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Research Article

Experimental control of Spanish broom (*Spartium junceum*) invading natural grasslands

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Abstract

A group of legumes generically known as brooms are among the most successful shrubs invading grasslands in South America and other regions. These species share a set of biological features that enhance their invasiveness, such as abundant and long-lasting seed banks, aggressive root systems and rapid growth, combined with their ability for re-sprouting after cutting or burning and for avoiding herbivores. They grow in dense stands that exclude native vegetation and are able to change ecological processes, increasing fire frequency and intensity, and fixing atmospheric nitrogen. The Spanish broom (*Spartium junceum*) is a shrub native form the Mediterranean that was introduced into the Argentine Pampas grasslands where it spreads over remnants of pristine ecosystems, threatening their biodiversity. This paper reports the results obtained after an adaptive management strategy aimed at controlling this species in a nature reserve, and compares the efficiency of different mechanical and chemical control techniques in terms of the number of plants killed and the effects on surrounding vegetation and on the recruitment of broom seedlings. Control was implemented in two phases, the first included three treatments: i) cut at the base of the plant, ii) cut followed by the immediate application of Togar (Picloram 3% + Triclopyr 6%, at a 5% dilution in diesel oil) on top of the cut stump, and iii) foliar spraying with Togar. The follow-up treatments, implemented one year later, consisted of spraying the re-sprouts with Togar (5% in diesel oil) or Glyphosate 36% (2% in water). The best option in terms of controlling Spanish broom was spraying the re-sprouts with Togar which gave 100% mortality of the treated plants, compared with values of 40% - 100% re-sprouting for the other options tested. None of the methods was associated with an increase in seedling recruitment, nor with significant changes in the vegetation in the immediate vicinity of the controlled brooms.

Key words: invasive alien species; chemical control; Glyphosate; Togar; adaptive management

Introduction

Invasion of natural and semi-natural habitats by alien species is one of the most serious challenges for biodiversity conservation, nevertheless this issue has traditionally received less consideration in conservation planning, and also by the public, in comparison with other problems like overexploitation and pollution (Coblentz 1990; Mooney and Hobbs 2000; Mooney et al. 2005). The ecological effects of the excessive exploitation of natural resources, as well as those associated with pollution, can be diluted with time, and eventually neutralized by spontaneous natural processes after the cessation of their causes, whereas the impact of invasive species persists and usually becomes more serious with time, representing a permanent threat in the absence of management (Cronk and Fuller 1995; Mooney and Cleland 2001). In most cases, management actions are necessary for reducing the pervasive effects of invasive species (Wittenberg and Cock 2001), but this usually demands many resources and has to be implemented in the absence of complete knowledge about its efficiency and potential side-effects. These are the foundations for implementing control actions organized on an adaptive or "learning by doing" basis (Zalba and Ziller 2007).

Invasive trees and shrubs, in particular, have severely affected grasslands worldwide, changing dominant life-forms, reducing species and structural diversity, increasing biomass, disturbing vegetation dynamics and changing nutrient cycles (Richarson 1998; Ghersa et al. 2002). A group of plant species belonging to the legume family and generically known as brooms (*Cytisus scoparius, Spartium junceum, Cytisus striatus* and *Genista monspessulana*) can be cited among the most successful grassland invaders worldwide (California Invasive Plant Council 2008; Myers and Bazely 2003; Matthews and Brandt 2005; Westbrooks 1998; Whittenberg and Cock 2001; Bossard et al. 2000). Invasive ability of the plants in this group is supported by an aggressive root system; their ability to fix atmospheric nitrogen; and rapid, all-year-round growth, even on very poor, sandy, dry soils and under a wide range of pH. Another two ecological features make them successful invaders: as the plants grow their internal stems die and dry off, augmenting their flammability, which, in combination with brooms ability to re-sprout from the base of the burnt stems and to massively germinate after fire, leads to the advance of their stands following fire. On the other hand, their toxic tissues are rarely consumed by wildlife or cattle, enhancing their dominance in grazed areas (Barboni et al. 1994; LeBlanc 2001). Brooms colonize open, sunny areas on disturbed sites, e.g. roadsides, tracks and croplands, forming dense, mono-specific stands, associated with huge and long-lasting seeds banks. Stands are usually so dense that they swamp the native vegetation, impeding its regeneration and eventually exhausting its seed banks. Their ability to fix nitrogen results in soil “enrichment”, influencing ecological succession and conditioning any prospects for restoring the ecosystem to a pre-invasion state, even in the case of successful eradication of the invader (Cal IPC 2008; Haubensak et al. 2004; Hoshovsky 1986; Leblanc 2001; Mooney and Hobbs 2000; The Nature Conservancy 2000; Washington State NWCB 2007).

The ability of these plants to re-sprout after being cut makes broom invasions not easy to control. Mechanical extraction of the plants can be effective in the initial stages of invasion and before seed production, but if control is implemented in later stages, any disturbance in soil or vegetation can result in massive seedling recruitment and in consequent re-invasion. As has already been mentioned, fire promotes seed germination in broom, nevertheless severe fires (> 140°C) do kill Scotch broom (*Cytisus scoparius*) and successive moderate fires might kill the seedlings and young plants (Leblanc 2001) but there is no data on the effects of fire on other broom species. Chemical control has been often used to stop brooms from spreading, mainly using Glyphosate, Triclopyr, Picloram, Imazapir and 2,4 D, with differing results depending on the concentration, time and application method (Tu et al. 2001).

Spanish broom (*Spartium junceum*) is a ramose, perennial shrub, up to 4 m in height. Leaves are ephemeral and small (less than 1.5 cm long), placed in a sub-opposite to alternate orientation on new shoots only. It flowers in profusion in spring and summer (Parodi 1979). It is a native of the Mediterranean and Canary Islands and it was introduced into many countries as a garden plant and for controlling soil erosion. Few years separate its introduction into the USA in the middle of the XIX century from its escape into roadsides and uncultivated places, colonizing areas of conservation concern where it has become a threat to native biodiversity (Mc Clintock 1979). The species is subject to control campaigns in California, Washington and Oregon, as well as in New Zealand and Australia (Hoshovky 1986; Cal IPC 2008). It also behaves as invasive in the British Islands (Clement a Foster 1994) and in South America (Matthews and Brandt 2005).

Spartium junceum was introduced into Argentina from Europe. Within the new range it is capable of establishing spontaneous populations and spreading into abandoned or uncultivated land, canyons and cliff areas in the center of the country (Burkart 1952; Parodi 1978). During the last fifteen years, the species has shown a notable increase in its distribution range and abundance at different locations of the Argentine Pampas (Sanhueza and Zalba 2009) and its presence threatens the conservation of the last pristine remnants of this ecosystem (Figure 1). Therefore its control was targeted as one of the top priority actions in the strategy for managing invasive species at the Ernesto Tornquist Provincial Park (ETPP), a protected area in the southwest of Buenos Aires province that plays a key role in the conservation of the whole biome. Experimental control of this species started in ETPP in 2003, aimed at stopping it from spreading and, at the same time, at gaining key knowledge about how to optimize its control. This paper compares the efficiency of

Figure 1. Spanish broom invading natural grassland at the Ernesto Tornquist Provincial Park (Photograph by Cristina Sanhueza).

different mechanical and chemical control techniques considering the number of plants killed by each method and also their effects on the surrounding non-target vegetation, as well as on the recruitment of broom seedlings.

Study area

Ernesto Tornquist Provincial Park extends over ca. 6.700 ha in the Sierra de la Ventana mountains, in Buenos Aires province (38º-38º10´S; 61º45´-62º02´W). The area comprises a high diversity of habitats in a heterogeneous landscape, an altitudinal gradient that includes the highest elevations in the Pampas (up to 1200 m above sea level) and an important diversity of soil types (Frangi and Botino 1995; Kristensen and Frangi 1995).

Climate is temperate, with a mean annual temperature of 14ºC. In January, the hottest month, mean temperature rises to 20,5ºC, with an absolute maximum of 40ºC, and in contrast, during July, the coldest month, the mean drops to 8ºC, with an absolute minimal of -10ºC and occasional snow-fall. Winters in the hills are more extreme than in the surrounding Pampas and risk of chilling extends until late spring (Burgos 1968). Mean annual rainfall in the reserve was 626 mm between 1993 and 2007 (ETPP rangers, pers. com.).

The reserve includes a high concentration of endemic taxa and others that are severely restricted outside its boundaries (Kristensen and Frangi 1995). The flora of the reserve comprises 554 species (413 natives and 141 introduced), representing 85% of all the species cited for Sierra de la Ventana mountains. Seventeen out of the 20 species that are endemic of these mountains grow inside the park (Long and Grassini 1997).

Methods

In April 2003 (early autumn) four circular, spontaneous, dense (more than 7 plants per m^2) stands of Spanish broom of ca. 15 m diameter were selected. Each stand was divided into radial quarters, and different control techniques were applied to three quarters of each stand: i) cutting at the base of the plant (less than 7 cm above the soil), ii) cut stump (cutting and then immediately applying herbicide on top of the freshly cut stump) using Togar (Picloram 3% + Triclopyr 6% at a 5% dilution in diesel oil, and iii) foliar spraying with Togar prepared at the same dilution. The fourth quarter of each broom stand was left as a control with standing brooms. Cuts were made with a chainsaw, herbicide applications on stumps were made using a 750 cm^3 squeeze bottle, and foliar spraying with a 750 cm^3 hand sprayer. Herbicides consumption was measured for the different application methods. The use of herbicides was carried out according to environmental security standards that were particularly strict, considering that the application was made in a protected area (Tu et al. 2001). Three or four $1m^2$ sampling plots were placed in each area, including the treatments and controls. Records were taken of changes in color, vigor and survival of the brooms, emergence of broom seedlings and percentage cover of all the accompanying plant species, except grasses that were clumped in a group due to problems of identification. The composition of plant communities was also recorded in two $1m^2$ sampling plots located outside the invaded area, near to the broom stands. Sampling was repeated every two months, over a period of ten months. Species richness and Shannon diversity index were calculated for each treatment and for the controls. Dominance/diversity plots were constructed for the different treatments and controls at the end of the sampling period. Changes in percentage cover of grasses, herbs and total vegetation were assessed during sampling for all treatments and controls. Data were analyzed with a two-Factor ANOVA with repeated measures on one factor, using SPSS 7.5 and multiple Sheffé comparisons.

A follow-up treatment was carried out one year after the initial experiment in the areas that were originally treated with cut and cut stump techniques only. Thirty plants that had re-sprouted after the initial treatment were selected in each quarter, ten of them were sprayed with Togar (5% in diesel oil), ten with Glyphosate 36% (2% in water) and ten were left as control. The volume of herbicide used and the plant size before and after the herbicide application were recorded. Plants were monitored every three months until 18 months after treatment, recording the number of survivors. Height, diameter and density of the resprouts were measured. Density of the resprouts was estimated as being high (percentage cover exceeding 70%), medium (percentage cover between 40 and 70%) and low (percentage cover lower than 40%).

The experience of spraying resprouts was replicated in 2006. For doing so, all the brooms in three $64m^2$ plots were cut during the summer (January 2006). One hundred resprouts were randomly choose at each plot (N=300) and sprayed with herbicide (Togar 5%), and another hundred plants were selected in a contiguous area to be used as controls. Resprouts were monitored every two months since spraying, recording broom survival during 21 months. Again, height, diameter and density of the resprouts were measured together with time and effort (man-hours) employed and volume of herbicide and diesel oil used.

Results

Ten months after the beginning of the control actions we found 93% (SD±2.87) re-sprouting in the cut and 51.9% (SD±28.61) in the cut-stump treatments. Sprayed brooms showed initial signs of being affected by the herbicide (stems changed color from green to brown or yellowish, looked dry and did not sprout or flower the following spring), nevertheless, they started to produce new stems and leaves from the base of the plant nine months later, resulting in 100% re-sprouting by the end of the experiment.

Eighteen months before the follow-up treatments, plants sprayed with Togar did not show any re-sprouting (100% mortality) whatever the initial treatment (cut or cut stump). In plants sprayed with Glyphosate, 87.5% of those that were initially cut re-sprouted, compared with only 40% of those treated with the cut stump technique in the first phase of the experiment, being this difference statistically significant ($p<0.05$; Figure 2).

Cut stump consumed 62 cm^3 of herbicide solution for every 100 treated brooms, most of them (>75%) being young plants with stems less than 1 cm wide at the cut height. Spraying the re-sprouts (follow up treatment) resulted in the use of 1,4 l of herbicide solution for every ten brooms with a mean height of 64 (SD±22,71) cm and 40,6 (SD±19,7) cm of width, both for Glyphosate (2% in water) and for Togar (5% in diesel oil). Density of the resprout was high in

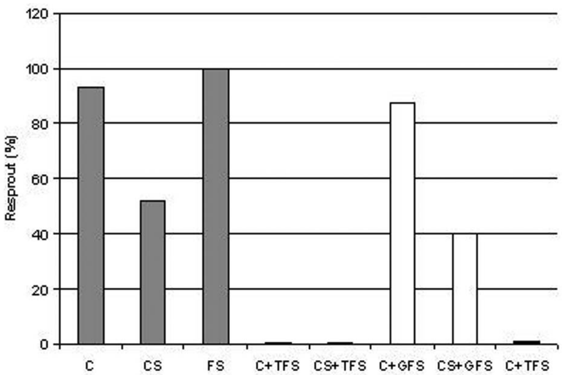

Figure 2. Percentage re-sprouting of Spanish broom ten months after initial treatments (grey columns), 18 months after follow-up treatments (white columns) and 21 months after the replication of spraying resprouts with Togar (black columns). Treatments: Cut (C); Cut stump (CS); Foliar spray (FS); Cut + Togar Foliar spray (C+TFS); Cut stump + Togar Foliar spray (CS+TFS); Cut + Gliphosate Foliar spray (C+GFS); Cut stump + Gliphosate Foliar spray (CS+GFS).

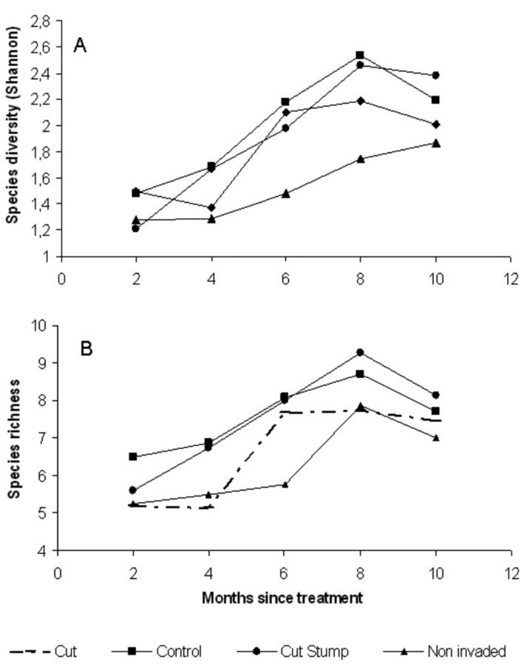

Figure 3. Changes in plant species diversity (A) and richness (B) following the application of different treatments for controlling invasive Spanish broom.

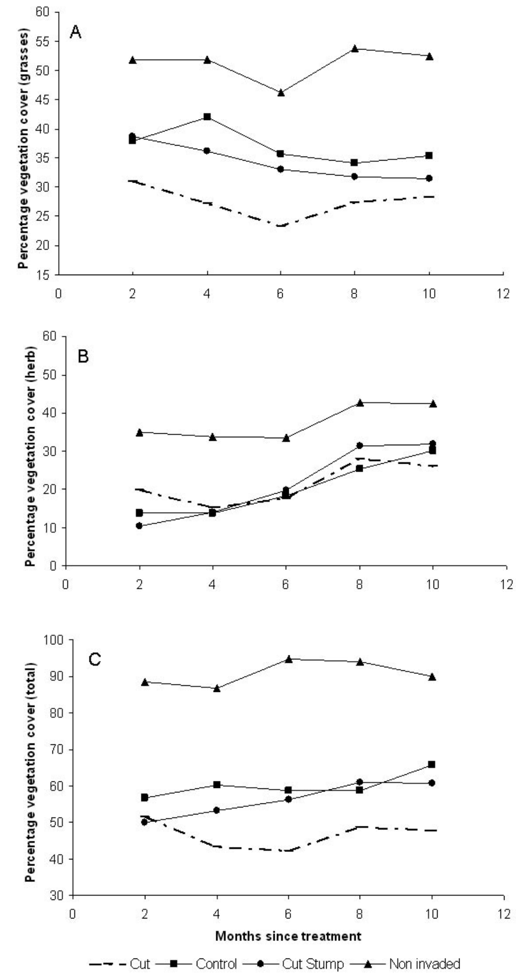

Figure 4. Changes in percentage cover of grasses (A), herbs (B) and total vegetation (C) following the application of different treatments for controlling invasive Spanish broom.

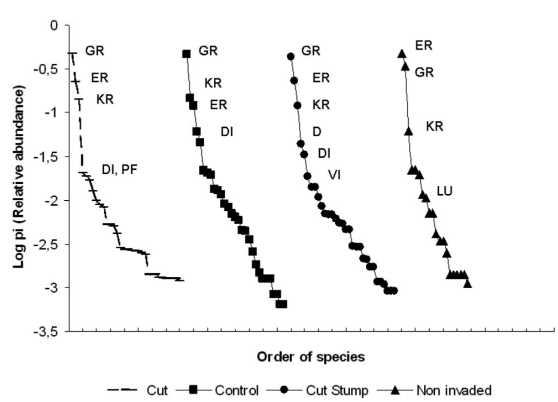

Figure 5. Dominance/diversity plots of vegetation samples associated with the application of different control techniques for Spanish broom in areas in Ernesto Tornquist Provincial Park. GR: grasses, KR: *Krapovickasia flavescens*, ER: *Eryngium stenophyllum*, DI: *Dichondra sericea*, PF: *Pfaffia gnaphalioides*, LU: *Lucilia acutifolia* and VI: *Vicia* sp.

47% of the cases, medium in 33% and low in the remaining 20%.

No significant interaction was found between the different treatments and time regarding the density of seedlings. Plant density increased sharply at the beginning of the essay and then decreased in all treatments and in the controls ($p<0,001$). No significant differences were found in seedlings emergence, neither between the treatments nor between them and the control plots with standing brooms.

None of the treatments differentially influenced species richness or diversity of the accompanying vegetation, and both variables followed similar temporal patterns (increasing during the experiment) in all the treatments, in controls with standing brooms and also at sites not affected by the invasion (Figure 3).

The percentage cover of grasses, herbs and total vegetation was always higher in plots outside the invaded area compared with the treatments and controls with brooms. Scheffé comparisons did not reveal any significant differences in these variables between treatments or between them and the samples with brooms ($p>0,05$; Figure 4).

Dominance/diversity plots show that the different treatments did not affect the pattern of plant species diversity either. Non invaded areas, plots with standing brooms and all treatments exhibited similar structures of plant species diversity, with a slightly greater evenness associated to areas outside the invaded sites (Figure 5). The same plants were also dominant in all cases: *Krapovickasia flavescens, Eryngium stenophyllum* and grasses. The most noticeable differences corresponded to a small set of species e.g. *Dichondra sericea*, that was not recorded in the non-invaded plots, but appeared in high densities in treated areas, and other less frequent species that were exclusive of some of the treatments: *Pfaffia gnaphalioides* (cut), *Lucilia acutifolia* (control) and *Vicia* sp. (cut stump).

The replication of the follow up treatment made in 2006 result in only 1% resprouting after 21 months, was used of 0,73 l of herbicide solution (togar concentration 5% in diesel oil) for every ten brooms with a mean height of 53,41 (SD±12,31) cm and 29,65 (SD±12,66) cm of width, and percentages of high, medium and low resprout density of 29%, 35% and 36%, respectively and time spend was 3 minutes for each resprout.

Discussion and conclusions

A method for controlling invasive plants should be evaluated not only in terms of its efficiency for killing the target species, but also in terms of any side-effects on the environment, its potential for promoting germination from the invader's seed bank, and the cost, both in monetary terms as well as in human effort. In this study we found that stem cutting, complemented with foliar spraying of re-sprouts with Togar, resulted in the complete eradication of Spanish broom without the need of any further herbicide application, being much more efficient than the cutting or cut stump techniques.

Chemical control of invasive species, especially in the case of woody plants, usually needs repeated applications of herbicides that result in increased environmental and economic costs (Duncan and McDaniel 1998; Reed et al. 2009; Stott and Parker 1995). Foliar spraying of re-sprouts in our experiments consumed a greater volume of herbicide than the cut stump treatment, nevertheless, the difference between these figures would be reduced if the need for repeated application on the cut stems is considered. This is also because re-sprouting after cutting usually implies the replacement of a initial single stem or a group of few stems by a greater number of new ones, preventing the repetition of the cut stump technique and leading to the need of foliar spraying.

The combination of mechanical and chemical control presented in this paper is not only appealing in terms of costs and impact reduction, but also because there is no need to re-visit the controlled areas with personnel and equipment, favoring natural regeneration of vegetation.

The efficiency of a method for controlling invasive species can change in space and time according to the characteristics of the habitat and to inter-annual variations in temperature and rainfall. The temporal replication of the method tested in this paper reinforces the results obtained, but more research is needed to expand our conclusions about its efficiency under other environmental conditions.

An interesting feature of the results presented in this paper is related to the variance in the volume of herbicide for spraying the resprouts, what is probably related to resprout size and density. Considering that the efficiency of the treatment was high across the whole range of resprout sizes it seems advisable to spray young resprouts in order to reduce the volume of herbicide needed.

Comparison of the efficiency of different methods is not easy as there may be many sources of variation in the chemical control of invasive plants, including the type and concentration of herbicide, the use of surfactants, the time of application, the size, vigor and phenological status of the plant, etc. Most reports concerning results associated with the control of invasive plants are not detailed enough to make any proper comparisons. However, while keeping all these limitations in mind, our results can be compared to those obtained by other managers and researchers working with invasive brooms. One of the first things that emerge from these comparisons is the low level of success we obtained when applying Glyphosate. This herbicide has been recommended for controlling brooms if applied during the growing season (Le Blanc 2001). Dunn (2002) reported a high success rate when applying Glyphosate for controlling *Cytisus scoparius* with a tractor-pulled aluminum bar that wipes the herbicide onto plants growing in dense stands. Oneto (1997) and Delvin et al. (2005) also stress the efficiency of both Glyphosate and Triclopyr for controlling *Cytisus scoparius* applied in spring or at the beginning of autumn. The reduced efficiency of herbicides applied to *Spartium junceum* might be related to the smaller leaf area of this species. Spanish broom is characterized by having few, small, fast dropping leaves, which is different to other species in the broom group. Considering this, and despite suggestions to treat all the brooms as being almost equivalent in terms of their control (Bio-Integral Resource Center 2010), we suggest that the results obtained with Scotch broom (*Cytisus scoparius*) and French broom (*Genista monspessulana*) should not be directly transferred for the management of *S. junceum*.

We did not find any changes in broom recruitment after control, compared with the values recorded in areas where the invasive plants were left uncontrolled. Brooms have abundant and persistent seed banks and seed germination is triggered by soil disturbance or fire, and so control methods that do not promote seed germination have an extra-advantage. Nevertheless this means that the species is still present in the area and a monitoring strategy is needed in order to assure continual success of control actions, even in the absence of the risk of re-invasion from nearby areas.

Finally, none of the methods applied in our trials resulted in any significant changes in the accompanying vegetation, which shows the low impact that chemical control has when properly and carefully applied. On the other hand, we were not able to detect any significant recovery of the native vegetation after control actions, apart from a slight increase in the percentage cover of herbs and a tendency of the species diversity values of controlled plots to become closer to those of the controls that were free of the invasive. More time is probably necessary for the vegetation to recover, especially considering the long-term effects that can be associated to the presence of brooms and some natural ecological limitations of this ecosystem, e.g. xeric conditions.

Spanish broom is an aggressive invader in southern Argentine grasslands. Its ecological characteristics and the extension of the invaded area result in the need for applying efficient control measures, such as the combination of mechanical and chemical control tested in this study. The use of herbicides in nature reserves is polemical, but the long term impact of the invader can greatly exceed any temporary side-effect on non-targeted components of the ecosystem. Our results can be taken as a preliminary indicator of the efficiency and specificity that the applied techniques can have for controlling this invasive alien in native grasslands.

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