Available online at www.sciencedirect.com
ScienceDirect
Forest Ecology and Management 255 (2008) 62–67
Forest Ecology and Management
www.elsevier.com/locate/foreco

What factors influence the collapse of trees retained on logged sites? A case-control study

P. Gibbons *, R.B. Cunningham, D.B. Lindenmayer

The Fenner School of Environment and Society, The Australian National University, Canberra ACT 0200, Australia

Received 4 April 2007; received in revised form 20 August 2007; accepted 29 August 2007

Abstract

Living trees (green trees) are intentionally retained on logged sites for many purposes such as wildlife conservation, future wood potential and aesthetics. Minimizing the risk that these trees collapse in the short-term will improve the chances that green-tree retention meets its objectives. In a retrospective case-control study, we identified factors significantly associated with the collapse of living trees retained on logged and slash-burnt sites in south-eastern Australia within 8 years of harvesting. Trees with incomplete crowns or trees with at least one visible cavity were, on average, at three times greater risk of collapse relative to trees with complete crowns or no visible cavities, respectively. Trees with fire-scarring, trees retained greater than 50 m from intact forest or trees retained in isolation were, on average, around twice the risk of collapse relative to trees without fire-scarring, trees retained within 50 m of intact forest or trees retained among other trees, respectively. When considered jointly, the significant factors in a model predicting the collapse of retained trees – tree height, tree diameter, crown form – were all associated with the health of trees. Choosing the healthiest trees possible for fulfilling their function, protecting trees from damage (e.g. fire) and retaining trees near, or among, other trees are likely to reduce the risk of collapse among retained trees and thus contribute to the effectiveness of green-tree retention in logged eucalypt forests.

Keywords: Green-tree retention; Wildlife trees; Habitat trees; Mortality; Windthrow

1. Introduction

Trees are routinely retained on logged sites in native forests for a range of reasons, such as: wildlife conservation (Hope and McComb, 1994; Gibbons and Lindenmayer, 2002; Hyvarinen et al., 2006), aesthetics (Paquet and Belanger, 1997; Ribe, 2005), a source of seed and a future timber resource (Florence, 1996).

These trees may need to remain standing for considerable periods to meet the objectives of their retention. Mature trees are often retained to 'lifeboat' species that do not persist in young logging regrowth or to provide habitat features that cannot be recruited within the typical logging rotation (Lindenmayer and Franklin, 2002). Trees retained for aesthetic reasons must remain standing for at least the period it takes for the surrounding logged areas to regenerate sufficiently to provide a canopy cover, which was 15–20 years in coniferous forests in British Columbia (Paquet and Belanger, 1997). Trees retained as a future timber resource must remain standing for the period it takes for the tree to reach a merchantable age or the period between cutting events.

The early collapse of trees retained on logged sites will undermine the effectiveness of green-tree retention. Factors that predispose retained these trees to collapse in logged areas appear to relate to the dimensions and health of individual trees and the location of these trees relative to other trees. The height, diameter and crown architecture of trees can influence the vulnerability of trees retained after logging to windthrow (Scott and Mitchell, 2005). Stem damage and subsequent decay from fungi and invertebrates have been associated with the collapse of trees (Putz et al., 1983; Mattheck et al., 1995; Whitford and Williams, 2001). This damage can be exacerbated by the intensity (Gibbons et al., 2000a) and frequency (Whitford and Williams, 2001) of post-logging fire. Exposure to wind from the loss, or change in configuration, of surrounding vegetation (Raphael and Morrison, 1987; Chen et al., 1992; Mitchell et al., 2001) have been implicated with the collapse of trees. Windthrow can be exacerbated by shallow soil depth and high soil moisture (Fraser, 1962).

* Corresponding author. Tel.: +612 6125 2562; fax: +612 6125 0757.
E-mail address: Philip.Gibbons@anu.edu.au (P. Gibbons).

0378-1127/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2007.08.020

Although eucalypt forests do not typically suffer severe windthrow events like some forest types of the northern hemisphere (Gordon, 1973; Savill, 1983), the rates of mortality and collapse observed among trees retained on logged sites in eucalypt are sufficient to undermine the objectives of green-tree retention—particularly in terms of perpetuating a supply of cavities for fauna which take longer to form (>120–240 years) than the typical logging rotation (<80 years) (Ball et al., 1999; Gibbons and Lindenmayer, 2002). In eastern Victoria Featherston (1983) observed that approximately 25% of retained trees died within 5 years of logging and slash-burning and in similar forest types in eastern Victoria and south-east New South Wales Gibbons et al. (2000a) found that trees retained on clearcut and slash-burnt sites died at average rates of 14–37% and collapsed at average rates of 0.5–1.5%, 2–5 years after logging. In montane ash forests Kefford (unpublished data, cited in Gibbons et al., 2000a) observed that 14–68% of trees retained on logged sites had died within 2–3 years after logging. In forests dominated by Jarrah (*E. marginata*) and Marri (*Corymbia calophylla*) in Western Australia, Whitford and Williams (2001) recorded relatively lower rates of collapse among trees retained after logging (2.0% per decade), with slightly higher rates of collapse among larger trees (2.4% per decade).

The aim of this study was to identify risk factors associated with the collapse of trees retained on logged sites in eucalypt forests in south-eastern Australia. We used these data to identify options for increasing the longevity of trees retained on logged sites and therefore improving the efficacy of green-tree retention.

2. Methods

This study was undertaken on logged sites in tall, lowland sclerophyll forest in East Gippsland, Victoria, south-eastern Australia (37°20′–37°50′S and 148°40′–149°30′E). Mean annual rainfall ranges from approximately 720–1200 mm. The dominant tree species in the study area were Silvertop Ash (*Eucalyptus sieberi* L.A.S. Johnson), White Stringybark (*E. globoidea* Blakely), Brown Stringybark (*E. baxteri* Benth.), Messmate (*E. obliqua* L'Her.) and Mountain Grey Gum (*E. cypellocarpa* L.A.S. Johnson).

The silvicultural system employed in the study area was clearfelling or clearcutting in units of up to 40 ha. Trees are retained for seed and wildlife conservation in these forests at a rate of around 9 m^2 of basal area ha^{-1} (Gibbons et al., 2000a) including large trees selected for wildlife conservation at a minimum rate of 5 per 15 ha. Logged areas are typically treated with a high-intensity burn in the autumn after harvesting to remove logging slash, promote seedfall and create a receptive seedbed.

Several approaches were considered for this study. A longitudinal study was considered to be beyond the available resources and time. A completely randomized design was rejected as too time consuming because of the number of plots required to obtain sufficient information on trees that had collapsed (large trees are generally retained in a low density and <1.5% of these are expected to collapse within 5 years of logging (see Gibbons et al., 2000a)). We therefore undertook a retrospective investigation. This was a matched case-control study (Collett, 1991)—a method typically employed in medical research in which patients that have a certain condition are compared with people who do not. In this study, collapsed trees (cases) were actively located within logged sites and randomly matched with standing trees (controls) for comparison.

In total, 17 logged sites each up to 40 ha and logged 4–8 years prior to the study were selected. Each site was divided into four strata representing the four quarters of the compass in which we actively searched for trees ≥50 cm DBH that had fallen (i.e. uprooted or snapped) after logging and slash-burning. The first fallen tree located in each stratum that met these criteria was selected. These were the cases. Each fallen tree was then matched with one standing tree ≥50 cm DBH randomly located in the same stratum. These were the controls. Whether a tree had fallen after logging and slash-burning was determined by the pattern of burning on the bole (i.e. evidence that the tree had burnt while standing), the presence of unburnt wood where the tree had snapped (indicating that the tree had collapsed after the slash burn), the persistence of small branchlets or leaves (indicating that the tree had collapsed relatively recently) and the relative position of fallen trees to material sawn during logging (indicating that the tree had fallen after logging). If we were unable to ascertain whether the tree had fallen before or after logging then the tree was not measured. A number of potential risk factors or explanatory variables were measured for each tree (Table 1).

For one to one matched data of this type, effects of variables and standard errors can be estimated using conditional logistic regression. This was achieved by: (1) considering data as having number of observations equal to the number of matched pairs, in this case 63; (2) calculating a set of new potential explanatory variables that are the differences between the case and control for each matched pair (for factors each unique difference between levels becomes the new level of the factor); and (3) estimating parameters in a conditional linear logistic regression model, where the response has a value of one for each observation and no constant term is fitted (Collett, 1991). In our analysis, all variables were first fitted separately and observed significance levels determined, and second, a 'best' set of risk factors was determined by sequentially dropping variables from the full model if their omission did not result in a significant change of deviance ($P < 0.05$).

Because a study of this nature is not random (we sought out the collapsed trees), we have effectively over-sampled the cases and therefore cannot calculate an unbiased probability of collapse among retained trees. However, we can analyse the conditions under which trees collapsed relative to trees that remained standing for each risk potential factor listed in Table 1. Parameter estimates and standard errors for a risk factor predicted using conditional logistic regression can be interpreted as logarithms of odds ratios (Collett, 1991). The odds ratio is the ratio of the odds of a tree collapsing if exposed to one level of a risk factor relative to the odds of a tree collapsing if exposed to the next level of the same risk factor.