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Does coarse woody debris density and volume influence the terrestrial vertebrate community in restored bauxite mines?

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ABSTRACT

Coarse woody debris (CWD) is a critical functional and structural component of forest and woodland ecosystems, providing habitat for many species, and is an important consideration in forest and woodland restoration. CWD is very slow to develop naturally so, to accelerate the return of CWD-dependent species to restored areas, CWD is commonly returned manually. However, few studies have tested the effectiveness of such a strategy. We investigated whether the provision of CWD, heaped into 'habitat piles' of varying density (0.4–5.7 piles ha^{-1}), was effective in accelerating recolonisation by reptiles, frogs and mammals into 3-year old restored bauxite mine-pits in south-western Western Australia. Both reptile and mammal communities, and the abundances of some individual species, differed significantly between unmined and restored forest but the provision of CWD had only a weak effect in accelerating recolonisation. *Acritoscincus trilineatus* abundance showed a weak positive relationship with habitat pile density and both *Cryptoblepharus buchananii* and *Christinus marmoratus*, species that are very rare in restoration, were recorded adjacent to habitat piles in two and one mine-pits respectively. The weak effects of CWD in accelerating recolonisation were likely due to the differences in vegetation between unmined and restored forest, resulting in restored forests being primarily inhabited by generalist species that did not require CWD, and the highest habitat pile densities being ⩽6% of log densities in unmined forest, suggesting that CWD-dependent species perceived all mine-pits as having similarly low levels of CWD, compared to unmined forest. Our results suggest that the provision of CWD in restored areas is critical to accelerate recolonisation of CWD-dependent fauna, but this will require consideration of both CWD spatial connectivity and temporal continuity. Spatial connectivity would be best achieved through CWD densities that approximate those in reference ecosystems, whereas temporal continuity will be harder to achieve, particularly in systems where CWD is slow to develop, and will require the development of innovative techniques and long-term management. However, ensuring the spatial connectivity and temporal continuity of CWD in restored areas should greatly increase their biodiversity value.

1. Introduction

Coarse woody debris (CWD) is a critical functional and structural component of forest and woodland ecosystems and is important for nutrient cycling (Fisk et al., 2002; Hafner et al., 2005), as carbon sources and sinks (Pacala et al., 2001; Van Miegroet et al., 2007), as habitat for saprophytic organisms (Küffer and Senn-Irlet, 2005; Yamashita et al., 2008) and as sites for plant germination and growth (Marx and Walters, 2008; Bailey et al., 2012) among other values (Lindenmayer et al., 2002). CWD is also critically important as habitat for many invertebrate and vertebrate species, with several faunal species being specialised for living on CWD (Sumner, 2006; Jacobs et al., 2007; Christie et al., 2012). Many studies have shown a link between CWD and the richness and abundance of both forest faunal communities and individual faunal species (Loeb, 1999; Lohr et al., 2002; Craig et al., 2012). These studies suggest that both the volume and type of CWD present in a forest exert the greatest influence on forest fauna with larger volumes and class sizes of CWD supporting the greatest richness and abundance of forest fauna (Grove, 2002; MacNally et al., 2002a; Vanderwel et al., 2006).

CWD is, thus, an important consideration in the planning and implementation of forest and woodland restoration (MacNally et al., 2002b; Christie et al., 2012). It is generally assumed that animals will naturally recolonise restored areas (Palmer et al., 1997),

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yet this may occur over very long timeframes for species that require mature habitat features, such as CWD, that are typically absent from young restored areas (Vesk et al., 2008; Craig et al., 2012). One management strategy to cater for these species is to provide CWD in restored areas (Bennett et al., 2000; Brennan et al., 2005), a strategy often used, especially post-mining, to accelerate faunal return (Brennan et al., 2005; Grigg and Steele, 2011). However, few published studies have examined whether the addition of CWD actually accelerates recolonisation by vertebrate fauna (but see MacNally et al., 2002a; Manning et al., 2013) and none in forest restored post-mining. Given that both the volume and type of CWD are known to influence faunal communities, these are the primary variables that need to be manipulated when returning CWD to restored areas. Large CWD in various stages of decay is preferable (Barclay et al., 2000; McCay, 2000; Alkaslassy, 2005) and the volume of CWD should mimic that found in reference communities as closely as possible (Brennan et al., 2005). Often CWD in restored areas, particularly post-mining, is placed in piles, called habitat piles, due to logistical considerations (Koch, 2007). The density of these habitat piles in restored areas is clearly of importance if CWD-dependent fauna are to successfully recolonise these areas.

Alcoa World Alumina Australia (hereafter 'Alcoa') have been undertaking revegetation of bauxite mine pits in the northern jarrah (*Eucalyptus marginata*) forest of south-west Western Australia since 1966, with revegetation techniques evolving since that time (Koch, 2007). Presently, CWD is returned to restored mine-pits in the form of habitat piles at a minimum of one habitat pile ha^{-1} (Grant and Koch, 2007). Despite the use of habitat piles for over 25 years, only four studies have been conducted on their use by vertebrate fauna and none have been formally published (Endersby, 1993; Mutzig, 1998; Bell, 2004; McGregor, 2011). Consequently, we know very little about how habitat pile densities and CWD volumes affect the abundance and recolonisation of CWD-dependent fauna.

We examined reptile, frog and small mammal communities in recently restored mine-pits containing a wide range of habitat pile densities, and in reference unmined sites. We focused on reptiles because they are the slowest group to recolonise restored sites in the jarrah forest (Nichols and Nichols, 2003) and a previous study that sampled vertebrates in restored sites away from habitat piles found that several CWD-dependent species were absent from young restoration (Craig et al., 2012). We also included frogs and small mammals as they are easily sampled on the same trapping arrays used for reptiles and their responses to habitat pile densities are largely unknown (but see Mutzig, 1998; Bell, 2004). In this study we sampled reptiles, frogs and small mammals adjacent to habitat piles in young restored sites with varying densities of habitat piles and asked the following questions: (1) does the provision of CWD in restored areas accelerate recolonisation by reptile, frog and small mammal species? and; (2) is the abundance of any reptile, frog or small mammal species related to habitat pile density or CWD volume?

2. Methods

2.1. Study area

This study was conducted on Alcoa's Huntly mine (32° 36′ S, 116° 06′ E), approximately 10 km north of Dwellingup in the northern jarrah forest of south-west Western Australia. The climate at Dwellingup is Mediterranean, with cool, wet winters and warm, dry summers. Rainfall averages 1240 mm yr^{-1} with more than 75% falling between May and September.

The jarrah forest prior to mining is dominated by two eucalypts, *E. marginata* and *Corymbia calophylla*, with a canopy up to 30 m in height. Typical midstorey species include *Banksia grandis* (Proteaceae) and *Bossiaea aquifolium* (Papillionaceae), while typical understorey species include *Acacia varia* (Mimosaceae), *Jacksonia sternbergiana* (Papillionaceae), *Lasiopetalum floribundum* (Sterculiaceae) and *Macrozamia riedleii* (Zamiaceae). Following mining, the minesite consists of a mosaic of unmined jarrah forest and restored mine pits of varying ages. Current restoration practices, used since 1988, involve reseeding with *E. marginata* and *C. calophylla* and 76–111 understorey species, and hand planting of "recalcitrant" species that do not return from seed (Koch, 2007). Restored minesites have similar plant species compositions to unmined jarrah forest, although dryland rush and sedge species are less common. CWD left from clearance of the original forest is returned to restored areas and then clumped into piles (called habitat piles; Fig. 1) at a density of one habitat pile ha^{-1} (and, therefore, differs in spatial distribution from CWD in unmined forest which rarely, if ever, occurs in piles and is relatively evenly distributed as single logs; see Fig. 1). Habitat piles consist, on average, of 3 large logs (>30 cm diameter), 1.4 small logs (<30 cm diameter) and 0.9 stumps (Grigg and Steele, 2011). For further details of mining and restoration procedures used see Grant and Koch (2007) and Koch (2007).

2.2. Experimental design and vertebrate sampling

We investigated the influence of habitat pile density on terrestrial vertebrates by examining vertebrate communities in 12 three-year old restored mine pits chosen to cover a broad range of habitat pile densities and standardised as much as possible for distance from unmined forest and vegetation density. We examined the effect of density directly, rather than indirectly through distance to habitat pile, by placing each trapping array adjacent to, and centred on, single habitat piles (Fig. 1). Trapping arrays followed the long axis of the pile and, unless arrays ran directly north-south, were placed on the north side of habitat piles. To estimate "desired" vertebrate densities in restored mine-pits, we also examined terrestrial vertebrate communities in four unmined forest sites to provide a reference. Arrays in unmined forest were placed next to large logs so that arrays from both treatments were adjacent to CWD.

We sampled terrestrial vertebrates using single trapping arrays at each site, which consisted of nine pit-traps (four 850 ml plastic take-away containers, three 20 L white plastic buckets and two 40 cm deep 15 cm diameter PVC tubing) located every 3 m along 29 m aluminium fly-wire drift-fences, two paired funnel traps placed along drift fences, approximately 7 m from each end, four Elliott traps placed 5 m either side of the two end pit-traps and single Sheffield cage-traps placed at one end of the drift fence (Craig et al., 2007). These trapping arrays provide accurate estimates of relative abundance across a range of restored and unmined forests (Craig et al., 2009). Vertebrates on all arrays were sampled for four consecutive nights in spring (9th to 13th October 2006), summer (27th November to 1st December 2006), autumn (12th to 16th March 2007) and winter (7th to 11th May 2007). All reptiles and mammals captured were individually marked and released at their site of capture.

2.3. Vegetation structure, CWD and landscape variables

We quantified nine structural variables at each site between 29th May and 12th June 2007 to explore relationships between terrestrial vertebrates and vegetation structure independently of CWD variables. Canopy cover was measured by taking four readings with densiometers, in the four compass directions, at each of 12 points located 5 and 10 m either side of the three 20 L bucket pit-traps. We measured distances from the nearest understorey