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Predicting sapstain and degrade in fallen trees following storm damage in a *Pinus radiata* forest

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ABSTRACT

Storm damage in production forests constitutes a major source of economic loss world wide, yet the retrieval of salvageable timber remains problematic. In particular, an inability to anticipate when sapstain and degrade will appear hampers the planning of log recovery operations. A study was conducted to monitor the deterioration of fallen trees following two winter storms causing wind and snow damage in a *Pinus radiata* plantation forest in the upper South Island of New Zealand. Percentage sapstain, incidence of basidiomycete decay fungi, and frequency of bark beetle infestation increased, while percentage sapwood moisture content decreased, over a period of 1 year. These changes proceeded more rapidly in fallen trees that were severed at stump height, to simulate breakage, than in those that were left partially rooted. There was little beetle activity at the time of the storms, but *Arhopalus ferus* (Coleoptera: Cerambycidae), and *Hylastes ater*, *Hylurgus ligniperda* and *Pachycotes peregrinus* (Coleoptera: Curculionidae: Scolytinae), were collected in flight traps during the following spring and summer. The predominant fungal species associated with sapstain was *Diplodia pinea*, while *Ophiostoma piceae* and *Grosmannia huntii* were isolated near the end of the period. The main decay fungi obtained were *Phlebiopsis gigantea*, *Stereum sanguinolentum*, and *Schizophyllum commune*. A generalized linear mixed model was constructed to predict the development of sapstain in fallen trees for conditions prevailing during the study after a storm at the same time of year. According to the model, a 10 m long butt log of 22 cm mid length diameter will have minimal stain (<10% of the cross sectional area affected) when cut from severed stems up to 4 months after the storm; if taken from still-rooted trees this period will extend to 1 year. However, because of large between-tree variation, economically productive log recovery will also depend on the proportion of trees that lie below an acceptable sapstain threshold. Further research is needed to determine regional and seasonal influences on the development of sapstain in fallen trees.

1. Introduction

Storms are a major cause of destruction in forests world wide (e.g. Gandhi et al., 2008; Grayson, 1989; Haymond and Harms, 1996; Nieuwenhuis and O'Connor, 2001; Strehlke, 1974). However, although much has been published describing the effects of individual storm events and how to manage stands to reduce potential damage, less information is available on the effective retrieval of large volumes of fallen wood after a storm (Childs, 1966; Gleason, 1982; Grayson, 1989). Options for reducing the cost of storm damage tend to be handicapped by a shortage of basic information necessary to plan log recovery operations. In particular there is uncertainty about the window of time available before logs become unsalvageable due to fungal staining or decay, and infestation by insects. Forest managers must often rely on personal experience and take an adaptive approach to management as circumstances change (Childs, 1966; Grayson, 1989; Strehlke, 1974). To overcome these constraints, and enhance wood recovery rates after storm damage, a program of systematic monitoring will be required (Butcher and Drysdale, 1991).

Some useful anecdotal information was recorded following two storms in 1964 and 1975, both in Canterbury, a drier part of the South Island of New Zealand. On both occasions, when fallen radiata pine (*Pinus radiata* D. Don) remained partially rooted trees were still salvageable after more than a year (Butcher and Drysdale, 1991; Childs, 1966; Wendelken, 1966). This result was independent of

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the timing of the storms, which took place at the end of winter and in early autumn, respectively. A similar outcome followed a major storm in the United Kingdom in autumn 1987, where the extent of timber degradation was dependent on whether trees were either broken or uprooted (Grayson, 1989). Sapstain remained low in stands of pine (*Pinus sylvestris* L. and *P. nigra* var. *maritima* (Ait.) Melville) during the first year after this storm because many of the windthrown trees were still partly rooted and foliage remained green throughout the summer (Dannatt and Garforth, 1989; Evans et al., 1989; cf. Eisenbarth, 1995). In New Zealand, Gleason (1982) and Littlejohn (1984) documented the industry experience following a storm in 1982 in a central North Island radiata pine forest. These reports did not clearly distinguish between snapped and intact uprooted trees. Very little degradation occurred until spring, 6 months after the storm when changes were made to the processing of both sawn timber and pulp wood following the appearance of a low incidence of sapstain (Gleason, 1982; Somerville et al., 1989). Infestation by bark- and wood-boring beetles was not an issue due to limited insect activity during the cooler autumn and winter periods.

On 30 July, 2008, a severe winter wind storm caused extensive uprooting and breakage in plantations of *P. radiata* in the Nelson region of the northern South Island of New Zealand. Heavy snow led to further damage elsewhere in the same region 2 weeks later, predominantly from uprooting, where trees fell with some roots still intact within the soil. About 2000 ha of plantation were affected by the storms over the whole region and a salvage operation was commenced to recover merchantable timber. Rapid development of sapstain was of particular concern with the approach of warm spring weather, which would favour the causal fungi and coincide with annual bark beetle (Scolytinae) flights (Hosking, 1977). These insects are significant as they are known vectors of sapstain fungi (e.g. Reay et al., 2006a,b; Romón et al., 2007). Although the event was unfortunate, the circumstances provided an opportunity to obtain quantitative information on the rate of sapstain development in the fallen trees. A study was therefore initiated in a forest on rolling hill country affected by the storm.

Priority was given to a number of variables. It was clear that a useful distinction should be made between snapped and partially rooted trees, which were likely to deteriorate at different rates. The degree of water saturation is well known as a regulatory factor within wood as moisture content values greater than 120% (dry weight basis) maintain low oxygen levels that prevent the growth of most (but not all) species of degrade fungi (Clifton, 1978; Hood and Ramsden, 1997; Hood et al., 1997; Liese, 1984; Metzler and Hecht, 2004; Peralta et al., 1993; Seifert, 1993). The objective of this study was therefore to monitor the rates of sapstain development and the associated biological agents of degrade in the fallen rooted and severed stems. A modelling approach was used to predict the period available for log retrieval under similar climatic conditions following a storm at the same time of year. In this paper we present our conclusions and suggest future research avenues for improving the management of timber salvage operations.

2. Materials and methods

2.1. Study sites

Five study sites, each approximately 200 m by 200 m, and ranging 6–18 km apart, were selected for monitoring. Stands varied in age (13–19 years), altitude (300–500 m a.s.l.), slope, and in type and date of storm damage. Site 3 experienced increased exposure to sunlight and wind prior to the completion of the study due to the salvaging of wind-damaged stands in the immediate vicinity. Climate data for the 15 months following the storms obtained from a permanent weather station situated within the forest are shown in Table S1.

A total of 20 fallen trees, 10 uprooted and 10 severed (snapped or cut), were arbitrarily selected and tagged at each site for a series of samplings during the 17 months period after the storms. Snapped stems were used during the first sampling, but because of a shortage of accessible naturally broken trees, the stems of 8 fallen trees per site were cut at stump height (ca. 0.5 m above original ground level) to simulate windsnap for subsequent samplings. This was done on 17–18 September 2008, at the time of the first sampling, 34 or 50 days after the severe wind and snowfall events, respectively. Sampling was undertaken on 6 occasions from 4 trees (2 severed and 2 rooted) at each site during each sampling time. However, on two occasions only 2 trees were sampled in order to spread sampling across the full period of sapstain development, which varied between severed and rooted stems. Sampling dates were therefore: 17–18 September 2008 (early spring), 10 November 2008 (late spring), 19 February 2009 (late summer), 28 April 2009 (autumn; severed trees, only); 8 July 2009 (winter); and 24 November 2009 (late spring; rooted trees, only).

2.2. Tree and disc processing

Sapstain development and bark beetle infestation was monitored by cutting discs from sample trees. Five 3 cm-thick discs were taken from each tree at intervals of 3 m (first sample time) or 2.5 m (remaining sample times) along the stem, offsetting slightly if this position coincided with a branch node. The initial disc was cut at stump height (0.5 m from the base) on rooted trees, or near the point of severance on severed trees. Discs were immediately labelled and sealed in plastic bags, and stored at 4 °C usually within 12 h, in order to minimise moisture loss and further fungal growth before measurement. Due to this destructive method of sampling, each tree was sampled only once.

Sapstain was recorded by photographing each disc using a specially constructed stage to compensate for image distortion, as follows. On each image, zones of stain and the position of the cambium were outlined manually as polygons using ESRI ArcGIS 9.3 (Redlands, California, USA) to estimate sapstain as a percentage of the whole disc (excluding bark). During the image analysis, no allowance was made for heartwood which, when present, occurred only in small amounts. Moisture content of the inner and outer sapwood was determined (dry weight basis) within 36 h of sampling. Two small blocks were cut from the sapwood at an arbitrary point around the circumference of each disc, one taken from the outer half and the other from the inner half along the same radius. Blocks were weighed at room temperature to constant mass before and after drying at 80 °C in a ventilated oven.

2.3. Insect sampling

A record was made of the occurrence of bark beetles and wood borers as potential carriers of sapstain fungi, as well as being direct agents of damage to salvageable wood in their own right. Beetle infestation of study trees was monitored from sampling time 3 (19 February 2009) onwards. During field sampling, 0.5 m lengths of stem were cut above but contiguous with the positions of discs 1 and 4, and a record made of any external evidence of beetle colonisation (entrance holes and frass) on these stem sections. In addition, all five sample discs were also assessed for beetle colonisation (i.e. presence of galleries with adults or larvae). Similarly, contact with the ground or another fallen stem was recorded as this is likely to influence the probability of beetle colonisation.

The phenologies of the bark beetles *Hylastes ater* (Paykull), *Hylurgus ligniperda* (F.), and *Pachycotes peregrinus* (Chapuis) (Coleoptera: Curculionidae: Scolytinae), and the longhorn beetle