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How does the replacement of native forest by exotic forest plantations affect the diversity, abundance and trophic structure of saproxylic beetle assemblages?

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ABSTRACT

Native forest in central Chile has been increasingly replaced by exotic forest plantations. In particular, saproxylic beetles could be highly sensitive to exotic forest plantations due to the clear-cutting management decreases deadwood accumulation while promoting the incompleteness of the decay cycle. We assessed the diversity and density of saproxylic beetle species at two spatial levels (habitat and microhabitat) and compared them among native Maulino forest (Native), Blue-gum eucalyptus plantations (Eucalyptus) and Monterrey pine plantations (Pine). We sampled for adult beetles at 972 logs and stumps. Although exotic plantations and Native had relatively similar amounts of deadwood, beetle species were less diverse and abundant in exotic plantations. Such a decreased density and diversity of saproxylic beetles in plantations depended on the substrate type (logs or stamps), decay stage of wood and trophic level. With the exception of Polyphagous, the richness of all species and trophic guilds decreased in forest plantations, with Eucalyptus supporting the lowest density and richness. The microclimate and the toxic leaf litter in Eucalyptus probably caused the woody biomass to be unsuitable for beetles. Although the guilds of late-successional species were underrepresented in Pine, our results provide the first evidence that saproxylic beetles benefit from exotic woody debris available in Chilean pine plantations. An increased beetle density at expenses of reduced species richness in Pine indicates that ecosystem services provided by saproxylic beetles are not limited in Pine. We suggest the conservation of saproxylic beetles in Pine plantations involves the retention of woody debris along the management cycle.

1. Introduction

Monoculture plantations of commercial species, such as pine (*Pinus* spp.) and eucalyptus (*Eucalyptus* spp.), are increasingly replacing temperate and tropical native forests worldwide, currently covering more than 7% of the global forest area (Payn et al., 2015). Sustainable management of forest plantations, as stated in the Strategic Plan for Biodiversity 2011–2020 of the Convention on Biological Diversity (CBD, 2010), is particularly difficult to achieve because forestry practices disrupt vegetation structure, soil properties and microclimate, thus promoting the loss of biodiversity and environmental services (Brockerhoff et al., 2008; Niklitschek, 2015). The widespread application of the clear-cutting system in pine and eucalyptus stands causes the simplification of forest and soil structure mainly during the early stages of plantation development (Rosenvald and Lõhmus, 2008; Pawson et al., 2011; Riffell et al., 2011). However, as forest plantation stands get old, they are increasingly perceived as a potential habitat by wildlife fauna (including threatened species), that find supplementary or alternative resources for survival and reproduction (Pawson et al. 2008; Ramirez-Collio et al., 2017). Forest management for wildlife conservation requires understanding how species respond to change of habitat quality through provision, or retention, of particular habitat

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features such as canopy-shaded sites, dense understory and coarse woody debris (Gossner et al., 2013a; Simonetti et al., 2013; Cerda et al., 2015).

Forest plantations are thought to act as potential habitats for biodiversity by resembling the structural heterogeneity of native forests (Brockerhoff et al., 2008; Pawson et al., 2010; Paquette and Messier, 2010, 2011). Nonetheless, this assumption is weakly supported for species that are closely related to ecosystem processes inherent to forest habitats, such as saproxylic beetles (deadwood-dependent species) by which tree mortality and wood decay rates are necessary for reproduction, growth and/or survival (Speight, 1989; Grove, 2002; Stokland et al., 2012). Indeed, the abundance and richness of saproxylic beetles are higher when increasing the availability and connectivity of suitable woody debris microhabitats (e.g., larger and decayed logs and stumps; see Schiegg, 2000, Müller and Bütler, 2010; Hjältén et al., 2010). Although the impacts of exotic forest plantations on native saproxylic beetles have not been studied in depth (e.g., see Lachat et al., 2006, 2007; Buse et al., 2010), several reasons do exist to state that pine and eucalyptus plantations could act as unsuitable habitats for saproxylic beetles. Forest plantations tend to accumulate reduced amounts of deadwood due to their short harvesting cycles (usually 10–20 years), as well as by the frequent removal of biomass from thinning, pruning or biofuel extraction (Rudolphi and Gustafsson, 2005; Jonsson and Siitonen, 2012). The wood-decaying process is abruptly interrupted during the clear-cutting operations, when logging wastes are mechanically destructed and burned, consequently preventing woody substrates to be colonized by late-successional saproxylic species (Hjältén et al., 2010; Seibold et al., 2015; Pons and Rost, 2017). Deadwood substrates are smaller and less diverse, coming from tree species that are taxonomically distant from native species, and hence, physically and chemically different (Jonsson and Siitonen, 2012). The subsequent application of insecticide, herbicide and fertilizers reduces the habitat quality for saproxylic biota (e.g., Miller and Miller, 2004; Przewloka et al., 2007).

Forest management intended to benefit saproxylic biota usually focuses on the retention and enrichment of deadwood in managed forest stands (Müller et al., 2015 Gossner et al., 2013b, 2016). However, the partial knowledge about how saproxylic species use and colonize deadwood in forest plantations may make these management prescriptions useless for conservation purposes. Saproxylic beetles conform a rich assemblage of interacting species, with some trophic guilds being more diverse under advanced stages of wood decay, such as Zoophagous (predators), Mycophagous, Xylomycophagous and Saproxylophagous (Vanderwel et al., 2006; Micó et al., 2015). The underrepresentation of saproxylic beetle species in forest plantations, however, could be compensated by the increased abundance of some beetle species using exotic deadwood, including exotic (i.e. non-native) beetle species that would facilitate the subsequent use of woody substrates by native species (Lachat et al., 2007; Bertheau et al., 2009; Buse et al., 2010; McCarthy et al., 2013). The conservation of saproxylic beetles diversity in forest plantations is justified by the environmental services rendered by them (Paquette and Messier, 2011). Saproxylic beetles act as a major driver of deadwood decay rates, contributing to the productivity of forest plantations by releasing nutrients, but also through decreasing the risk of fire (Edmonds and Eglitis, 1989; Fayt, 2004; Ulyshen, 2013, 2016).

Central Chile is considered a hotspot of biodiversity (Myers et al., 2000), with a high endemism of saproxylic beetles (see Paulsen, 2010). The accelerated loss and replace of the Maulino forest by fast-growth plantations of Blue gum eucalyptus (*Eucalyptus globulus*) and Monterrey pine (*Pinus radiata*), faces the challenge of achieving sustainable forest management focused on saproxylic beetle species with conservation concerns and the maintenance of environmental services provided by them. Here, we evaluate the diversity, composition and abundance of saproxylic beetles living in Maulino forest and exotic forest plantations (Blue gum eucalyptus and Monterrey pine) at two spatial levels: habitat (forest stands) and microhabitat (individual logs and different stages of decay). Specifically, we hypothesize that Maulino forest offers better habitat conditions for saproxylic beetles than eucalyptus and pine plantations. This hypothesis poses that forest plantations provide saproxylic beetles with low quality and quantity of deadwood, which reduces the persistence of beetle populations sensitive to anthropogenic forest disturbances, while altering the diversity and trophic structure of beetle communities. The following three predictions derived from this hypothesis were tested:

(i) At the habitat level, Maulino forest should support a more diverse assemblage of saproxylic beetles than forest plantations (eucalyptus and pine stands).
(ii) At the microhabitat level, individual logs and stumps in Maulino forest should have a higher abundance and richness of saproxylic beetles than those in forest plantations, with those differences being more pronounced as logs or stumps become more decayed.
(iii) Trophic guilds associated with logs and stumps in an advanced state of decay should be poorly represented in forest plantations.

2. Materials and methods

2.1. Study area

The study was conducted at the Coastal Range of the Maule Region, South-Central Chile (35°36′10″S, 72°20′60″W and 36°00′36″S, 72°20′60″W), an area originally covered by Maulino forest, and more recently, dominated by extensive plantations of Blue gum eucalyptus (*Eucalyptus globulus*) and Monterrey pine (*Pinus radiata*) (Fig. 1). Saproxylic beetles were sampled in 24 different stands, with eight stands per habitat type, including fragments of native Maulino forest, stands of "mature" (20–30 years-olds) Monterrey pines and stands of mature (10–13-year-olds) Blue gum eucalyptus; hereinafter referred to as Native, Pine and Eucalyptus, respectively. Pine and Eucalyptus were selected to represent the dominant type of forest management applied in the study area, which considers the retention of deadwood. Thus, the few stands (n = 2) where we did not detect deadwood pieces were not included for analysis because in these stands logging wastes are intensively extracted by local communities for firewood and coal production. The minimum distance between stands was ca. 2 km. The area of Native ranged between 25 and 50 ha and were composed by secondary forests dominated by *Nothofagus glauca*, and accompanied by *Cryptocaria alba*, *Laurelia sempervirens*, *Persea lingue* and *Nothofagus obliqua*. Trees in Native were 15–20 m in height and 20–40 cm in diameter at the breast height (DBH). The understory vegetation at Native covered 50 to 75%, and was composed mainly by native young trees, shrubs and creepers. The size of Pine ranged between 100 and 400 ha. Pine trees were 25–35 m in height and 20–35 cm in DBH. The understory at Pine covered 20–50% and was composed mainly by the native and exotic shrubs. The size of Eucalyptus ranged between 50 and 100 ha. Eucalyptus trees were 15–20 m in height and 15–25 cm in DBH. The understory of Eucalyptus covered 15–35% and was composed by native and exotic shrubs (e.g. *Teline monspessulana* and *Rubus constrictus*). The identity of deadwood varied among habitats. In Native, deadwood included *Nothofagus* logging residues from charcoal harvesting and from naturally fallen branches and trunks. In Pine and Eucalyptus, deadwood was composed by logging wastes from clear cutting, thinning and pruning of pine plantations. Eucalyptus were first rotation stands, therefore, lacked coarse woody debris (> 6 cm diameter) from eucalyptus trees, but *Pinus* logging wastes remained from the previous plantations (see below for Section 2.3).

2.2. Saproxylic habitat

We characterized each habitat type (Native, Pine and Eucalyptus) at the stand-level by estimating variables recognized to influence