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INVASION NOTE

Fire as mediator of pine invasion: evidence from Patagonia, Argentina

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Abstract Fire has been found to promote or halt biological invasions. Pine trees (genus *Pinus*) are highly invasive in the southern hemisphere and the effect of fire on their invasion ability is not clear. An analysis of *Pinus* spreading after wildfires in Patagonia reveals that there is a high risk of pines becoming invasive if ignition frequency increases in Patagonia. Also plantations could increase fire intensity and/or frequency in Patagonia, creating a potential positive feedback between invasion and wildfires. The effect of fires on pine invasion was modulated by precipitation. In areas where precipitation was lower than 800 mm fires did not promote pine invasion. However, in areas with higher precipitation there was a strong promotion of pine invasion by fire, after a lag time. These results show that fire, a disturbance more frequent now in the region, can promote pine invasion.

Keywords Pine plantations · Spreading · Time lag · Wildfires · Precipitation gradient · Tree invasions

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Introduction

Disturbances are well known to promote plant invasion, however the effect of different disturbances may be diverse in different areas (Hierro et al. 2006). For example, fire can promote or retard plant invasion (ĎAntonio et al. 1999). However, for some species, like pines, fire is a particularly important disturbance that can facilitate their invasion (Agee 1998; Higgins and Richardson 1998). Pines, like many other invader plant species, have the potential to change fire regimes by altering fuel loads or fuel connectivity (Brooks et al. 2004; Cóbar-Carranza et al. 2014), and hence for example, increase or decrease fire intensity. Therefore, even when pines invade wildfire-prone habitats, local adapted species may be threatened due to the new fire regime (Keeley et al. 2011). Pines' exceptional capability to establish after fire along with their ability to change fire regimes, may be an advantage over less fire adapted native species. These characteristics could contribute to create a positive feedback which may promote pine invasion (Richardson and Bond 1991, Simberloff et al. 2010; Cóbar-Carranza et al. 2014). Fire can also halt pine invasions, if the pine species are more vulnerable than the natives to fires, or if the fire regime is too frequent for them to seed before the next fire. Also fires can increase environmental harshness for new seedlings during drought periods, limiting the recruitment of new pines. In Patagonia, it is still an open question if fires can promote or halt the invasion of pines, and the objective of this article is to try to understand this. We hypothesize

that fire has site specific effects on pine invasion depending on the vegetation and overall environmental conditions. Here, we discuss evidence of pine invasions after fires that affected plantations and its surrounding vegetation along a precipitation gradient in Patagonia.

Case study in Patagonia

It is estimated that in northwestern Patagonia, Argentina, there are between 700,000 and 2,000,000 ha suitable for plantations with fast growing exotic pines (Schlichter and Laclau 1998). However, there is a lack of knowledge about how to manage the plantations to get the optimal economic yield and at the same time minimize the ecological risks from invasion and fire. The pines were first planted for commercial purposes in the 1970s, with *Pinus ponderosa, P. contorta* and *P. radiata* planted most frequently. Natural wildfire has been a recurrent disturbance for as long as there have been humans in the area (Veblen et al. 2011). The fires are intensified in areas with poorly managed pine plantations where the increased fuel load creates fast spreading crown fires, in areas that only had surface fires before (Veblen et al. 2003, 2011). Unplanned (and unforeseen) wildfires have burnt ca. 5 % of the planted areas, producing a high risk of losses in plantations. The total area of wildfires affecting afforestations at a regional level during the last decade is c.a. 5599 ha/year (Defossé et al. 2011) out of the 79,000 total. Most current plantations are of very young pines (last census showed 56 % are non reproductive individuals) (Loguercio and Dececchis 2006), so it is likely that the areas affected will sharply increase with time. We report, as a detailed case study, data on pine regeneration outside the burned plantations to study the pine spreading in Patagonia. We studied the establishment of pines after fires, suspecting that the establishment success of pines outside of the plantations would be high, since the pine species planted have special adaptations to regenerate after fire (Agee 1998). In addition we document the time since the last fire and the establishment period of the pine outside the burned plantations, which could estimate the time lag of the exotic pine to spread.

Methods

The study was conducted in northwestern Patagonia, Argentina, from Bariloche, Rio Negro province in the north, at 41°S, to Trevelin, Chubut province, in the south at around 43°S. Northwestern Patagonia in Argentina is an area with dramatic landscape changes over short distances. From the Andes, with peaks of around 2000 meters in the area, out into the steppe, the precipitation changes from more than 3000 to less than 500 mm/year over a distance of only 80 km (Veblen et al. 2003). The corresponding change in vegetation ranges from temperate rainforest, mesic and xeric forests, open woodland and shrublands, to steppe with low shrubs and bunchgrasses.

We studied the spreading of pines from burned plantations located in three natural vegetation types: steppe, shrubland and open woodland. The steppe receives about 500–600 mm of precipitation per year. The dominate species are the bunchgrasses *Stipa speciosa* and *Festuca pallescens*, as well as the dwarf shrub *Mulinum spinosum*. In the shrublands the mean precipitation is from around 600–1000 mm/year. The dominate species are xeric shrubs that reach a height of about 1–3 meters, such as *Schinus patagonicus*, *Diostea juncea*, and *Berberis buxifolia*, and the deciduous tree *Nothofagus antarctica.* Near the ecotone with the steppe, *Austrocedrus* stands form open woodlands with bunch grasses and low shrubs such as *Discaria articulata* and *Mulinum spinosum*, under mean annual precipitation as low as 600 mm (Veblen et al. 2003).

The years of the fires, age of the plantation at the time of the fire, and natural community types were documented for all the study sites. We recorded pine establishment inside and outside burnt plantations to study the spreading of pines after fire in 2002–2003, and in 2009–2011 we re-sampled 11 of the same sites monitored before. However, the dry steppe sites were not included in the analysis because we did not find pine seedlings (individuals less than 10 cm tall) or saplings (individuals taller than 10 cm) outside the burned plantations. Inside and outside each burnt plantation two transects were placed with plots of 3×3 m (9 m^2). Transects of 100 meters consisted of 10 squares plots located at each 10 meters. For sites with no evident establishment of pines outside the plantation an area of approximately one hectare was scanned for visible pine individuals and the squares of the transects were closely surveyed to detect any small seedlings.

Mann–Whitney test was used to compare the mean number of pine seedlings and saplings (total

individuals) recorded in 2002–2003 between plantations located in different gradient of precipitation (more and less than 800 mm of precipitation/year). Comparisons of pine recruitment in and out of the plantations and time sampling (2002–2003 vs. 2009–2011) were tested using the non-parametric Wilcoxon test (Zar 1996). Dependent variables were densities of seedlings and saplings of exotic conifers growing out from the subsample of plantations located in more than 800 mm in the gradient of precipitation and recorded in 2002–2003 and 2010–2011. The differences in the number of individuals between 2002–2003 and 2009–2011 were calculated from the same subsample.

We also compared our results with previously published results from unburned areas (Simberloff et al. 2003, Sarasola et al. 2006 and Dezzotti et al. 2009) to compare the observed patterns of invasion with and without fire.

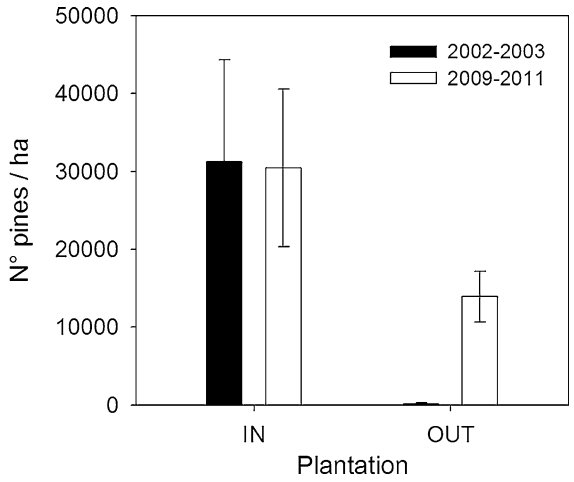

Fig. 1 Mean number of pines establishing inside and outside the burnt plantations located in northwest of Patagonia, recorded in 2002–2003 and re-sampled in a subsample of sites in 2009–2011. Approximately 7 years after the first survey and 17 years since fire, we recorded a high establishment of pines near burnt plantations (13,931.92 ± 109.98 pines/ha)

Results

In 2002–2003 the number of pines found at the different locations varied from 74 to c.a. 80.000 individual/ha inside the plantations. Outside the plantations establishment of pines was scarce and could be found only at two sites, reaching the mean value of 158.7 pines/ha (Fig. 1). The sites where the pines had established in the natural community both had plantations that were 35 years old or older at the time of fire and were located in areas with high precipitation (>800 mm). They were also the sites where the pines were regenerating the most vigorously inside the old plantations and where the fire age was older. The importance of precipitation on the establishment of pines after fires was tested comparing mean number of established pines in areas with a precipitation of 800 mm/year or less to those that had over 800 mm/year. In 2002–2003, the mean number of established pines after fire in the dry areas (1517.06 ± 783.42 pines/ha) were significantly lower than in the wetter areas (27,752.75 ± 11,876.14/ha) (Z 2.98, $P < 0.002$). The low values of seedlings and saplings found in the steppes probably were due, at least in part, to sheep grazing (Sarasola et al. 2006).

In austral summer 2009–2010 and 2010–2011, we re-sampled 11 of the 17 sites studied in 2002–2003. Except the driest areas (steppe), in the other 7 re-sampled sites we found on average a high density of pines spreading outside of the plantations. In general we approximately recorded a significant high establishment of pines near burnt plantations: 13,931.92 ± 109.98 (ES) pines/ha compared to density values recorded in 2002–2003 (U: 2.36, $P < 0.001$; Fig. 1). The years since fire were 9.1 ± 2.9 (ES) in the first survey (2002–2003) and 17.1 ± 2.6 (ES) in the second survey (2009–2011).

Discussion

Our results show a strong regeneration of pines outside the burned plantations in the natural communities, viewing this successful establishment as a possible start of a large scale invasion. After 8–9 years we recorded in seven of the re-sampled sites a high establishment of pines near burnt plantations (in average 13.930 pines/ha). We recorded higher pine regeneration densities compared with previous published results from unburned plantations: Sarasola et al. (2006) recorded no more than 3367 pines spreading in local ecosystems, Simberloff et al. (2003) and Dezzotti et al. (2009) counted 172 and 6.9 pines/ha respectively outside the plantations. Therefore it is likely that the high densities of *Pinus* recruitment found in our study are due to effects of fire which is

Table 1 Characteristics of the studied plantations: age of plantation at the time of fire, year of fire, number of individuals/ha on first survey (2002–2003), number of individuals/ha on the second survey (2009–2011), and pine species, for each plantation

Site	Age of plantation at the time of fire	Year of fire	No of individuals/ha on first survey (2002–2003)	No of individuals/ha on second survey (2009–2011)	Pine species
1	35	1985	741	10,555.5	*Pinus radiata*
2	25	1985	0	10,703	*Pinus ponderosa*
3	35	1987	370	26,238	*Pinus contorta*
4	15–20	1991	0	4776	*Pinus contorta*
5	15–20	1999	0	9101	*Pinus contorta*
6	19	2001	0	9930	*Pinus contorta*
7	20	2002	0	26,210	*Pinus radiata*

known to increase pine recruitment both in its native and exotic ranges.

We found a significant difference of the establishment success of pines depending on the precipitation, with higher establishment in moister sites than in drier sites. Rejmánek (1989) suggested that as a general rule there are more invaders in mesic environments, and that it decreases towards both ends of the moisture gradient. One reason for the lesser establishment of pines in dry areas might be the summer droughts (Despain 2001) and in the Patagonian steppe it could be also the overgrazing (Paruelo et al. 2006, Sarasola et al. 2006). The age of the plantations and the time since fire are factors that could influence the spreading of pines (Table 1). In accordance with other studies and with what had happened in areas where pines invaded after being planted, in the present study older plantations had pine establishment outside plantations limits and, moreover, had much more vigorous regeneration inside the plantation.

One striking result of this study is the time lag of invasion after fire. Invasions did not occur immediately after fire which suggests that some mechanisms were retarding the invasion. Absence of proper mycorrhizal fungi due to a previous absence of inoculum in the system (Nuñez et al. 2009) or the lack of proper vectors of the mycorrhizal fungi (Nuñez et al. 2013) may be behind the observed pattern of slow invasion or absence of invasion. Also, lack of vegetation cover that protects small seedlings from herbivory and dissection could also explain the slow invasion or lack of invasion after the fire disturbance. Time lags are common in invasion and can have important management implications, since people controlling the spread of pines may need to be actively searching for invasion for several years after disturbance.

The predicted increase in extreme and severe fire events due to climate-induced changes in Northern Patagonia could be enlarged in view of current land-use practices, including the conversion of extensive areas of native forests to plantations of non-native fire prone species (Veblen et al. 2011). The accumulation of fuel from plantations to the natural ecosystems is variable, but certainly higher than contributions from most native vegetation which tend to be treeless areas. The example provided by the case study suggests that the association of pine plus fire can trigger their invasion, which can produce a positive feedback cycle of fires and pine invasions, with clear deleterious effects, particularly on local forest ecosystems that were previously dominated by native non-fire-adapted tree species.

The structural changes that plantations produce on native communities are important not only for biodiversity losses but also because they affect fire recolonization processes (Nuñez and Raffaele 2007). These changes alter native species establishment and likely increase the chances of invasions of the exotic conifers inside the plantation and also outside them, and fire seems to be promoting the spread and perpetuation of the studied non-native pines.

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