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To cite this article: Mariano P. Grilli & Romina Fachinetti (2018): Can forest pattern affect the distribution and abundance of *Arhopalus rusticus* (Coleoptera: Cerambycidae)? A landscape perspective in central Argentina, International Journal of Pest Management, DOI: [10.1080/09670874.2018.1498559](https://doi.org/10.1080/09670874.2018.1498559)

To link to this article: <https://doi.org/10.1080/09670874.2018.1498559>



Published online: 29 Nov 2018.



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Can forest pattern affect the distribution and abundance of *Arhopalus rusticus* (Coleoptera: Cerambycidae)? A landscape perspective in central Argentina

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ABSTRACT

Since 2006, *Arhopalus rusticus* (Coleoptera: Cerambycidae) has expanded its range in the pine production area of Córdoba Province (Argentina). In this paper, we analyse the effect of landscape pattern on the distribution and abundance of *A. rusticus*. Land cover was estimated using Landsat 8 scenes. Landscape was quantified by estimating the Total Class Area, which showed a positive relationship with *A. rusticus* abundance, and Mean Euclidean distance and Mean Shape index, which had a negative relationship. Since its arrival, *Arhopalus rusticus* has proved to be a successful invader, affected by the landscape pattern of the patches.

ARTICLE HISTORY

Received 27 March 2018
Accepted 3 July 2018

KEYWORDS

Landscape configuration;
Arhopalus rusticus;
abundance; pine forest

Introduction

Habitat fragmentation is usually described as the disruption of a once large continuous block of habitat into a less continuous one, mainly caused by human activity (Lord and Norton 1990). It can be defined either as a process that causes fragmentation, or as an outcome, *i.e.* the state of being fragmented (Wiens 1995). The most obvious example of this fragmentation is the conversion of a landscape into a patchwork of crop fields by agriculture or forestry (Wilcove et al. 1986). In the case of specialised herbivorous insects, the breeding habitat is defined by the spatial availability of host plants that form suitable patches (Lewis and Basset 2007). The presence of a species, its population density, dynamics and biotic interactions depend on processes much greater than a single habitat (Thies et al. 2003). It is therefore important to approach the study of populations from a landscape perspective, considering the spatial arrangement, size, connectivity and quality of the habitat patches in order to understand local patterns and processes (Tscharntke and Brandl 2004).

The relationship between patch size and insect density is a central issue in pest control (Bukovinszky et al. 2005). The main objective in this area has been to quantify the pattern and to explore the underlying mechanisms (Fahrig 2003). Among the mechanisms proposed is the resource concentration hypothesis (Root 1973). This predicts

that specialist herbivorous insects will be more abundant in large host patches, because they find them more easily and stay there longer than in smaller host patches (Root 1973). This implies higher emigration rates from smaller patches into larger patches. Since this hypothesis was originally formulated, many studies have empirically quantified these relationships for a diverse set of organisms, but their results have been quite variable (Hambäck and Englund 2005). The main issue underlying this theory is that the habitat patch is considered as the natural area for recording species abundance. But even if the limit of the patch could be established, insects make frequent movements to the matrix or through the matrix (Schultz et al. 2012). Moreover, the capacity of an insect to move from one patch to another will be fundamentally affected by the patches' isolation. Patch isolation is rather difficult to measure. For habitat patches in fragmented landscapes, isolation has to be measured in different ways, depending on landscape characteristics and the species' ability to use the surrounding habitat. Briefly, isolation can be described as an actual measure of the amount of habitat in the landscape and will depend on the insect's gap-crossing ability and on the hostility of the matrix surrounding the patch (Prugh et al. 2008). This is why a better understanding of the spatial dimension of population dynamics can improve our comprehension of their driving forces.

In Córdoba Province in the central region of Argentina, there is an area of 13325 hectares of introduced pine forests (CNA INDEC 2008). These are mainly of *Pinus elliottii* and *Pinus taeda*, versatile species that are very well adapted to the region. These cultivated woodlands form discrete patches, interspersed in a matrix dominated by natural pastures and shrublands.

Arhopalus rusticus, an invading species of Cerambycidae, was detected for the first time in these forests in 2006 (López et al. 2007). *Arhopalus* (Cerambycidae: Aseminae) is a Northern Hemisphere genus with about 25 species and subspecies, whose larvae develop in coniferous trees (Villiers 1978), and it is present in all major biogeographic regions of the world through the spread of trade (Özdikmen 2014). *A. rusticus* is a common species of cerambycid in pine forests of North America, Central and Northern Europe, Siberia, Korea, Mongolia, Japan, North China and North Africa and was later introduced into Australia and the Neotropical Region (Özdikmen 2014). The species is found mainly in conifers of the genus *Pinus* (Özdikmen 2013). The larvae infest the roots and the base of the stems of healthy, stressed or dead trees, occasionally damage structural timbers (Özdikmen 2013) and can potentially cause tree decline and loss of timber value (Kolk and Starzyk 1996).

Although *Arhopalus* sp. does not cause serious damages within healthy forests, its behaviour of using crevices as day time refuge makes it an important pest of timber and export logs affecting the trade because its condition of a serious quarantine pest (Stanaway et al. 2001, Pawson et al. 2010). Considering that *Arhopalus rusticus* is a quarantine species, and its presence can be a threat to wood products trade, in this paper we propose to determine how the configuration and composition of pine plantations affects the distribution and abundance of *A. rusticus* in order to make recommendations for forest planning and management, and ultimately discuss pest management strategies.

Methods

Study area

The study was performed in the centre-west of Córdoba Province (Argentina), in an area ranging from 31° 33' 30" S, 64° 59' 21" W in the north, to 32° 40' 58" S, 64° 33' 59" W in the south. This is the main pine production region in the centre of the country. The study area is mainly mountainous, dominated by shrublands and high-altitude grasses with exotic pine forests of *Pinus taeda* and *P. elliottii*.

Insect sampling

Adults of *A. rusticus* were collected using cross-vane panel traps made of two crosswise black plastic sheets, 50 cm tall by 30 cm wide, mounted over a plastic funnel at 2 m above the ground. The cross-vane design was chosen because it is more effective than other trap designs for capturing borers (McIntosh et al. 2001). The traps were baited with turpentine, composed mainly of α -pinene, β -pinene and other terpenes (100 ml), and ethanol 70% (100 ml), in two different recipients. The combination of ethanol and α -pinene and β -pinene is an effective bait for *A. rusticus* (Wang et al. 2014). Collection cups contained a solution of water with sodium chloride as a preservation agent. To analyse the abundance of *A. rusticus* inside host patches, samplings were carried out during the two spring and summer seasons from 2013 to 2015. During both seasons, 33 pine patches were randomly selected within the study area. At each site, five traps were placed close to each other, a minimum of 30 m apart. Each sampling season, traps were deployed in November, 50 m into the pine forest, and were checked and lures replaced every 30 days, beginning in November and finishing in March. The samples collected from the traps were processed in the laboratory under a stereomicroscope. Insect abundance was recorded as total individuals collected in each trap at each sampling site.

Land-cover estimation

Eight Landsat scenes, frames 229/82, and 229/83, which have a pixel size of 30 m, were employed to estimate the land cover of the study area using TerrSet (Eastman 2015) software. A supervised classification was used to estimate land use. Classification of land use by remote sensing is based on the different spectral characteristics of the different materials of the earth's surface. Basically, the classification process attempts to categorise all the pixels of a digital image, assigning them to one or more land cover classes. The supervised classification is performed by an operator who defines the spectral characteristics of the classes by identifying areas where the ground cover is known, called training areas (Janssen and Gorte 2004). One hundred and twenty-eight training areas were recorded for the classification. To facilitate the detection of pine patches, five classes were considered in the analysis: pine forest (host patch), shrublands, grasslands, exposed rock or naked soil and water, which formed the matrix. For analysis, only pine patches were considered. Once the spectral signatures of the classes of interest were obtained, we proceeded to classify the image by applying the algorithms of

Fisher's Linear Discriminant classifier (Landgrebe 2003), one of the most powerful hard supervised classifiers (Eastman 2015). An accuracy assessment was made by generating a random set of locations to verify the true land-cover type. We applied an error matrix to compare the classes obtained with the real ground classes found in the field and to tabulate the overall proportional error (Congalton and Green 1999).

Landscape quantification

For landscape analysis three class metrics were computed for pine patches: Total Class Area (CA), Mean Shape Index (SHAPE_MN), and Mean Euclidean Distance (ENN_MN). Class metrics are values integrated over all the patches of a given type (class) in a certain area (McGarigal et al. 2012). Each class metric was estimated based in a 9 km circle area centred in the focal patch, given the previous results of estimates of mean flight distance of *Arhopalus rusticus* using flight mills (Grilli and Fachinetti 2017). All the landscape metrics were estimated using FRAGSTATS 4.2 (McGarigal et al. 2012). The class metrics were computed as follows:

Total Class Area (CA)

Total Class Area is a metric that is affected by the number and size of patches. It is a direct measure of the amount of landscape comprised by a particular patch type, in this case pine patches. This metric approaches zero as the patch type becomes increasingly rare in the landscape (McGarigal and Marks 1995).

Mean Shape Index (SHAPE_MN)

Shape Index is a perimeter area ratio calculated for each patch. SHAPE equals patch perimeter (m) divided by the square root of patch area (m²), adjusted by a square standard. Shape Index increases without limit as patch shape becomes more irregular. At a class level, the mean value of the shape indexes calculated in the landscape is employed (SHAPE_MN).

Mean Euclidean Distance (ENN_MN)

Mean Euclidean Distance is the distance (m) to the nearest neighbouring patch of the same type, based on shortest edge-to-edge distance for all the patches of the same class in the landscape. Euclidean distance increases as the distance to the nearest neighbour of a certain patch increases.

Data analysis

To analyse the effects of selected class metrics on *A. rusticus* abundance, a generalised linear mixed model with a Poisson error distribution was applied. Class metrics were set as explanatory variables, and insect abundance as the response variable. Model selection was performed using Akaike's information criterion (AIC) to compare candidate models, including the biologically meaningful non-redundant explanatory variables progressively, from a single variable to the whole set of proposed variables. Coefficients and confidence intervals were estimated for each variable in each model. Collinearity between variables was checked by estimating the Variance Inflation Factor (VIF). All the analyses were conducted using the 'glmer' module in R 3.4.0 for Windows (R Development Core Team 2017).

Results

Land cover

Classification of land cover showed that 45% of the area is covered by grasslands, 32% by shrublands, 18% is exposed soil and rock, 2% is water (mainly small rivers and artificial lakes) and pine forests represent only 3% of the area. The algorithm employed for classification proved very precise. The error matrix accounted for 86% of overall accuracy of the land use classification for the study period. This accuracy was increased for pine woodlands by manually correcting pine patches using Google Earth[®] information (Figure 1).

Arhopalus rusticus abundance

The mean abundance of *Arhopalus rusticus* appears to vary between sites and between studied periods. Mean values of captured individuals at each sampling site ranged from 0.67 to 16 individuals in the first period and from 0 to 10.13 individuals during the second period (Figure 2).

Relationship between Class metrics and the abundance of Arhopalus rusticus

Class metrics for pine patches were generated for all the 33 sampling sites in the studied area (Figure 3). The Akaike Information Criterion (AIC) was employed to find the model including the metrics that best explained the abundance of *A. rusticus* in the field. The model included the class metrics as covariables, and patch, site, trap and date as random effect factors. We found that the most parsimonious model (with the lowest AIC) was the one that included all three class metrics proposed: a

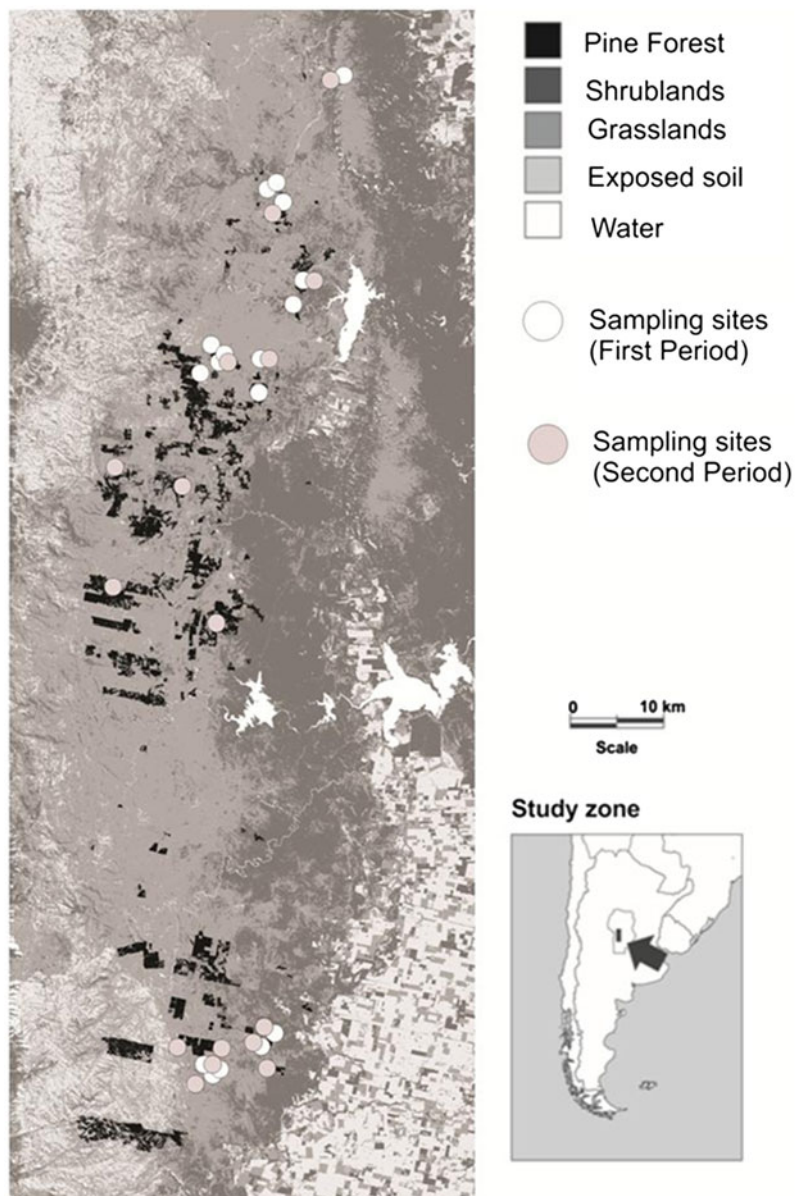


Figure 1. Study area showing different land covers.

landscape composition metric (CA), a shape metric (Shape_MN), and an isolation metric (ENN_MN). No collinearity was detected between the class metrics employed. All the variables included were significant (Wald Chi-square test), and a confidence interval (95%) was estimated. The full model showed that Total Class Area of pine patches (CA) has a positive relationship with *A. rusticus* abundance, while shape (Shape_MN) and isolation (ENN_MN) have a negative relationship (Table 1).

Discussion

A key assumption in landscape ecology is that spatial patterns have a significant influence on flows of materials, energy and information through the landscape (Wu and Hobbs 2002). Considering that only a minuscule area of the studied landscape is composed of pine woodlands, its pattern becomes a key

feature to understanding *Arhopalus rusticus* distribution. There are two main measures of landscape pattern: composition and configuration (Li and Reynolds 1994). In this work, we quantified landscape pattern through three class metrics: Total Class Area of pine patches (CA), Mean Euclidean Distance of pine patches (ENN_MN) and Mean Shape Index of pine patches (Shape_MN).

Despite the variability observed in the mean abundance of insects captured at the different sites, we found a positive relationship between Total Class Area (CA) of pine patches and *A. rusticus* abundance, i.e., the greater the area occupied by pine patches within the 9 km diameter landscape, the more abundant is *A. rusticus*. We also found a negative ratio between the Mean Euclidean distance between patches (ENN_MN) and the abundance of *A. rusticus* in the focal patch. In other words, the more isolated the pine patches within the 9 km

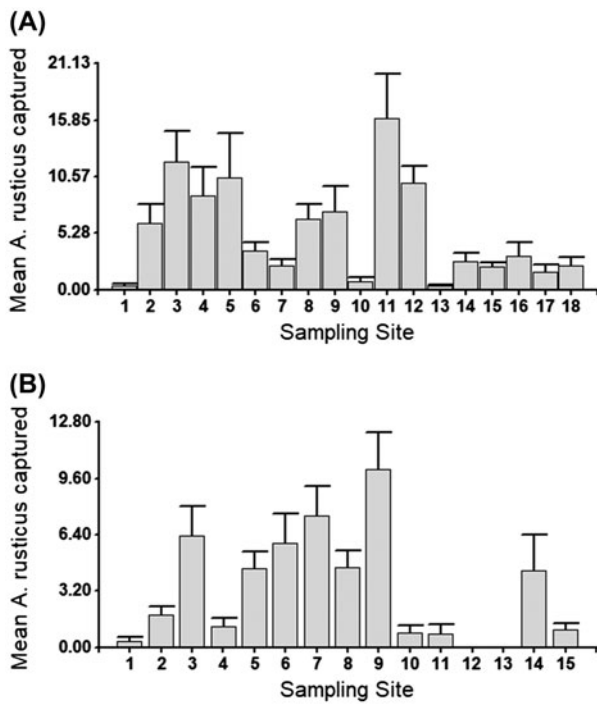


Figure 2. Mean number of individual of *Arhopalus rusticus* captured in each sampling site and in each year. A = 2013; B = 2014.

landscape area surrounding the sampling site, the lower the abundance of the insect pest or, in other words, an increase in the total amount of pine patches and in the proximity of these patches means a direct increase in the abundance of *A. rusticus*. This result is consistent with the resources concentration hypothesis (Root 1973; Kareiva 1983).

Different studies show that inter-patch distance can influence population dynamics within the patch, mainly because of its effect on immigration and emigration. Isolated patches have lower density (Hanski et al. 1994) and lower growth rates (Fahrig and Merriam 1985) because landscape connectivity affects the movement of organisms between patches (e.g. Haddad 1999). Population abundance and the distance to other host patches in the landscape have a direct effect on net movement rates between host patches (Moilanen and Nieminen 2002), but distance inevitably increases the cost of dispersal, meaning that fewer dispersers successfully reach other host patches (Haddad 1999). Mortality rates may increase with distance, due to greater exposure to predation (Yoder et al. 2004) or to the loss of body mass during movement through the landscape (Baker and Rao 2004). In each case, there will be a different pool of immigrants, and the isolation of a particular patch will depend not only on the distance, but also on the area represented by the surrounding patches. Patch isolation thus depends on the amount of habitat within some distance of the patch (Fahrig 2013). And this seems to be exactly our case: in those areas in which patches are small

and isolated, the individual can count only on the resources within those patches, but in those areas in which pine patches are larger and closer, they have the chance to move to a new patch if the resources within the patch in which they were born are not suitable enough.

We also found a negative relationship between patch border complexity (Mean Shape Index) and *A. rusticus* abundance; i.e., those areas that have patches with less complex borders tend to have higher *A. rusticus* abundance. According to the principle of shape and function, those patches with more complex shapes should promote exchange between the inner patch and the outer environment (Su et al. 2015). In our case, the areas with patches with less complex borders probably tend to lose fewer individuals to the non-host matrix than those patches with more complex borders. The general theory indicates that, as perimeter-to-area ratio increases, emigration from the focal patch also increases (Turchin 1998). This permeability of the host patch edge is species-dependent (Duelli et al. 1990) and will be determined by the proportion of potential emigrants that reach the patch boundaries and the probability of crossing them (Stamps et al. 1987). In turn, the proportion of potential emigrants will depend both on the amount of edge in relation to the area of the patch and the movement patterns of an individual within that patch (Tischendorf et al. 2005). Moreover, emigration from a suitable habitat patch is an individual decision dependent on the perception of boundaries (Schtickzelle and Baguette 2003) and thus determines emigration rates. Several species of insects, including longhorn beetles, are able to perceive the patch boundary and change their behaviour to stay in the patch (Schtickzelle et al. 2006). Fahrig and Paloheimo (1988) found that one of the most important determinants of mean population size is the proportion of individuals dispersing from the habitat patches. High dispersal rates generally result in lower population sizes. In addition, Tischendorf et al. (2005) found that, with an increased probability of boundary-crossing from habitat to matrix, the population density decreases significantly.

Specialist herbivores are more likely to find and remain in large patches of their host plant (Connor et al. 2000) and here the underlying idea is that the higher densities of insects in large patches are mainly caused by movement between patches. In our case, an increase in the total amount of pine patches leads to a direct increase in the abundance of *A. rusticus*, as they can freely move between patches because of their proximity. In most patchy populations, immigration arrives from habitats within the neighbourhood of the patch. In terms of

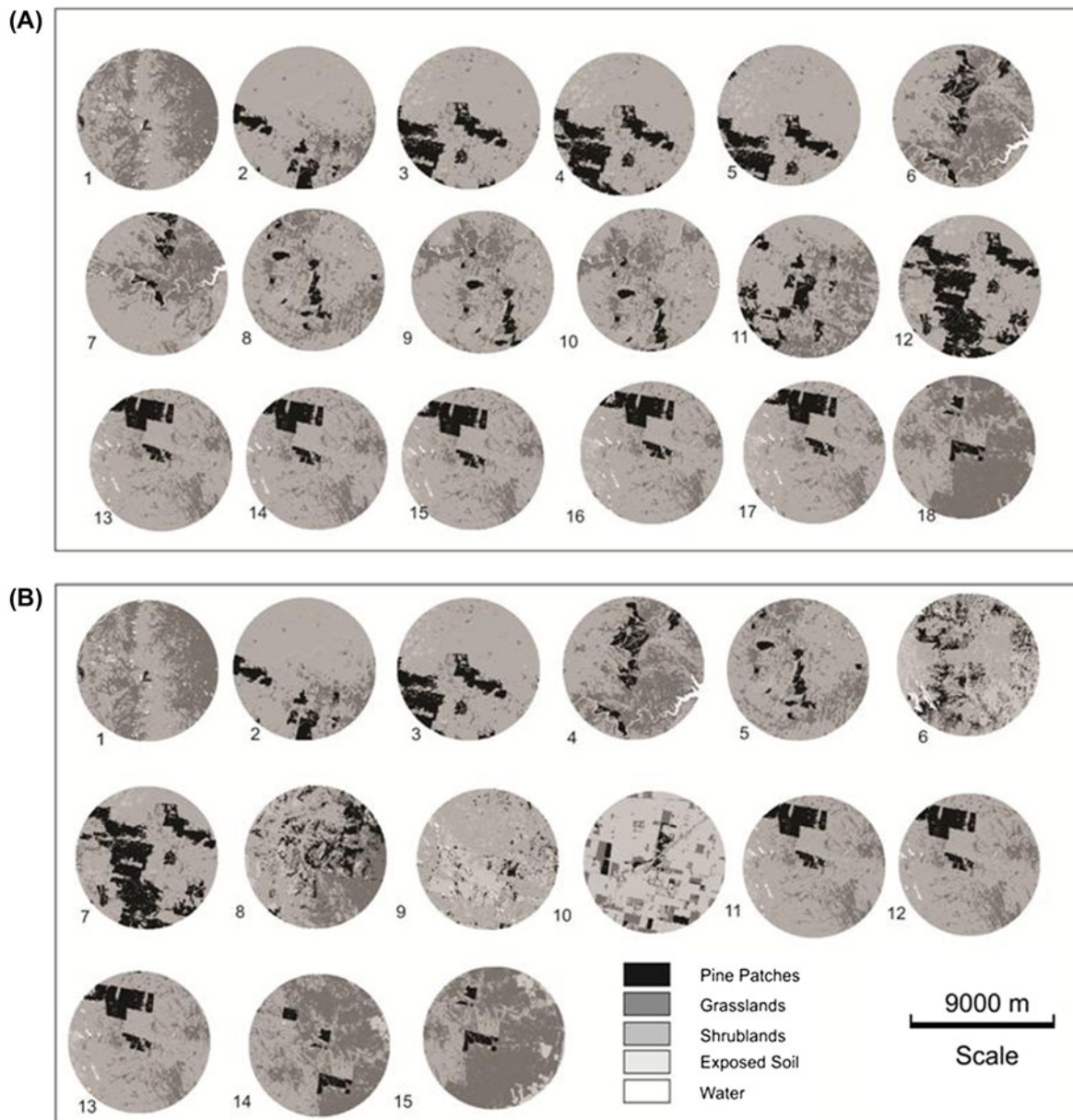


Figure 3. Landscape areas from which Class metrics were obtained. Traps were placed in the centre of the circle. A = 2013; B = 2014.

Table 1. Generalized linear mixed models explaining the abundance of *Arhopalus rusticus* in each site based on class metrics (SHAPE_MN: Mean Shape Index; ENN_MN: Mean Euclidean Distance; CA: Total Class Area of Pine patches). AIC, Akaike's information criterion, VIF, Variance Inflation Factor.

Model	AIC	Selected variables	Coefficient	VIF	95% confidence interval
M ₀	5040	Null Model	–	–	–
M ₁	2291.6	CA	0.0007	–	0.0002 0.0012
M ₂	2300.9	SHAPE_MN	–0.1047	–	–0.3551 0.1457
M ₃	2282.4	ENN_MN	–0.0006	–	–0.0008 –0.0003
M ₄	2281.6	CA	0.0013	1.50	0.0007 0.0018
		SHAPE_MN	–0.5348	1.50	–0.8260 –0.2437
M ₅	2281.2	CA	0.0004	1.08	–0.00001 0.0008
		ENN_MN	–0.0005	1.08	–0.0008 –0.0002
M ₆	2283.7	SHAPE_MN	–0.1011	1.00	–0.34104 0.1387
		ENN_MN	–0.0006	1.00	–0.0008 –0.0003
M ₇	2275.94	CA	0.0009	1.08	0.0005 0.0013
		SHAPE_MN	–0.4169	1.00	–0.4189 –0.4150
		ENN_MN	–0.0004	1.08	–0.0006 –0.0001

island biogeography, it can be considered that the mainland of each patch is the nearest suitable habitat patch, or the nearest patch weighted by area, or the summed area of all patches surrounding the focal patch. Habitat area and isolation are closely correlated. Since its arrival in the central area of Argentina, *Arhopalus rusticus* has proved to be a successful invader, reaching all the pine patches in the area. This is probably due to the dispersal capability of the insect (Grilli and Fachinetti 2017) but it is clear that landscape pattern plays a major role in the distribution of its population. The species have managed to build a bigger population in those areas where patches are closer and larger, and so the exchange of individuals is easier and the amount of suitable hosts is higher.

There are no reports of the presence of *Arhopalus rusticus* in other pine production areas of Argentina. In a way this fact can be considered as good news, letting the authorities to take the necessary measures in order to avoid the arrival of the pest to these areas, or if not possible, to reduce its impact. Our results show that an area-wide integrated pest management can be a suitable approach for this pest. Landscape patterns can affect ecosystem processes (Zhao et al. 2015). As we showed, class level metrics have an effect on the distribution and abundance of *A. rusticus*. And the modification of the landscape at a class level can be an approach for forestry planning with undeniable benefits. The simple action of increasing the separation between pine patches and making them as irregular as possible would, according to our results, affect the abundance of the pest.

Acknowledgements

This work was carried out in part with a grant provided by the Agricultural Ministry of Argentina (SAFO 111, Unidad Para el Cambio Rural, Ministerio de Agricultura, Ganadería y Pesca, Proyecto BIRF 7520) and the University of Córdoba - Secyt 313/2016. The author wants to thank to two anonymous reviewers and the Assistant Editor of IJPM for the useful comments on a previous version of this manuscript.

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