

EFFECT OF LIVESTOCK ON THE GROWTH OF ROSA RUBIGINOSA IN A MOUNTAIN RANGE: A DENDROCHRONOLOGICAL APPROACH

MESTRE L.^{1*}- CHARTIER M.²- RENISON D.²

¹CADIC-CONICET

Calle Bernardo A. Houssay 200, Ushuaia 9410, Argentina.
(phone: +54-02901-422310; fax: +54-2901-430644)

²CERNAR-IIByT, -CONICET-UNC,

Av. Velez Sársfield 1611, Córdoba X5016GCA, Argentina.
(phone: +54-0351 433 4141/4404)

* Corresponding Author

e-mail: lucianamestre@hotmail.com

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Abstract. In the present study, we used dendrochronological tools to determine the effect of domestic livestock on the cumulative radial growth of *Rosa rubiginosa*, a shrub native to Europe that has been introduced to the mountains of central Argentina. We described *R. rubiginosa* growth rings, we built a ring width chronology using 18 stems from a homogeneous site, and finally compared rings width in 40 individuals distributed in areas with and without livestock but otherwise similar. Our results demonstrated the negative effect of livestock on the cumulative radial growth of invasive species *R. rubiginosa*. In this sense, the livestock would be acting as a biotic filter for the invasion of this species in the mountains of Córdoba (Argentina) and may be considered as a tool to reduce *R. rubiginosa* growth in invaded areas, where livestock will not cause other damages. We consider that the measurement of annual ring width against datable basal stems represents a simple method for the determination of radial growth rates. This approach could be particularly useful for monitoring the effects of land management practices on the invasion of woody species.

Key words: *Dendroecology, invasive species, radial growth rate, Argentina.*

Resumen. En el presente estudio se utilizaron herramientas dendrocronológicas para determinar el efecto del ganado doméstico sobre el crecimiento radial acumulado de *Rosa rubiginosa*, un arbusto nativo de Europa que ha sido introducido en las Sierras del Centro de Argentina. Se describió los anillos de crecimiento de *R. rubiginosa*, se construyó una cronología con el ancho de los anillos utilizando 18 fustes de un sitio homogéneo y finalmente se comparó el ancho de anillo en 40 individuos distribuidos en áreas con y sin ganado. Nuestros resultados demostraron el efecto negativo del ganado sobre el crecimiento radial acumulado de la especie invasora *Rosa rubiginosa*. En este sentido, el ganado estaría actuando como un filtro biótico ante la invasión de esta especie en las Sierras Centrales de Córdoba (Argentina) y puede ser considerado como una herramienta para reducir el crecimiento de *R. rubiginosa* en áreas invadidas, donde el ganado doméstico no cause otros daños. Consideramos que la medición del ancho de anillo anual representa un método simple para la determinación de las tasas de crecimiento radial; en conclusión, se sugiere la utilización de la dendrocronología como una herramienta particularmente útil para monitorear los efectos de las diversas prácticas de manejo del suelo sobre la invasión de especies leñosas.

Palabras claves: *Dendroecología, especie introducida, tasa de crecimiento radial, Argentina.*

Introduction

Biological invasions are considered a key driver of global environmental change (Vitousek et al. 1997; Sala et al. 2000; Castro-Díez et al. 2004). There is a growing number of studies reporting impacts of alien plants on recipient ecosystems, like alteration of hydrological and nutrient cycles, soil properties (Mack et al. 2000; Figueroa et al. 2004; Lake and Leishman 2004), as well as reduction of fitness and growth of resident plants (Vilà et al. 2011).

To be an invasive species, the introduced species must overcome the abiotic and biotic filters offered by the recipient ecosystem. These filters act differently on the different stages of the invasion process (colonization, establishment, etc.), in turn, affecting differently the different stages (reproduction, dispersion, survival, etc.) of the life cycle of the introduced species (Theoharides and Dukes 2007). Biotic filters are barriers to invasion created by the action or presence of living organisms. While biotic filters will not necessarily prevent the germination of seeds or the spread of introduced species, these filters can affect survival, growth, and reproduction (Theoharides and Dukes 2007).

In this context, livestock can act as a biotic filter delaying the growth of the introduced species (Theoharides and Dukes 2007), whether directly by browsing the aerial tissues or indirectly by effects of soil compaction and erosion. Conversely, many authors have reported that livestock can favour the introduced species' growth by reducing intense competition for light, nutrients, and water (Davis et al. 2000; Hierro et al. 2005). Given that no clear patterns have been found on the effects of livestock on the invasion rate of plant species, we consider necessary to study the effects of livestock grazing on the invasion process before deciding whether to use or not to use livestock grassing as a tool to manage plant invasions.

As a general rule, plant growth is modulated by external drivers like climate, topography, soil properties, disturbance degree, etc. (Morales Tejada 1993; Schweingruber 2007). The growth rate can be reliably estimated through repeated measurements of morphometric variables (crown diameter, total height, etc.) or by the application of dendrochronological techniques. In general, dendrochronological techniques can be used to study the annual ring growth of plant species, including trees, shrubs, dwarf shrubs, and herbs (Schweingruber 2007). A lot of work has been conducted on tree species, but little is known about other species which have been taken into account only in the last decades (Schweingruber and Poschlo 2005; Winchester et al. 2007).

Dendrochronology is a method of dating based on the analysis of ring patterns (Avilés et al. 2007), and represents a powerful tool to study the ecology of biological invasions.

The species *Rosa rubiginosa* L. known as sweet briar is native to Europe and has been introduced to several countries in the southern hemisphere, including Argentina (Damascos 1992; 2008). This opportunist shrub is found in disturbed environments with altered vegetation structure and available light increases (Damascos and Gallopin 1992; Zimmermann et al. 2011). Early studies have reported that *R. rubiginosa*, like other species of the genus *Rosa* (Schoch et al. 2004), presents well marked growth rings (Zimmermann et al. 2011; 2012).

To date, in Argentina, *R. rubiginosa* has been cited as an invasive plant in Patagonia and in the mountains of central Argentina. In the first region, this species is considered an aggressive invasive plant because it forms impenetrable mats occupying large areas

and thus out-compete native species (Damascos 1992; Bran et al. 2003; Aguirre et al. 2009). In the central Argentina, *R. rubiginosa* is invasive in the sense that it replaces natural plant communities (Richardson et al. 2000), but it is not as widespread as it is in Patagonia. The limited distribution of the species in central Argentina in comparison to Patagonia is probably due to its comparatively later introduction rather than to less favourable abiotic or biotic conditions (Zimmermann et al. 2010). However, little is known about the factors that influence *R. rubiginosa* growth and distribution in the mountains of central Argentina.

The objective of this study is to determine the radial growth rate of the shrub *Rosa rubiginosa* in sites with and without livestock in the mountains of central Argentina. This work represents part of a regional effort to identify the factors that influence the process of invasion of alien woody species.

Methods

Study area

The study was performed in the Córdoba Mountains (900–2800 m a.s.l.) in central Argentina (Fig. 1) which extend for over 200 km in an N-S orientation. At its upper ranges the vegetation consists of a mosaic of tussock grasslands, grazing lawns, outcrop communities, *Polylepis australis* woodlands and eroded areas with exposed rock surfaces (Cingolani et al. 2004). The mean temperatures of the coldest and warmest months are 10.9 and 14.5°C (at 1700 m a.s.l.), respectively, with no frost-free period. Mean annual precipitation is 895 mm, with most rainfall concentrated in the warmer months from October to April.

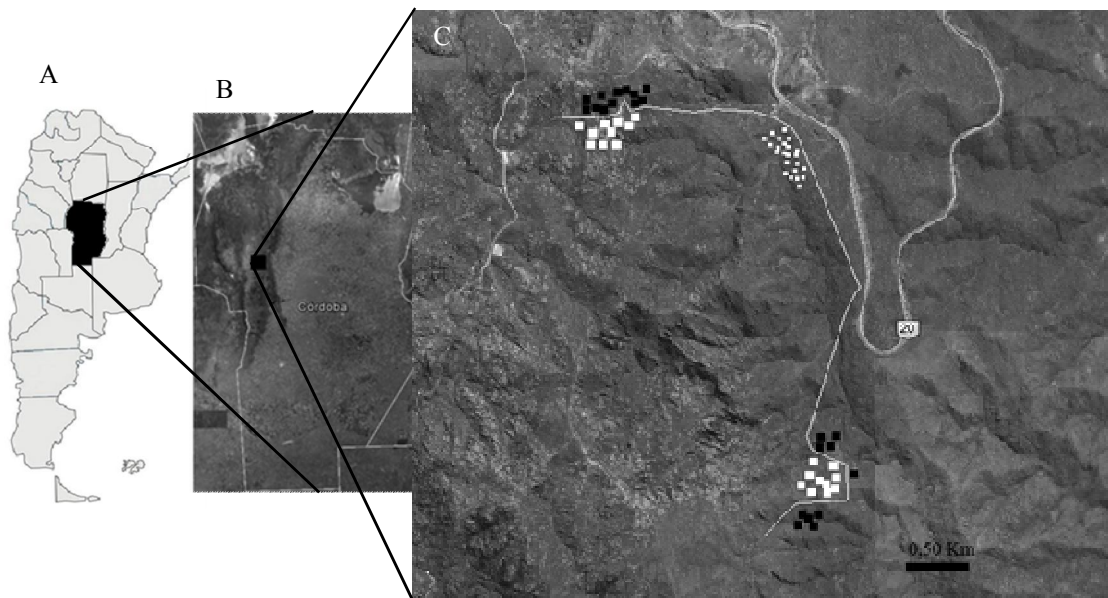


Figure 1. (A) Location within Argentina of Province of Córdoba (in black) where mountains of central Argentina are located. (B) Córdoba province and the study area indicated by a square. (C) North-East section of “Quebrada del Condorito” National Park, where dots represent samples for the different treatments: reference chronology (small white boxes); sites without livestock (big white boxes) and with livestock (big black boxes). The continuous line indicates the limits of the National Park.

The main economic activity in the area is extensive livestock rearing, which together with incidence of fires ignited to promote pasture re-growth, have caused serious problems of erosion and woodland degradation (Cingolani et al. 2003; 2004; Marcora et al. 2008; Renison et al. 2010). In 1997, the creation of the National Park “Quebrada del Condorito” (hereafter “National Park”) determined a substantial change in livestock management regimes, with great portions of livestock exclusion inside the National Park and grazing with moderate to intense stocking rates outside the National Park (Giorgis et al. 2010). In the sites with livestock, the predominant plants are graminoid or herbaceous creeping species like *Muhlenbergia peruviana*, *Alchemilla pinnata*, *Carex fuscua* and *Relbunium richardianum*, while sites with livestock exclusion have greater horizontal and vertical structural diversity predominating tall grasses like *Deyeuxia hieronymi*, *Poa stuckertii* and *Festuca tucumanica* (Nai-Bregaglio et al. 2002; Cingolani et al. 2003).

Sample collection

The *R. rubiginosa* samples were collected in NE sector of the National Park (1600m a.s.l., 31°37'15.0''S and 64°40'62.1''W), which concentrates the highest density of adult individuals in the area (Calamari and Calamari 2009). In the field, the individuals were selected haphazardly, attempting to choose the larger plants so as to obtain a longer time span. The stem with the largest circumference of each selected individuals was cut at ground level. The stems' cross sections were allowed to air-dry for ~20 days and we then sanded them sequentially with 80 to 320 grit sanding belts. Each ring was dated to the year of formation, in accordance to Schulman convention for the southern hemisphere and using a binocular magnifier with a 40X magnification power (Stokes and Smiley 1968). Next, the transverse sections were scanned using a high resolution scanner (1200 ppp). The program Image Pro Plus 4.5 (Spring 2011) was used to determine the ring widths with a precision of 0.01 mm. The samples that presented greater degree of eccentricity or difficulty in delineating the growth rings were measured between two and four radios in each cross section.

Ring width chronology

To verify the annual formation of growth rings we built a reference chronology of *R. rubiginosa* using 20 *R. rubiginosa* individuals from within an exclosure area (Fig. 1C). The samples were processed as previously described and cross-dated by visual and cross comparison of 32 series from 18 stems. Parts of the analyzed series were excluded due to lack of good cross-dating. The quality of this cross-dating and the chronology was verified by means of the COFECHA program (Holmes 1983). Similarities between the chronologies were evaluated using conventional dendrochronological statistics: correlation coefficients, mean sensibility, standard deviation and autocorrelation (Swetnam et al. 1988; Delgado 2000). To build the reference chronology, width values of the 32 series were averaged for each year ring. So, the obtained chronology represents average annual variations in radial growth of *R. rubiginosa* in the study area.

It was not necessary to standardize ring width series due to the reduced number of years of the temporal series studied and because there was no clear growth trend (Pers. com. Fidel Roig).

Effect of livestock on radial growth

In order to evaluate the effect of livestock on the growth rate of invasive *R. rubiginosa* populations we identified two sites where plants were found in adjoining fields in and out of the National Park (*Fig. 1C*). In each site, we haphazardly chose 22 samples, 11 within the National Park (without livestock) and 11 in the adjoining fields (with domestic livestock), totalling 44 samples. Livestock in adjoining fields consisted mainly of cattle, but also a few horses, at densities of around 0.8 cattle equivalent/ha. The samples were processed as previously described; they were measured between 2 and 4 radii in each transverse section. Then, radii were averaged to obtain a reliable series for each cross section. The reference chronology was used to verify the assigned calendar years in each measured series.

To compare the radial growth rate in sites with and without livestock we performed a repeated measures analysis of variance, where radial growth of year 1 through 7 was the within subject response variable, and livestock presence was the predictor variable with two categories (presence and absence, with 20 and 22 samples respectively). We did not include study site in the model after checking that there were no differences in cumulative radial growth between the two study sites. The age of seven years was selected as a cut point to include a plant in the study because few plants were older than this age and including them would lower sample size even further. We also tested at what age cumulative radial growth became significantly different with and without livestock by performing a Tukey test. The assumptions of normality and homogeneity of variances were corroborated and significant level was determined at $P \leq 0.05$.

Results

Characteristics of the Rosa rubiginosa's wood

The transverse sections of a basal portion of the stem of *R. rubiginosa* clearly showed distinct anatomical elements (*Fig. 2*). The pith and radii were relatively large and well defined. The annual growth rings were marked, with circular to semicircular porosity (Esau 1982). The vessels were perfectly aligned and the major diameter was located in the early-wood, but they decreased in size and density as they entered the zone of the latewood. Moreover, the vessels were found to be progressively more solitary and dispersed at the end of the growing period. The analyzed samples showed a concentric radial growth during the first years, with increasing eccentricity at later ages. The limits set between two vegetative periods were unclear only, when the transverse sections with high degree of eccentricity showed stems with incomplete rings. In general, we obtained few samples with false rings (22% of the analyzed samples) and, we did not find cases with absent rings.

Chronology ring width of Rosa rubiginosa

The reference chronology covered a period of 14 years (1997-2010) and was based on the average of the annual growth rings of 18 individuals (*Fig. 3*). Ring width had an average value of 1.16 mm ($EE \pm 0.73$) ranging between 0.06 to 4.40 mm. We confirmed similarities in ring patterns by the cross-dating of 32 series of *R. rubiginosa* stems growing within the enclosure (National Park). The statistics used to measure the quality of the chronology indicate a common signal in the interannual variations of radial

growth among the individual samples that integrated the chronology. The chronology showed a high ($\bar{r}=0.76$) correlation among the 18 stems. The mean sensitivity of standardized ring width indices for standard chronology was 0.52, indicating high variability in growth rings between consecutive years. The autocorrelation index was not significant ($0.32 p > 0.01$), therefore the ring width in a particular year could not be related to the width of previous years.

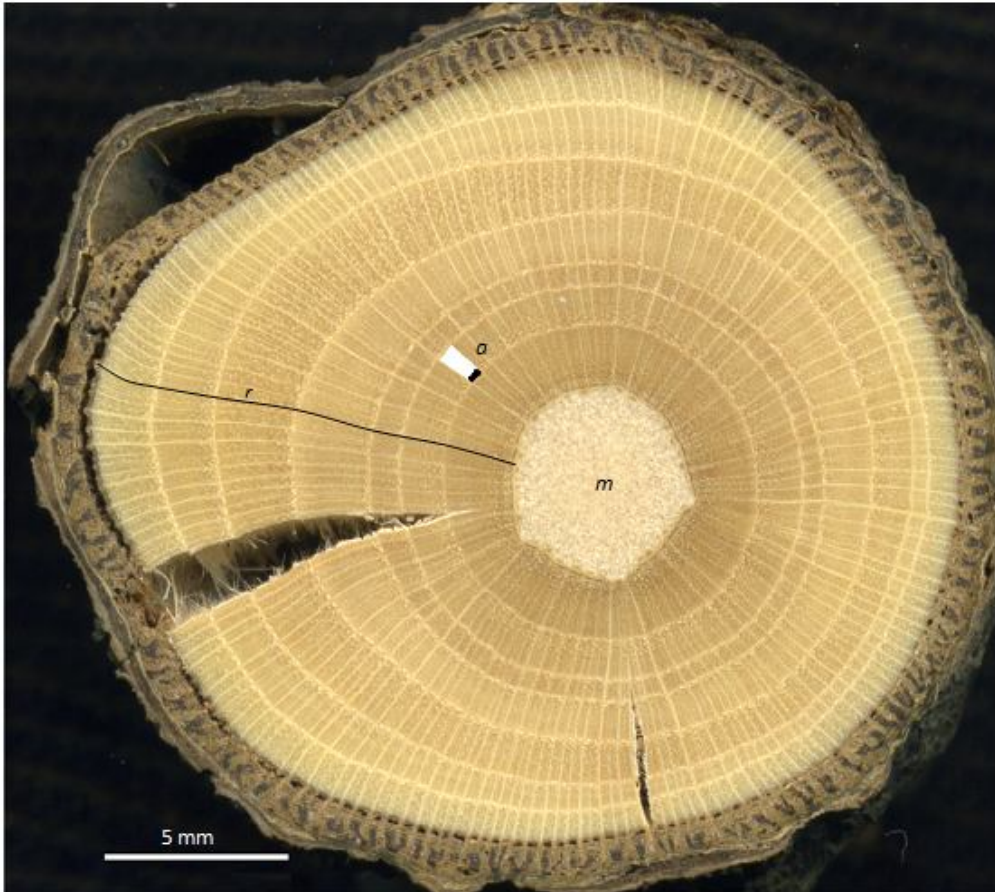


Figure 2. Cross section of *Rosa rubiginosa* stem. The letters indicate: a, growth ring including early-wood (black) and latewood (white); r, radio; m, pith.

Effect of livestock on radial growth rate

The oldest stem was 13 years old and was found in the area with livestock, while the youngest stem, 4 years, was found in the enclosure area. For plants seven years old or older ($N = 12$ without livestock and $N = 10$ with livestock), ring growth was smaller in sites with livestock than without (average for the 7 years, 0.92 ± 0.06 mm/year and 1.16 ± 0.06 respectively, repeated measures ANOVA: $F_{0.05, 1, 20} = 7.94$; $p = 0.01$). The difference in ring growth between livestock conditions was similar for every age except at the 4th and 7th years when the differences were almost zero (< 0.1 mm; Fig. 4A). Differences with and without livestock in cumulative radial growth were not significantly different when comparing plants of ages 1 and 2 years ($p = 0.99$ and 0.26 respectively) and became significant at age 4 and thereafter up to age 7 ($p < 0.01$ in all cases; Fig. 4B).

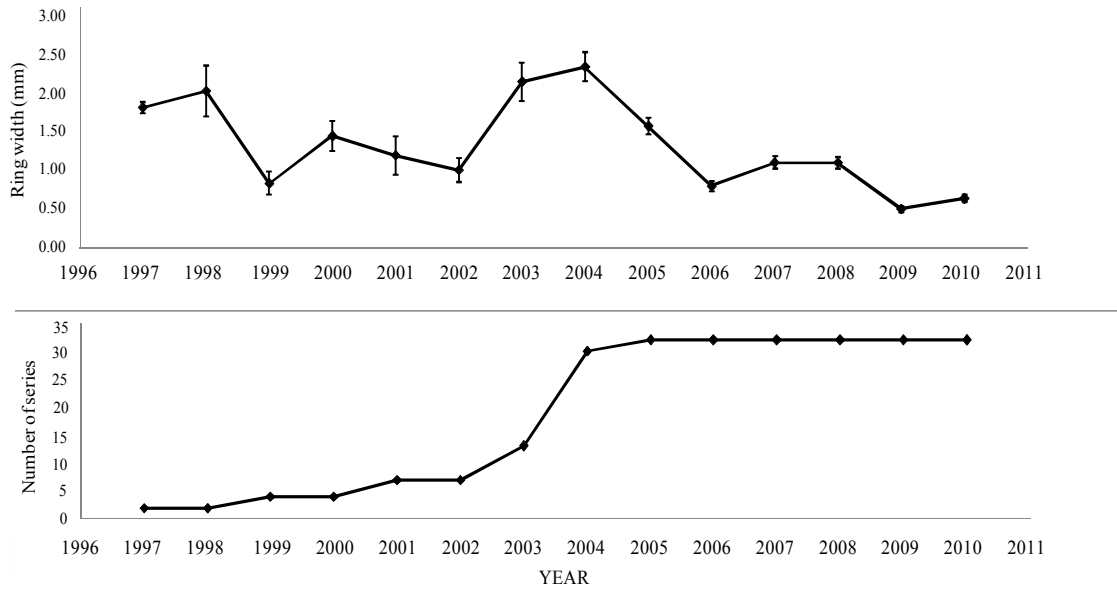


Figure 3. Shrub-ring chronology based on mean width of growth rings (upper graph) and corresponding number of samples (lower graph) for the *Rosa rubiginosa* growing within the National Park Quebrada del Condorito, Córdoba. Vertical bars represent standard error.

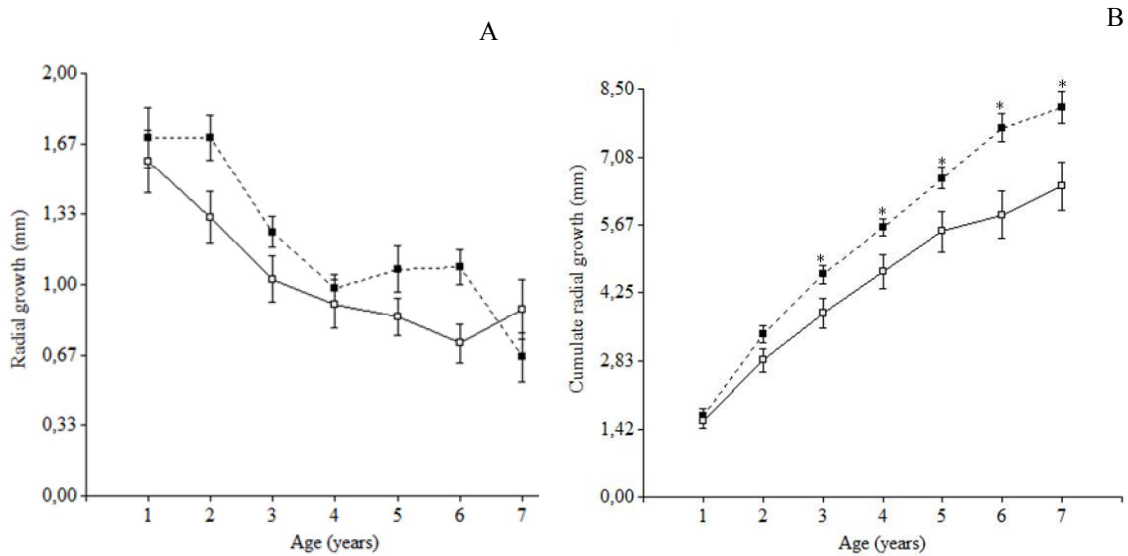


Figure 4. Radial growth (A) and cumulate radial growth (B) of *Rosa rubiginosa* in relation to age, in sites without (continuous line) and with (dotted line) livestock in the mountains of central Argentina. * Statistical differences at $P \leq 0.05$.

Discussion

Characteristics of the wood and ring width chronology

The growth rings of *R. rubiginosa* were clearly defined, with circular to semicircular porosity and usually solitary and scattered vessels (Fig. 2). This distribution pattern of

the vessels has been found in other species of *Rosa*, like *R. canina* (Schoch et al. 2004) and *R. glauca* (Zhang et al. 1992). Generally, the cross sections showed concentric increments in radial growth in the juvenile stage, changing gradually towards an eccentric growth with increasing age. This could be explained by light competition between stems or neighbouring plants.

The analysis of the transverse sections of *R. rubiginosa* presented an accurate chronology based on annual ring width measurements of 18 individuals selected from the ungrazed (exclosure) area (Fig. 3). The synchronization of growth pattern of *R. rubiginosa* was revealed by the high intercorrelation value, indicating the annual formation of growth rings. On the other hand, the mean sensitivity was high in relation to other species that grow in limiting environments of South America like *Polylepis pepeii* from Andean highland (0.30, Roig et al. 2001) and *Margyricarpus pinnatus* from semiarid steppe of Patagonia (0.30, Chartier et al. 2009). The mean sensitivity represents a measure of the effect of environmental conditions on radial growth which varies annually. Seasonal and yearly fluctuations in precipitation and temperature are the most common factors correlated to growth in sensitive species (Swetnam et al. 1988). However, in our study we did not find significant correlations between width ring and climatic variables. This could be explained by the short period covered by the chronology (14 years). Similarly, the reduced chronology probably explains why *R. rubiginosa* did not present a growth trend as a function of age.

Trees and other plants with annual growth rings (including dwarf shrubs, shrubs, and herbs) can play a key role in many dendroecological studies (Schweingruber and Poschod 2005; Bär et al. 2006). In this sense, except for long-lived tree species, plants other than trees have been largely ignored by dendrochronologist around the world (Winchester et al. 2007). However, plants other than trees have been taken into account in certain studies in the last decades, like the shrubs *Empetrum rubrum* (Roig 1988) and *M. pinnatus* (Chartier et al. 2009) from Patagonian steppe Argentina, and *Cistus ladanifer* evergreen species from European Mediterranean system (Patón et al. 1998). Thus, our results emphasize the dendroecological potential of shrubs and sub-shrubs species, especially in those areas where the presence of trees is scarce or absent, or where the shrubs are dominant.

Effect of livestock on radial growth

The results of our study show that livestock has a negative effect on radial growth of *Rosa rubiginosa*. While in the early years cumulative radial growth of *R. rubiginosa* was similar in sites with and without livestock, these differences increased with age and were significantly different at three and thereafter even with the small samples sizes we used (Fig. 4). Reasons for the negative effect of livestock on *R. rubiginosa* growth could be due to browsing, soil compaction and erosion, and the elimination of neighbouring competition which in harsh mountain environments may facilitate the growth of woody species acting as nurses.

A small percentage of our study plants had signs of browsing (authors personal observations), highlighting the low preference of livestock for this species at least with the low stocking rates found at our study site (as reported for *R. rubiginosa* in the Swiss Jura Mountains by Smit et al. 2007). The high density of thorns in aerial tissues of *R. rubiginosa* is probably the reason for these low browsing rates (Damascos 2008). Even though tissues lost to browsing are relatively low, given the harsh mountain environment of our study area, these losses could be contributing to the reduction on

ring growth in our study plants. Livestock could also be affecting the radial growth rate indirectly through trampling and impoverishment of the soil surface conditions (e.g., infiltration, soil and nutrient loss by erosion). Due to cold dry winters the soils of mountains of Central Argentina are especially vulnerable to erosion and sensitive to the pressure of livestock hooves which compacts soils (Cingolani 2008; Renison et al. 2010). A reduction in fitness due to the effects of livestock on soil properties was shown on native shrubs and trees of *Polylepis australis* in our study area (Renison et al. 2004) and thus could also be affecting *R. rubiginosa*.

Finally, livestock had been excluded in the National Park for 15 years at the date of our study, with a consequent partial restoration of native vegetation cover and structure which could be facilitating *R. rubiginosa* growth. In stressful mountain environment like in our study area, plants can have positive effects on each other as was found for *P. australis* seedlings in our study area (Landi and Renison 2010). This facilitation by neighbour plant cover can be due to accumulation of nutrients, provision of shade, amelioration of wind or extreme temperatures (Callaway et al. 2002). Thus facilitation by existing vegetation could also be contributing to the difference found in radial growth in our study species with and without livestock sites.

In that way, the livestock would be acting as a biotic filter (Theoharides and Luke 2007), retarding to a certain extent the growth of invasive species *R. rubiginosa* in mountains of central Argentina and consequently retarding the invasion processes. As livestock is also known to favour *R. rubiginosa* by dispersing Rose hips (Vila et al. 2011), the outcome of livestock introduction in areas invaded with *R. rubiginosa* will depend on the balance between its negative effects on growth and its positive effects on dispersal, which is possibly context dependant. As an example, livestock will possibly be a useful tool for retarding the invasion processes in areas where there is no limitation by dispersal, i.e. the last remnant patches of native vegetation (tolerant to grassing) in densely invaded areas. Many studies have demonstrated that during the stage of severe invasion, eradication or control is economically unviable, producing irreversible environmental damage (Hulmes 2006), thus these sites could be used for livestock grazing if this slows down the invasion. In this context, the measurement of annual ring width against datable basal stems represents a simple method for the determination of radial growth rates which may be used by government departments, environmental managers and conservationists to help resolve the diversity of invasive alien species problems. This approach could be particularly useful for determining the effects of land management practices on recent invasion of woody species where historical data regarding this process are scarce or absent.

Conclusion

Our study demonstrated the negative effect of livestock on cumulate radial growth of invasive species *Rosa rubiginosa*. In this sense, the livestock would be acting as a biotic filter for the invasion of this species in the mountains of Córdoba (Argentina) and may be considered as a tool to reduce *R. rubiginosa* growth in invaded areas, where livestock will not cause other damages.

Moreover, our study highlights the usefulness and importance of the application of dendrochronology to understand the woody invasion processes, emphasizing the dendrochronological potential of shrub and sub-shrub species. This approach could be

particularly useful for monitoring the effects of land management practices on recent invasion of woody species.

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