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Spatial dynamics of *Fabiana imbricata* shrublands in northwestern Patagonia in relation to natural fires

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Abstract. Fire is a critical disturbance in the structuring and functioning of most Mediterranean ecosystems. In northwestern Patagonia, vegetation patterns are strongly influenced by fire and environmental heterogeneity. Dendroecology, together with satellite imagery and GIS, have been demonstrated to be useful tools in studies that relate to fire effects with patches, patterns and species dynamics at landscape scale. Such studies can be approached from landscape ecology, which has evolved in the last years supported by the development of remote sensing and GIS technologies. This study evaluates the spatial dynamic of *F. imbricata* in response to fire using remote sensing, GIS and dendrochronology techniques, at landscape scale. Two sites were evaluated and one of them was affected by fire in the year 1999. The digital processing images (using the NBR spectral index) and the dendroecological analysis verified this. A fire, occurring in 1978, was also detected by the analysis of *F. imbricata* growth rings. The relation between *F. imbricata* shrubland dynamics and spatial configuration with fire, land topography and hydrography was established in the study area.

1 Introduction

Fire is a critical disturbance in changing the structure and functioning of an ecosystem (Pickett and White, 1985) although ecosystems and species can adapt to wildfires (Bond and Van Wilgen, 1996). Fire effects on soil and vegetation are strongly associated with fire regime (Bond and Van Wilgen, 1996) which is highly sensitive to changes in climate and in land use (Veblen et al., 1999b; Medina, 2003). Changes in fire regime are one of the determining factors of vegetation cover (Kitzberger and Veblen, 1999). Therefore, the knowledge of the fire regime, and its climate and anthropogenic modifications, is of great importance to foresee vegetation responses and its changes. Vegetation recovering after fire depends on species characteristics and on weather conditions before and after the disturbance (Bond and Van Wilgen, 1996). For example, traits that allow shrubs post-fire recovery are the resprouting capacity, the recruiting of new individuals from the seed bank or both (Keeley, 1977; Gonzales and Ghermandi, 2008). Regeneration and persistence success of obligate seeders (Keeley et al., 2006) depends on the fire frequency, which would determine if the individuals will reach sexual maturity before the next fire (Bellingham and Sparrow, 2000; Bond and Migdley, 2003).

Dendrochronology is one of the most used methodologies in the study of disturbances regime and dynamics (Kitzberger et al., 2000) and also in the reconstructing of fire histories (Medina, 2003). Dendrochronological techniques have been used in many studies of shrub ecology related to climate change and human disturbances (Haase, 1986; Morales et al., 2005; Barichivich et al., 2009). This methodology gives an accurate determination of the shrubs age, especially in nonsprouting species (Keeley, 1993). Along with this, the use of remote sensing has helped researchers identify the active and past fires and, therefore, to determine the fire regime of a region, if data series are complete and consistent (Johnson and Gutsell, 1994; Díaz-Delgado, 2001; Morgan et al., 2001). In this sense, remote sensing has proved to be a sound alternative to the mapping of burned areas (Heredia et al., 2003) because it not only gives an extensive coverage of wide areas, but also it provides comprehensive information about them (Mitri, 2007). At the same time, it involves a series of advantages when compared with traditional methods. Some of these are the panoramic perspective, the information of non-visible regions of the spectrum, and the repeated cover of the same land portion in comparable observation conditions (Chuvieco, 2002). Numerous studies have been developed in the last decade for the cartography of burned areas

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at local scale with medium-high resolution images (Cocke et al., 2005; Epting et al., 2005; Heredia et al., 2003) and also at a global scale with low spatial resolution sensors like NOAAAVHRR, SPOTVegetation and Terra MODIS (Silva et al., 2005; Stroppiana et al., 2002). Another advantage of fire mapping by satellite images, is that the information of the burned area can be easily integrated with thematic layers of vegetation, land use and environment in a geographic information system (GIS) to analyse the relationship between fire and these variables.

The analysis of vegetation changes can be approached from landscape metrics that are used to make quantitative measurements of the spatial pattern found in a map, an aerial photography or a satellite image (Frohn, 1998). Landscape changes can be analysed through the alteration dynamic of the spatial pattern (Irastorza Vaca, 2006) and, therefore, can be related to phenomena occurring in the landscape (e.g. disturbances). From this point of view, the integrated use of these tools (dendrochronology, remote sensing, GIS) allows us to evaluate the relationships between disturbances such as fire, with vegetation dynamics and to relate them to landscape characteristics (the organization of landscape elements, topography, hidrography).

In the forest – steppe ecotone of northwestern Patagonia – vegetation patterns are strongly influenced by fire (Veblen and Lorenz, 1987), topography, substrate type and possibly the depth of water tables (Anchorena and Cingolani, 2002). Here, fire regime and environmental heterogeneity create a vegetation mosaic of grasslands and *Fabiana imbricata* shrublands (Ghermandi et al., 2004). In this region, for the last 100 years, fire regime has been affected by climate variation, related to ENSO phenomena, and also by human land use (Veblen et al., 1999; Kitzberger et al., 2005). Precipitation exceeds the normal average during El Niño years producing higher rates of vegetation growth and consequently higher fuel accumulation. After this, the occurrence of a drier phase of La Niña will dry the fuel favouring the occurrence and spread of intense and severe fires (Veblen et al., 1992; Ghermandi et al., 2004). Extensive fires have occurred in northwestern Patagonia after three El Niño events followed by a strong La Niña event since 1972 to 1999 (National Weather Service Climate Prediction Centre, 2008; Ghermandi, unpublished).

Fabiana imbricata is a shrub characteristic of the Northwestern patagonian ecotone and that is frequently found in rocky substrates, and also drainage lines and streams, suggesting that it may be a facultative phreatophyte (Anchorena and Cingolani, 2002). This obligate seeder species recruits new individuals after a disturbance (Ghermandi et al., 2010) forming coeataneous shrublands (Ruete, 2006). According to this, high rates of *F. imbricata* recruitment were detected after a severe fire followed by a wet spring and models suggest that this is the best situation for the growth of *F. imbricata* shrublands, also at different fire frequencies (Ghermandi et al., 2010). Global climate change models suggest an increase in the frequency and amplitude of the ENSO phenomena and for this more recruitment windows could be expected for *F. imbricata*.

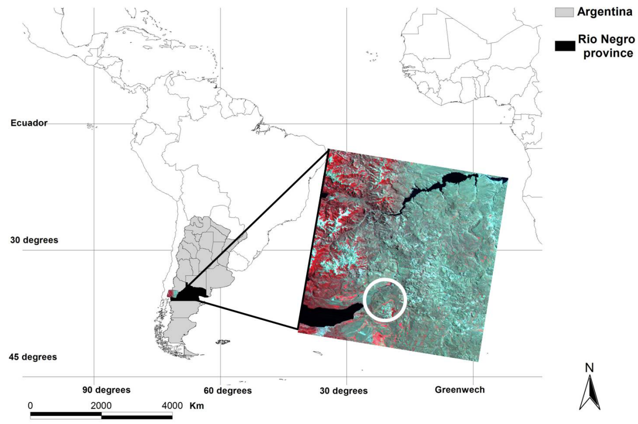

Fig. 1. Study area. Zone of sampling included in image Landsat Path Row 232 88.

Northwestern Patagonian grasslands are the most productive of the region and the main source for cattle and sheep breeding. Frequent fires could stimulate *F. imbricata* encroachment which means a setback for grassland palatable species and, therefore, a decrease in the forage availability, thus a consequential reduction of the stocking capacity.

The main objective of this study is to determine, at a landscape scale, the spatial dynamics of *F. imbricata* shrublands in response to fire using GIS and remote-sensing tools, and dendrochronology techniques in northwestern Patagonian grasslands.

2 Methods

2.1 Study site

The study was carried out at the San Ramón ranch, located 30 km east of Bariloche (Río Negro province), NW Patagonia, Argentina (41°03′19″ S–71°01′50″ W) (Fig. 1). This 23 846 ha ranch is situated in the Andean foothills and its main economic activity is livestock production. The climate is temperate with a Mediterranean precipitation regime, with 60% of precipitation occurring between May and August and mean annual precipitation of 580 mm. The mean annual temperature is 7 °C, with January (22 °C mean maximum temperature) and July (−3 °C mean minimum temperature) the warmest and coldest months, respectively (Meteorological Station, San Ramon ranch). Strong W-NW winds blow frequently throughout the year, accentuating water stress in the warm season. Topography is undulating with numerous rocky outcrops (Anchorena et al., 1993). Soils are moderately developed, of sandy-loam texture, with superficial horizons containing scarce organic matter (Gaitan et al., 2004). Vegetation is classified as the phytogeographical Sub Andean district (Cabrera, 1971; León et al., 1998) that is characterised by tussock grasses. *Stipa speciosa* grassland dominates in the low sectors and *Festuca pallescens* grassland in the high sectors (Boelcke, 1957), with scattered shrubs of *Senecio bracteolatus*, and *Mulinum spinosum* (Ghermandi et al., 2004), leaving some areas covered by native shrublands of *Fabiana imbricata* and *Discaria articulata* (Anchorena et al., 1993; Anchorena and Cingolani, 2002). Incursions from the forest biome include upland types such as small patches of *Austrocedrus chilensis*. Patagonia grasslands are the most productive in the region, being widely used for forestry and stockbreeding. Grazing and fire are the more frequent grassland disturbances that strongly influence vegetation dynamics in this area. In January 1999, a wildfire burned 17 500 ha (60% of the total ranch area) (Ayesa and Barrios, 1999), and quickly spread because of an exceptional 1998–1999 drought, caused by a strong La Niña event (National Weather Service, Climate Prediction Center). The study was conducted in two similar and nearby sites with different fire histories (here called fire and control). Concerning the "fire site", two fire events are known, the oldest one occurred 36 years ago, whereas the second one occurred 10 years ago. It is also known that the 1999 fire (10 years ago) did not affect the "control site".

2.2 Species description

Fabiana imbricata Ruiz et Pavón (Solanaceae), is a native evergreen shrub, characterised by its longevity (approx. 150 years) and which is 1.5–3 m tall. Its geographical distribution ranges from Mendoza to the center of Chubut in Argentina, and from Atacama to Valdivia in Chile. This species has stems with a high density of imbricata leaves and it has axillary flowers situated in axillary or terminal branches. Its fruit is a septicide capsule of 6 mm which contains many reniform seeds of approx. 0.8–1.2 mm, which have a reticulate seed coat (Correa et al., 1971; Gonzalez, 2002). The flowering period extends from September to January. This species forms persistent seed pools in the soil (Gonzalez and Ghermandi, 2008) and its regeneration after a fire depends on seedling production (obligate seeder). The aerial parts of *F. imbricata* are used for medicinal purposes as a diuretic, digestive agent and to relieve kidney ailments (Razmilic et al., 1994) but it has no value as forage specie for cattle and sheep breeding. This species produce well-demarcated growth rings that can be easily identified (Barichivich et al., 2009).

2.3 Geoprocessing data

The 1999 fire-damaged area was determined by using TM satellite imagery processing (10 February 1999 Landsat 5 image, Path Row 232 88). Normal Burned Index (NBR) (Key and Benson, 1999) was tested to discriminate burned and unburned areas. The NBR Index is defined as follows:

$$\mathrm{NBR}_{i,j} = (\mathrm{NB7}_{i,j} - \mathrm{NB4}_{i,j}) / (\mathrm{NB7}_{i,j} + \mathrm{NB4}_{i,j}) \qquad (1)$$

where $\mathrm{NB7}_{i,j}$ and $\mathrm{NB4}_{i,j}$ represent the values of the pixels i, j in the bands 7 and 4 of the Landsat TM images.

Global position system (GPS) was used for mapping the existing shrublands and to determine the vegetation pattern in the field in the two sites. The resulting data were then processed in the laboratory with GIS software (ArcGis). The determination of the vegetation pattern, the localization and the extension of the existing shrublands has been enabled by the use of GIS tools. The thematic layers of the existing shrublands were superimposed with the thematic layers of the shrublands previous to 1970 (San Ramón vegetation map, Anchorena et al., 1993) by using GIS technology in order to estimate the temporal change in the shrublands location. After this, the 1999 wildfire data was also superimposed. All of the spatial data were then converted to the Gauss Kruguer (Zone 1) projection system, using the WGS84 system as a datum and ellipsoid of reference.

2.4 Dendroecological sampling and analysis

For the purpose of counting the growth rings of *F. imbricata* to determine the shrublands age in the field, we cut stumps off this species at ground level. These samples were sanded in the laboratory and, in order to count the growth rings a magnifying glass was used. The fire site has three shrublands, called here Main shrubland, Nearby I and Nearby II, respectively. In order to obtain the cuttings, and due to the rugged topography of the "fire site", we produced a gradient in altitude in the Main shrubland, by delimiting three areas or sub-sites (10 m × shrubland width). These areas, hereafter named transects, were perpendicular to the main slope. In the lowest altitude sub-site (nearby the foothill), we cut 111 shrubs; in the sub-site of medium altitude, we cut 10 shrubs and in the highest altitude sub-site, we cut 8 shrubs. The difference in the number of shrubs sampled was due to the fact that the shrubland's relative density is lower in the highest zones. In the Nearby I and in the Nearby II shrublands, that were supposed to be originated after the 1999 fire, ten shrubs were cut in each of them. As a consequence of the flat topography and the distance to the rocky outcrop, a completely randomized sampling design was used in the "control site". This site has three shrublands (Shrubland I, Shrubland II and Shrubland III) from which 66 shrubs were cut. The location of the transects ("fire site") was previously determined on the satellite image and placed in the field with GPS. For the purpose of testing the relationship between *F. imbricata* spatial dynamics and the wildfires, the transects were uploaded to the GIS and the age of the shrubs was correlated to the known fires. The shrublands age was estimated as the arithmetic mean of the cut shrubs age, but also median and mode were analysed.

2.5 Landscape metrics

In order to identify the pattern generated by the patches in both sites, the data of the mapped shrubs were loaded in the GIS, calculating, at the same time, the characteristic measurements of the patches for each of the shrublands (Forman and Gordon, 1986). The indices measured were:

- A = Patch size (ha)
- P = Perimeter (m^2)
- S = Patch shape index
- I = Interior-to-edge ratio

where patch shape index and interior-to-edge (respectively) are defined as follows:

$$S = P/(2\sqrt{\pi}A) \quad (2)$$

$$I = A/P \quad (3)$$

3 Results

3.1 Geoprocessing data

The NBR index was calculated on the Landsat TM image dating from 10 February 1999 (sixteen days after the outbreak of fire), after it had been geometrically corrected. Figure 2a shows the unprocessed image with a combination of bands 4, 3 and 2, whereas Fig. 2b exhibits the results obtained by the digital process. An adequate contrast between the burned and the unburned areas was generated in the image by the NBR index, allowing us to determine the burned area, which was then converted into a shape file data format and loaded to the GIS software (Fig. 2c).

Data from those shrublands mapped with GPS, the area damaged by fire in 1999, as well as the contour lines, were superimposed in the GIS software. After this process, it was also possible to determine the shrublands location in both sites in relation to the 1999 fire and the land topography (Fig. 3). The shrubland orientation is parallel to the main ground slope (25%) in the "fire site", being the lower part of the shrubland at an altitude of approximately 975 m a.s.l. and the higher part at an altitude of 1050 m a.s.l. On the other hand, two of the shrublands (Shrubland II and Shrubland III) show a tendency to be located parallel to the contour lines in the "control site", whereas the remaining one (Shrubland I) borders a water course. Figure 4 shows each site in detail, while Fig. 5 the position of the rocky outcrop in relation to the shrublands – this is one of the main factors determining the fire behaviour in this region, as it acts as a natural fire break.

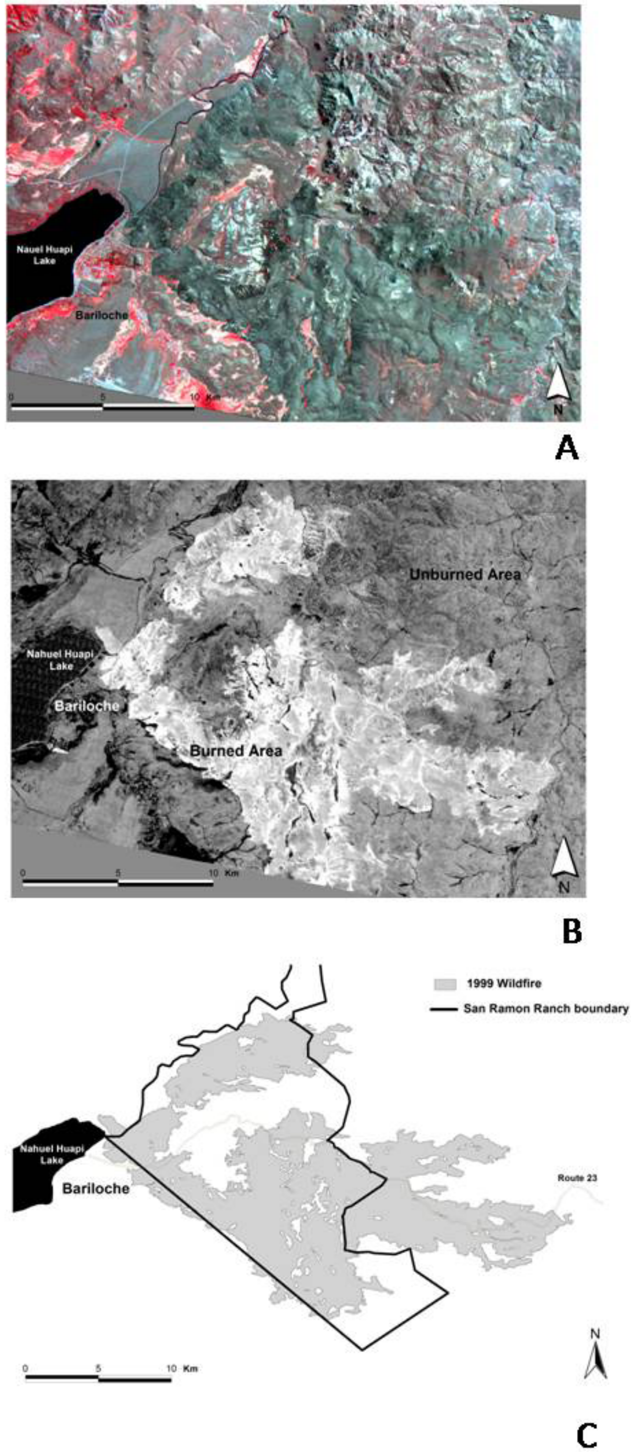

Fig. 2. Image digital processing. **(A)** Unprocessed Landsat TM image from the 10 February 1999, with a combination of bands 4, 3 and 2. **(B)** Landsat TM image from 10 February 1999, after the NBR index was calculated **(C)** Fire data in shape file data format. This figure shows the area damaged by fire in relation to the ranch area.

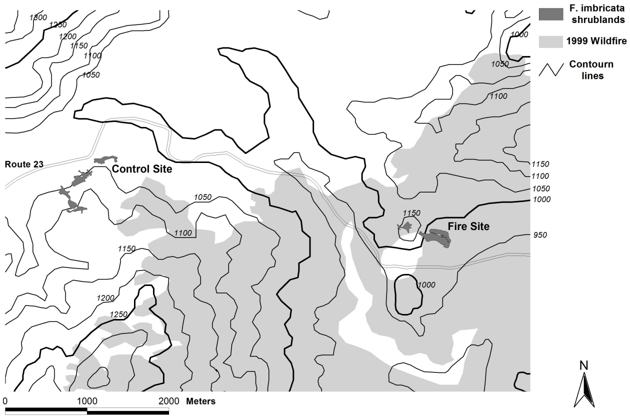

Fig. 3. Map of the area under study. This figure shows the mapped shrublands, the area damaged by the fire of 1999, as well as the topography of both sampling sites.

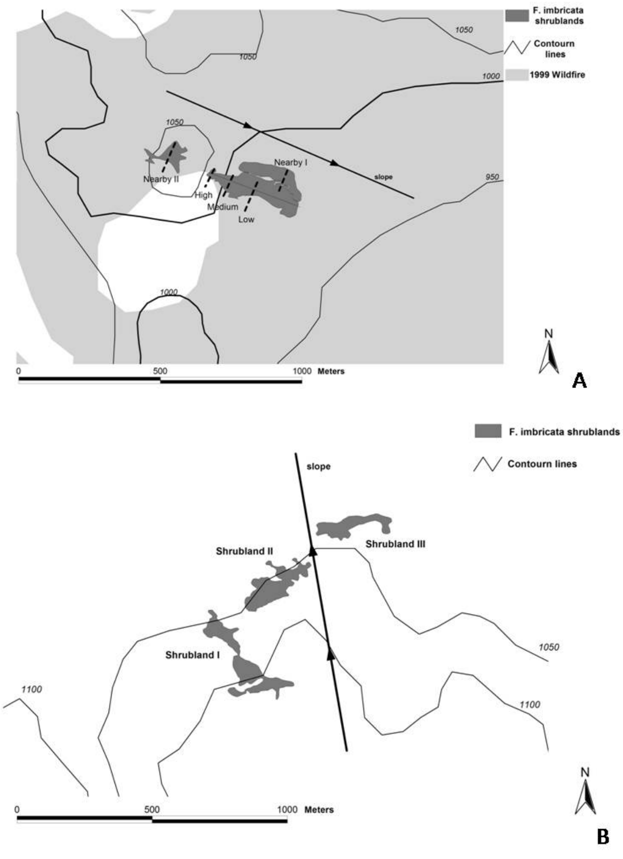

Fig. 4. Map showing in detail the location of the shrublands under study in relation to the 1999 fire and the topography. **(A)** Fire site. **(B)** Control site (this site was undamaged by the fire in 1999).

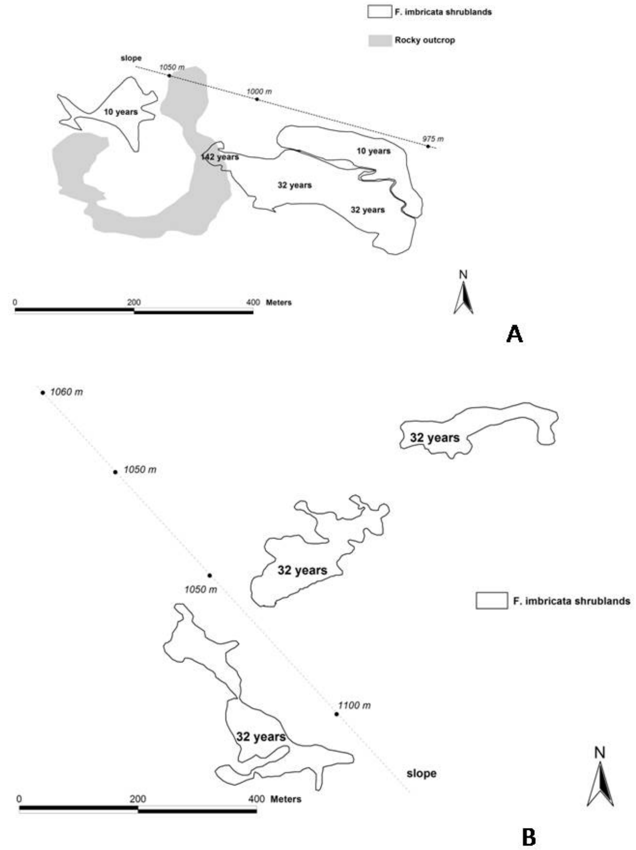

Fig. 5. Spatial distribution of shrubs ages in both study sites. **(A)**. Fire site. **(B)** Control site.

Finally, those *F. imbricata* shrublands included in the vegetation map of the ranch (Anchorena et al., 1993) (which was generated based on a series of aerial photographs dating from 1968), were also loaded to the GIS. Even though no differences can be found in the general location of the patches after comparing the shrublands existing in 1968 with the current ones in the sites under study, there is a shrubland patch, in the “fire site”, which is not present in the vegetation map of the ranch (Fig. 6a); in addition, an important difference can be observed in one of the shrublands in the “control site” (Fig. 6b).

3.2 Dendroecological analysis

Figure 7 shows the age frequency distribution graphs for the shrubs sampled in both sites; while Tables 1 and 2 sum up the descriptive statistical parameters.

In the “fire site” three age groups can be found, whereas there seems to be only one in the “control site”. The age pattern in the “control site” can be discriminated by analysing individually the sub-sites (Fig. 8). Here, in the two nearby shrublands sampled (named here Nearby I and Nearby II, respectively) and that were post-fire 1999, the average age of all shrubs was ten years, showing a coincidence between the year of their establishment and the year in which the fire occurred (1999). Concerning the main shrubland, the shrubs mean age is around 32 years in two of the sub-sites (low and

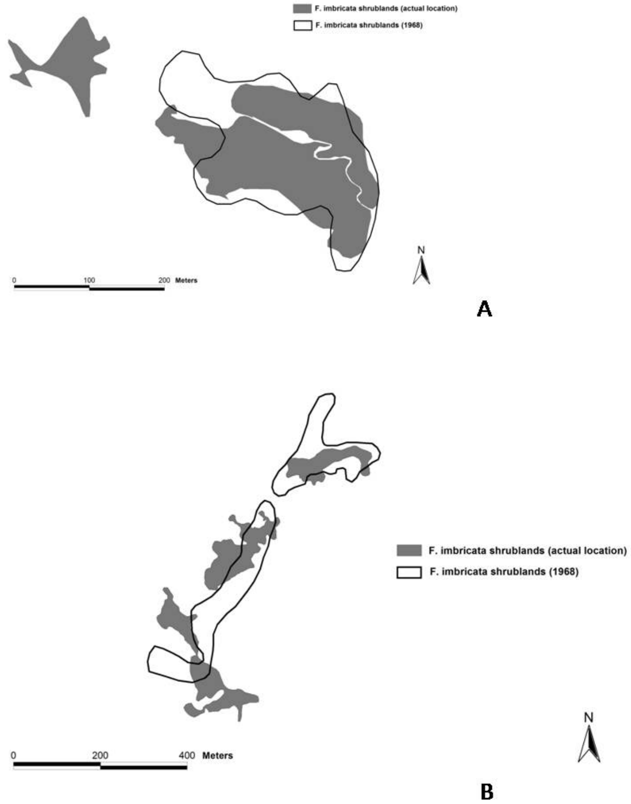

Fig. 6. Temporal change (1968–2009) in the *F. imbricata* shrublands under study. **(A)** Fire site. **(B)** Control site.

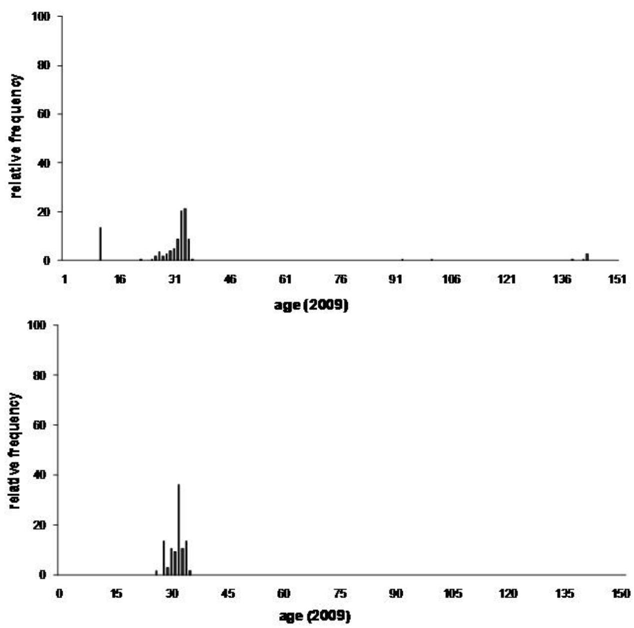

Fig. 7. Frequency distribution of ages for shrubs sampled in the both study sites. **(A)** Fire site. **(B)** Control site.

Table 1. Descriptive statistics of ages for both sampling sites and for each sampling sub-site in the "fire site".

Parameter	Fire site	Control site
mean	33.8	31.4
median	32	32
mode	33	32
s deviation	24.9	2.0
range	132	9
maximum	142	35
minimum	10	26
n	149	66

Parameter	Low transect	Medium transect	High transect	Shrubland nearby 1	Shrubland nearby 2
mean	31.2	32.7	125.8	10	10
median	32	33	140	10	10
mode	33	32	142	10	10
s deviation	2.6	0.8	23.3	0	0
range	14	2	50	0	0
maximum	35	34	142	10	10
minimum	21	32	92	10	10
n	111	10	8	10	10

medium transects), but in the remaining zone (high transect) next to the rocky outcrop (Fig. 5a), the age for most of the shrubs measured was around 142 years, indicating that the spatial configuration of age is closely associated to the closeness to the rocky outcrop. On the other hand, in the "control site", the age of all shrubs was around 32 years; no other shrub groups were found showing a different age. Figure 5 shows the spatial configuration of age in both sampling sites.

3.3 Landscape metrics

Table 2 sums up all landscape metrics used for the patches measured in both sites. No statistically significant differences ($\alpha = 5\%$) were found between the fire and the "control site" in any of them. Mean values for the patch size were in the order of 1.56 ha for the "fire site", and 1.42 ha for the "control site", where all areas were more homogeneous than in the "fire site". A different tendency is apparent for the patches perimeter, having a lower mean value and a lower deviation in the "fire site". A higher medium value in the patch size and a lower perimeter renders the "fire site" with a lower interior-to-edge ratio (18.6 vs. 14.6).

4 Discussion

The digital processing of the satellite image dating from February 1999 to determine the burned area made it possible to determine the boundaries of the 1999 fire. Many authors have reported the NBR index as a good index for the determination of burned areas (Key and Benson, 2001; Heredia et al., 2003; Miller and Thode, 2007; Gajardo et al., 2008)

Table 2. Landscape metrics estimated for the studied *Fabiana imbricata* shrubland patches.

Fire site					
Parameter	Main shrub.	Nearby Shrub. I	Nearby shrub. II	mean	St deviation
Area (Ha)	2.82	1.26	0.59	1.56	1.14
perimeter (m)	994	728	582	768	208.9
shape index	1.67	1.83	2.14	1.87	0.24
interior to edge ratio	28.4	17.3	10.1	18.6	9.18
Control site					
Parameter	Shrubland I	Shrubland II	Shrubland III	mean	St. deviation
Area (Ha)	1.82	1.50	0.96	1.42	0.43
perimeter (m)	1365	949	654	989.5	357.9
shape index	2.86	2.18	1.88	2.3	0.49
interior to edge ratio	13.3	15.6	14.7	14.6	1.16

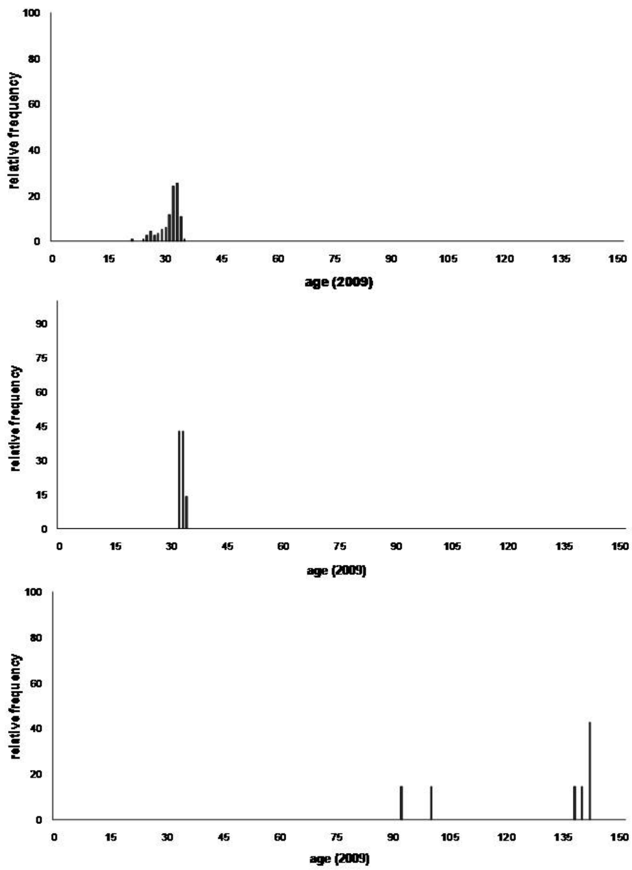

Fig. 8. Frequency distribution of ages for shrubs sampled in main shrubland of the fire site. **(A)** Frequency distribution of ages for shrubs in the low transect. **(B)** Frequency distribution of ages for shrubs in the medium transect. **(C)** Frequency distribution of ages for shrubs in the high transect.

although it has scarcely been used in the Patagonian steppe region. The satisfactory result obtained by using the NBR index in this study is in agreement with those reported by Bran et al. (2003), in a study in which this index had been used and which was carried out in northeastern Patagonia. The fire dating from 1999 in the San Ramon ranch has been, taking its magnitude into account, one of the most conspicuous in the history of the region. The characteristics of the area burned by fire have been studied by several authors (Dentoni et al., 1999; Ayesa and Barrios, 1999) even though the analysis of those images was only visual, and no spectral index was used. In that sense, this study complements the data obtained in previous studies, while offering good possibilities for further studies to evaluate and monitor fires in this region.

The dendroecological analysis enabled the determination of the areas which had been affected by fire in 1999 in the "fire site". Here, the age of all shrubs sampled in the two nearby sites coincide with the period of time passed since the fire of 1999. This same analysis showed a unimodal frequency distribution, with low dispersion and being the statistics of central tendency, which estimate the age, grouped around 32 years for shrubs located in the lower and in the middle part of the slope of the main shrubland. The same pattern was found in the "control site", which confirms that *F. imbricata* regenerates after fire showing no recruitment of new individuals in the subsequent years, thus, forming even-aged shrublands (Ruete, 2006). It can be concluded that, taking into account the average age (32 years) encountered in shrubs (separated 3 km from each other) in both sites, it was possible to determine that the fire which occurred in 1978 damaged both sites. In relation to this, a fire that occurred at the San Ramon ranch in the same year was reported in the study of de Caso (1984), although there is no specific data concerning the area of the ranch affected by this fire.

Likewise, this study does not specify the type of fire and the conditions under which it developed, though it mentioned that it was a natural fire, with a decrease of 50% coverage and individuals of arboreal *Berveris sp.* and *Maytenus boaria* were severely affected and so we assume it was a wildfire of high severity. No satellite image can be found for that year to verify the fire occurrence, but the dendrocronological analysis, together with the above mentioned study, show that those sites were affected by the fire in 1978. The average age for shrubs analysed in the main shrubland in the high transect ranges from approximately 139 to 142 (with the exception of two being 92 and 100, respectively). The longevity of those shrubs and its spatial location on the rocky substrate indicate that *F. imbricata* is sheltered by the rocky outcrop from fire. These rocky outcrops are cited as shelters for plants and animals by many authors (Ward and Anderson, 1998; Douglas et al., 2000; Galende and Raffaele, 2007; Speziale, 2010). In the site under study, the area in which the high transect of the shrublands is located was called "Rocky/sheltered" by Anchorena and Cingolani (2002); besides, it is the habitat for isolated groups of dispersed individuals of *Austrocedrus chilensis*, often multi-stemmed (Pastorino et al., 2004) and scattered shrubs. The results obtained in this study could indicate that these zones can be considered as good shelters for *F. imbricata* when threatened by fire. According to this, there are no rocky outcrops bordering the shrubland in the "control site", and the dendroecological analysis shows that there is only one age group in which no long-lived individuals were present; this could indicate that the site was uniformly burned (having no sheltering areas). The spatial configuration showing a gradient of soil cover from the top to the bottom of the slope beginning with rocky outcrops, followed by *Austrocedrus chilensis* woody islands and ending in *F. imbricata* shrublands (Ghermandi et al., 2009) indicates that both the *F. imbricata* shrublands and the rocky outcrops act as natural fire breaks that shelter *A. chilensis* from fire. The results obtained in this study show no significant differences in the patch metrics analyzed in both sites; however, further evaluation including more sampling sites is needed. The mean size of patches at both sites is very similar (1.56 at the fire site vs. 1.42 in the control site), while there seems to be major differences in the patches form (1.87 vs. 2.3 in shape index and 18.6 vs. 14.6 in the interior to edge ratio for fire site and control site, respectively). Size is a major variable that affects biomass, production and nutrient per unit area and species composition and diversity (Forman and Gordon, 1986). However, in this study, we found no evidence that the natural fires are related to the size of the patch. Also, the shape is one of the more important variables in the landscape because this is related to the patch's edge effect. The patches' edges play an important role in the ecosystem behaviour, as the environmental conditions and the species composition found there differ from those existing inside the patches (Forman and Gordon, 1986). With regard to fire, the fuel load produced in the patches' edges and its influencing area, is different from that which exists inside the patch and the surrounding matrix, and can determine the area, the size and the direction of the fire front (La Croix et al., 2008). Consequently, further research is needed to find out the relationship between the metrics of those patches of *F. imbricata* and environmental variables such as fire, topography and hydrography, in order to integrate these data with the establishment, expansion and the dynamic of this species. Both the shrubland shape and the interior-to-edge ratio appear to be more closely related to the hydrography, the topography and the micro-topography than to the fire effect. The "Shrubland 1" borders the water course in the "control site", with small deviations which are produced by the soil micro-topography. The two remaining shrublands in this site (far away from the water course and having a smooth slope) are located parallel to the contour lines (see Fig. 4b). In the "control site", the Main shrubland and the Nearby I present a longer shape and are orientated parallel to the steep slope of the ground (25%), which appears to influence their shape and location. On the other hand, the Nearby II shrubland, located in a place which is almost flat, the shape does not conform to any topographic pattern.

For instance, Anchorena and Cingolani (2002) have reported that *F. imbricata* was found bordering stream and water courses and, according to that study, this could be associated with the fact that this species is a facultative phreatophyte. Regarding this, we believe that this pattern is generated by the hydric dispersion of the seeds – as they are extremely small and without appendices and, therefore, they are not disseminated by the wind to farther distances. The post-fire recruitment of new *F. imbricata* individuals occurs when there is a wet spring after a fire (Ghermandi et al., 2010); accordingly, and as a consequence of the hydric conditions of soil bordering the streams, this species could generate corridors like those normally seen in the area under study. Therefore, it is an important fact to take into account, as the dispersion has shown to be an essential factor in the spatial structure of communities (Heinz et al., 2005).

In relation to the analysis of the temporal change in the location of *F. imbricata* in the "fire site", a new shrub focus has been found, but no shape or size changes can be observed in the patches of the rest of the site. This site burned twice (in 1978 and in 1999) after the aerial photographs used to make the vegetation map were taken (1968). There is no new shrub focus in the "control site", which burned only once since 1968; however, one of the shrublands shows a difference in size and shape when compared to those shrublands existing in the map. This patch is located on the hydric course, which supports the theory concerning dispersion. Fire is considered a controlling factor of grasslands woody encroachment (Bragg and Hulbert, 1976; Heisler et al., 2003; Heisler et al., 2004) even though the *F. imbricata* encroachment appears to be increased by fire.

The integrated application of the tools used in this study, has made it possible to determine *F. imbricata* spatial dynamics of the analysed sites, showing the potential of these studies at landscape scale, in relation to fire. Our results show, for this study area, that the population dynamics and the spatial configuration of *F. imbricata* are related to fire, but also to the soil topography and hydrography.

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