex. The aims of the present work were to determine:

1) the effect of the volcanic eruption on vegetation cover and on seed bank abundance.
2) the effect of the ash fall on short-term (one season) vegetation recovery and on seed bank recharge (by post eruption seed production).

2. Materials and methods

2.1. Description of the Puyehue-Cordón Caulle volcanic complex and the study area

The Puyehue-Cordón Caulle Volcanic Complex (PCCVC) is located at 40.5° S, 72.2°W in the Southern Volcanic Zone of the Chilean Andes. This complex extends between the Cordillera Nevada caldera (1799 m a.s.l.) and the Puyehue stratovolcano (2236 m a.s.l.) with a fissure system between them named Cordón Caulle (1793 m a.s.l.) (Lara et al., 2006). The PCCVC is one of the most active volcanic complexes in the Southern Andes with eight eruptions occurring in the twentieth century (Lara et al., 2006). The most recent eruption of the volcano complex occurred on June 4, 2011 (SERNAGEONIM, 2014), and according to its high volcanic explosivity index (VEI = 4), it was considered large and infrequent. The volcano complex remained active with decreasing intensity until September 2012, and the emitted ash was distributed by the prevailing western winds beyond the eastern Andes on a vast area of Argentinean Patagonia (Gaitán et al., 2011) (Fig. 1).

Our study was carried out in a semiarid grassland of Northwestern Argentinean Patagonia (30 km E of Bariloche, at the San Ramón ranch; 41°04′S, 70°51′W) located 100 km from the eruption zone. Soil was covered by an average of 3 cm of tephra (Gaitán et al., 2011; Ghermandi and Gonzalez, 2012) (Fig. 1), with particle size ranging from 0.001 to 0.025 mm. To avoid the negative effects of ash fall on livestock, they were temporarily removed from the grassland soon after the eruption. Climate is temperate with a mean annual precipitation of 586 mm (Mediterranean regime with 60% of rainfall accumulated in autumn and winter) and a mean annual temperature of 8.7 °C (San Ramón's Meteorological Station, located 1 km away from the study area). Strong W-NW winds blow frequently throughout the year, accentuating water stress in summer (Godagnone and Bran, 2009). The landscape originated from volcanic activity and presents a relief of smooth plains and hills with numerous rocky outcrops, eroded by the glaciers in the Pleistocene and covered by ash from volcanoes located in Chile during the Holocene (Anchorena et al., 1993; Anchorena and Cingolani, 2002). Dominant soils are moderately developed (Haploxerolls) with sandy-loam texture and superficial horizons containing moderate organic matter (Gaitán et al., 2004). Vegetation cover is approximately 60% and consists of a matrix dominated by the tussock grasses *Pappostipa speciosa* ((Trin. and Rupr.) Romasch, ex *Stipa speciosa*) and *Festuca pallescens* (St. Yves) Parodi, and by scattered mid-sized shrubs such as *Mulinum spinosum* (Cav.) Pers. and *Senecio bracteolatus* Hook etArnott. Gaps (bare areas between tussocks and shrubs) are colonized by small native herbs like *Plagyobothrys verrucosus* (Phil.) Johnst, *Triptilion achilleae* Ruiz et. Pavón, and *Microsteris gracilis* (Hook.), and by exotic herbs like *Draba verna* ((L.) Bess. ex *Erophila verna*), *Holosteum umbellatum* (L.), and *Rumex acetosella* (L.) (Ghermandi and Gonzalez, 2009). Bare soil ranges from 29% to 60%.

2.2. Sampling design

2.2.1. Pre- and post-eruption vegetation and seed bank data

To assess the effect of the volcanic ash deposition on vegetation and soil seed bank, we compared pre- and post-eruption species composition and abundance in gaps. Pre- and post-eruption data sets were collected in the same seasons with similar meteorological conditions (i.e. accumulated precipitation and mean temperature). We collected the post-eruption vegetation data on Nov 2011 (in spring, five months after eruption) from 20 gaps covered by ash ('ash treatment': see detailed sampling in Section 2.2.2). Pre-eruption data were collected in the same study area in Nov 2008 from 50 gaps, where a 0.25 m^2 frame was used to sample the gaps (data published in Franzese and Ghermandi, 2012a).

We collected post-eruption soil samples to evaluate seed bank on April 2012 (in autumn, after seed dispersal and before seed germination) in the same gaps used for vegetation sampling (soil of 'ash treatment': detailed sampling in Section 2.2.2). Pre-eruption seed bank was estimated by the seedling emergence method from soil samples collected in April 2001, in 20 gaps from similar grasslands, and within the same vegetation community, located 3 km away from the current study area in the same paddock (Ghermandi and Gonzalez, 2009). Considering the similarity in plant community, meteorological conditions, and land management during the compared periods, we expected that the observed differences in the analyzed variables are mainly due to the effect of ash deposition.

2.2.2. Ash and ash removal treatments

To assess the short-term effect of ash removal on vegetation recovery and on seed bank recharge, we compared species composition and abundance of vegetation and soil seed bank in gaps with and without ash.

On October 2011 (four months post-eruption), we randomly selected 40 similar-sized gaps (0.46 ± 0.05 m^2) within 1-ha grassland that were assigned to two treatments (n = 20): a) 'ash removal treatment': where we removed the ash using trowels, brushes and a handheld vacuum (minimizing damage to surviving plants), and