

French broom (*Teline monspessulana*) invasion in south-central Chile depends on factors operating at different spatial scales

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Abstract The interaction between plant attributes, environmental factors and the history of human intervention determines which species show a more invasive behavior and which areas are more likely to be invaded. Identifying which factors favor the invasion and which constraint it, remains an essential goal for understanding the process of invasion and to provide a stronger scientific basis for designing management actions to reduce susceptibility to invasion. In this paper we analyze the relative role of different environmental factors in plant invasion, in particular the comparison between human versus climatic and biotic variables at different spatial scales. Furthermore, we show how these factors interact to influence the distribution and abundance of an invasive plant. We have built mixed models to explain the presence and abundance of a renowned invasive species in the south-central area of Chile, *Teline monspessulana* (French broom, Fabaceae). We recorded the presence and

cover of this invasive shrub in a series of transects along the main roads of the study area. For each transect we recorded variables at different spatial scales related to climate and land use. We found that the presence and cover of *T. monspessulana* are strongly related to proximity to roads, urban areas and locations with higher rainfall. Although this shrub is present in most of the landscape, it is most abundant in shrublands and forest plantations. In a complex human-dominated landscape matrix, shrublands and forest plantations act as a source of propagules from which new areas can be invaded. Interestingly, the presence of this species can be better predicted by combining predictors taken at two hierarchical levels, the so-called transect and plot scales, whereas the species abundance only depends on factors at the plot level. The presence and abundance of this species is highly dependent on human disturbance, and the occurrence of certain landscape elements closely linked to land management is critical to the performance of this species. Maintaining a dense tree canopy cover and reducing the use of fire could help reduce the rate of expansion of this species across the landscape.

Keywords Brooms species · Distribution modeling · *Genista* · Invasive plant

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Introduction

Factors determining which species are more invasive and which places are more likely to be invaded are

related to plant attributes (invasiveness) as well as community attributes (invasibility) (Alpert et al. 2000). The invasion process, especially in earliest stages, is strongly mediated by human activity. After the arrival of non-native propagules and their establishment, factors such as disturbance regimes (natural or anthropogenic), climatic conditions, and resistance of the native biota, will determine the success of the invasion (Pauchard and Alaback 2004; Catford et al. 2009). On the other hand, plant traits associated with the regional frequency of non-native plant species may differ from those that relate to their frequency or local dominance (Speek et al. 2011).

Understanding the factors that affect plant invasion is critical for developing appropriate management and control strategies and also to understand the generality of mechanisms implicated in the invasions success. Differences in land use and management influence variation in both the level of invasion and its impact on biodiversity (Jauni and Hyvönen 2010). On the other hand, landscape scale drivers of invasibility tend to be complex. Thus, depending on the complexity of the landscape matrix and climatic variability, a myriad of interactions between land management and landscape factors can promote or prevent the invasion at a regional scale. Worldwide, one of the families with a higher invasive potential is the family Fabaceae, topping the lists of invasive plants in most of the continents especially in the case of shrubby invaders (Pyšek 1998; Fuentes et al. 2008; Jiménez et al. 2008; Pyšek et al. 2008; Pauchard et al. 2011). A major focus of study within the Fabaceae has fallen on a group of invasive shrubs known as brooms and gorses. Several genera present a high number of well recognized invaders such as *Cytisus*, *Genista* and *Ulex* originating mainly from the Mediterranean basin, constitute a global concern threatening whole ecosystems in temperate and mediterranean regions (e.g. Sheppard and Hosking 2000; Valderrabano and Torrano 2000; Buckley et al. 2003, Potter et al. 2009). All brooms and gorses have some outstanding morphological characteristics such as green shoots and aphyllous shoots in some cases, with the *Ulex* spp. showing the greatest differences from the rest, with leaves modified into green spines. One of the main characteristics of this group is their ability to form large seed banks (Sheppard et al. 2002; Alexander and D'Antonio 2003a) and its ability to resprout (Reyes et al. 2009) which makes them particularly difficult to remove

once they have occupied a new site (Alexander and D'Antonio 2003b; Baesa and Roy 2008). Despite that there are over 740 species of non-native plants naturalized in Chile (Fuentes et al. 2013), only a small fraction of these species are invasive and pose a risk to local biodiversity with an unusually high number of them being Fabaceae (Quiroz et al. 2009b). Although many of the Fabaceae have been present for at least two centuries, the level of knowledge about the ecology and distribution of these invasive species in Chile is still very basic and only in the last 20 years has it significantly improved (Quiroz et al. 2009a). This is certainly surprising since there is a general consensus that their performance, especially for the most conspicuous species, is critical for economic and environmental issues (Holmes et al. 2009). Thus, knowing what factors determine their spread is essential to reduce current and future impacts (Parker et al. 1999; Jauni and Hyvönen 2010).

One of the most widely distributed invasive brooms in south-central area of Chile is *Teline monspessulana* (L.) K. Koch. Originally from the Western Mediterranean Basin, this species behaves as invader in several regions of the world (e.g. Australia, New Zealand, USA; Johnson 1982; Adams and Simmons 1991; Bossard 2000; Alexander and D'Antonio 2003a). In Chile, this species occurs on a vast latitudinal range from the Valparaíso to Los Ríos Regions in Chile (between 33° and 40°S), both in the understory of degraded forests and in heavily disturbed areas where it outcompetes most native species (Matthei 1995). Similar to other invasive broom species, *T. monspessulana* is a nitrogen fixer, which is able to colonize highly disturbed mineral soils (e.g. Haubensak et al. 2004; Drake 2011; García et al. 2012). One of the most outstanding features of the species in its invasive range is the ability to accumulate large seed-banks with more than 8,000 seeds m⁻² (García et al. 2010), while in its native range it can only accumulate less than 4,000 seeds m⁻² (Herrera et al. 2011). Mechanical soil disturbances, especially after fire, lead to large increases in seed germination from the seed-bank (Alexander and D'Antonio 2003b; García et al. 2010).

The first records of *T. monspessulana* growing naturally in Chile date back to 1847 (Matthei 1995). Its rapid expansion, after more than a century in Chile, is probably linked to human activities (Quiroz et al. 2009b). For instance, it is highly probable that the invaded range was linked with the proliferation of forest

activities in central Chile (Aguayo et al. 2009). As a consequence a major change in land use, the establishment of exotic forest plantations, has occurred together with the extension of the invader. At this point it is essential to know which factors limit the extent of *T. monspessulana* in terms of climate, landscape structure, and human activity. The aim of this study was to identify the factors that best explain the distribution and abundance of *T. monspessulana* at the landscape scale considering potential explanatory predictors at hierarchical spatial scales from the local stand to the site using data collected on transects located next to four of the principal highways that cross south-central Chile.

Our research aims to advance understanding of the basic process that has led to the Mediterranean woody brooms becoming one of the most successful invasive groups worldwide. By better understanding the mechanisms that underlay this invasion we hope that these studies will help provide a more robust scientific framework for developing risk models to aid in the design of more effective management strategies to constrain the spread of *T. monspessulana* across the landscape.

Methods

Study area

The study area is located in the Biobío and La Araucanía Regions, in south-central Chile, between 36° 35' and 38° 25' S. The climate is temperate-Mediterranean, with differences in rainfall caused by latitude and distance to the sea, varying between 1,000 and 3,000 mm. Approximately 70 % of the annual precipitation falls between May and August, the dry season varies between 3 and 5 months. The average annual temperature is approximately 12 °C and the annual temperature range 10 °C. This region has been highly influenced by human activities. Currently, the main land uses are non-native tree plantations and agricultural activities which together cover around 60 % of the area (Aguayo et al. 2009).

Data collection

During February 2008, we marked 109 locations evenly distributed along four of the principal highways which cross the study area (Fig. 1). These

locations were separated systematically approximately 5 km from each other. Within each location we established one rectangular transect perpendicular to the road, alternating systematically on each side of the road. Transects were 10 × 50 m and were divided into five plots of 10 × 10 m. On each plot we measured the presence/absence (1/0) of *T. monspessulana* and its canopy cover (percentage of plot occupied by the invader by visually estimating the ground projection of their canopies). The position of each plot in the transect was considered as the distance of the plot to the road. In addition, the dominant land use in the plot was recorded. The land uses categories considered here were: (1) Forest plantations: sites mainly occupied by managed plantations of *Pinus radiata* or *Eucalyptus* spp. includes juvenile and adults plantations; (2) Shrublands: areas dominated by native or non native shrubs, both generally. All shrublands areas had high degradation; (3) Pastures: highly degraded sites dominated by non-native grass species, most of them being abandoned croplands (natural grasslands not are present in the study area) and (4) Croplands: arable lands under cultivation.

We recorded the altitude and geographical position of locations, before we calculated a proximity index to the biggest urban areas (as an indirect measure of the anthropogenic influence). This index was calculated adding the linear distance of each transect to the cities of Concepcion, Chillan, Los Angeles, Arauco and Angol. With the geographical position of each transect and the data of the Agroclimatic Atlas of Chile (Santibáñez and Uribe 1993), we obtained precipitation and evapotranspiration variables for each transect (Table 1). Our method captures different factors at different scales. Each Route represents different landscapes, the transects recorded conditions at the local scale and plots recorded the factors operating a microsite scale.

Statistical analyses

Absence data is critical for determining the distribution of a species, but certain population attributes (e.g. cover) can only be measured in plots with actual presence. In order to analyze the presence/absence data set, we worked with all plots (539 plots from 109 transects, plots within bodies of water; six plots; were left out of analyses). For analyzing cover data we consider only plots in transects with presence (i.e. at

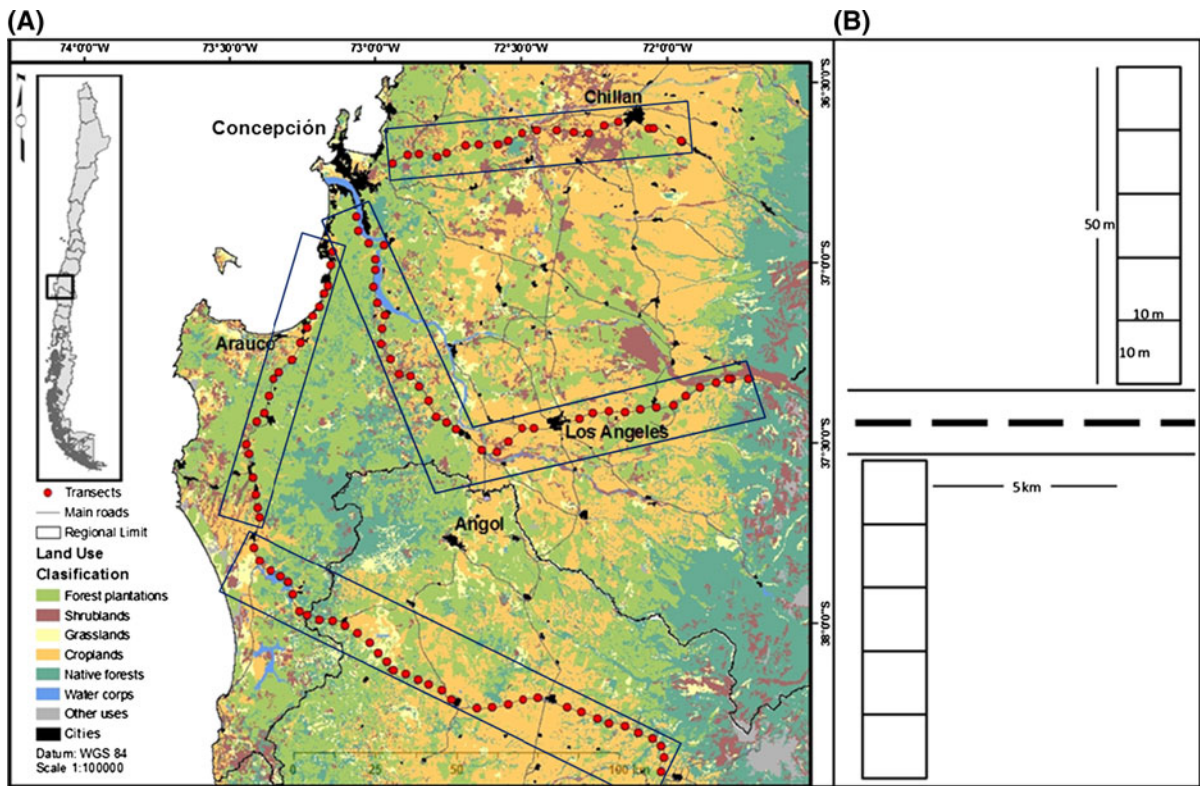


Fig. 1 a Map of the study area depicting the different land covers in the south-central zone of Chile. The dots indicate the 109 locations which were evenly distributed along 4 routes

which also are delineated with *polylines*. b Diagram of the location of each transect in relation to the reference road

Table 1 Description of the independent variables used in the GLMM analyses for the probability of presence and cover of *T. monspessulana* in four of the main route of the south-central area of Chile

Level	Variable	Description
Route		
Transect	Elevation	Elevation (meters above sea level)
	Evapotranspiration	Annual potential evapotranspiration
	Precipitation	Total annual precipitation (mm)
	Proximity index to urban areas	Sum of the distances to the biggest cities of the area
Plot	Road distance	Perpendicular distance of plots to the road
	Land use	A multinomial variable with the following possible states: Forest plantations, Shrubland, Pasture and Cropland

least one plot of the five on each transect) and transects without presence but which were adjacent to transects with reported presence (424 plots from 86 transects). This was done to include areas where *T. monspessulana* propagules were assumed to be present but no establishment had occurred.

Generalized linear mixed models

The *T. monspessulana* presence data on plots had an unbalanced and hierarchical structure, with plots nested within transects and transects nested within routes. In order to overcome the problem of correlation between data points at different scales, a typical characteristic of hierarchical data structures, we analysed the data using a multilevel approach considering plots, transects and routes as random factors, and applying a mixed modelling (Verbeke and Molenberghs 1997). Because the response variable was the presence/absence of *T. monspessulana* on a plot,

which clearly departs from the standard normality assumption, we used generalized linear mixed models (hereafter GLMM; McCullagh and Nelder 1989; Breslow and Clayton 1993). GLMMs for presence of *T. monspessulana* were performed assuming a binomial distribution of errors with logit link and using the restricted maximum-likelihood (REML) method (Patterson and Thompson 1971). On the other hand, GLMMs for cover of *T. monspessulana* were performed assuming a normal distribution of errors with identity link and using the quasi-likelihood method. Because our data were unbalanced, we used Satterthwaite’s method to determine the approximate denominator residual degrees of freedom for statistical tests (Verbeke and Molenberghs 1997).

To analyse the effects at different levels of *T. monspessulana* on plots, we considered plots nested within transects, transects nested within routes, and routes as random factors (variance components), and elevation, evapotranspiration, precipitation, proximity index to urban areas, road distance, and land uses as fixed effects (Table 1). Effects of random factors were tested using Wald Z statistic tests and those of fixed factors were tested with F tests.

Logistic regression

In order to build risk maps, we used the logit link function to transform the linear predictor (the combination of explanatory variables) to a measurement scale suitable for our binomial data set. This function is (see Crawley 2005):

$$\log\left(\frac{p}{1-p}\right)$$

where *p* is probability. As a consequence the probability *T. monspessulana* is present is expressed by the model:

$$p(x) = \frac{e^{(\beta_0 + \beta_1 X_1 + \dots + \beta_k X_k)}}{1 + e^{(\beta_0 + \beta_1 X_1 + \dots + \beta_k X_k)}}$$

where *X_k* is the explanatory variable and *β_k* is the estimated parameter of variable *X_k*.

We used only the variables found significant in the previous GLMMs and for simplicity; we did not take into consideration the random terms of the original models.

The statistical analysis were performed using SPSS 15 and SAS® (Littell et al. 1996).

Results

The comparison between the Pearson correlation coefficient at the transect level (Table 2) showed that elevation is correlated with precipitation, evapotranspiration and proximity index to urban areas. At the plot scale, road distance and land use are not correlated (Table 3).

At the landscape scale, *T. monspessulana* was present at 60.6 % of the transects. Routes showed no differences in the presence of *T. monspessulana* (GLMM, Table 4). Presence of *T. monspessulana* was related to some transect and plot variables (GLMM, Table 5). At the transect level, presence of *T. monspessulana* was positively related to precipitation and negatively to the proximity to urban areas;

Table 3 Pearson correlation among independent variables in plots (n = 539)

	Road distance	Land use
Road distance	1	0.012
Land use		1

* Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Table 2 Pearson correlation among independent variables in transects (n = 109)

	Elevation	Evapotranspiration	Precipitation	Urban areas index
Elevation	1	-0.313**	0.237*	0.666**
Evapotranspiration		1	-0.427	0.090
Precipitation			1	-0.427
Urban areas index				1

* Correlation is significant at the 0.05 level

** Correlation is significant at the 0.01 level

Table 4 Unconditional means model for (A) the probability of presence of *T. monspessulana* (539 plots from 109 transects in 4 routes). Analysis based on a GLMM with binomial errors and logit link using REML estimation. (B) cover of *T. monspessulana* (424 plots from 86 transects in 4 routes). Analysis based on a GLMM with normal errors and identity link using REML estimation. Random effects were tested using Wald tests in both cases

Variable	Estimate (\pm ES)	Z value	p
(A) Presence of <i>T. monspessulana</i>			
Route	3.7621 \pm 4.7099	0.80	0.2122
Transect (Route)	10.3866 \pm 2.0080	5.17	<.0001
Plot (Transect)	0.3217 \pm 0.0219	14.67	<.0001
(B) Cover of <i>T. monspessulana</i>			
Route	27.2198 \pm 62.1032	0.44	0.3306
Transect (Route)	423.35 \pm 75.3467	5.62	<.0001
Plot (Transect)	202.40 \pm 15.6585	12.93	<.0001

transects away from the cities have less probability of being occupied by *T. monspessulana*. At the plot level, presence decreased as the distance to the road increased. Land use was also associated to *T. monspessulana*

Table 5 Generalized linear mixed model for (A) the probability of presence of *T. monspessulana*. Analyses were based on a GLMM with binomial errors and logit link using REML

Level	Variable	Estimate (\pm ES)	DF	Test-value	p
(A) Presence of <i>T. monspessulana</i>					
Transect	Elevation	0.0054 \pm 0.0040	1, 47.7	1.82	0.1842
	Evapotranspiration	0.0034 \pm 0.0044	1, 79	0.60	0.4421
	Precipitation	0.0025 \pm 0.0009	1, 99.5	6.74	0.0109
	Proximity index to urban areas	-0.0326 \pm 0.0081	1, 11.1	16.26	0.0019
Plot	Road distance	-0.1047 \pm 0.0099	1, 490	112.62	<.0001
	Land use		3, 459	9.38	<.0001
	Shrubland (respect forest plantation)	0.5326 \pm 0.5931			
	Pasture(respect Forest plantation)	-1.7070 \pm 0.5571			
	Cropland (respect forest plantation)	-6.0771 \pm 1.5067			
(B) Cover of <i>T. monspessulana</i>					
Transect	Elevation	0.0114 \pm 0.0223	1, 24.5	0.26	0.1015
	Evapotranspiration	0.0077 \pm 0.0099	1, 63.4	0.62	0.4355
	Precipitation	0.0074 \pm 0.0054	1, 80.5	1.85	0.1771
	Proximity index to urban areas	-0.0875 \pm 0.0362	1, 2.78	5.83	0.1015
Plot	Road distance	-0.1622 \pm 0.0526	1, 351	9.51	0.0022
	Land use		3, 406	12.88	<.0001
	Shrubland (respect forest plantation)	10.2043 \pm 3.615			
	Pasture (respect forest plantation)	-9.5009 \pm 3.702			
	Cropland (respect forest plantation)	-11.4811 \pm 4.358			

Table 6 Pairwise comparison for presence of *T. monspessulana* between all land uses

	Shrubland	Pasture	Cropland
Forest plantation	0.3697	0.023	<.0001
Shrubland	-	0.011	<.0001
Pasture		-	0.0039

presence with Pastures and Croplands having a lower overall presence.

Forest plantations and Shrublands have equal probability of presence, followed by Pastures and Croplands (Table 6). Contour maps indicating the probability of presence of *T. monspessulana* built from our models (Fig. 2) showed the different behavior of the invasion based on the different land uses. The probability of presence of *T. monspessulana* was higher in areas close to urban areas with high rainfall and near to the road, decreasing from Shrublands (and Forest Plantations) to Pastures and Croplands.

The average canopy cover for the species in the plots was 18.8 % \pm 1.33 (mean \pm SE) with values

estimation. (B) cover of *T. monspessulana*. Analyses were based on a GLMM with normal errors and identity link using REML estimation

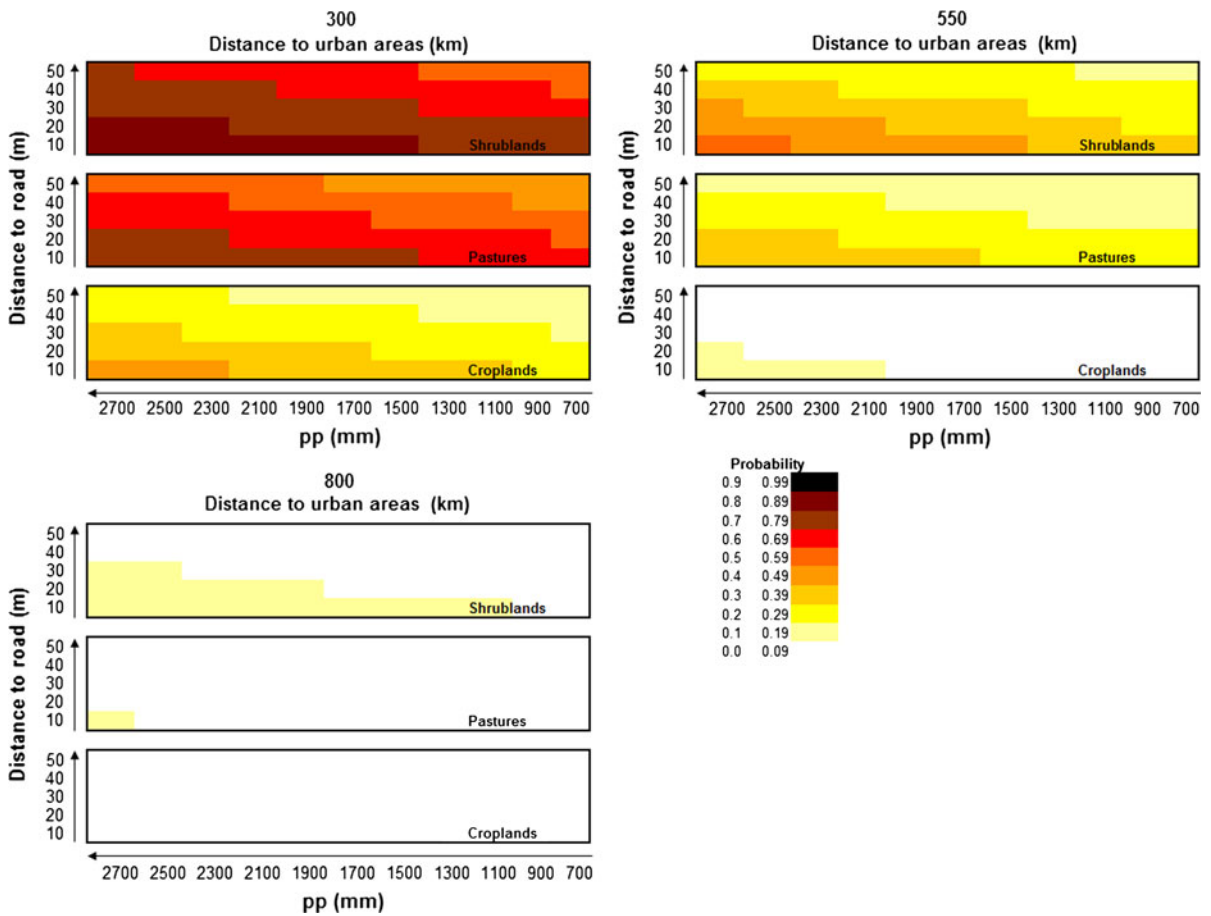


Fig. 2 Contour maps for the probability that *T. monspessulana* to be present at different distance values of the proximity index to urban areas (boxes 300, 550 and 800 km) and different land

uses (sub-boxes Shrubland, Pasture, Croplands). Axes represent gradients of precipitation (mm) and distance to road (m). Forest plantation was used like reference group

ranging between 0 and 88 %. Routes showed no differences in the cover of *T. monspessulana* (GLMM, Table 4).

Cover of *T. monspessulana* was related only with variables at plots level (GLMM, Table 5). The cover decreased as the distance to the road increased and changed depending on land uses. Compared to Forest plantations the values of cover increases in Shrublands and decreases in Pastures and Croplands.

Discussion

Factors linked to human activity together with some climate predictors explain the distribution of *T. monspessulana*. In fact, it was present with more probability in areas with comparatively higher annual

precipitation and near to urban areas and roads. In terms of land use, its presence is higher in shrublands and forest plantations followed by pastures and it was almost non-existent in croplands. These results highlight the importance of human activities over climate conditions to explain invasion patterns at multiple scales: While the species is promoted by low mid-level disturbances (e.g. forestry), most extreme disturbances such as agriculture maintain *T. monspessulana* at low densities in climatic suitable environments.

Each of the selected routes presents conditions that differ from each other, especially the coastal route which crosses the region from north to south and has a higher rainfall. However, at this level of analysis, route peculiarities are not a significant factor in determining *T. monspessulana* invasion. It is interesting that the presence of this species can be better

predicted by combining predictors involving two hierarchical levels, transect and plot. Thus the ability of a species to establish in a particular area depends mainly on habitat conditions which are linked to predictors at the transect level, whereas the faculty to form dense populations once propagules reach a new site operates on a smaller spatial scale. At this scale the extent of disturbances also plays a major role.

Disturbances caused by human activities are one of the most important factors determining the presence of invasive plants (Gassó et al. 2009). Areas near the most populated urban areas have more abundant and severe disturbances. The metropolitan area of Concepción, the biggest urban area of the region, is surrounded by a highly disturbed matrix containing non-native forestry plantations, small scale agriculture fields and dispersed fragments of secondary native forest (e.g. Pauchard et al. 2006), with a high density of roads and a growing number of human-caused wildfires (CONAF 2011). Accordingly our results also show that in sites located close to major urban areas the probability of finding *T. monspessulana* populations is significantly higher. Proximity to urban areas appear to be a proxy of a complex set of variables and their interactions which should be studied in more depth to understand its specific association to a particular invasion (e.g. road density, fire frequency, propagule pressure).

Generally, alien species thrive in mesic, disturbed habitats with high availability of resources, such as light and nutrients (e.g. Rejmánek 1989; Milbau and Nijs 2004). Climatic similarity between native and introduced range may play an important role on the plant invasions (Kivinen et al. 2006; Jiménez et al. 2008). *T. monspessulana* currently has invaded the most humid part of the Mediterranean region of Chile, which matches closely with the climate on its natural range (Bossard 2000). Even more, our results also show there is still land with favorable conditions for the future invasion of *T. monspessulana*.

It is a well-documented pattern that roadside verges generally tend to have a higher richness of non-native species than adjacent habitats (e.g. Parendes and Jones 2000; Gelbard and Belnap 2003; Pauchard and Alaback 2004; Seipel et al. 2011). Roads serve multiple functions that enhance non-native species invasion, they act as corridors or agents for dispersal, provide suitable habitat, and contain reservoirs of propagules for future episodes of invasion (Parendes

and Jones 2000). *T. monspessulana* seems to be using roads as main dispersal corridors to reach different habitats. Furthermore, the effectiveness of roadside corridors for the migration of invasive plant species has often been linked to altered site conditions along roads due to increased disturbance, e.g. bare soil proportion (Scott and Davison 1985; Greenberg et al. 1997; Gelbard and Belnap 2003). For *T. monspessulana*, the material for the construction of roads, in many cases, is extracted from degraded and invaded areas favoring the establishment of the species and other non-native species (e.g. *Acacia dealbata*). This link between roads and invasive plant species performance and spread can be extended far away the road even at more than 100 m from roadside verges (Gelbard and Belnap 2003). However, in the case of *T. monspessulana* the highest densities are found in the first 20 m, which is the area most frequently affected by anthropogenic disturbances. The high level of invasion in the road margins may be related to the intensity and the type of traffic, as well as the role of disturbances caused by the management activities in the surrounding lands and the availability of established populations acting as propagule sources.

Small scale environmental factors and propagule pressure have been reported as key elements determining an invasive species distribution (Thomsen et al. 2006). Land use directly affects the invasion process because it modifies disturbance regimes and environmental conditions (Pauchard and Alaback 2004; Jauni and Hyvönen 2010). The highly disturbed landscape dominant in the study area showed ideal conditions for the invasion process of *T. monspessulana*, especially in Forest plantation and disturbed Shrublands. Our results are similar to those found in other forested ecosystem where the proportion of invasive plants was the highest in disturbed areas near to road and field margins; reaching the lowest proportion in less disturbed habitats like native forest margins, grasslands and other habitat types (Pauchard and Alaback 2006; Jauni and Hyvönen 2010).

The colonization and establishment of alien plant species seem to increase with the amount of bare ground and light availability (Foster et al. 2002; Milbau and Nijs 2004). The height of the vegetation affects alien species by reducing light (Jauni and Hyvönen 2010). The intense shade inside dense adult forest plantations seems to be an obstacle for the establishment and growth of *T. monspessulana* (García

et al. 2007). But the habitat modification produced by thinning, harvests tasks (clearcutting), and the subsequent establishment of a new plantation leave exposed mineral rich soil and increases the availability of light, creating the necessary conditions for the establishment of new plants from the *T. monspessulana* seed bank. Additionally, the burning of wastes, widely used by forestry companies, would increase the germination of seeds that are stimulated by fire (Alexander and D'Antonio 2003a; García et al. 2010). In several ecosystems in the world broom species have shown a notorious capability to generate a positive feedback with fire (Alexander and D'Antonio 2003a, b; Mandle et al. 2011). Well preserved natural shrublands free of alien plants are very infrequent in the study area. Most shrublands which correspond to highly degraded native forests or abandoned croplands recolonized by native and introduced species, appear to be a suitable habitat for the establishment of *T. monspessulana* due to its relatively high light availability and constant and intense disturbances (e.g. presence of cattle and removal of firewood), especially wildfires (Pauchard et al. 2008; García et al. 2010).

Worldwide, agricultural habitats are among the most invaded habitats, especially by herbs (Chytrý et al. 2005; Vilà et al. 2007; Pyšek et al. 2009). Among agricultural habitats, arable lands are the most easily invaded by alien plants, whereas natural and semi-natural grasslands undergo lower levels of invasion (Chytrý et al. 2005, 2008; Pyšek et al. 2009). Agricultural lands occupy a significant surface of south-central Chile (Aguayo et al. 2009). However, this shrub shows the lowest presence in agricultural areas. The low presence of *T. monspessulana* inside croplands can be a direct consequence of intense and frequent weed control practiced in these areas.

Fires are one of the most recognized factors that promote the invasion of brooms (Alexander and D'Antonio 2003a; Pauchard et al. 2008; García et al. 2010; Mandle et al. 2011). Although, the presence of fire was not considered in this study, our results show an indirect relationship, since the factors that promote the invasion of *T. monspessulana* are also closely related to the occurrence of wildfires. According to annual statistics of wildfires (CONAF 2011), approximately 99 % of fires are anthropogenic origin, 30 % are arson, hence in areas close to population centers are frequently affected by fires. Similarly, 30 % of fires start in areas adjacent to roads, due to the transit

of people and vehicles. Therefore, ca.55 % of the area affected by fires in the region occurs in shrublands and forest plantations (CONAF 2011), which are the same places with higher probability of presence of *T. monspessulana*.

In a complex landscape matrix with a strong human influence, like in south-central Chile, land uses and intensity can change within a few kilometers. *T. monspessulana* populations are concentrated in Shrublands and Forest plantations from where the species can spread acting as a source of propagules that can quickly invade adjacent less favourable sites. The control and management of alien plant species should be targeted at frequently disturbed and more intensively managed habitats to prevent invasions to undisturbed natural habitats (Jauni and Hyvönen 2010). In undisturbed areas, monitoring for early detection of new focus of invasion is recommended. Furthermore, the management practices, which increase the level of disturbance, should be reduced to prevent or minimize the establishment or spread of invasive plants (Hobbs and Huenneke 1992; Cole et al. 2007). The elimination of fire as a tool to control undesirable vegetation inside forest plantation appears to be the first measure to reduce the spread of *T. monspessulana*. Actions should be taken to reduce the number and intensity of wildfires, especially at the interface between invaded sites and native vegetation fragments. Besides limiting the advance of the invasion, both measurements are important for native biodiversity conservation in the highly fragmented landscapes of south-central Chile. The eradication of a broom species such as *T. monspessulana*, which is highly spread in the landscape, is an unrealistic goal especially in a developing country like Chile, who has limited resources for conservation and restoration. The goal of range managers should be to minimize the damage caused by this species on native ecosystems, with special attention to those most vulnerable areas. Although broom species are classified as very invasive, especially evident in areas with humid Mediterranean and also temperate climates, their abundance appear to be more related to factors operating at local scales rather than to climatic factors that cover large territorial extensions. Therefore, the invasion of these species could be further linked to the degradation of a particular ecosystem more than to changes in precipitation and temperature due to climate change, although climate change might be favoring these species indirectly through an increase of wildfires.

This paper highlights the importance of recognizing the effects of the sampling scale on the response variable. The spatial pattern of a particular event of invasion can be explained by several mechanisms operating at various scales (Pauchard and Shea 2006). Thus, even when a region having the environmental conditions for the successful establishment of an invader, his local performance may be given by the existence of interspecific competition operating at micro-site scale. At the landscape scale, agricultural areas are known to contain a high alien species richness (Chytrý et al. 2005). However, abundance of a woody invader at the plot scale, in a heavily anthropogenic agricultural area is highly reduced by agricultural techniques and therefore this landscape mean abundance is relatively low. To properly quantify or predict the pattern of an invasive species, it is first necessary to clearly identify the key mechanisms of success and the scale at which they operate.

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