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Microclimate through space and time: Microclimatic variation at the edge of regeneration forests over daily, yearly and decadal time scales

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ABSTRACT

A major aim of sustainable forest management is the maintenance or recolonisation of harvested areas by species that were present pre-disturbance. Forest influence (a type of edge effect that focuses on the effect of mature forests on adjacent disturbed forest) is considered to be an important factor that contributes to the ability of mature forest species to re-colonise disturbed areas. Forest influence occurs in two main ways by: (1) by providing a source of propagules or individuals for recolonisation; and (2) by its influence on the biotic and abiotic conditions of the disturbed forest. This study focuses on forest influence's impact on microclimate conditions of adjacent disturbed areas regenerating after harvesting. In particular, the study investigates whether microclimate within a regenerating forest changes with increasing distance from a mature forest edge, and whether the magnitude of microclimatic change varies over diurnal, seasonal and successional time scales.

Results of the study showed that the microclimate of regenerating forests is affected by the distance to a standing mature forest. Temperature, relative humidity, vapour pressure deficit, and the short-term fluctuations of these microclimate parameters were influenced by nearby mature forest. In addition, the study found that the magnitude of forest influence changes over diurnal, seasonal and successional time scales. For example, it was discovered that forest influence is greatest during the middle of the day, during the summer months when solar heating is greatest and on hot windy days. Critically, the impact of forest influence peaked around ~27 years after disturbance in the areas studied, with less influence shortly after disturbance. We speculate this is due to lower levels of midday shading in the ~7 year old forest. Forest influence on microclimate persisted in regeneration areas that were harvested 45 years ago, although the magnitude and importance of the effect was low.

We conclude that proximity to mature forest stands (forests influence) impacts the microclimate of forests regenerating after disturbance, although the response is quite variable through time. Our results provide insight into the role of microclimate on the ability of mature forest species to successfully re-colonise after disturbance. Management practices, such as aggregated retention and other forms of retention forestry, which increase the proportion of harvested area under forest influence, may provide a mechanism to promote the re-colonisation of mature-forest species.

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1. Introduction

Sustainable forest management is increasingly focused on facilitating the survival and/or re-establishment of biodiversity in forests regenerating after disturbance (Franklin et al., 1997; Lindenmayer et al., 2012). Within disturbed landscapes, edges between disturbed and mature forest patches become prominent ecological features. These edges allow the flow of energy, nutrients and species from one forest type to another (Murcia, 1995; Strayer et al., 2003; Hufkens et al., 2009). While almost all previous studies of edge effects have focused on the impact of disturbed forests on adjacent mature forest (e.g. Harper et al., 2005), it has recently become clear that the inverse edge effect (the impact of mature forest on adjacent disturbed forest or 'forest influence') affects the recolonisation of disturbed areas by mature-forest species. Forest influence includes biological processes, such as the distance that species can disperse from mature forest, as well as physical

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characteristics, such as how microclimate changes with distance from mature forest (Mitchell and Beese, 2002; Beese et al., 2003). Forest influence is characterised both by magnitude – how different the edge-influenced zone is from a non-edge influenced zone (Harper et al., 2005), and geographic scale – the distance from an edge up to the most interior area in which conditions are still significantly different from unaffected interior conditions (depth of edge influence) (Chen et al., 1992; Harper and Macdonald, 2001).

As mature and regenerating forests differ markedly in microclimate, it is reasonable to expect gradients rather than abrupt changes in microclimate across the boundary between these forests. Such gradients are well studied in traditionally examined edge effects into undisturbed forest (Matlack, 1993; Chen et al., 1995; Gehlhausen et al., 2000), but only a few studies have examined the inverse edge effects of 'forest influence' on microclimate, these studies occur in either forests next to permanent/newly deforested areas (Cadenasso et al., 1997; Davies-Colley et al., 2000; Huggard and Vyse, 2002), and 4–7 year old regenerating forest (Redding et al., 2003; Heithecker and Halpern, 2007). Related studies have shown that temperature (both soil and air), humidity, light levels and wind speed of disturbed forest all change with distance from a stream (Anderson et al., 2007; Rykken et al., 2007), although streams would be expected to create different microclimatic conditions than anthropogenically created edges. Microclimate gradients are important to understand because change impacts many forest organisms – such as beetles (Grimbacher et al., 2006) and bryophytes (Proctor, 1990; Stewart and Mallik, 2006) – and functional processes within ecosystems, including nutrient and water cycles (Chen et al., 1995; Riutta et al., 2012). Several studies have proposed that microclimatic effects can contribute significantly to forest influence on species re-establishment in disturbed areas (Hansen et al., 1993; Tabor et al., 2007; Baker et al., 2013b; Fountain-Jones et al., accepted for publication).

A major driver of microclimate in the understorey of a forest is the amount of light that reaches an area (Matlack, 1993). Although the density of the immediate overhead canopy is the strongest determinant of the quantity of light (Matlack, 1993; Davies-Colley et al., 2000), shading from more distant mature trees in nearby undisturbed forest also can reduce understorey irradiation levels in disturbed areas (Young and Mitchell, 1994; Cadenasso et al., 2003; Godefroid et al., 2006), and therefore create forest influence. Microclimatic forest influence can extend past the point where shading from a mature forest is significant (Godefroid et al., 2006), potentially through the flow of cold, moist air into the regeneration forest.

The small amount of literature on microclimatic forest influence all focuses on single aged forests, generally in the years immediately after disturbance. However, changes in the magnitude and geographic scale of microclimatic forest influence on long, medium and short time scales should be expected because similar effects have been observed in studies of interior edge effects (Mesquita et al., 1999; Denyer et al., 2006). However this concept has only been examined once previously for forest influence (Dovčiak and Brown, 2014), in American hardwood forests. Increases in canopy cover as disturbed forests age are likely to cause decreases in the magnitude of forest influence as the microclimate of the regeneration forest ultimately returns to pre-disturbance conditions (Halpern and Lutz, 2013). As well as changes with forest age, the magnitude and distance of forest influence is expected to change over shorter time scales. For example, edge effects into mature forest vary with precipitation (Harper et al., 2005), solar irradiation (Miller, 1980; Davies-Colley et al., 2000; Xu et al., 2002), wind speed (Chen et al., 1995; Davies-Colley et al., 2000), time of day (Saunders et al., 1999; Denyer et al., 2006) and season (Young and Mitchell, 1994; Silbernagel et al., 2001; Wright et al., 2010). Periodic changes in the magnitude of microclimatic forest influence could result in unique species responses depending on the phenology of the species. For example, beetle communities showed strong seasonal patterns in Tasmanian wet forests (Grove and Forster, 2011) and the germination and shoot elongation of Australian rainforest plants was affected by growing season temperature (Read, 1989).

This study will focus on the poorly investigated question of how forest influence changes over time. This information will facilitate forest management planning that aims to enhance species persistence in disturbed landscapes. Knowledge of the duration, and short-term temporal shifts, in forest influence could be combined with knowledge of the landscape and species' life histories to better predict the outcomes of management. We use evidence from transects running from mature forests into three age classes of regenerating forest. Based on previous studies of microclimate in disturbed forests and the impact that edge effects has on microclimate in mature forests, we hypothesised that:

(1) mature forests have more stable microclimates than regenerating forests;
(2) the differences in microclimate between mature forest and regenerating forest diminish as regenerating forests develop (i.e. there is microclimatic succession);
(3) the microclimate of regenerating forest near an edge with mature forest will more similar to mature forest conditions than microclimate of the interior of the regenerating forest (i.e., there is microclimatic forest influence);
(4) the magnitude of forest influence will change with time on short (diurnal), medium (seasonal) and long (successional) time scales; and
(5) forest influence on microclimate will vary with background conditions of rainfall, wind, and temperature.

2. Methods

2.1. Study sites

We studied 15 sites in the southern production forests of Tasmania, Australia (Fig. 1A). Each site contained mature forest adjacent to forest regenerating after clearfell burn and sow (CBS) timber harvesting. This silviculture involved removal of all major trees and piling of all other vegetation followed by a regeneration burn and aerial sowing of eucalypt seed. Apart from substantial quantities of coarse woody debris habitat and rare individual trees left in some sites, CBS harvesting effectively removes the majority of flora and fauna, requiring re-establishment post-disturbance. The mature forest contained emergent trees of *Eucalyptus obliqua* and/or *Eucalyptus regnans* averaging >30 m tall, over a closed canopy of rainforest trees (*Nothofagus cunninghamii* and/or *Atherosperma moschatum* with other species such as *Eucryphia lucida*, *Phyllocladus aspleniifolius* and *Anodopetalum biglandulosum*).

2.2. Experimental design

Five sites in each of three age classes of regeneration forests were selected: "~7 year old" forest, harvested between 2002 and 2007; "~27 year old" forests, harvested between 1983 and 1989; and "~47 year old" forests, harvested between 1966 and 1972. The CBS harvesting was relatively consistent across all age classes apart from slightly higher levels of coarse woody debris in older sites. The ~7 year old regenerating forest typically had a sparse canopy of eucalypt trees on average 7 m tall; the ~27 year old forest typically had reached canopy closure, with a canopy ~22 m tall; and the ~47 year old forest had closed canopy ~27 m tall. The mature forest was not significantly damaged by wind or fire during or after the timber harvest activities. All sites were chosen

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