Forest Ecology and Management 341 (2015) 37–44

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Tree hollows and forest stand structure in Australian warm temperate *Eucalyptus* forests are adversely affected by logging more than wildfire

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ARTICLE INFO

Article history:
Received 14 October 2014
Received in revised form 17 December 2014
Accepted 22 December 2014
Available online 22 January 2015

Keywords:
Logging
Fire
Tree hollows
Eucalyptus
Australia

ABSTRACT

Ecologically sustainable forest management aims to maintain biodiversity values within managed forest ecosystems. A key habitat component within Australian forest ecosystems are hollow-bearing trees which are crucially important for fauna species requiring tree hollows for diurnal shelter and nesting. The effect of disturbance regimes, in particular logging and fire, on hollow dynamics is poorly understood. The aim of this study was to determine the relationships between logging intensity and fire frequency on hollow abundance and forest stand structural attributes in two different eastern Australian *Eucalyptus* forest types.

We found that average stand tree diameter at breast height was negatively correlated to logging intensity. Logging intensity was negatively correlated with tree diameter at breast height (DBH), and the density of both hollow-bearing trees and hollows. Losses of hollow-bearing trees and hollows occurred through an interaction between logging intensity and fire frequency, resulting in an absence of recruitment of hollow trees. However in unlogged forest, fire was positively correlated to the density of hollows. Under a regime of frequent fire, in areas that have had some degree of logging activity, a net loss of hollows may occur. We recommend additional hollow recruitment trees be retained on logged sites in the future if no net losses of hollows are to occur in the future, or for wider unlogged buffers to be established adjacent to the cutting area.

1. Introduction

Tree hollows are semi-enclosed cavities that form in a range of tree species (Gibbons and Lindenmayer, 2003; Ranius et al., 2009; Remm and Lohmus, 2011). In the northern hemisphere, they are important for the conservation of a range of vertebrate fauna including woodpeckers (Hartwig et al., 2004; Roberge et al., 2008), flying squirrels (Hanski et al., 2000; Shafique et al., 2009; Pyare et al., 2010), microbats (Lucan et al., 2009) along with large forest owls (Saurola, 2009), and even invertebrate fauna (Jansson et al., 2009), many of which are threatened due to declines in the hollow resource. In Australia, tree hollows are a key habitat component for animals (Goldingay, 2009; Goldingay, 2012). They are required for breeding and shelter by more than 15% of the vertebrate fauna, in particular mammalian taxa (Gibbons and Lindenmayer, 2003). Many forest fauna species, such as forest owls and gliding possums, are obligate hollow users that depend on the presence of old, hollow-bearing trees for their continued occupancy, and these species are sensitive to forestry practices that reduce the availability of this resource (Kavanagh, 2004; Kavanagh et al., 2004; Lindenmayer et al., 2012; Lindenmayer et al., 2014; Eyre, 2007).

In Australian forests hollow formation is slow, with small hollows taking at least 80 years to form (Koch et al. 2008), while larger hollows, suitable for occupation by animals such as forest owls, may take as long as 220 years (Goldingay, 2012; Gibbons and Lindenmayer, 2003). Consequently, the hollow resource needs to be carefully managed within Australian forests. Within the northern hemisphere vertebrate fauna are known to excavate hollows (Bull et al., 1992; Hartwig et al., 2004). By contrast, forest vertebrates in Australian forests do not build hollows. Hollow formation is dependent upon termites gaining access and the subsequent fungal decay of internal heartwood (Mackowski, 1984); processes that may be facilitated by branch shear following wind (Harper et al., 2005) or fire (Inions et al., 1989).

Ecologically Sustainable Forest Management (ESFM) aims to maintain biodiversity in multi-use forests (Kotwal et al., 2008). ESFM relies on the identification of forest indicators including species, habitat attributes and processes that can act as sentinels for

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http://dx.doi.org/10.1016/j.foreco.2014.12.023
0378-1127/

ecosystem health (Lindenmayer et al., 1999; Lindenmayer et al., 2000a; Lindenmayer et al., 2006). The status of forest habitat elements such as tree hollows are particularly important in this regard (Lindenmayer et al., 2006; Gibbons and Lindenmayer, 2003; Burgman, 1996; Ranius et al., 2009; Remm and Lohmus, 2011). In the fire-prone, *Eucalyptus* dominated forests of Australia, detailed insights into the effects of logging and fire regimes on the dynamics (i.e. losses and gains) of hollows are required in order to conserve vertebrate fauna and meet ESFM guidelines (Eyre, 2005; Goldingay, 2012). Logging preferentially removes large, usually older, rather than small (i.e. younger) trees and therefore reduces the number of trees of a suitable size and age for hollow formation (Lindenmayer et al., 2012; Lindenmayer et al., 2014). Such losses are additional to those that result from the natural collapse of existing hollow trees (Gibbons et al., 2010; Lindenmayer et al., 2012). Current logging practices in Australia require the reservation of hollow-bearing trees (HBT) and future recruitment trees during logging. The specified tree retention densities vary across different management jurisdictions (e.g. 1–10 HBT ha^{-1}; Anon, 1999; Gibbons and Lindenmayer, 2003). Within unlogged eucalypt forests, the density of HBTs generally ranges from 10 to 25 ha^{-1} (Kavanagh and Stanton, 1998; Ross, 1999; Gibbons et al., 2000a). Retention rates are therefore significantly lower than the naturally occurring density of hollow-bearing trees. In some forests up to 20 cutting cycles have occurred over the last 150 years, thus densities are often significantly lower than in unlogged or less frequently harvested forests (MacKowski, 1984, Forests NSW unpublished compartment histories).

Fires affect hollow dynamics by causing both losses and gains in Australian forests (Adkins, 2006). Substantial losses of hollow-bearing trees (i.e. 15–70%) have been measured across a range of eucalypt forest ecosystems as a direct consequence of fires (Inions et al., 1989; Murphy and Legge, 2007; Parnaby et al., 2010; Lindenmayer et al., 2012). By contrast, Munks et al. (2007), Taylor and Haseler (1993) and Whitford (2002) have each found that trees with fire-induced basal injuries were more likely to contain a hollow than trees without injuries in Tasmanian and Western Australian sclerophyll forests. In *Eucalyptus obliqua* forest in Tasmania, Koch et al. (2008) determined that hollow production in dry forests was faster than in mesic forests, potentially as a result of a regime of more frequent fire.

Research is lacking that considers the interaction between fire and logging regimes in influencing average tree size, basal area and resultant hollow abundance. In particular, differing combinations of fire frequency and intensity may alter the balance between loss of hollow-bearing trees and hollow formation. This balance is further affected by logging. The aim of this study was to determine the effects of fire frequency and logging intensity on forest structural attributes, tree hollows and HBTs in a warm temperate forest landscape in south-eastern Australia. We predicted that:

(1) The percentage of trees with tree basal injury will be positively related to fire frequency. This process is a precursor to tree collapse, and so has the potential to remove existing and potential HBTs.
(2) Average diameter at breast height (DBH) and stand basal area (BA) will be negatively related to logging intensity due to the preferential removal of large trees. This process will be amplified by higher frequencies of fire because fires also remove large trees.

We therefore predicted that the net effect of the processes in (1) and (2) may result in a reduction of hollows via the loss of large trees, as a result of increasing logging intensity and/or fire frequency. In particular, hollow loss under frequent fire may be compounded in the long term by an absence of recruitment due to a lack of suitably sized trees.

2. Method

2.1. Study area

This study was located in the contiguous *Eucalyptus* forests of the Dorrigo, Guy Fawkes and Chaelundi plateaux, New South Wales, Australia, approximately 500 km north of Sydney (Fig. 1). The climate of the study area is warm temperate, with between 1100 and 1950 mm of rainfall per annum with an autumn maximum (Bureau of Meteorology, 2012). The forest is extensive and mostly unfragmented with some losses due to clearing for agriculture situated predominantly along fertile flats of large rivers and streams. Two different forest types were selected for sampling. These were a wet sclerophyll forest (WSF) dominated by New England Blackbutt (*Eucalyptus andrewsii* ssp. *campanulata*), Sydney Blue Gum (*E. saligna*), Tallowwood (*E. microcorys*) and Silvertop Stringybark (*E. laevopinea*), classified as Forest Type 163 (Baur, 1989), and a dry sclerophyll forest (DSF) dominated by Spotted Gum (*E. henryii*), Grey Gum (*E. biturbinata*) and Northern Grey Ironbark (*E. siderophloia*), classified as Forest Type 74 (Baur, 1989).

Approximately 60 years of timber extraction has occurred in the study area; however, in recent decades significant areas have been converted from State Forests to conservation reserves in which logging is excluded. Selective logging, which targets large, straight trees for sawlogs, commenced on the study sites in the 1960s. Logging rotation intervals in the study area are currently between 15 and 30 years with most logged sites previously logged twice (Forestry Corporation NSW unpublished data). Riparian areas within the majority of sites have been logged though this practice ceased recently. Logged areas are usually subjected to a fuel reduction 'slash' burn to reduce coarse woody debris and to assist the establishment of *Eucalyptus* regeneration (Forestry Corporation NSW unpublished data).

The fire season is late winter to early summer (August to December). Major, intense fires (>50,000 ha) occurred in 1994 and also in 2000, 2001 and 2002. These were coincident with hot, dry, windy weather. Smaller, less intense fires (<1000 ha) are commonly lit by leaseholders (graziers) in most years but usually under milder weather conditions. Approximately 10% of the study area has remained unburnt since 1980.

2.2. Site selection

Digitised data layers were obtained for vegetation type (CRA vegetation; produced by NSW National Parks and Wildlife Service; NSW NPWS) which was supplemented by examining a forest type layer (Forests NSW; Baur, 1989) prior to field verification. Fire and logging histories were also obtained (Forests NSW for State Forest areas and NSW NPWS for NPWS areas). Logging records included the volume of timber removed and the year of each logging event (Forests NSW unpublished data). Fire history, usually for wildfires only, was reliable from 1980-present, but included only the perimeter of the fire and no data were available for fire severity or patchiness. Fire frequency was categorised for both the wet and dry sclerophyll forests as: (1) a regime of very infrequent fire (i.e. no recorded fire); (2) infrequent fire (1 fire since 1980), (3) frequent fire (2 fires since 1980), and; (4) very frequent fire (3 fires since 1980). The latter category occurred exclusively within the dry sclerophyll forest (Table 1).

Sites were selected so that treatment combinations were spread and inter-mixed. This occurred through ensuring that sites of the same logging intensity and fire frequency were dispersed away