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What level of native beetle diversity can be supported by forestry plantations? A global synthesis

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Complete List of Authors:	López-Bedoya, Pablo A.; Universidad de Caldas Magura, Tibor; HNP Directorate, ; Edwards, Felicity A.; The University of Sheffield Edwards, David P.; The University of Sheffield Rey-Benayas, Jose M.; Universidad de Alcala de Henares Lövei, Gabor; Aarhus University, Department of Agroecology ; Noriega, Jorge Ari ; Museo Nacional de Ciencias Naturales, Departamento de Biogeografía y Cambio Global
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What level of native beetle diversity can be supported by forestry plantations? A global synthesis

Running title: Forestry plantations and beetle diversity

Abstract. 1. Forestry plantations have been established globally to meet timber demands, often leading to the conversion of natural to artificial forests. Forestry plantations may support natural elements of forest biodiversity, but understanding their role in the maintenance of biodiversity is a crucial question.

2. We perform a meta-analysis of 48 studies to determine how forestry plantations relative to natural forests influence the species richness and abundance of three important coleopteran groups (*i.e.*, ground beetles, rove beetles, and dung beetles) of natural forests, given their essential role in ecosystem functioning.

3. We assessed whether beetle responses depended on taxonomic group, geographical location, native or exotic character of the planted tree species, and associated management characteristics (*i.e.*, composition, size, age, and connectivity of the plantations).

4. We found that forestry plantations negatively affected coleopteran species richness and abundance compared to natural forests. The negative impact was most severe in plantations with exotic tree species and located in tropical biomes.

5. Species richness and abundance of beetles significantly increased with plantation age in native plantations, but decreased in exotic ones. Also, small plantations close to native forest

had higher beetle species richness and abundance than ones located far away from native forest.

6. Stop the conversion of natural forests to plantations, the use of native tree species, and lengthening rotations is critical for allowing biodiversity recovery in forestry plantations, combined with a robust conservation strategy to protect threatened biodiversity and ecosystem functioning.

Keywords: Carabidae, Conservation, Ecological indicators, Exotic, Insect diversity, Native, Natural forest cover, Staphylinidae, Scarabaeidae.

Pablo A. López-Bedoya[1,2]

Tibor Magura[3]

Felicity A. Edwards[4]

David P. Edwards[4]

José M. Rey-Benayas[5]

Gábor L. Lövei[6]

Jorge Ari Noriega[7,*]

[1]Grupo de Investigación en Ecosistemas Tropicales, Facultad de Ciencias Exactas y Naturales, Universidad de Caldas, Calle 65 # 26-10, A.A 275, Manizales, Colombia.

[2]Grupo de Ecología y Diversidad de Anfibios y Reptiles, Facultad de Ciencias Exactas y Naturales, Calle 65 # 26-10, A. A. 275, Universidad de Caldas, Manizales, Colombia.

[3]Department of Ecology, University of Debrecen, 4032 Debrecen, Hungary.

[4]Department of Animal and Plant Sciences, University of Sheffield, Sheffield, S10 2TN, UK.

[5]Dpto. de Ciencias de la Vida, Universidad de Alcalá, 28805 Alcalá de Henares, España.

[6]Department of Agroecology, Aarhus University, Flakkebjerg Research Centre DK-4200 Slagelse, Denmark.

[7]Laboratorio de Zoología y Ecología Acuática – LAZOEA, Universidad de Los Andes, Bogotá, Colombia.

**Corresponding author: jnorieg@hotmail.com*

Introduction

Establishing forestry plantations has become a global strategy to enhance timber supply, and paper pulp demand (ITTO, 2016; Pirard *et al*., 2016), and provide essential ecosystem services, especially climate change-mitigating carbon sequestration (Paul *et al*., 2008) and watershed protection (Lamb *et al*., 2005; Paquette & Messier, 2010; Baral *et al*., 2016). Governments have promoted forestry plantations through international agreements (*e.g*., Bonn Challenge) and local or regional policies (Bull *et al*., 2006), an action that has led to a worldwide increase of ca. 3 million ha annually between 2010 and 2020 (FAO, 2020). Forestry plantations currently occupy ~290 million ha, of which ~60% is distributed throughout the non-tropical biomes of Asia, Europe, and North America (FAO, 2020). In these areas, both native and exotic species (*e.g.*, *Eucalyptus* spp., *Fagus* spp., *Picea* spp., *Pinus* spp., *Quercus* spp.) are extensively used. However, in tropical biomes, exotic species such as *Eucalyptus* spp. are used more frequently due to their fast growth and tolerance of a wide range of conditions (Simonetti *et al.*, 2012; Payn *et al.*, 2015; FAO, 2020).

Given the marked reduction in natural forests and their continued replacement by forestry plantations (see Keenan *et al.*, 2015; Payn *et al.*, 2015), it is crucial to understand the potential role of plantations as alternative habitats for biodiversity (Brockerhoff *et al.*, 2008). Forestry plantations frequently have a negative effect on vertebrate diversity (Barlow *et al.*, 2007a), including amphibians (Kudavidanage *et al.*, 2012), birds (Castaño-Villa *et al.*, 2019), and mammals (Begotti *et al.*, 2018), or invertebrates, such as coleopterans (Horák *et al.*, 2019; Méndez-Rojas *et al.*, 2021) or butterflies (Kudavidanage *et al.*, 2012). However, other studies found biodiversity levels within plantations to match those found in natural forests, particularly non-tropical biomes (Plexida *et al.*, 2014; Magura *et al.*, 2015). A global understanding of the relative merits of forestry plantations as biodiversity supporters thus remains a core question. Ascertaining the characteristics associated with forestry plantations that favor higher biodiversity levels is important in making management recommendations. Studies have focused on the identity, origin (native or exotic) (Proença *et al.*, 2010; Horák *et al.*, 2019), composition of planted tree species (Piotto, 2008), as well as tree plantation purposes (*i.e.*, commercial or protective) (Brockerhoff *et al.*, 2008), planted area, age (Humphrey *et al.*, 1999; Kerr, 1999; Castaño-Villa *et al.*, 2019) and degree of isolation from natural forest remnants (Begotti *et al.*, 2018; Castaño-Villa *et al.*, 2019).

Coleoptera (Arthropoda: Insecta) form an exceptionally diverse group, distributed worldwide, that has important functional roles in almost every ecosystem (Samways, 2005;

Schowalter, 2008; New, 2010). In particular, ground beetles (Carabidae), rove beetles (Staphylinidae), and dung beetles (Scarabaeidae) contribute to several important ecosystem processes, including pest regulation, removal of organic matter, secondary seed dispersion, maintaining soil structure, and nutrient cycling (Rainio & Niemelä, 2003; Henle *et al*., 2004; Spector, 2006; Nichols *et al*., 2008; Magura *et al*., 2015). They have been frequently used to quantify impacts associated with loss or degradation of natural forests (Nichols *et al*., 2007; Magura *et al*., 2017) and evaluate the effect of subsequent land-use changes (Rainio & Niemelä, 2003; Edwards *et al*., 2014, 2017). Local studies on forestry plantations, when compared to natural forests, have shown a variety of responses in these coleoptera groups, from severe reductions to positive responses on species richness or abundance (see Gardner *et al*., 2008; Taboada *et al*., 2010; Gries *et al*., 2012; Lange *et al*., 2014; Magura *et al*., 2015; Milheiras *et al*., 2020). This indicates that specific management characteristics or geographic locations modify the effects of forestry plantations. We currently lack a global synthesis of beetle responses to plantation context and management, with previous evaluations restricted to single regions (*e.g*., Palearctic; Paillet *et al*., 2010), or not assessing the impacts of management characteristics (*e.g*., Nichols *et al*., 2007; Fuzessy *et al*., 2021; Méndez-Rojas *et al*., 2021).

Here, we perform a global meta-analysis on the response of ground, rove, and dung beetles to forestry plantations, including how their location and management characteristics (*e.g*., age, size, origin, and a mixture of planted tree species) influence the diversity and abundance of these important reference groups. Forestry plantations simplify forest composition and structure, and certain number of beetle species are closely linked with conditions that developed over long time with natural forest, as a result we predict that forestry plantations will (H1) support lower species richness and abundance of the three taxonomic groups than natural forests, and (H2) have positive effects modulated by native species implementation, or forestry plantations proximity to natural forests.

Material and Methods

Literature search and inclusion criteria

The literature search and selection followed the PRISMA methodology (Moher *et al*., 2009), which only considers indexed articles (Nakagawa *et al*., 2017). We searched the Scopus and Web of Science databases using the search terms: (forest* OR regenerat* OR plantat* OR restorat* OR "land-use") AND (scarabaei* OR "dung beetle*" OR carabid* OR "ground beetle*" OR staphylinid* OR "rove beetle*"). We use these search terms based on the possibilities of inclusion of different articles assess a broad spectrum of land cover or land uses (including forestry plantations). We found 3675 articles, published between January 1950 and July 2020. We deleted duplicate results, articles that include other families, or developed other topics, such as molecular biology, or behavioral studies. We retained 487 studies containing the topic of interest, namely Carabidae, Staphylinidae, and/or Scarabaeidae species richness and/or abundance. The full text of these articles was assessed and filtered using the following criteria: (i) compared beetle species richness and/or abundance between natural forests (control) and forestry plantations (treatment), and (ii) presented descriptive sample statistics, including the mean values for species richness and/or abundance in control and treatment stands, their standard deviation (or other data from which these could be calculated), and sample sizes. Under these criteria, 48 articles were retained for data extraction (many of these articles sampled the richness or abundance of these beetle's families by using pitfall traps; see Fig. S1).

(Fig. 1 here)

We used natural forest definition proposed by Chazdon *et al*., (2016); and forestry plantations were classified as for commercial timber production or protective/conservation purposes (Stephens & Wagner, 2007; Simonetti *et al*., 2012). Agricultural plantations (*e.g.*, cocoa, coffee, oil palm, rubber, or fruits; Castaño-Villa *et al*., 2019) were excluded from this study. Some identified "restoration sites" (Audino *et al*., 2014; Derhé *et al*., 2016; Bowie *et al*., 2019) were included, as tree planting and management are directly related to conservation efforts and classified as forestry plantations established for conservation purposes (Lamb *et al*., 2005; Chazdon, 2008). When articles presented results as medians and interquartile ranges, we used the method proposed by Hozo *et al*. (2005) and modified by Wan *et al*. (2014) to obtain the means and standard deviations. Additionally, for articles that evaluated various sampling sites, geographical locations, or vegetation cover types (*e.g.,* Magura *et al*., 2002; Lange *et al*., 2014) each case study was considered independently (Fontúrbel *et al*., 2015). Likewise, if articles presented different sampling periods (*e.g*., several years), each was considered separately (Borenstein *et al*., 2009; Mengersen *et al*., 2013).

Calculating the effect size

Effect size was estimated using the Hedge's *d* statistic, which uses weighted standardized deviations (Hedges & Olkin, 1985). The use of Hedge's *d* is widespread in ecological studies that compare two groups since it presents the results in a continuous distribution (Gurevitch *et al*., 2001; Borenstein *et al*., 2009). We used random-effects models (Borenstein *et al*., 2009) for which studies with different geographical locations (mostly primary studies) were the random effect, and plantation attributes (see below) were fixed effects. Random-effects models also reduce the bias generated when comparing datasets of different sample sizes (Konstantopoulos & Hedges, 2010).

Variables and moderators

The global effect associated with the replacement of natural forests by forestry plantations was estimated collectively for species richness and abundance of the three selected beetle taxa. We analyzed the (fixed) effects of the following nine categorical moderator variables: (i) taxonomic group (*i.e.*, ground beetles, rove beetles, dung beetles), (ii) origin of the planted species (native or exotic), (iii) biome type (tropical between 23º N and 23º S or non-tropical), (iv) interaction between species origin and biome type (*i.e.*, non-tropical-exotic, non-tropical-native, tropical-exotic, tropical-native), (v) planted species (*i.e.*, *Eucalyptus*, *Quercus*, *Pinus*, and others), (vi) plantation composition (monoculture or mixed), (vii) plantation purpose (commercial or protective), (viii) plantation connectivity in the landscape (connected to or isolated from natural forests), and (ix) plantation size (small: ≤400 ha or large: ≥1000 ha; there were no plantations between these two size categories). To determine whether forestry plantations were connected to natural forests, we used the landscape definition of Driscoll *et al*. (2013), *i.e.,* connected plantations were defined as those in which the sampling location was separated from natural forest smaller than 500 m (Larsen & Forsyth, 2005; Hendrickx *et al*., 2013; Cerda *et al*., 2015; da Silva & Hernández, 2015).

Statistical analysis

To determine the heterogeneity between variables, we estimated the between-group homogeneity ($Q_{between}$), a statistic with X^2 distribution that compares the variation within and between the different levels of the variables (Higgins *et al*., 2003). A $Q_{between}$ value with p <

0.05 indicates significant effect variation (*i.e.*, there is no unidirectional, common effect). We used this statistic because it is the best fit for the random-effects models we ran compared with other heterogeneity measurements such as I^2 or τ^2 (Borenstein *et al.*, 2009). Finally, we constructed meta-regression models, separately for native and exotic plantations, using plantation age as the continuous variable to determine its effect on beetle species richness and abundance (Thompson & Higgins, 2002). Not all articles reported all variables, particularly tree species, plantation composition, age, size, or purpose. In this case, we only evaluated those from which information was available (Table S1).

Publication bias

Meta-analyses may suffer from publication bias, resulting in missing studies (Borenstein *et al.*, 2009). As studies reporting neutral effects were unlikely published, we estimated the number of non-published neutral effect studies that would be necessary to obtain non-significant effects in our analyses using the Rosenthal test (Hillebrand, 2008). This test is robust when the confidence number is ≥5N + 10, N being the number of case studies. We favored this test because of its reasonable adjustment to random model analyses (Jennions *et al.*, 2013). Duval & Tweedies' (2000) trim and fill method was used when significant asymmetry was found. This analysis evaluates the asymmetry in reported study outcomes and recalculates the average global effect and confidence intervals to validate whether the obtained results are reliable (Duval & Tweedie, 2000). Lastly, we used each article's ID as a random effect to determine whether the number of case studies per article influenced the direction and size of effects (see Supplementary results). All analyses were performed with the Comprehensive Meta-Analysis 3.0 software (Borenstein *et al.*, 2005).

Results

Overview of forestry plantation database

Of the 48 articles analyzed, we obtained 185 and 167 comparisons of beetle species richness and abundance, respectively, between plantations and natural forests (Table S1). Studies were distributed in 24 countries (Fig. 1): Brazil, China, and Poland had the most studies (we found articles performed in two countries or more; Table S2). Also, some boreal regions, especially North America (Canada and United States of North America), Scandinavian countries or Russia, did not present articles included in this meta-analysis. Mostly due to its exclusion due to the absence of the necessary statistical metrics (see inclusion criteria on methods). For the total number of comparisons, both non-tropical (68%) and tropical (22%) biomes were represented. Ground beetles were the most studied beetle group with 51% of the comparisons found, followed by dung beetles and rove beetles with 31.2% and 17.8%, respectively. Exotic plantations were studied in 49.44% of the comparisons, and most of them (84%) were planted as monocultures, often with *Pinus* spp. (23% of total comparisons came from such plantations) or *Eucalyptus* spp. (15% of total comparisons). Several mixed forestry plantations included exotic species such as *Acacia* or *Swietenia* spp. (25.9% of comparisons), and in some very particular cases abandoned plantations of exotic species were also used in forestry plantations established for conservation purposes (10% of comparisons).

Overall beetle species richness and abundance

Replacement of natural forests by forestry plantations was detrimental to overall species richness (d = -1.090, CI = [-1.321, -0.859], $p < 0.001$; Fig. 2a) and abundance (d = -0.438, CI = [-0.646, -0.231], $p < 0.001$; Fig. 3a) of beetles. Species richness did not vary among taxa

($Q_{between}$ = 2.568, df = 2, p = 0.276; Fig. 2b). In contrast, beetle abundance differed among taxonomic groups ($Q_{between}$ = 19.181, df = 2, p < 0.001; Fig. 3b), with dung and rove beetles showing significantly more negative response than ground beetles.

(Fig. 2, 3 here)

Effects of planted tree species and biome interaction

Plantations of native species showed a smaller negative effect than plantations of exotic species either for species richness ($Q_{between}$ = 26.729, df = 1, p < 0.001; Fig. 2c) or abundance ($Q_{between}$ = 5.852, df = 1, p = 0.015; Fig. 3c). Biome type also affected species richness ($Q_{between}$ = 11.971, df = 1, p < 0.001; Fig. 2d) and abundance ($Q_{between}$ = 17.088, df = 1, p < 0.001; Fig. 3d), with a greater negative effect of plantations in tropical biomes. Furthermore, the interaction between biome and the native or exotic character of plantations showed a significant effect for both species richness ($Q_{between}$ = 67.132, df = 3, p < 0.001) and abundance ($Q_{between}$ = 26.934, df = 3, p < 0.001).

Plantations composed of native species had negative effects only in the tropics, with no effect found in non-tropical biomes, while in exotic plantations detrimental effects were found in both non-tropical and tropical biomes (Fig. 2e; Fig 3e). Beetle species richness ($Q_{between}$ = 149.66, df = 9, p < 0.001; 2f) and abundance ($Q_{between}$ = 38.189, df = 9, p < 0.001; 3f) was dependent on the genus of the planted tree species. Thus, plantations of *Acacia*, *Eucalyptus*, *Picea*, *Pinus,* and *Tectona* spp. caused significantly stronger negative effects than those of *Alnus*, *Eremanthus*, *Fagus,* or *Quercus* spp.

Effects of plantation management

The mixed vs. monocultural character of the plantations did not matter: both had a similarly negative effect on the species richness ($Q_{between}$ = 1.139, df = 1, p = 0.285; Fig. 2g) as well as the abundance ($Q_{between}$ = 0.053, df = 1, P = 0.816; Fig. 3g) of beetles. Likewise, the purpose (commercial or protective) for establishing a plantation had no effect on either beetle species richness ($Q_{between}$ = 0.906, df = 1, p = 0.340; Fig. 2h) or abundance ($Q_{between}$ = 1.205, df = 1, p = 0.272; Fig. 3h). However, forestry plantations establishing for protective purpose showed a neutral effect for beetle abundance.

Effects of the landscape around plantations

We found a negative effect on species richness in forestry plantations that were isolated from natural forest, but a neutral response when a forestry plantation was connected to a natural forest ($Q_{between}$ = 9.358, df = 1, p = 0.0022; Fig. 2i). There was no impact of connectivity on abundance ($Q_{between}$ = 0.973, df = 1, p = 0.323; Fig. 3i), although we found a neutral effect for forestry plantations connected to natural forests. Species richness decreased significantly irrespective of plantation size ($Q_{between}$ = 1.199, df = 1, p = 0.273; Fig. 2j), whereas there was a size-dependent effect on abundance, which only decreased in large-sized plantations ($Q_{between}$ = 7,598, df = 1, p = 0.0058; Fig. 3j).

Effects of plantation age

Plantation age had a significant effect on both beetle species richness and abundance (Fig. 4). However, the response direction was markedly different in plantations with native or exotic tree species; in native plantations, beetle species richness and abundance significantly increased with plantation age (slope = 0.0075, $p < 0.001$; $Tau^2 = 1.716$; Fig. 4a and slope = 0.0065, $p < 0.001$; $Tau^2 = 2.125$; Fig. 4c; respectively), whereas in exotic plantations both decreased significantly (slope = -0.0201, $p < 0.001$; $Tau^2 = 1.710$; Fig. 4b and slope = -0.017, $p < 0.001$; $Tau^2 = 1.420$; Fig. 4d; respectively).

(Fig. 4 here)

Publication bias

The Rosenthal confidence test indicated that 9940 and 4213 case studies with neutral effects were necessary to obtain non-significant results for species richness and abundance in our analysis (when this value is compared with the safety threshold of 935 and 845 cases, respectively). The direction and size of the effect for species richness in 'trim-and-fill' analysis did not vary; however, beetle abundance showed a neutral tendency (Table S3; Figs. S2, S3). We obtained significant heterogeneity values for species richness ($Q_{between} = 767.023$, df = 35, $p < 0.001$) and abundance ($Q_{between} = 299.823$, df = 39, $p < 0.001$), indicating that the number of case studies per article did not distort the direction and size of effects. Our meta-analysis showed a small bias for beetle abundance due to the larger number of case studies with negative effects. However, our results should still be reliable and not affected by the omission of articles with neutral effects. Nevertheless, we recommend caution in interpreting the results associated with beetle abundance.

Discussion

Our global meta-analysis on the effect of forestry plantations on native beetle diversity support our research hypotheses, revealing that species richness and abundance of ground, rove and dung beetles were generally lower than in natural forests (H1), and that geographical location and management affected the conservation value of plantations (H2). This points to the need to halt conversion of natural forest to plantation and the inclusion of native species on longer rotations.

Forestry plantations support lower levels of beetle diversity than natural forests

Our results showed lower species richness and abundance of beetle's assemblages in forestry plantations compared to natural forests. Previous single regional studies conclude that plantation expansion at the expense of natural forests contributes to global biodiversity loss, threatening native species assemblages, their functioning, and the ecosystem services they provide (Paillet *et al*., 2010; Newbold *et al*., 2015; Magura & Lövei, 2019). The negative response of the studied ground, rove, and dung beetle assemblages to forestry plantations also indicated the harmful consequences caused by conversion of natural ecosystems into intensively managed lands on organisms at various trophic levels (Barlow *et al*., 2007a; Paillet *et al*., 2010).

Ground and rove beetles are extremely sensitive to changes in environmental and habitat characteristics caused by plantation establishment (Pohl *et al*., 2008; Koivula, 2011). Compared to natural forests, soil temperature in plantations is higher, and humidity is lower (Lange *et al*., 2014; Senior *et al*., 2017). Likewise, plantation maintenance results in a more open canopy and less leaf litter, coarse woody debris, fewer herbs, and shrubs compared to native forests (Paillet *et al*., 2010; Lange *et al*., 2014). These changes likely alter the availability of food: the density of other ground-dwelling invertebrates (for ground and rove beetles: Niemelä *et al*., 2007; Magura *et al*., 2015; Nagy *et al*., 2015) and leaf-litter nutrients (for rove beetles: Barlow *et al*., 2007b).

Multiple abiotic and biotic factors could explain changes in the abundance and diversity of dung beetle assemblages after the establishment of a plantation (Nichols *et al.*, 2007). Habitat structure and microclimatic conditions (*i.e.*, light intensity, soil and air temperature, humidity), which differ in plantations versus natural forest, are crucial factors in determining the species composition (Hanski & Cambefort, 1991; Davis *et al.*, 2002; Gardner *et al.*, 2008) and community assembly (Audino *et al.*, 2017) of dung beetles. Moreover, forestry plantations can modify the availability of dung by influencing the presence/absence of mammals (Barlow *et al.*, 2007a) and, in turn, the quantity and quality of dung resources, causing a lower diversity of dung beetles (Gardner *et al.*, 2008).

Plantation origin and biome are critical factors for beetle diversity

The negative impact of plantations on beetle species richness and abundance was more pronounced in tropical than non-tropical biomes, supporting previous single regional studies (Grimbacher *et al.*, 2007; Chaudhary *et al.*, 2016) that emphasize that tropical species, are very sensitive to habitat alteration (associated with prevalence of beetle forest specialists in tropical biomes due to the greater number of micro-habitats; *see* Halffter, 1991; Davis *et al.*, 2001). Our evaluation found that the implementation of exotic plantations had more detrimental effects on beetle species richness and abundance, especially in the tropics and particularly related with tropical forest, where such plantations are primarily composed of exotic species (Payn *et al.*, 2015; FAO, 2020). Local studies on invertebrate biodiversity in exotic forestry plantations revealed similar effects (Gardner *et al.*, 2008; Robson *et al.*, 2009; Roberge & Stenbacka, 2014; Nagy *et al.*, 2015; Beiroz *et al.*, 2016; Milheiras *et al.*, 2020).

The establishment of exotic tree plantations radically alters the forest structure and species composition, modifying ecological processes, and the structure of food webs that can lead to cascading effects (Brockerhoff *et al*., 2008; Liebhold *et al*., 2017). By contrast, native plantations of locally occurring tree species could serve as substitute habitats for forest beetle species (Brockerhoff *et al*., 2008; Méndez-Rojas *et al*., 2012; Magura *et al*., 2015). The similar levels of beetle species richness and/or abundance in natural forest and native forestry plantations can be explained by the existence of similar habitat structure and plant species composition, leading to favorable microclimates and food resources (Haddad *et al*., 2009; Magura *et al*., 2015).

Effects of the landscape around plantations

Forestry plantations that are small and connected to natural forests show less severe negative effects on beetle species richness and/or abundance. Local-scale studies have found that beetle richness or abundance decreased markedly within the surrounding matrix versus natural forest (Davies & Margules, 1998; Hendrickx *et al*., 2009; Barnes *et al*., 2014; Tóthmérész *et al*., 2014). Plantations isolated from natural forests may be out of reach for dispersing beetles, whereas connectivity allows the dispersion of beetles into plantations from the natural forest (Davis *et al*., 2001; Gries *et al*., 2012; Cerda *et al*., 2015). Higher species richness in smaller plantations may also be related to the edge effect, enabling the influx of matrix species into these plantations (González-Vainer *et al*., 2012; Magura *et al*., 2017). In contrast, larger plantations likely exclude both forest specialist and matrix species, reducing their overall species richness (Magura *et al*., 2017).

Effects of plantation age

The success and extent of beetle recolonization fundamentally depend on the origin of the planted tree species. Favorable environmental conditions, resembling those of the original forest, may be slower to appear in exotic than native plantations, decreasing the chance of successful recolonization by native beetle species (Brockerhoff *et al*., 2008; Nagy *et al*., 2015). In exotic plantations, after canopy closure, the number and abundance of open-habitat and generalist species begins to steeply decline (Pohl *et al*., 2007; Brockerhoff *et al*., 2008; Lange *et al*., 2014; Nagy *et al*., 2015). In contrast, canopy closure in native plantations supports the recruitment of additional native woody plants, makes more intensive litterfall, and thus creates the microhabitat complexity and favorable microclimates necessary for forest specialist beetle species (Dent & Wright, 2009; Koivula, 2011; Lange *et al*., 2014). Thus, successful recolonization of forest specialist beetle species results in a significant increase in diversity and abundance in native plantations (Audino *et al*., 2014; Nagy *et al*., 2015). Nevertheless, a complete recovery of native beetle species abundance and diversity is a slow process, taking >45 years in non-tropical (*e.g*., Magura *et al*., 2015) and >60 years in tropical (*e.g*., Yu *et al*., 2004, 2006; Sakchoowong *et al*., 2008; Noriega *et al*., 2021) biomes.

Conclusions and conservation recommendations

We found that the replacement of natural forests with forestry plantations negatively affected the species richness and abundance of three speciose and important beetle families, Carabidae, Staphylinidae and Scarabaeidae, and that the impact was more severe in forestry plantations of exotic origin and located in tropical biomes. To retain native forest beetle communities and associated ecosystem functions and services, particularly in the biodiversityrich tropical biome, we recommend planting native tree species, allowing them to mature, maintaining connectivity to natural forests and manage forestry plantations as near-natural forests. Such silvicultural methods favor mixed species composition and site-adapted tree species, ensuring the long-term persistence of native forest (Pommerening, 2006; Baral *et al.*, 2016; Pirard *et al.*, 2016).

Where continuous vegetation cover is not feasible, we recommend implementing multi-purpose native plantations rather than using exotic species because beetle abundance and diversity are better conserved in native plantations (Stephens & Wagner, 2007; Baral *et al.*, 2016). As plantation age significantly increased both species richness and abundance of beetles in native plantations, we recommend postponing the timber harvest in some stands of native plantations. We also found that more extensive and more isolated (generally also exotic) plantations negatively influenced beetle species richness and/or abundance, pointing to the need for improving landscape-scale connectivity. Thus, establishing exotic forestry plantations in small areas and connected to natural forests could reduce adverse effects on the diversity of these beetles. Finally, although in our meta-analysis different countries with forestry tradition located in boreal biomes (*e.g.*, North America, Scandinavian countries, or Russia) were not included because of the lack of necessary statistical data (*see* results); we conclude that our findings can be applied on these regions based on studies carried out at a local level (*e.g.*, Pohl *et al.*, 2007).

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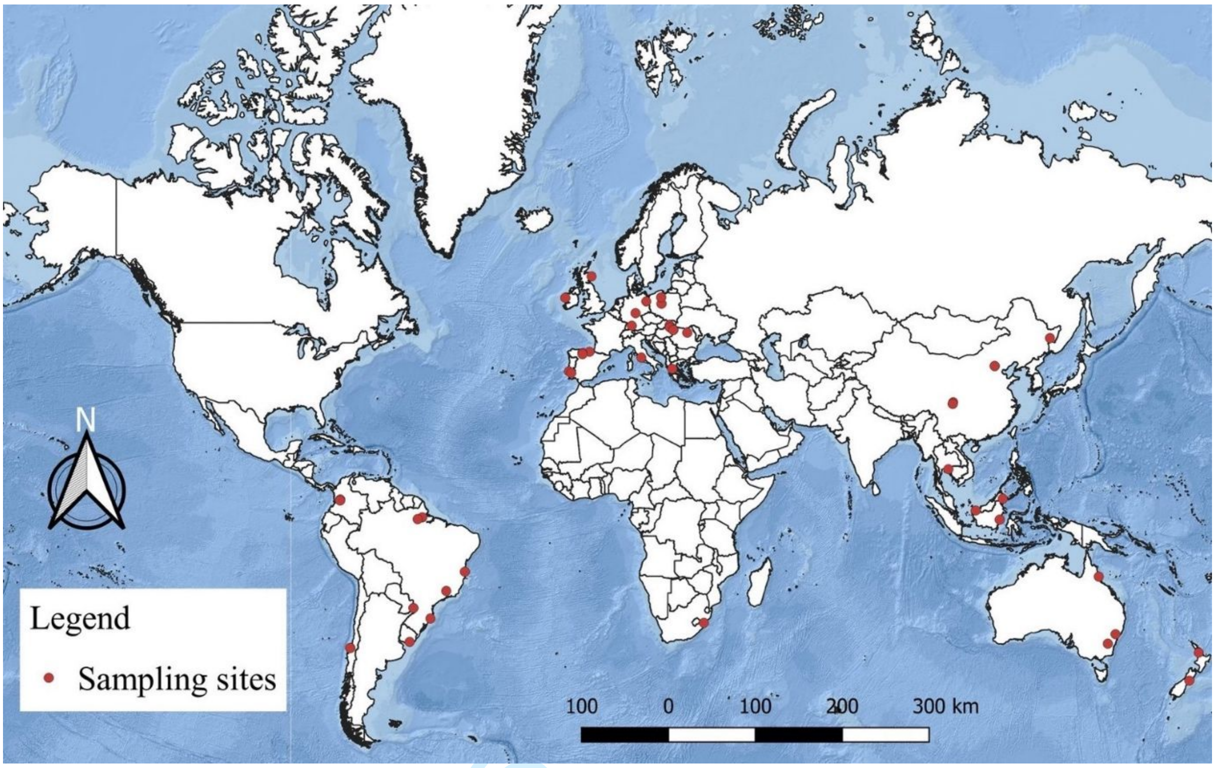
Figure legends

Fig. 1 Location of the 48 primary studies, by country, that were used in the meta-analysis. Some sampling sites include more than one article performed in different years.

Fig. 2 Effect of natural forest conversion to forestry plantations on beetle species richness. Average values and 95% confidence intervals are given for: (a) the overall effect, (b) taxonomic group, (c) origin of the planted species, (d) biome type, (e) interaction between species origin and biome type, (f) genus of the planted species, (g) plantation composition, (h) plantation's purpose, (i) plantation connectivity, and (j) plantation size. The number of case studies for each level of the moderator variable is in parenthesis. Asterisks indicate that confidence intervals are significantly different from zero ($^{NS}p \geq 0.05$, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$). Q_b represents the homogeneity in group comparisons.

Fig. 3 Effect of natural forest conversion to forestry plantations on beetle abundance. Average values and 95% confidence intervals are given for: (a) the overall effect, (b) taxonomic group, (c) origin of the planted species, (d) biome type, (e) interaction between species origin and biome type, (f) genus of the planted species, (g) plantation composition, (h) plantation's purpose, (i) plantation connectivity, and (j) plantation size. The number of case studies for each level of the moderator variable is in parenthesis. Asterisks indicate that confidence intervals are significantly different from zero ($^{NS}p \geq 0.05$, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$). Q_b represents the homogeneity in group comparisons.

Fig. 4 Relationship between plantation age and beetle species richness (a, b) and abundance (c, d) in plantations with native (a, c) and exotic (b, d) tree species.



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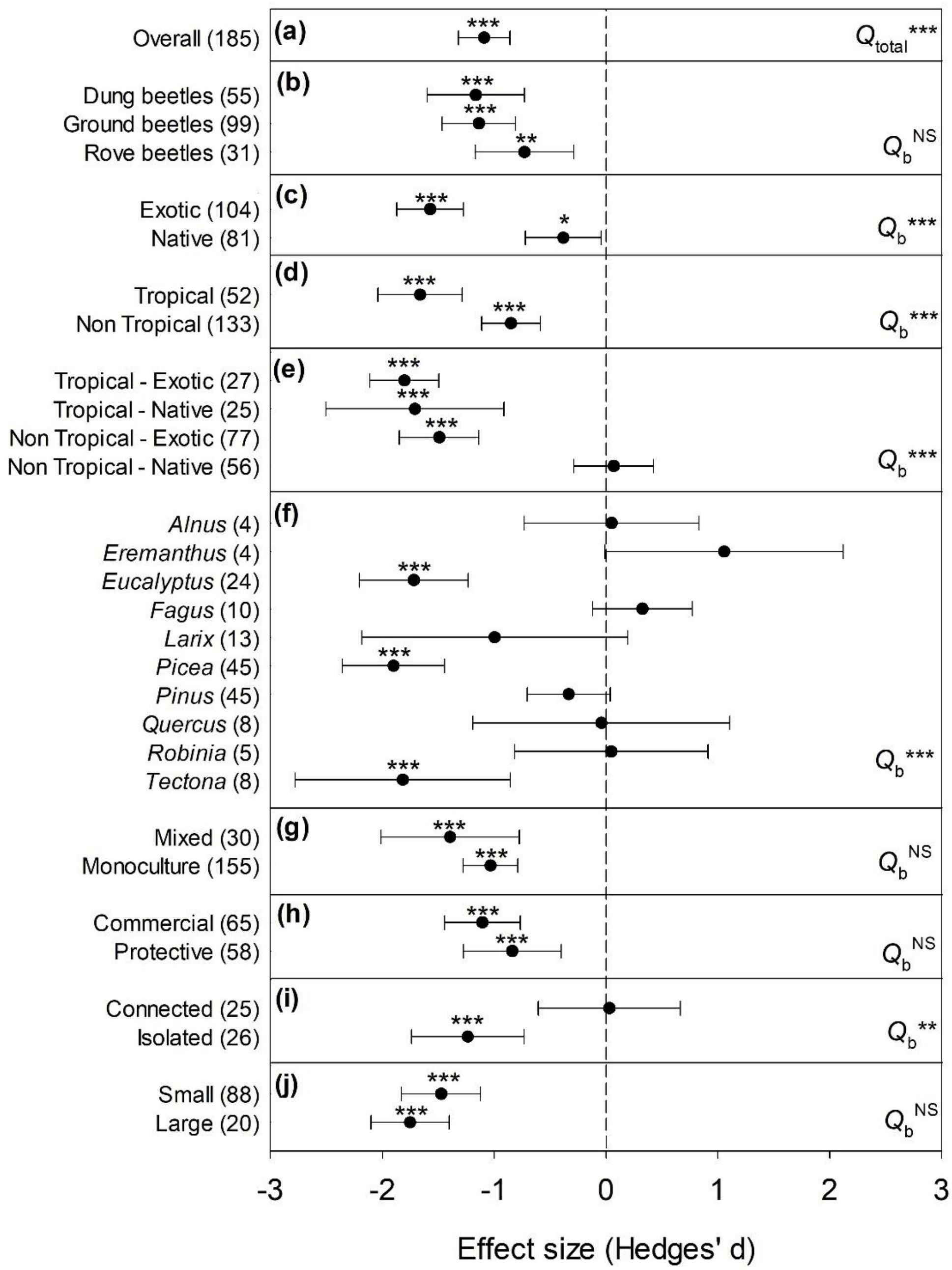

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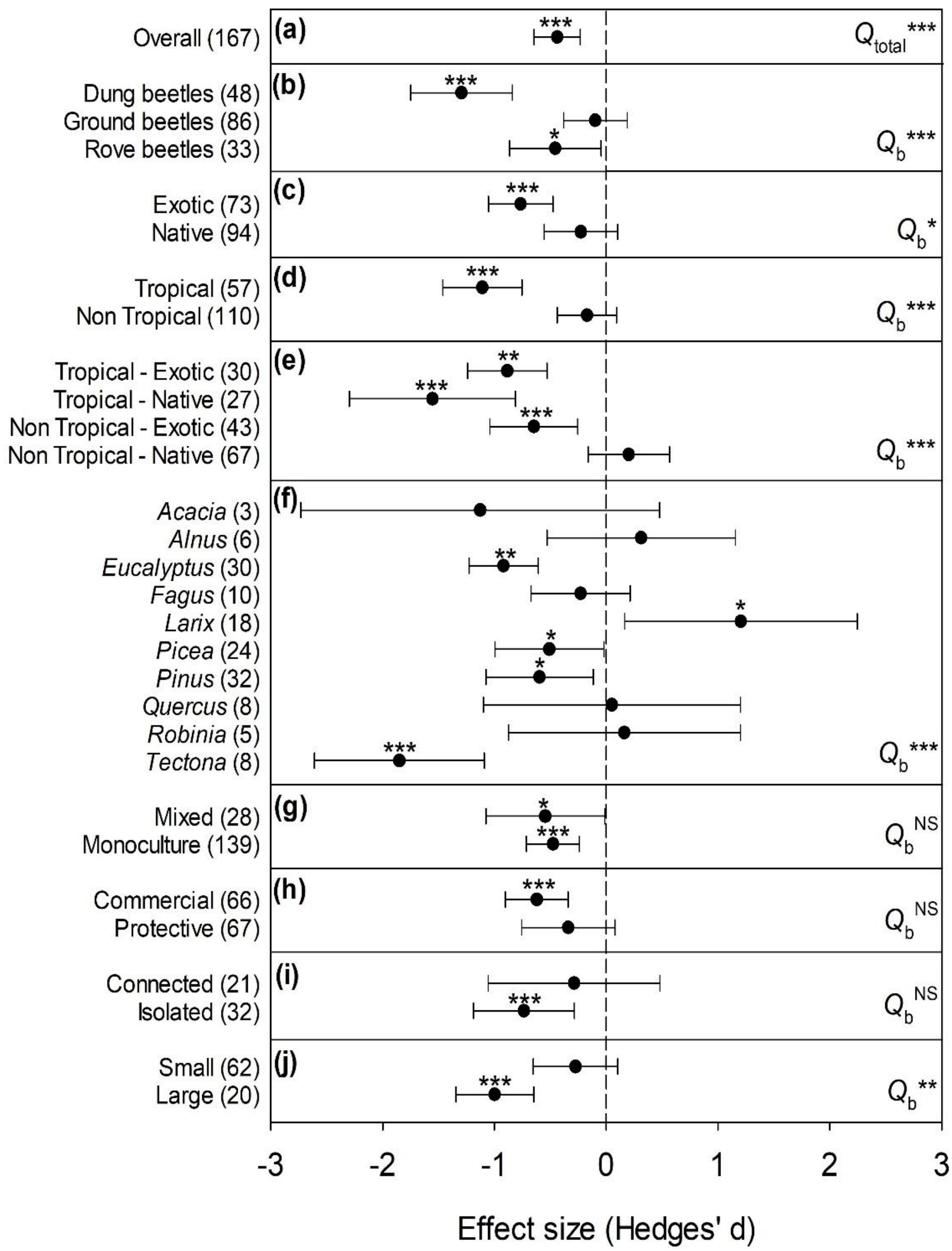
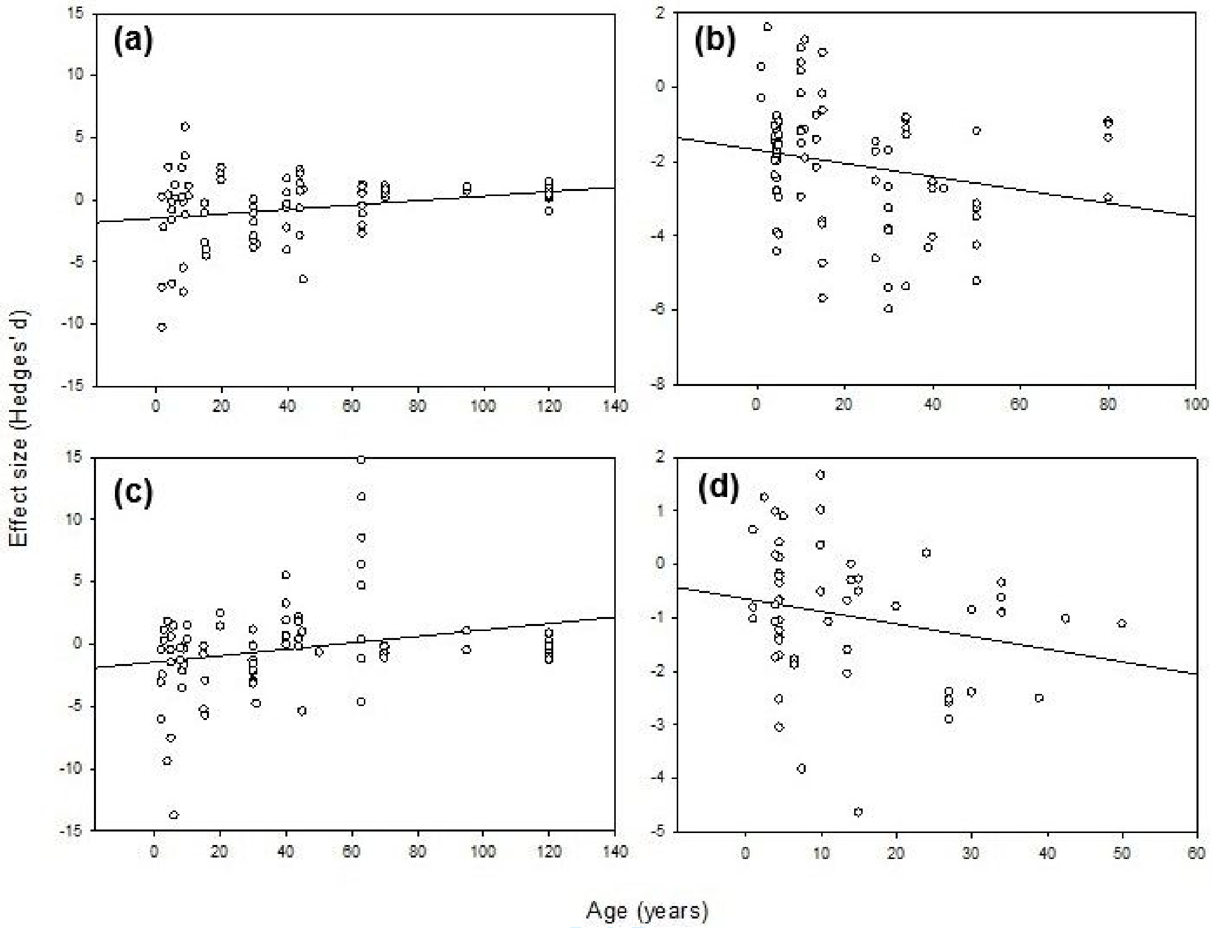


Fig. 3 Effect of natural forest conversion to forestry plantations on beetle abundance. Average values and 95% confidence intervals are given for: (a) the overall effect, (b) taxonomic group, (c) origin of the planted species, (d) biome type, (e) interaction between species origin and biome type, (f) genus of the planted species, (g) plantation composition, (h) plantation's purpose, (i) plantation connectivity, and (j) plantation size. The number of case studies for

each level of the moderator variable is in parenthesis. Asterisks indicate that confidence intervals are significantly different from zero ($^{NS}p \geq 0.05$, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$). Q_b represents the homogeneity in group comparisons.



759

760 **Fig. 4** Relationship between plantation age and beetle species richness (a, b) and abundance

761 (c, d) in plantations with native (a, c) and exotic (b, d) tree species.

SUPPLEMENTARY MATERIAL

What level of native beetle diversity can be supported by forestry plantations? A global synthesis

Pablo A. López-Bedoya[1,2], Tibor Magura[3], Felicity A. Edwards[4], David P. Edwards[4], José M. Rey-Benayas[5], Gábor L. Lövei[6], Jorge Ari Noriega[7,*]

[1]Grupo de Investigación en Ecosistemas Tropicales, Facultad de Ciencias Exactas y Naturales, Universidad de Caldas, Calle 65 # 26-10, A.A 275, Manizales, Colombia.

[2]Grupo de Ecología y Diversidad de Anfibios y Reptiles, Facultad de Ciencias Exactas y Naturales, Calle 65 # 26-10, A. A. 275, Universidad de Caldas, Manizales, Colombia.

[3]Department of Ecology, University of Debrecen, 4032 Debrecen, Hungary.

[4]Department of Animal and Plant Sciences, University of Sheffield, Sheffield, S10 2TN, UK

[5]Dpto. Ciencias de la Vida, Universidad de Alcalá, 28805 Alcalá de Henares, España.

[6]Department of Agroecology, Aarhus University, Flakkebjerg Research Centre DK-4200 Slagelse, Denmark

[7]Laboratorio de Zoología y Ecología Acuática – LAZOEA, Universidad de Los Andes, Bogotá, Colombia.

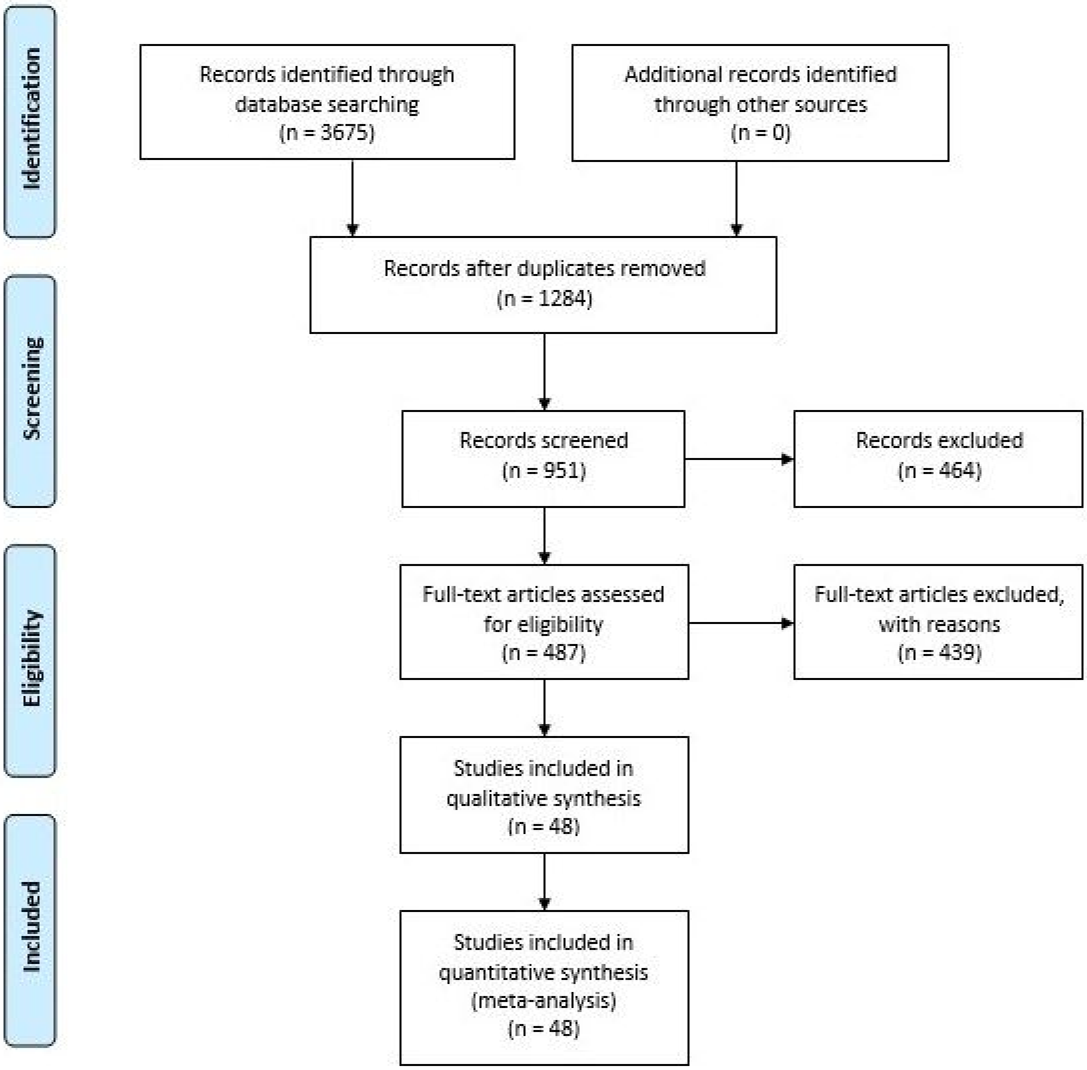


Fig. S1. Flow diagram according to the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-analysis) carried out in this study.

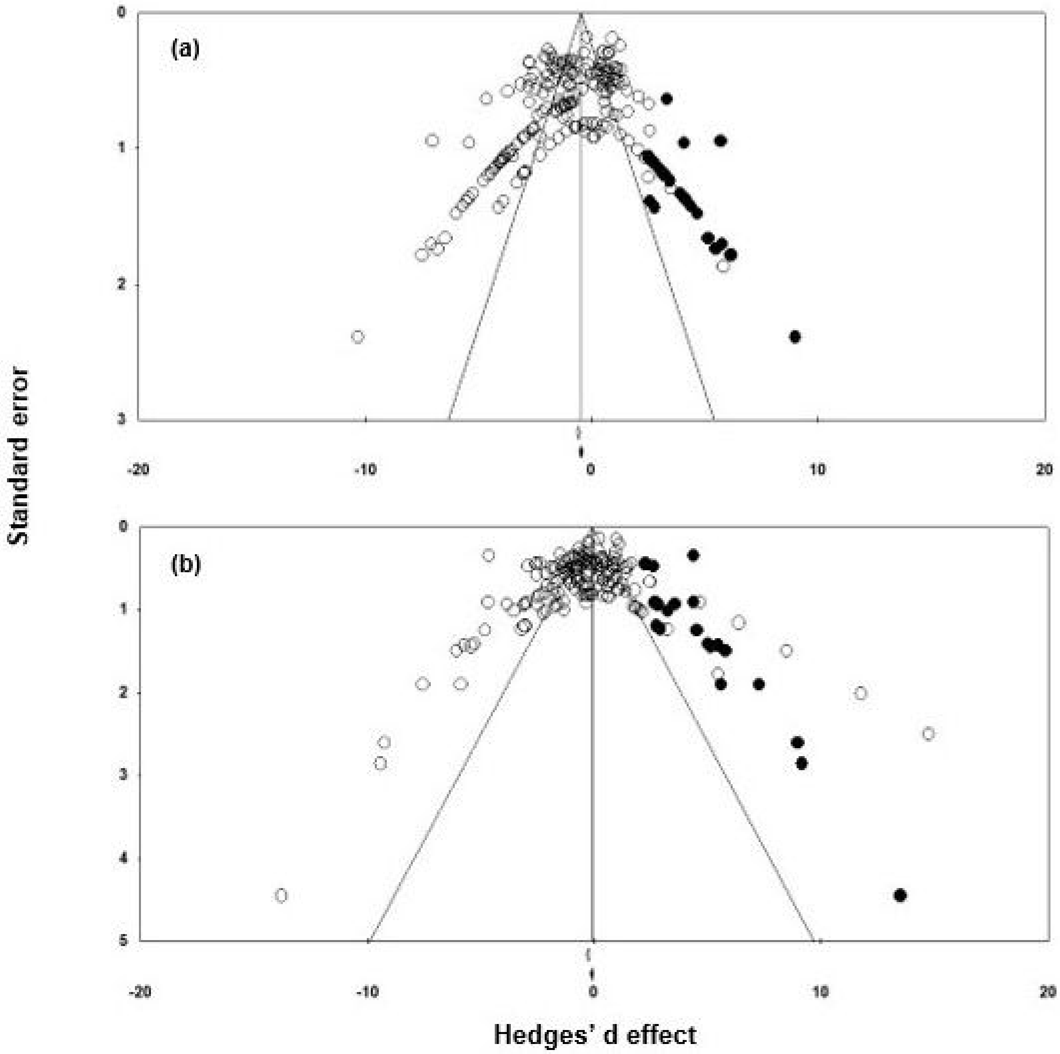


Fig. S2. Funnel plot for beetle species richness (a), and abundance (b). Open circles represent observed case studies and solid circles represent imputed case studies after trim and fill procedures. Open diamonds indicate the observed effect size (mean point estimate), and solid diamonds indicate the adjusted effect size.

Table S1. Summary information of primary studies used in the meta-analysis, detailing the assessed metrics, beetle group, origin of planted species, biome type, plantation composition, plantation purpose, plantation connectivity, plantation size, plantation age (years), and planted species. Some primary studies provided more than one case study, namely different sampling locations or different sampling time, which were considered as independent cases. Hedge's d and variance values (Var) are reported.

Ref.	Metric	Group	Origin	Biome	Composition	Purpose	Landscape	Age	Size	Tree genera	Hedge's d	Var
1	Richness	Dung beetle	Native	Tropical	Mixed	Protective	No data	15,5	< 400 ha	No data	-4,536	1,429
1	Richness	Dung beetle	Native	Tropical	Mixed	Protective	No data	8,5	< 400 ha	No data	-7,467	3,188
1	Richness	Dung beetle	Native	Tropical	Mixed	Protective	No data	2	< 400 ha	No data	-10,309	5,713
1	Richness	Dung beetle	Native	Tropical	Mixed	Protective	No data	15,5	< 400 ha	No data	-4,026	1,210
1	Richness	Dung beetle	Native	Tropical	Mixed	Protective	No data	8,5	< 400 ha	No data	-5,515	1,921
1	Richness	Dung beetle	Native	Tropical	Mixed	Protective	No data	2	< 400 ha	No data	-7,071	2,900
1	Abundance	Dung beetle	Native	Tropical	Mixed	Protective	No data	15,5	< 400 ha	No data	-5,740	2,047
1	Abundance	Dung beetle	Native	Tropical	Mixed	Protective	No data	8,5	< 400 ha	No data	-3,533	1,024
1	Abundance	Dung beetle	Native	Tropical	Mixed	Protective	No data	2	< 400 ha	No data	-6,053	2,232
1	Abundance	Dung beetle	Native	Tropical	Mixed	Protective	No data	15,5	< 400 ha	No data	-2,950	0,835
1	Abundance	Dung beetle	Native	Tropical	Mixed	Protective	No data	8,5	< 400 ha	No data	-2,199	0,642
1	Abundance	Dung beetle	Native	Tropical	Mixed	Protective	No data	2	< 400 ha	No data	-3,086	0,876
2	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	Connected	20	< 400 ha	*Quercus*	2,537	0,451
2	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	Connected	20	< 400 ha	*Quercus*	1,560	0,326
2	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	Connected	20	< 400 ha	*Quercus*	2,063	0,383
2	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	Connected	20	< 400 ha	*Quercus*	2,452	0,438
2	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	Connected	20	< 400 ha	*Quercus*	1,410	0,312
2	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	Connected	20	< 400 ha	*Quercus*	2,480	0,442
3	Richness	Ground beetle	Native	Non-tropical	Mixed	No data	No data	No data	< 400 ha	*Pinus*	0,045	0,200
3	Abundance	Ground beetle	Native	Non-tropical	Mixed	No data	No data	No data	< 400 ha	*Pinus*	0,090	0,200
4	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-1,759	0,259
4	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-2,781	0,293
4	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-2,448	0,322
4	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-1,891	0,216
4	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-1,979	0,277
4	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-2,805	0,296
4	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-1,149	0,220
4	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-1,014	0,169
4	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-0,818	0,206
4	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-1,468	0,190
4	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-1,368	0,232
4	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-1,239	0,178

4	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-1,710	0,255
4	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-0,673	0,158
4	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-2,530	0,331
4	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-1,424	0,188
4	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-0,177	0,192
4	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-0,361	0,152
4	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	0,123	0,192
4	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-0,224	0,151
5	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	4	No data	*Pinus*	0,985	0,022
5	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	24	No data	*Pinus*	0,201	0,020
6	Abundance	Rove beetle	Native	Non-tropical	Mixed	Protective	Connected	3	< 400 ha	No data	1,093	0,575
6	Abundance	Ground beetle	Native	Non-tropical	Mixed	Protective	Connected	3	< 400 ha	No data	0,259	0,504
7	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Larix*	-0,503	0,229
7	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Pinus*	-1,154	0,259
7	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Larix*	1,209	0,263
7	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Pinus*	0,598	0,232
7	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Larix*	0,962	0,248
7	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Pinus*	0,472	0,228
7	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Larix*	-2,127	0,348
7	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Pinus*	-2,758	0,434
7	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Larix*	6,368	1,349
7	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Pinus*	-4,665	0,827
7	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Larix*	14,748	6,264
7	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Pinus*	4,661	0,826
7	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Larix*	11,760	4,064
7	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Pinus*	0,370	0,226
7	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Larix*	8,503	2,231
7	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	63	No data	*Pinus*	-1,207	0,263
8	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	No data	No data	*Eucalyptus*	-7,010	0,893
8	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	No data	No data	*Eucalyptus*	-0,509	0,129
9	Richness	Dung beetle	Exotic	Tropical	Mixed	Commercial	Connected	No data	No data	*Sweitenia* and *Acacia*	-2,745	0,130
9	Richness	Dung beetle	Exotic	Tropical	Mixed	Commercial	Connected	No data	No data	*Sweitenia* and *Acacia*	-1,774	0,091
9	Richness	Dung beetle	Exotic	Tropical	Mixed	Commercial	Connected	No data	No data	*Sweitenia* and *Acacia*	-1,927	0,113
9	Richness	Dung beetle	Exotic	Tropical	Mixed	Commercial	Connected	No data	No data	*Sweitenia* and *Acacia*	-2,083	0,108
9	Richness	Dung beetle	Exotic	Tropical	Mixed	Commercial	Connected	No data	No data	*Sweitenia* and *Acacia*	-2,736	0,136
10	Richness	Dung beetle	Native	Tropical	Mixed	Protective	No data	2,5	< 400 ha	No data	-2,273	0,823
10	Richness	Dung beetle	Native	Tropical	Mixed	Protective	No data	9	< 400 ha	No data	-1,247	0,597
10	Richness	Dung beetle	Native	Tropical	Mixed	Protective	No data	15	< 400 ha	No data	-1,070	0,572
10	Abundance	Dung beetle	Native	Tropical	Mixed	Protective	No data	2,5	< 400 ha	No data	-2,489	0,887
10	Abundance	Dung beetle	Native	Tropical	Mixed	Protective	No data	9	< 400 ha	No data	-1,549	0,650
10	Abundance	Dung beetle	Native	Tropical	Mixed	Protective	No data	15	< 400 ha	No data	-0,855	0,546

11	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Protective	No data	34	No data	*Picea*	-5,380	0,924
12	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-4,441	1,386
12	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-1,593	0,527
12	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-3,910	1,164
12	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-0,769	0,430
12	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-1,060	0,456
12	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	0,408	0,408
12	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-3,057	0,867
12	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4,5	> 1000 ha	*Eucalyptus*	-0,676	0,423
13	Richness	Dung beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	11	No data	*Pinus*	1,271	0,060
14	Richness	Dung beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	11	No data	*Pinus*	-1,919	0,073
15	Richness	Dung beetle	Native	Non-tropical	Mixed	Protective	No data	2	No data	*Eucalyptus*	0,222	0,671
15	Richness	Dung beetle	Native	Non-tropical	Mixed	Protective	No data	8,5	No data	*Eucalyptus*	-0,219	0,671
15	Abundance	Dung beetle	Native	Non-tropical	Mixed	Protective	No data	2	No data	*Eucalyptus*	-0,509	0,688
15	Abundance	Dung beetle	Native	Non-tropical	Mixed	Protective	No data	8,5	No data	*Eucalyptus*	-0,300	0,674
16	Richness	Dung beetle	Exotic	Non-tropical	Monoculture	No data	Isolated	15	< 400 ha	*Pinus*	0,924	0,036
16	Richness	Rove beetle	Exotic	Non-tropical	Monoculture	No data	Isolated	15	< 400 ha	*Pinus*	-0,180	0,032
16	Abundance	Dung beetle	Exotic	Non-tropical	Monoculture	No data	Isolated	15	< 400 ha	*Pinus*	-4,645	0,119
16	Abundance	Rove beetle	Exotic	Non-tropical	Monoculture	No data	Isolated	15	< 400 ha	*Pinus*	-0,283	0,033
17	Richness	Dung beetle	Native	Tropical	Monoculture	Commercial	Connected	4	No data	*Eremanthus*	0,364	0,761
17	Richness	Dung beetle	Native	Tropical	Monoculture	Commercial	Connected	6	No data	*Eremanthus*	0,063	0,834
17	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Connected	1	No data	*Eucalyptus*	-0,290	0,757
17	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Connected	4	No data	*Eucalyptus*	-1,443	0,849
17	Richness	Dung beetle	Native	Tropical	Monoculture	Commercial	Connected	4	No data	*Eremanthus*	2,582	0,750
17	Richness	Dung beetle	Native	Tropical	Monoculture	Commercial	Connected	6	No data	*Eremanthus*	1,132	0,571
17	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Connected	1	No data	*Eucalyptus*	0,555	0,432
17	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Connected	4	No data	*Eucalyptus*	-1,347	0,449
17	Abundance	Dung beetle	Native	Tropical	Monoculture	Commercial	Connected	4	No data	*Eremanthus*	-9,430	8,160
17	Abundance	Dung beetle	Native	Tropical	Monoculture	Commercial	Connected	6	No data	*Eremanthus*	-13,773	19,803
17	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Connected	1	No data	*Eucalyptus*	-5,870	3,621
17	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Connected	4	No data	*Eucalyptus*	-9,247	6,808
17	Abundance	Dung beetle	Native	Tropical	Monoculture	Commercial	Connected	4	No data	*Eremanthus*	1,805	0,580
17	Abundance	Dung beetle	Native	Tropical	Monoculture	Commercial	Connected	6	No data	*Eremanthus*	1,416	0,611
17	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Connected	1	No data	*Eucalyptus*	0,641	0,437
17	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Connected	4	No data	*Eucalyptus*	0,167	0,368
18	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	No data	Isolated	No data	No data	*Pinus*	0,434	0,409
18	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	No data	Isolated	No data	No data	*Pinus*	-0,737	0,427
19	Richness	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	9	No data	*Pinus*	3,498	1,686
19	Richness	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	8	No data	*Pinus*	0,152	0,836
19	Richness	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	9	No data	*Pinus*	5,828	3,497
19	Richness	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	8	No data	*Pinus*	2,514	1,465
19	Abundance	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	9	No data	*Pinus*	-0,410	0,681
19	Abundance	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	8	No data	*Pinus*	-0,343	0,845
19	Abundance	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	9	No data	*Pinus*	-1,700	0,908
19	Abundance	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	8	No data	*Pinus*	-1,331	1,010

20	Richness	Ground beetle	Native	Non-tropical	Mixed	No data	No data	95	No data	*Pinus* and *Abies*	0,660	0,527
20	Richness	Ground beetle	Native	Non-tropical	Mixed	No data	No data	95	No data	*Pinus* and *Abies*	0,973	0,559
20	Abundance	Ground beetle	Native	Non-tropical	Mixed	No data	No data	95	No data	*Pinus* and *Abies*	-0,499	0,516
20	Abundance	Ground beetle	Native	Non-tropical	Mixed	No data	No data	95	No data	*Pinus* and *Abies*	1,045	0,568
21	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	70	No data	*Picea*	0,906	0,307
21	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	0,066	0,267
21	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	0,685	0,266
21	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	70	No data	*Picea*	0,640	0,346
21	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	0,394	0,198
21	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	0,729	0,186
21	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	70	No data	*Picea*	1,110	0,259
21	Richness	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	1,049	0,240
21	Richness	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	70	No data	*Picea*	0,150	0,284
21	Richness	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	-0,948	0,289
21	Richness	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	-0,962	0,276
21	Richness	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	70	No data	*Picea*	0,500	0,341
21	Richness	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	0,229	0,196
21	Richness	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	0,380	0,177
21	Richness	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	70	No data	*Picea*	0,787	0,242
21	Richness	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	1,436	0,263
21	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	70	No data	*Picea*	-0,175	0,284
21	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	-1,285	0,308
21	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	-0,773	0,269
21	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	70	No data	*Picea*	-0,304	0,336
21	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	-0,553	0,202
21	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	0,052	0,174
21	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	70	No data	*Picea*	-0,720	0,240
21	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	0,816	0,230
21	Abundance	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	70	No data	*Picea*	-0,250	0,285
21	Abundance	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	-1,257	0,306
21	Abundance	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	0,241	0,257
21	Abundance	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	70	No data	*Picea*	-0,818	0,354
21	Abundance	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	-0,472	0,200
21	Abundance	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	-0,199	0,175
21	Abundance	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	70	No data	*Picea*	-1,108	0,259
21	Abundance	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	120	No data	*Fagus*	0,857	0,232
22	Abundance	Ground beetle	Native	Non-tropical	Mixed	Protective	Connected	50	< 400 ha	*Populus*	-0,689	0,071
23	Richness	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	40	< 400 ha	*Picea*	0,530	0,690
23	Richness	Rove beetle	Native	Non-tropical	Mixed	Protective	No data	40	< 400 ha	*Larix*	1,659	0,896
23	Richness	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	40	< 400 ha	*Picea*	-0,682	0,705
23	Richness	Rove beetle	Native	Non-tropical	Mixed	Protective	No data	40	< 400 ha	*Larix*	-0,365	0,678
23	Richness	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	40	< 400 ha	*Picea*	-2,275	1,098
23	Richness	Rove beetle	Native	Non-tropical	Mixed	Protective	No data	40	< 400 ha	*Larix*	-4,084	2,056

23	Abundance	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	40	< 400 ha	*Picea*	3,224	1,533
23	Abundance	Rove beetle	Native	Non-tropical	Mixed	Protective	No data	40	< 400 ha	*Larix*	0,668	0,704
23	Abundance	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	40	< 400 ha	*Picea*	5,468	3,158
23	Abundance	Rove beetle	Native	Non-tropical	Mixed	Protective	No data	40	< 400 ha	*Larix*	0,612	0,698
23	Abundance	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	40	< 400 ha	*Picea*	1,881	0,961
23	Abundance	Rove beetle	Native	Non-tropical	Mixed	Protective	No data	40	< 400 ha	*Larix*	-0,056	0,667
24	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Protective	No data	27	No data	*Picea*	-1,470	0,141
24	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Protective	No data	27	No data	*Picea*	-2,526	0,200
24	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	34	No data	*Picea*	-0,892	0,122
24	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	34	No data	*Picea*	-0,816	0,120
24	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Protective	No data	27	No data	*Picea*	-1,740	0,153
24	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Protective	No data	27	No data	*Picea*	-4,624	0,408
24	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	34	No data	*Picea*	-1,288	0,134
24	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	34	No data	*Picea*	-1,106	0,128
24	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Protective	No data	27	No data	*Picea*	-2,379	0,190
24	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Protective	No data	27	No data	*Picea*	-2,596	0,205
24	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	34	No data	*Picea*	-0,902	0,122
24	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	34	No data	*Picea*	-0,628	0,117
24	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Protective	No data	27	No data	*Picea*	-2,535	0,200
24	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Protective	No data	27	No data	*Picea*	-2,905	0,228
24	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	34	No data	*Picea*	-0,910	0,123
24	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	34	No data	*Picea*	-0,350	0,113
25	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	5	< 400 ha	*Picea*	0,892	0,137
25	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	15	< 400 ha	*Picea*	-0,512	0,129
25	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	30	< 400 ha	*Picea*	-0,851	0,136
25	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	50	< 400 ha	*Picea*	-1,122	0,145
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	5	< 400 ha	*Picea*	-1,523	0,516
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	5	< 400 ha	*Picea*	-3,982	1,193
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	15	< 400 ha	*Picea*	-5,693	2,021
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	15	< 400 ha	*Picea*	-4,750	1,528
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	30	< 400 ha	*Picea*	-5,417	1,867
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	30	< 400 ha	*Picea*	-5,988	2,193
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	50	< 400 ha	*Picea*	-5,231	1,768
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	50	< 400 ha	*Picea*	-4,262	1,308
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	5	< 400 ha	*Picea*	-1,300	0,484
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	5	< 400 ha	*Picea*	-2,979	0,844
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	15	< 400 ha	*Picea*	-3,608	1,051
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	15	< 400 ha	*Picea*	-3,699	1,084
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	30	< 400 ha	*Picea*	-3,813	1,127
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	30	< 400 ha	*Picea*	-3,873	1,150
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	50	< 400 ha	*Picea*	-3,503	1,014
26	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	50	< 400 ha	*Picea*	-3,267	0,934
27	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	5	< 400 ha	*Picea*	-1,568	0,163
27	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	15	< 400 ha	*Picea*	-3,702	0,339
27	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	30	< 400 ha	*Picea*	-2,695	0,238
27	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	50	< 400 ha	*Picea*	-3,136	0,279

27	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	5	< 400 ha	*Picea*	-0,934	0,139
27	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	15	< 400 ha	*Picea*	-0,630	0,131
27	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	30	< 400 ha	*Picea*	-1,709	0,171
27	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	50	< 400 ha	*Picea*	-1,184	0,147
28	Richness	Ground beetle	Native	Non-tropical	Monoculture	Commercial	No data	5	< 400 ha	*Quercus*	-1,653	0,112
28	Richness	Ground beetle	Native	Non-tropical	Monoculture	Commercial	No data	15	< 400 ha	*Quercus*	-0,311	0,084
28	Richness	Ground beetle	Native	Non-tropical	Monoculture	Commercial	No data	45	< 400 ha	*Quercus*	0,786	0,090
28	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Commercial	No data	5	< 400 ha	*Quercus*	-1,502	0,107
28	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Commercial	No data	15	< 400 ha	*Quercus*	-0,190	0,084
28	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Commercial	No data	45	< 400 ha	*Quercus*	0,967	0,093
29	Richness	Ground beetle	Exotic	Non-tropical	Mixed	Commercial	No data	No data	< 400 ha	*Pinus*	0,479	0,290
29	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	No data	< 400 ha	*Pinus*	0,343	0,141
29	Richness	Ground beetle	Exotic	Non-tropical	Mixed	Commercial	No data	No data	< 400 ha	*Pinus*	-0,421	0,317
29	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	No data	< 400 ha	*Pinus*	-0,926	0,183
29	Richness	Ground beetle	Exotic	Non-tropical	Mixed	Commercial	No data	No data	< 400 ha	*Pinus*	0,674	0,342
29	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	No data	< 400 ha	*Pinus*	0,639	0,188
29	Abundance	Ground beetle	Exotic	Non-tropical	Mixed	Commercial	No data	No data	< 400 ha	*Pinus*	0,560	0,293
29	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	No data	< 400 ha	*Pinus*	0,330	0,141
29	Abundance	Ground beetle	Exotic	Non-tropical	Mixed	Commercial	No data	No data	< 400 ha	*Pinus*	0,580	0,323
29	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	No data	< 400 ha	*Pinus*	0,344	0,169
29	Abundance	Ground beetle	Exotic	Non-tropical	Mixed	Commercial	No data	No data	< 400 ha	*Pinus*	0,994	0,363
29	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	No data	< 400 ha	*Pinus*	0,911	0,197
30	Richness	Dung beetle	Exotic	Tropical	Monoculture	Protective	Connected	No data	No data	*Fraxinus*	-1,892	0,289
30	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Protective	Connected	No data	No data	*Fraxinus*	-2,127	0,313
30	Abundance	Dung beetle	Native	Tropical	Monoculture	Protective	Connected	No data	No data	*Alnus*	-1,411	0,250
30	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Protective	Connected	No data	No data	*Fraxinus*	0,977	0,224
30	Abundance	Dung beetle	Native	Tropical	Monoculture	Protective	Connected	No data	No data	*Alnus*	1,373	0,247
31	Richness	Rove beetle	Native	Tropical	Monoculture	Protective	No data	5	No data	*Alnus*	-0,866	0,199
31	Richness	Rove beetle	Native	Tropical	Monoculture	Protective	No data	10	No data	*Alnus*	0,250	0,183
31	Richness	Rove beetle	Native	Tropical	Monoculture	Protective	No data	5	No data	*Alnus*	-0,239	0,183
31	Richness	Rove beetle	Native	Tropical	Monoculture	Protective	No data	10	No data	*Alnus*	1,066	0,208
31	Abundance	Rove beetle	Native	Tropical	Monoculture	Protective	No data	5	No data	*Alnus*	-0,492	0,187
31	Abundance	Rove beetle	Native	Tropical	Monoculture	Protective	No data	10	No data	*Alnus*	0,374	0,185
31	Abundance	Rove beetle	Native	Tropical	Monoculture	Protective	No data	5	No data	*Alnus*	0,565	0,189
31	Abundance	Rove beetle	Native	Tropical	Monoculture	Protective	No data	10	No data	*Alnus*	1,477	0,231
32	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4	> 1000 ha	*Eucalyptus*	-2,383	0,570
32	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4	> 1000 ha	*Eucalyptus*	-1,044	0,379
32	Richness	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4	> 1000 ha	*Eucalyptus*	-1,975	0,496
32	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4	> 1000 ha	*Eucalyptus*	-1,749	0,461
32	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4	> 1000 ha	*Eucalyptus*	-0,767	0,358
32	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Isolated	4	> 1000 ha	*Eucalyptus*	-1,077	0,382
33	Richness	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	No data	No data	*Quercus*	-2,533	0,721
33	Richness	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	31	No data	*Quercus*	-3,610	1,052
33	Richness	Rove beetle	Exotic	Non-tropical	Monoculture	Protective	No data	39	No data	*Pinus*	-4,332	1,338
33	Richness	Rove beetle	Exotic	Non-tropical	Monoculture	Protective	No data	30	No data	*Robinia*	-3,265	0,933
33	Abundance	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	No data	No data	*Quercus*	-1,813	0,564

33	Abundance	Rove beetle	Native	Non-tropical	Monoculture	Protective	No data	31	No data	*Quercus*	-4,805	1,555
33	Abundance	Rove beetle	Exotic	Non-tropical	Monoculture	Protective	No data	39	No data	*Pinus*	-2,506	0,714
33	Abundance	Rove beetle	Exotic	Non-tropical	Monoculture	Protective	No data	30	No data	*Robinia*	-2,396	0,687
34	Abundance	Dung beetle	Exotic	Tropical	Monoculture	No data	Connected	No data	No data	*Eucalyptus*	-0,735	0,214
34	Abundance	Dung beetle	Exotic	Tropical	Monoculture	No data	Isolated	No data	No data	*Eucalyptus*	-0,733	0,213
34	Abundance	Dung beetle	Exotic	Tropical	Monoculture	No data	Connected	No data	No data	*Eucalyptus*	-0,790	0,216
34	Abundance	Dung beetle	Exotic	Tropical	Monoculture	No data	Isolated	No data	No data	*Eucalyptus*	-0,783	0,215
35	Richness	Dung beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	10	< 400 ha	*Robinia*	0,433	0,146
35	Richness	Dung beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	10	< 400 ha	*Robinia*	-0,173	0,143
35	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	10	< 400 ha	*Robinia*	1,040	0,162
35	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	10	< 400 ha	*Robinia*	0,658	0,151
35	Abundance	Dung beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	10	< 400 ha	*Robinia*	0,355	0,145
35	Abundance	Dung beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	10	< 400 ha	*Robinia*	-0,517	0,148
35	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	10	< 400 ha	*Robinia*	1,015	0,161
35	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	10	< 400 ha	*Robinia*	1,666	0,192
36	Richness	Dung beetle	Exotic	Non-tropical	Monoculture	No data	Connected	No data	No data	*Pinus*	0,976	0,165
36	Richness	Dung beetle	Exotic	Non-tropical	Monoculture	No data	Connected	No data	No data	*Pinus*	0,506	0,083
36	Richness	Dung beetle	Exotic	Non-tropical	Monoculture	No data	Connected	No data	No data	*Pinus*	0,983	0,165
36	Richness	Dung beetle	Exotic	Non-tropical	Monoculture	No data	Connected	No data	No data	*Pinus*	0,515	0,083
36	Richness	Dung beetle	Exotic	Non-tropical	Monoculture	No data	Connected	No data	No data	*Pinus*	1,162	0,171
36	Richness	Dung beetle	Exotic	Non-tropical	Monoculture	No data	Connected	No data	No data	*Pinus*	0,729	0,085
36	Richness	Dung beetle	Exotic	Non-tropical	Monoculture	No data	Connected	No data	No data	*Pinus*	1,299	0,176
36	Richness	Dung beetle	Exotic	Non-tropical	Monoculture	No data	Connected	No data	No data	*Pinus*	0,788	0,086
37	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	20	No data	*Pinus*	-0,791	0,240
37	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	1	No data	*Pinus*	-1,028	0,252
37	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	1	No data	*Pinus*	-0,810	0,240
38	Richness	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-1,838	0,948
38	Richness	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	0,003	0,667
38	Richness	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-3,310	1,580
38	Richness	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-2,976	1,405
38	Richness	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-2,938	1,386
38	Richness	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-0,663	0,703
38	Richness	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-3,887	1,926
38	Richness	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-1,103	0,768
38	Abundance	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-2,256	1,091
38	Abundance	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-0,149	0,669
38	Abundance	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-3,025	1,429
38	Abundance	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-2,117	1,040
38	Abundance	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-3,060	1,447
38	Abundance	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-1,329	0,814
38	Abundance	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-3,197	1,518
38	Abundance	Rove beetle	Native	Tropical	Monoculture	Commercial	No data	30	< 400 ha	*Tectona*	-1,585	0,876
39	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	13,5	> 1000 ha	*Pinus*	-2,157	0,527
39	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	13,5	> 1000 ha	*Pinus*	-1,410	0,416
39	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	13,5	> 1000 ha	*Pinus*	-0,759	0,357
39	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	13,5	> 1000 ha	*Pinus*	-2,053	0,509

39	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	13,5	> 1000 ha	*Pinus*	-1,607	0,441
39	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	Isolated	13,5	> 1000 ha	*Pinus*	-0,683	0,353
40	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	2,5	< 400 ha	*Pinus*	1,610	0,530
40	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	11	< 400 ha	*Pinus*	-1,142	0,465
40	Richness	Ground beetle	Exotic	Non-tropical	Mixed	Commercial	No data	42,5	< 400 ha	*Pinus, Fagus, Fraxinus, Quercus*	-2,740	0,775
40	Richness	Ground beetle	Exotic	Non-tropical	Mixed	Commercial	No data	80	< 400 ha	*Pinus, Fraxinus, Ilex, Quercus*	-0,956	0,446
40	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	2,5	< 400 ha	*Pinus*	1,246	0,478
40	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	11	< 400 ha	*Pinus*	-1,081	0,458
40	Abundance	Ground beetle	Exotic	Non-tropical	Mixed	Commercial	No data	42,5	< 400 ha	*Pinus, Fagus, Fraxinus, Quercus*	-1,027	0,453
40	Abundance	Ground beetle	Exotic	Non-tropical	Mixed	Commercial	No data	80	< 400 ha	*Pinus, Fraxinus, Ilex, Quercus*	0,811	0,433
41	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	10	< 400 ha	*Pinus*	-2,963	0,839
41	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	40	< 400 ha	*Pinus*	-4,048	1,219
41	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	80	< 400 ha	*Pinus*	-2,990	0,847
41	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	10	< 400 ha	*Pinus*	-1,522	0,516
41	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	40	< 400 ha	*Pinus*	-2,596	0,737
41	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	80	< 400 ha	*Pinus*	-1,359	0,492
41	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	10	< 400 ha	*Pinus*	-1,161	0,467
41	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	40	< 400 ha	*Pinus*	-2,563	0,728
41	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	80	< 400 ha	*Pinus*	-0,926	0,443
41	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	10	< 400 ha	*Pinus*	-1,201	0,472
41	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	40	< 400 ha	*Pinus*	-2,740	0,775
41	Richness	Ground beetle	Exotic	Non-tropical	Monoculture	No data	No data	80	< 400 ha	*Pinus*	-0,984	0,448
42	Abundance	Ground beetle	Exotic	Tropical	Monoculture	No data	No data	14	No data	*Acacia*	0,000	0,167
42	Abundance	Rove beetle	Exotic	Tropical	Monoculture	No data	No data	14	No data	*Acacia*	-0,304	0,169
43	Abundance	Dung beetle	Exotic	Tropical	Monoculture	Commercial	Connected	7,5	< 400 ha	*Acacia*	-3,835	0,875
44	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	No data	No data	*Pinus*	-0,320	0,506
44	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	No data	No data	*Larix*	0,631	0,525
44	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	No data	No data	*Pinus*	-0,282	0,505
44	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	No data	No data	*Larix*	1,027	0,566
44	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	No data	No data	*Pinus*	-1,756	0,693
44	Abundance	Ground beetle	Native	Non-tropical	Monoculture	Protective	No data	No data	No data	*Larix*	-0,435	0,512
45	Abundance	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	30	< 400 ha	*Larix*	1,122	0,042
45	Abundance	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	30	< 400 ha	*Larix*	-0,199	0,037
46	Richness	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	5	No data	*Larix*	-6,800	3,019
46	Richness	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	15	No data	*Larix*	-3,464	1,117
46	Richness	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	45	No data	*Larix*	-6,457	2,766
46	Abundance	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	5	No data	*Larix*	-7,560	3,625

46	Abundance	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	15	No data	*Larix*	-5,280	1,999
46	Abundance	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	45	No data	*Larix*	-5,419	2,082
47	Richness	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	44	< 400 ha	*Picea*	1,269	0,801
47	Richness	Ground beetle	Native	Non-tropical	Mixed	No data	No data	44	< 400 ha	*Larix*	2,388	1,142
47	Richness	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	44	< 400 ha	*Picea*	0,667	0,704
47	Richness	Ground beetle	Native	Non-tropical	Mixed	No data	No data	44	< 400 ha	*Larix*	2,054	1,018
47	Richness	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	44	< 400 ha	*Picea*	-2,912	1,373
47	Richness	Ground beetle	Native	Non-tropical	Mixed	No data	No data	44	< 400 ha	*Larix*	-0,729	0,711
47	Abundance	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	44	< 400 ha	*Picea*	2,047	1,016
47	Abundance	Ground beetle	Native	Non-tropical	Mixed	No data	No data	44	< 400 ha	*Larix*	2,134	1,046
47	Abundance	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	44	< 400 ha	*Picea*	1,816	0,941
47	Abundance	Ground beetle	Native	Non-tropical	Mixed	No data	No data	44	< 400 ha	*Larix*	1,767	0,927
47	Abundance	Ground beetle	Native	Non-tropical	Monoculture	No data	No data	44	< 400 ha	*Picea*	0,392	0,679
47	Abundance	Ground beetle	Native	Non-tropical	Mixed	No data	No data	44	< 400 ha	*Larix*	-0,221	0,671
48	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	6,5	No data	*Eucalyptus*	-1,780	0,233
48	Abundance	Ground beetle	Exotic	Non-tropical	Monoculture	Commercial	No data	6,5	No data	*Eucalyptus*	-1,884	0,241

References: 1 = Audino *et al*. (2014) *Biological Conservation*, **169**, 248-257; 2 = Baini *et al*. (2012) *Forest Ecology and Management,* **286**, 183-191; 3 = Balog *et al*. (2012) *North-Western Journal of Zoology*, **8**, 215-222; 4 = Beiroz *et al*. (2016) *Insect Conservation and Diversity*, **10**, 94-106; 5 = Berndt *et al*. (2008) *Biodiversity and Conservation*, **17**, 1171-1185; 6 = Bowie et al. (2019) *New Zealand Journal of Ecology*, 43, 1-11; 7 = Cheng *et al*. (2018) *Acta Ecologica Sinica*, **38**, 3097-3019; 8 = da Silva *et al*. (2008) *Agriculture, Ecosystems and Environment* ,124, 270-274; 9 = Davis *et al*. (2001) *Journal of Applied Ecology*, **38**, 593-616; 10 = Derhé *et al*. (2016) *Journal of Applied Ecology*, **53**, 1714-1724; 11 = Fally & Gormally (1998) *Forest Ecology and Management*, 110, 263-273; 12 = Gardner *et al*. (2008) *Journal of Applied Ecology*, **45**, 883-893; 13 = Giménez-Gómez *et al*. (2018a) *Insect Conservation and Diversity*, **11**, 554-564; 14 = Giménez-Gómez *et al*. (2018b) *Biodiversity and Conservation*, **27**, 3201-3213; 15 = Gollan *et al*. (2011) *Insect Conservation and Diversity*, **4**, 123-131; 16 = González-Vainer *et al*. (2012) *Neotropical Entomology*, **41**, 366-374; 17 = Gries *et al.* (2012) *Insect Conservation and Diversity*, **5**, 175-185; 18 = Henríquez *et al*. (2009) *Acta Oecologica*, **35**, 811-818; 19 = Ings & Hartley (1999) *Forest Ecology and Management*, **119**, 123-136; 20 = Kosewska *et al*. (2018) *Community Ecology*, **19**, 156-167; 21 = Lange *et al*. (2014) *Forest Ecology and Management*, **329**, 166-176; 22 = Lik (2010) *Annales de la Société Entomologique de France*, **46**, 425-438; 23 = Luo *et al*. (2013) *Environmental Entomology*, **42**, 7-16; 24 = Magura *et al*. (2000) *Biological Conservation*, **93**, 95-102; 25 = Magura *et al*. (2002) *European Journal of Soil Biology*, **38**, 291-295; 26 = Magura *et al*. (2003) *Biodiversity and Conservation*, **12**, 73-85; 27 = Magura *et al*. (2006) *Community Ecology*, **7**, 1-12; 28 = Magura *et al*. (2015) *Forest Ecology and Management*, **339**, 117-126; 29 = Martínez *et al*. (2009) *Annals of Forest Science*, **66**, 304-304; 30

= Medina *et al*. (2002) *Biotropica*, **34**, 181-187; 31 = Méndez-Rojas *et al*. (2012) *Revista Colombiana de Entomologia*, **38**, 141-147; 32 = Milheiras *et al*. (2020) *PeerJ*, **8**, e8486; 33 = Nagy *et al*. (2015) *Journal of Insect Conservation*, **19**, 1075-1087; 34 = Niero & Hernández (2017) *Biotemas*, **30**, 37-48; 35 = Plexida *et al*. (2014) *Applied Ecology and Environmental Research*, **12**, 661-679; 36 = Pryke *et al*. (2013) *Biodiversity and Conservation*, **22**, 2857-2873; 37 = Russek *et al*. (2017) *Journal of Insect Conservation*, **21**, 943-950; 38 = Sakchoowong *et al*. (2008) *Entomological Science*, **11**, 301-313; 39 = Sweaney *et al*. (2015) *Biological Conservation*, **186**, 1-11; 40 = Taboada *et al*. (2008) *Basic and Applied Ecology*, **9**, 161-171; 41 = Taboada *et al*. (2010) *European Journal of Forestry Research*, **129**, 31-45; 42 = Tsukamoto & Sabang (2005) *Pedobiologia*, **49**, 69-80; 43 = Ueda *et al*. (2015) *Journal of Insect Conservation*, **19**, 765-780; 44 = Warrer-Thomas *et al*. (2014) *Forest Ecology and Management*, **334**, 369-376; 45 = Yu *et al*. (2004) *Entomologica Fennica*, **15**, 129-137; 46 = Yu *et al*. (2006) *Forest Ecology and Management*, **231**, 169-177; 47 = Yu *et al*. (2008) *Forest Ecology and Management*, **255**, 2617-2625; 48 = Zahn *et al*. (2009) *Applied Ecology and Environmental Research*, **7**, 297-301.

Table S2. Number of articles associated with forestry plantations by country

Country	Articles number
Argentina	2
Australia	3
Brazil	6
Chile	2
China	6
Colombia	2
Germany	1
Grecia	1
Hungria	2
Indonesia	2
Ireland	1
Italy	1
Malaysia	1
Mexico	1
New Zeland	2
Poland	6
Portugal	2
Rumania	1
Serbia	1
Scotland	1
South Africa	1
Spain	3
Thailand	1
Uruguay	1

Table S3. Observed and adjusted overall effect size values after Duval & Tweedie (2000) trim and fill procedure.

(a) Species richness				
	Studies trimmed	Effect estimate	Lower limit	Upper limit
Observed values		-1.090	-1.321	-0.859
Adjusted values	26	-0.659	-0,895	-0.422
(b) Abundance				
Observed values		-0.487	-0.703	-0.271

Adjusted values	23	-0.092	-0.326	0.142

Bogotá, 30 June 2021

Dear Prof. Raphael Didham
Editor in Chief
Insect Conservation and Diversity

Receive a cordial greeting.

We are resubmitting the manuscript entitled "**What level of native beetle diversity can be supported by forestry plantations? A global synthesis**" (ICDIV-21-0097), by Pablo A. López-Bedoya, Tibor Magura, Felicity A. Edwards, David P. Edwards, José M. Rey-Benayas, Gábor L. Lövei & Jorge Ari Noriega, to be considered for publication as a research article in Insect Conservation and Diversity.

At the end of this letter, you will find the original correspondence with the comments of the editor and two reviewers, together with our replies. We believe these reviews have improved considerably both the quality and soundness of the research.

Thank you for considering this manuscript for publication.

Yours sincerely,

Jorge Ari Noriega, on behalf of all co-authors

03-Jun-2021

Dear Dr. Noriega:

Manuscript ID ICDIV-21-0097 entitled "**What level of native beetle diversity can be supported by forestry plantations? A global synthesis**" which you submitted to Insect Conservation and Diversity, has been reviewed. The comments of the reviewers are included at the bottom of this letter.

The reviewers have recommended publication, but also suggest some minor to moderate revisions to your manuscript. In particular, please address the issue of whether the coverage of the meta-analysis is truly 'global' in extent, as mentioned by reviewer 1. I invite you to respond to the reviewers' comments and revise your manuscript accordingly. In your cover letter, please include a detailed point-by-point response to the reviewer comments, indicating how they have been addressed in the revised manuscript.

R./ Thanks for your valuable comments and time. Following your advice, we reviewed the minor to moderate suggestions to the manuscript carefully, and response point-by-point to each of the comments of the two reviewers. We also address carefully the coverage issue of the meta-analysis that reviewer 1 mentioned.

We recognise that the impact of the COVID-19 pandemic may affect your ability to return your revised manuscript to us within the requested timeframe. If this is the case, please let us know.

You will be unable to make your revisions on the originally submitted version of the manuscript. Instead, revise your manuscript using a word processing program and save it on your computer. Please also highlight the changes to your manuscript within the document by using the track changes mode in MS Word or by using bold or colored text. If you do decide to use track changes then please also submit an additional version with track changes accepted for ease of reading for referees and editors.

Once the revised manuscript is prepared, you can upload it and submit it through your Author Center.

When submitting your revised manuscript, you will be able to respond to the comments made by the reviewer(s) in the space provided. You can use this space to document any changes you make to the original manuscript. In order to expedite the processing of the revised manuscript, please be as specific as possible in your response to the reviewer(s).

Because we are trying to facilitate timely publication of manuscripts submitted to Insect Conservation and Diversity, your revised manuscript should be uploaded as soon as possible. If it is not possible for you to submit your revision in a reasonable amount of time (preferably within 30 days), we may have to consider your paper as a new submission.

Once again, thank you for submitting your manuscript to Insect Conservation and Diversity and I look forward to receiving your revision.

Sincerely,

Prof. Raphael Didham

Editor, Insect Conservation and Diversity

Associate Editor Comments to Author:

Associate Editor

Comments to the Author:

The manuscript has now been assessed by 2 reviewers. Both judgements were very positive. Nevertheless, they both made suggestions that would improve the manuscript even further. Therefore, I recommend revising the manuscript accordingly.

R./ Thanks for your valuable comments and positive feedback. Following your advice, we reviewed the manuscript, and response to each of the comments and suggestions of the two reviewers.

Reviewer(s)' Comments to Author:

Reviewer 1

This paper addresses an important issue through a simple but highly relevant question in the title: "What level of native beetle diversity can be supported by forestry plantations?" It uses a meta-analysis approach to show that forestry plantations negatively affect richness and abundance of ground, rove and dung beetles compared to natural forests. Authors also show that the negative impact was most severe in plantations with exotic tree species and located in tropical biomes. I made some suggestions to improve the language but a native English speaker could help to make it more completely.

I was surprised that the boreal zone was completely absent from the paper as there is no study in North America, as well as in Scandinavian countries and Russia. This is strange as authors refer to some papers from boreal zone (Pohl from Canada, Koivula and Niemela from Finland). This is unfortunate as plantations are heavily used in these countries as recognized by authors at line 63. It would worth knowing if the main conclusions of the present meta-analysis (using small plantations, close to natural forests and using native trees) are applicable in the boreal zone. At line 64 of the introduction, authors say that there are numerous plantations in North America. Why are there none in your meta-analysis? Besides, at line 77, they report that studies found biodiversity levels within plantations to match those found in natural forests, particularly in some Nearctic and Palearctic non-tropical biomes, which in fact include the boreal zone. Rather than ignoring the boreal zone, authors should explain why no studies qualified for their meta-analysis and in the Discussion refer to the boreal zone and how their results may apply or not.

R./ Thanks to the reviewer to point out this important issue. In our meta-analysis, articles located in boreal biomes were not included as no studies were found that met the established criteria. Despite this, different investigations in boreal systems were mentioned in the introductory section as the reviewer mentioned. When searching for scientific literature in the databases consulted, articles were obtained for the boreal biome, however, the inclusion criteria that we used filtered those articles (*e.g.*, Yi & Moldenke 2005 – USA, Pohl *et al*. 2007 – Canada, Oxbrough *et al*. 2010 – Ireland). The main two reasons of this exclusion were: i) the studies evaluate a forestry plantation without having a natural forest as a control and ii) the studies did not present the statistical dispersion measures needed to be included in the article. In some cases, these articles in boreal biomes, were limited to presenting the absolute beetle richness or abundance and did not present data on the mean or standard deviation. However, we truly believe that our findings associated with the management used in forestry plantations can be applied in different biomes (tropical and non-tropical) even without having articles from some of these specific biomes. In addition, following the advice of the reviewer, we include an explanation related to the absence of articles included from these boreal biomes in the results section (L211-215). Finally, we also include in the discussion section the possible application of our results on those boreal biomes (L406-410).

For these reasons, authors should not present their study as a "global" meta-analysis as it mainly addresses Europe and South America, with some insight into southeast Asia and Australia-New Zealand but not North America, Africa (only 1 site), Scandinavia, Russia, Japan… where plantations are also used.

R./ We understand the point of view of the reviewer; however, we believe that the meta-analysis is a global study. We include 48 articles (12 Tropical and 36 Non-Tropical biomes) distributed in 24 countries on 5 continents. This is a global perspective without any doubt. Not including boreal biome studies, as they do not meet the inclusion criteria, is not an intentional decision and we believe is not affecting the clear global pattern that we are founding. And although countries such as the USA, Canada, Russia, and Scandinavian countries are very important, their non-inclusion does not condition that the study has a global character.

Thus, they should explain why they haven't been able to cover more countries or the boreal zone as well as other countries. Also, as they incorporated ground, rove and dung beetles into their meta-analysis, I guess that pitfall traps were used in most studies. Such information should be provided. Follows are some specific comments on various parts of the manuscript:

R./ Done. We provide information about the absence of included studies of some non-tropical biomes (see above). Also, following the suggestion of the reviewer, we include information in the materials and methods section about the capture method used in most of the articles included (L132-133).

Abstract

L7: change "although often via the conversion of natural forest" by "often leading to the conversion of natural to artificial forests."

R./ Done. We made the suggested change (L7).

L10: change wording for "globally" as explained above.

R./ Done. We delete this word in the sentence.

L20: Technically, it might not be the age of plantation that influence beetle richness and abundance but attributes that change with age (ex: coarse woody debris, forest structure, litter…) and as a result it would be better to write "Species richness and abundance of beetles significantly increased with plantation age in native plantations, but decreased in exotic ones. Also, small plantations close to native forest had higher beetle species richness and abundance than large ones located far away from native forest."

R./ Done. We made the suggested change (L20-23).

L23: change "allowing them to mature is critical to creating biodiversity-friendly forestry plantations…" by "lengthening rotations is critical for allowing biodiversity recovery in forestry plantations…"

R./ Done. We made the suggested change (L24-25).

Introduction

L55: You present a meta-analysis aimed to respond to a question and it is not a good idea to respond to this question in the first sentence of the paper. I suggest removing this sentence which is also incorrect as the loss and fragmentation of natural forests is not related to timber plantation expansion but rather to enhance timber production as explained in the second sentence.

R./ Done. We removed this sentence of the introduction section.

L86-89: "In general, these studies show that forestry plantations composed of native or mixed species, small size, and if planted for conservation purposes can positively affect species richness or abundance of forest-inhabiting invertebrates and/or vertebrates". Again, I suggest removing this sentence as you do not need to respond to the title question in the Introduction. Let the data speak in the Results section and keep this sentence for the Discussion.

R./ Done. We removed this sentence of the introduction section.

L104: change "moderate" for "modify"

R./ Done. We made the suggested change (L99).

L110: worldwide? I suggest rewording for reasons explained above.

R./ Done. We removed "worldwide" in the sentence.

L112-115: the rationale behind hypotheses should be explained. For instance, in (H1), you could remind that plantations simplify forest composition and structure and as a result, we may expect that beetle diversity should follow the same trend. For (H2), you should explain that exotic planted trees bring natural forests farther than native trees and as a result, we may expect that a certain number of species, closely linked with conditions that developed over long time with natural forests, should suffer thus reducing diversity.

R./ Done. We made the suggested change (L107-109).

Material and methods

L217: native rather than exotic species?

R./ Done. We change the phrase to explain that abandoned plantations of exotic species were used in conservation plans (L223).

L221: I don't understand that you have used "regenerat*", "restor*" or "land-use" as research terms as they are not relevant to the question asked in the title. Also, why were the terms abundance and species richness not crossed with Forest* and Plantat*? It would have avoided to gather 3675 articles, from which only 48 were retained, i.e. just slightly more than 1%!

R./ Thanks to the reviewer to point out this issue. We use these search terms in order to increase the possibilities of inclusion. Different articles assess a broad spectrum of land cover or land uses (including forestry plantations) and therefore in the title, summary or keywords section do not directly refer to forestry plantations, using more general terms. In other cases, they refer to forestry plantations as artificial regeneration or restoration, so we conclude that the use of these terms within our search, can offer a greater number of results by minimizing the exclusion of results. We understand it was a great work but we are confident with our results. Following the comment of the reviewer, we include a summary explanation in methods section (L120-122).

L124: why 85% of the studies were rejected at the first step? It is not clear.

R./ Done. We included in the text a clear reason of rejected studies in the first step (L123-124).

L129: change "treatments stand' by "treatment stands"

R./ Done. We made the suggested change (L130).

Results

Authors mainly compared the treatments between them using Qb but this test compares the homogeneity in treatments groups. In my understanding, a non-significant Qb test indicates that a significant difference between treatments is not detected because of heterogeneity of variance in compared groups. However, often there are significant differences from neutral effects for one treatment, but not for the other and these differences should also be highlighted. For instance, beetle abundance did not differ between isolated and connected plantations but the negative effect was significant for isolated plantations while it was not for connected plantations.

R./ Done. We agree with the reviewer and we include in the results section a more detailed associated with statistical results (L257-260, 266-267). Also see below each point.

L209: this is not apparent on the map (Fig. 1) that most studies came from Brazil, China and Poland. Maybe you will need to add a table to make it clearer.

R./ Done. We included an additional Table S2 in the Supplementary material (L211-212).

L226: rove beetles were also significantly less abundant than the neutral effect while abundance of ground beetles did not differ from the neutral effect.

R./ Done. Thanks to the reviewer to help us to correct this. We change this sentence according with the statistical results (L231).

L243-245: should remain on significant effects. Only 4 tree species produced significant negative effects on both species richness or abundance and one (Larix) had positive effect on abundance. You do not need to compare with Alnus and others as there was no significant effect on these. Also, you should compare the same tree species or group of tree species for abundance and species richness. For instance, Acacia and Swetenia are combined for abundance but not for species richness. It is important to maintain coherence in the treatments, otherwise, it raises more questions than responses.

R./ We understand the main concern of the reviewer. In order to maintain consistency in the treatments, some of the implemented tree genera (those treatments with more than one genus) were eliminated (*Pinus* and *Abies* and *Swietenia* and *Acacia*). However, we clarify that it is very difficult to maintain coherence between the genera of trees evaluated for the beetle species richness and abundance metrics, given the different attributes of local forestry plantations. For this reason, we consider maintaining the different arboreal genera although these genera are not present for both beetle species richness and abundance (see Fig. 1, 2).

L250: I would rather write: “Likewise, the purpose (conservation or timber supply) for establishing a plantation had no effect on either beetle species richness or abundance”.

R./ Done. We made the suggested change (L257).

L252: for beetle abundance, the negative effect was not significantly different than the neutral effect in plantations used for conservation.

R./ Done. We included this suggested result in the text (L259-260).

L258: Ok, but beetle abundance was significantly lower than the neutral effect in isolated plantations while not in connected ones. This should also be highlighted.

R./ Done. We included this suggested result in the text (L266-267).

L263: r^2 of these relationships should be provided

R./ For meta-analyses using random effects models in the meta-regression, r^2 values are not used. In this case Tau^2 values are included (L276-279).

Discussion

L288: it is not really a global meta-analysis as there is no studies coming from the boreal zone (North America, Scandinavian countries, Russia) where plantations are also widely used, as well as from Africa where there is only one study. In fact, the study covers Europe, South America, Australia-New Zealand and southeast Asia.

R./ We already discuss this point and argue our point of view. We believe that the meta-analysis that we performed is a global study because it includes 48 articles (12 Tropical and 36 Non-Tropical biomes) distributed in 24 countries on 5 continents. Not including boreal biome studies, as they do not meet the inclusion criteria, is not an intentional decision and we believe is not affecting the global pattern that we are founding.

To simplify, I would combine the first two sentences as follows:

“Our meta-analysis on the effect of forestry plantations on native beetle diversity support our research hypotheses, revealing that species richness and abundance of ground, rove and dung beetles were generally lower than in natural forests (H1), and that location and management affected the conservation value of plantations (H2)”.

R./ Done. We made the suggested change (L298-301).

L297: Decline refers to time. I would rather re-write the sentence for: “Our results showed lower species richness and abundance of beetles in forestry plantations compared to natural forests”.

R./ Done. We made the suggested change (L306).

L303: change “… transformation of natural ecosystems into silvicultural land…” by “…conversion of natural ecosystems into intensively managed lands…”

R./ Done. We made the suggested change (L312-313).

L307: it is strange to refer to North American and Scandinavian studies to say that ground and rove beetles are extremely sensitive to changes in environmental and habitat characteristics caused by plantation establishment while there is no studies from these areas of the world in this meta-analysis.

R./ We clarified this doubt above. We refer to these articles in the text, but they were not included in the analysis because they do not meet the inclusion criteria: i) the studies evaluate a forestry plantation without having a natural forest as a control and ii) the studies did not present the statistical dispersion measures needed to be included in the article.

L329: you should explain why forest specialists in tropical forests are more sensitive to habitat alteration than in non-tropical forests. Are forest specialists more prevalent in tropical forests due to the greater number of microhabitats?

R./ Done. We include this explanation in the text (L338-340).

L339: yes but mainly in non-tropical forests. Getting deeper in the explanation vs the previous comment could help better understand the mechanisms behind these differences and would help generalize recommendations. I think that the arguments are present in the following sentence. It just need to be widenned to tropical forests and placed in appropriate place in the discussion.

R./ Done. We include this explanation in the text (L341-342).

L349: change “beetles reveal a marked decrease in species richness or abundance…” for “beetle richness or abundance decreased markedly…”

R./ Done. We made the suggested change (L359).

L394: we are not "creating" exotic forestry plantations… you should rather say: "Thus, establishing exotic forestry plantations…"

R./ Done. We made the suggested change (L404).

Reviewer 2

Comments to the Author

The authors present the results from a meta-analysis of 48 studies to compare species richness and abundance of 3 coleopteran groups between forestry plantations and natural forests. The methodology is clearly presented and consistent. The results provide a clear picture of the effects of forestry plantations when replacing « natural » forests. These results are briefly discussed and support some general recommendation for forest managers.

However, I have three minor concerns:

- The expression « natural forest » need to be defined as some forest controls used in several studies (Paillet et al, 2010 or Lang et al, 2014 for example) are actually forests that have been abandoned for only few decades. The authors also use the expression « native forest » (L 311) or « native stands » (L 386) as synonymous. Please use consistent expression througouht the manuscript.

R./ Thanks to the reviewer to point out this important issue. We completely agree. We accepted this suggestion and reviewed the manuscript and established a consistent vocabulary (*e.g*., L327). Also, we included a definition of natural forest for clarity in the manuscript (L137).

- On statement in the abstract (LL 21-22) is equivocal. As in all cases, the plantations have negative effects, one should talk about « less worse case scenario » rather than mentioning «positive effect ». Which is in line with the discussion and conclusion of the paper (« less sever negative effect », LL 347-348, or « reduce adverse effects », LL 395-396). I also recommand to take up the statement of LL 293-294 in the abstract.

R./ Done. We agree with this valid comment and we made the suggested change in the text (L20-25).

- The authors quoted three papers to support the idea that biodiversity levels in plantation match those found in natural forests (LL76-78). But Kerr (1999)'s and Pawson et al (2013)'s papers did not provide any data about this idea. In the the latter, the authors even wrote that « the establishment of plantation forests that replace natural vegetation typically causes biodiversity losses locally ».

R./ Done. Thanks to the reviewer to point out this issue. We have reviewed the articles in detail, and we have decided to change them to others papers that better support the idea expressed in the text (L76).