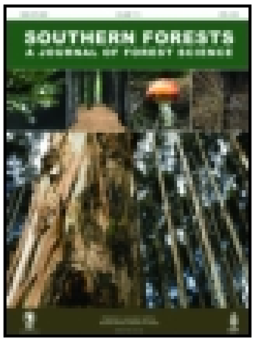

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A synthesis on the impact of non-native conifer plantations on ant and beetle diversity in north-western Patagonia

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Softwood forestry with non-native tree species is increasing worldwide and especially in many developing countries of the Southern Hemisphere. Tree plantations are beneficial in environmental and socioeconomic aspects, but at the same time there are recognised costs associated with afforestation. Our aim was to revise the existing information on the impact of exotic conifer plantations in north-western Patagonia on insect biodiversity. A total of five studies were selected and, in these, not every insect group responded in a similar manner to the habitat replacement. There was a tendency towards a reduction in abundance and species richness of several insects inside pine plantations. This change in abundance and richness was especially evident for ant assemblages and when pine plantations were dense. Beetle assemblages, in turn, showed diverse responses to the replacement of native vegetation with forests depending on the native habitat matrix. Our findings confirm that practices that reduce tree density (via thinning or during plantation) should be recommended to minimise their impact on insect biodiversity in north-western Patagonia. The consistent behaviour of ant assemblages, coupled with their abundance, ease to sample and unambiguous taxonomy make them reliable candidates for long-term monitoring of the impact conifer forestation in north-western Patagonia, as well as probably in other regions of the world in which non-native pines replace natural environments.

Keywords: ants, beetles, biodiversity, forestry, Patagonia, pine plantations

Introduction

Softwood forestry with non-native trees is increasing worldwide and especially in many developing countries of the Southern Hemisphere (Wingfield et al. 2015). It is widely accepted that non-native tree plantations can be beneficial in some environmental and socio-economic aspects (e.g. soil protection, ecosystem restoration and regional economic development; Schlichter and Laclau 1998; Brockerhoff et al. 2008; Wingfield et al. 2015). Such benefits likely drive the promotion of plantation forestry in many regions. At the same time, there are recognised environmental costs associated with afforestation. Plantations may strongly modify the habitats on which they grow, in many aspects and at different spatial and temporal scales. Trees, especially non-native species planted on otherwise treeless landscapes, can often become invasive and modify habitat structure, alter soil characteristics, consume large amounts of water and even generate irreversible changes in native biodiversity and ecosystem functioning (Brockerhoff et al. 2008; Richardson et al. 2008; Brockerhoff et al. 2013; Pawson et al. 2013; Thompson et al. 2014).

In South America more than 12 million ha of land are planted with non-native fast-growing tree species such as *Pinus* spp., *Eucalyptus* spp. and *Populus* spp. These plantations are located in natural forest areas and also in drier grassland areas. These forest plantations are established for the production of timber, pulp and fuel, and largely consist of intensively managed, even-aged and regularly spaced stands of single species usually with low levels of genetic variation (FAO 2010). In Argentina, forestry is an expanding activity, currently covering 1 120 411 ha, most of which is in two contrasting regions: the north-eastern, subtropical region (880 000 ha); and the south, in Patagonia covering nearly 97 400 ha (DPF 2014).

In Patagonia, plantations of North American fast-growing conifers, such as *Pinus ponderosa* and *P. contorta*, is a relatively new activity (since 1970), promoted by the state. In this region, plantations are deployed in the forest–steppe ecotone, a transition zone east of the Andes mountain range, dominated by xeric forests and gramineous steppe. This region has been subjected, since the beginning of the twentieth century, to heavy sheep grazing (Bertiller and Bisigato 1998). Despite the fact that the surface area in this region that is devoted to forestry remains small, some work has suggested that forest plantations for wood production purposes may rapidly increase (Loguercio and Deccechis 2006).

To date, several studies have focused on the potential benefits and impacts of pine afforestation on the Patagonian steppe in order to guide development policies in the region (Schilchter and Laclau 1998). Some previous baseline work suggested that negative environmental impacts and changes on native biodiversity of the forest plantations might still be regionally low, partly due to the reduced area still planted (reviewed in Gyenge et al. 2010). While longer-standing, more widely developed forestry in Patagonia may impact local economies can be envisioned, their long-term effects on native habitats at local and regional scales remains largely unknown.

In north-western Patagonia, a number of studies have collected information on the impact of North American conifer plantations on the native biodiversity of plants, insects, birds and mammals (e.g. Candan et al. 2006; Corley et al. 2006; Paritsis and Aizen 2008; Lantschner et al. 2008, 2011, 2012; Corley et al. 2012). Despite the fact that each of these papers provides important data for given sites (i.e. specific stands or habitats replaced by the pines; a specific taxon) at given times (e.g. one-year sampling), generalising their findings and reaching robust conclusions may not be straightforward. Different results among these studies are not unexpected because it is known that different organisms display different responses to habitat disturbance, mainly because of their different life histories (e.g. food or habitat requirements). Thus, synthesising the information on the impact of pine plantations on biodiversity of Patagonian insects remains a challenge.

Our aim was to summarise the existing information on the impact of exotic conifer plantations in north-western Patagonia on biodiversity, focusing on insects. Insects are the dominant and most diverse biological group in terrestrial ecosystems. They are involved in a variety of fundamental processes for the functioning of natural systems (e.g. pollination, seed dispersal, soil aeration and turnover, the breakdown of dead organic materials and nutrient recycling) and, particularly, insects are sensitive to changes in environmental conditions and anthropic management. We proposed to collate the existing information in an attempt to describe general patterns and, if possible, identify key insect taxa that may prove reliable to monitor the direction changes may take with an increased cultivated surface area.

Methods

Studies of biodiversity of insect assemblages in exotic forest plantations of north-western Patagonia

We compiled the existing studies that compared the biodiversity of different insect taxa between pine plantations and the original vegetation in north-western Patagonia (39°50′ to 41°20′ S, 71°16′ to 71°10′ W; Figure 1). The sampling procedures of these studies were, in general terms, comparable (Table 1): (1) sampling was carried out in independent sites (mainly January and February); (2) sites included pure or mixed exotic conifer plantations stands (*Pinus ponderosa*, *Pinus contorta*, *Pinus radiata* and *Pseudotsuga menziesii*), paired with surrounding native vegetation areas (steppe, *Austrocedrus chilensis* and *Nothofagus dombeyi* forests) as a control; and (3) environmental variables characterising stand structure (i.e. tree cover, tree diameter at breast height, tree density and understory cover) were recorded as candidate explanatory variables of changes in abundance, richness and composition of different functional groups of insects.

The estimates of species richness and abundance can be influenced by differences in sample sizes. However, in accordance with Cheli and Corley (2010), it would be enough to use a minimum of three pitfall traps per plot and to leave them at least for 10 d filled with a propylene glycol solution to obtain reliable data on the structure of a community of ground-dwelling arthropods in the Patagonian steppe. Furthermore, in the case of pine plantations, where abundance could be lower than in steppe areas, and to increase captures, trapping effort was set to be at least twice the minimum effort for the arid steppe. Sampling completeness evaluation, when done (Corley et al. 2006, 2012), shows more than 85% of the expected species richness for the study area sampled with the reported effort. We included here only studies that met or exceeded these conditions, and where comparable in terms of the taxa studied (Table 1). Therefore, a qualitative comparison of the selected works in the region can show us reliable trends in insect community changes.

Results

A total of five studies have looked at changes in the abundance, richness and composition of insect taxa in conifer plantations replacing native vegetation of north-western Patagonia (Table 2). The insect groups chosen for comparison were ants and beetles, because these were sampled in most studies likely due to their abundance, ease of capture and known taxonomy.

Changes of insect abundance, diversity and composition as consequence of exotic forest plantations in north-western Patagonia

As expected, neither insect group responded in a similar manner to the habitat replacement by forest plantations (Table 2; Figure 2). There was a tendency towards a reduction in abundance and species richness of given taxa inside pine plantations. This drop in abundance and richness was especially evident for ants, and when pine plantations were dense (Corley et al. 2006, 2012; GEPI 2016; Figure 2). Beetles, in turn, showed diverse responses to the replacement of native vegetation with forests depending on the native habitat matrix. In steppe environments, there was an increase in beetle abundance in pine plantations when compared with that found in native vegetation sites (Rusch et al. 2004; Corley et al. 2012; GEPI 2016; Figure 2). Beetle abundance and species richness decreased in conifer plantations compared with that of *Nothofagus dombeyi* forests (Paritsis and Aizen 2008).

Beetle assemblages composition changed between natural habitat and forest plantations, while ant assemblages varied to different degrees depending on the study analysed (Table 2; Corley et al. 2006, 2012; GEPI 2016). Given the lack of knowledge on the life history of most species dwelling in north-western Patagonia, it is not possible to evaluate any functional patterns associated with these changes in composition.

Discussion and conclusions

Overall, the substitution of native habitats by exotic conifer plantations has an obvious effect on the assemblages of native insects in north-western Patagonia. Each insect

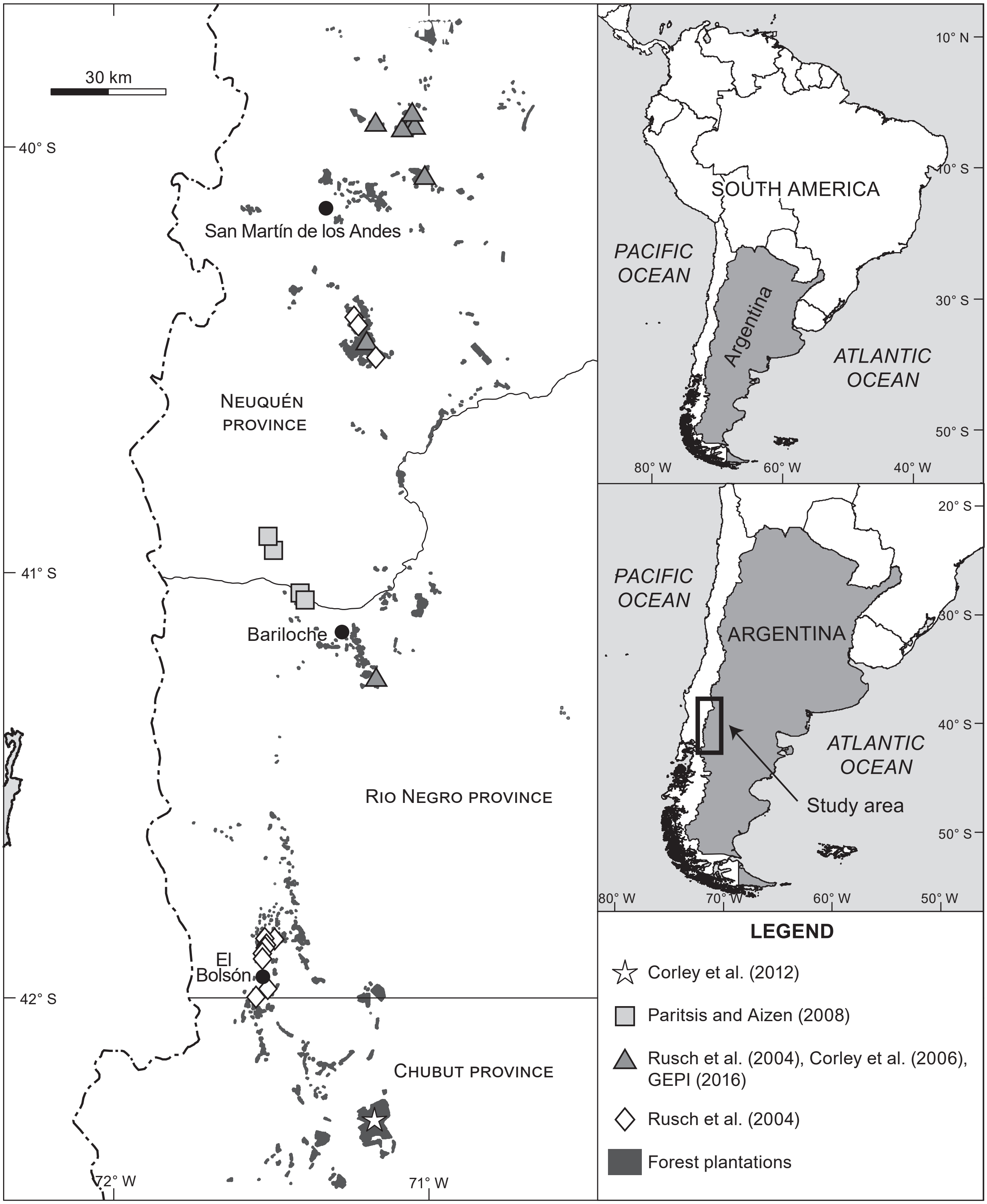

Figure 1: Map of the study sites in north-western Patagonia, Argentina

group responds, to some extent, in a different fashion. This is likely due to their different habitat requirements, such as temperature and humidity or food availability, besides depending on different biotic factors such as the presence and distribution of competitors (Lövei and Sunderland 1996; Hoffman and Andersen 2003). A reduction in abundance, species richness and changes in species composition is a clear trend for the studied taxa sampled in conifer

Table 1: Studies of the impact of exotic conifer plantations on insect diversity in north-western Patagonia, Argentina. Sparse plantations are those in which canopy cover was less than 80% (i.e. understory cover was more than 50% on average); see Rusch et al. (2004)

Study	Habitats replaced	Insect taxa	Sampling period	*N* sites (paired)	Vegetation types	Sampling method	Environmental variables
Rusch et al. (2004)	Patagonia steppe and *Austrocedrus chilensis* forest	Hymenoptera (Formicidae), Coleoptera, Lepidoptera	2001/02 (summer)	8 steppe + 3 *A. chilensis* forest	Native vegetation (steppe or *A. chilensis* forest), sparse pine plantation, dense pine plantation	Pitfall (25 traps per plot × 21 d), Malaise trap (1 trap per plot × 3 d)	Tree density, cover, height and DBH; understory species richness and cover
Corley et al. (2006)	Patagonia steppe	Hymenoptera (Formicidae)	2001/02 (summer)	7	Native vegetation (steppe), sparse pine plantation, dense pine plantation	Pitfall (25 traps per plot × 21 d)	Tree cover, understory cover.
Paritsis and Aizen (2008)	*Nothofagus dombeyi* forest	Coleoptera	2001 (summer)	4	Native vegetation (*N. dombeyi* forest), dense conifer plantation	Pitfall (8 traps per plot × 20 d)	Tree density, cover, height and DBH; understory species richness and cover; % bare soil; % leaf litter cover; leaf litter depth
Corley et al. (2012)	Patagonian steppe	Hymenoptera (Formicidae) and Coleoptera	2008 (summer)	10	Native vegetation (steppe), pine plantation	Pitfall (9 traps per plot × 10 d)	Tree height, crown diameter, trunk base diameter understory cover, soil surface moisture
GEPI (2016)	Patagonian steppe	Hymenoptera (Formicidae) and Coleoptera and Lepidoptera	2015 (summer)	8	Native vegetation (steppe), dense pine plantation	Pitfall (9 traps per plot × 14 d), Malaise trap (1 trap per plot × 7–14 d)	Tree density, cover and DBH; understory cover

plantations in north-western Patagonia in comparison with the different native habitats, in the works reviewed here.

In general, our results show that more open tree stands displayed a lower impact on insect abundance and diversity. Higher tree density is typically accompanied by a reduction in native understory vegetation (Aubin et al. 2008), which is thought to contribute to the generally reported impoverishment of the insect assemblages (e.g. ants, beetles and moths; Rusch et al. 2004; Corley et al. 2006; Paritsis and Aizen 2008). Most plantations in the region are planted at high densities (Loguercio and Deccechis 2006). These observations suggests that for ants in north-western Patagonia, practices that contribute to prevent crown closure (i.e. thinning), which allow for the development of understory vegetation, would reduce their impact. In addition, as has been shown by Corley et al. (2012), wastes generated from pruning provide favourable microhabitat that may further benefit some beetle species.

We also observed that changes in insect abundance and richness due to the replacement of native vegetation with exotic pine plantations differed depending on which type of vegetation was replaced, particularly for beetles. In steppe areas, beetle species richness and abundance tend to increase or remain similar in pine plantations than in the steppe, whereas in areas dominated by native *Nothofagus* forests, insect richness and abundance decreased in dense pine plantations (see Table 2). A possible explanation for this pattern is that when replacing steppe areas, structural changes of the vegetation are so important that most beetle species may not find suitable habitats within a forested landscape. Therefore, the steppe beetle community is partially replaced with a new assemblage, likely composed of species that select cooler microhabitats, higher soil moisture content or more food and shelter resources associated with the presence of wood wastes.

Accordingly, studies worldwide have also noted that exotic tree plantations are less favourable habitats for some native insects than the replaced habitats. Plantations are typically less suitable for Coleoptera (Fahy and Gormally 1998; Jukes et al. 2001; Pawson et al. 2009; Cerda et al. 2015), Formicidae (Cunningham et al. 2005), Lepidoptera (Luque et al. 2007; van Halder et al. 2008) and Orthoptera (Bieringer and Zulka 2003), suggesting also that the loss of some of the structural components found in the native habitats (i.e. understory vegetation and old or dead trees) are an important factor affecting beetles.

Beetles and ants are known to respond quickly to habitat disturbance by fire, grazing (Farji-Brener et al. 2002; Sasal et al. 2015) and forest management practices in Patagonia (Corley et al. 2006, 2012). In our study, both groups showed changes in abundance and diversity associated with pine afforestation. However, ants displayed more consistent changes (reduced abundance and richness in plantations in four studies) throughout habitat types, location and management practices deployed. This consistency in sensitivity of ants to environmental changes suggests that this group could be a reliable estimator of the impact of land-use change on biodiversity (see also Andersen 1997). The consistent behaviour of ant assemblages, coupled with their abundance, ease to sample and unambiguous taxonomy make them reliable

Table 2: Main results of studies of the impact of exotic conifer plantations on insect diversity in north-western Patagonia, Argentina. DPP = dense pine plantations, NF = native forest, S = steppe, SPP = sparse pine plantations

Group	Parameter	Rusch et al. (2004)	Corley et al. (2006)	Paritsis and Aizen (2008)	Corley et al. (2012)	GEPI (2016)
Ants	Abundance	NF = SPP > DPP	S = SPP > DPP	–	S > DPP	S > DPP
	Species richness[1]	No data	Inconclusive	–	S < DPP	S > DPP
	Composition[2] (ANOSIM)	No data	S ≠ DPP, S = SPP, SPP = DPP	–	S = DPP	S = DPP
Beetles	Abundance	DPP > S	–	NF > DPP	S < DPP	S = DPP
	Species richness[1]	No data	–	NF > DPP	S > DPP	S > DPP
	Composition[2]	No data	–	NF = DPP	S ≠ DPP	No data

[1] Species richness based on rarefaction curves
[2] Differences in species composition based on analysis of similarity (ANOSIM; Clarke 1993)

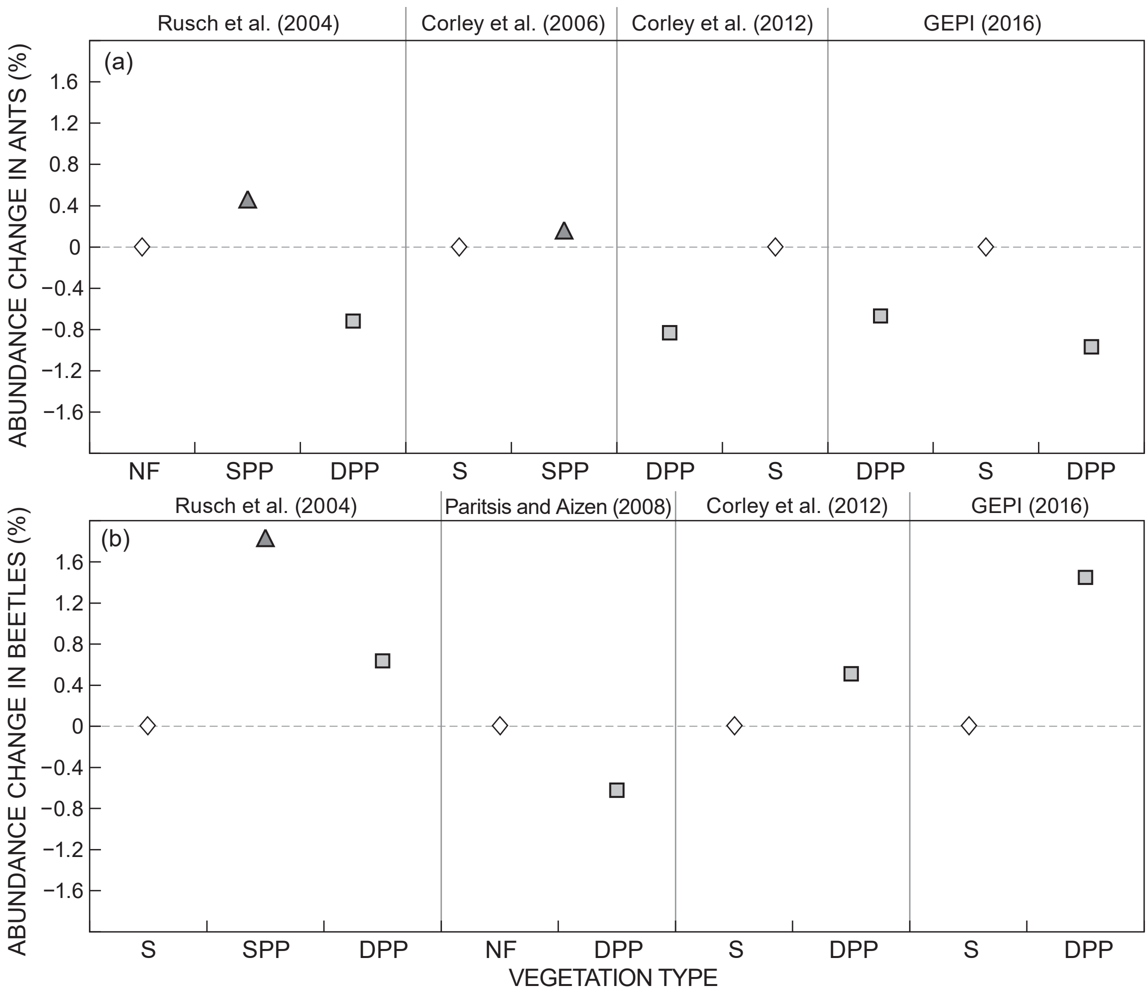

Figure 2: Percentage change in ant (a) and beetle (b) abundance among native vegetation and exotic plantations observed in different studies of north-western Patagonia reviewed here. DPP = dense pine plantations, NF = native forest, S = steppe, SPP = sparse pine plantations

candidates for long-term monitoring of the impact of conifer forestation in north-western Patagonia, as well as probably in other regions of the world in which non-native pines replace natural environments.

The results observed for the insect taxa reviewed in this study are also consistent with those found for other wildlife species in plantation landscapes of north-western Patagonia. Birds were observed to be less abundant and diverse in pine plantations compared with both steppe and forest native environments (Lantschner et al. 2008; Paritsis and Aizen 2008; Pescador and Peris 2014). In addition, bird species composition changed when plantations replaced steppe areas, but not when replacing forests (Lantschner et al. 2008; Paritsis and Aizen 2008). Small mammals also decreased in richness and abundance in pine plantations with respect to the native forest–steppe transition zone

(Lantschner et al. 2011), as well as most carnivore species (Lantschner et al. 2012). These recent studies also found that presence of most species was not only directly related to habitat structure, but also to the complexity or heterogeneity of the vegetation structure and landscape attributes. At stand scales, most studies observed that sparse plantations had a lower impact on bird and mammal species abundance and diversity than dense plantations, and understory cover was the most important factor determining species richness and abundance inside pine plantations for all groups (Lantschner et al. 2008, 2011, 2012; Paritsis and Aizen 2008), whereas at landscape scales, habitat use by most species was associated with the type of vegetation replaced and its surface area (Lantschner et al. 2008, 2012). Consequently, and in accordance with the results observed for ants and beetles, we highlight the importance of designing and managing forested landscapes at multiple spatial scales to sustain their use by the maximum number of species possible.

Currently, the impact of conifer plantations on the biodiversity of Patagonian insects is not considered severe, because the planted area is still low and restricted in geographical distribution. However, in the near future, the amount of area subjected to plantation forestry will likely increase, and consequently management strategies that minimise change to natural communities, coupled with reliable monitoring techniques, will be necessary to ensure the environmental sustainability of plantation forestry. Existing studies are temporally limited because these only involve a single sampling season. Long-term monitoring is necessary to evaluate the persistence of changes caused by plantation forestry on the biodiversity of insects in north-western Patagonia throughout the productive cycle, including post-harvest environments. High costs of sampling, collection and classification limit the implementation of regular biodiversity monitoring. Despite the controversy that surrounds the use of certain taxa as indicators of biodiversity for the whole community, monitoring ants may prove highly effective to evaluate insect biodiversity in Patagonia.

Despite the limited number of studies available, through our synthesis and in light of other related work, we show that pine plantations generally reduce insect biodiversity in north-western Patagonia. Impacts of this activity on different groups are dependent on the original vegetation matrix on which pines are established. Furthermore, a consistent outcome across the studies revised here is that ants may prove a reliable taxon for monitoring long-term changes as those expected to occur over the long cycle of plantation forestry and to test mitigation actions (Corley et al. 2006; Berndt et al. 2008; Brockerhoff et al. 2008; Lindenmayer and Hobbs 2004; Pawson et al. 2011). Although significant knowledge has been gained over the past decade on the impacts of exotic conifer plantations on insect biodiversity in Patagonia, there is still a lack of knowledge on the ecological meaning of those changes for ecosystem functioning. Future studies need to evaluate the consequences of biodiversity changes for key processes in Patagonian ecosystems through mechanistically oriented assessments.

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