Forecasting sapstain after windthrow in pine plantations

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Abstract

Data on sapstain incidence, previously collected at different locations throughout New Zealand during a simulated windthrow project, were compared with weather records covering the same period. This was undertaken to see if daily online fire weather data may be used to anticipate the progress of sapstain within fallen *Pinus radiata* stems after storms. The variable Drought Code, selected as the most appropriate fire weather index, was found not to be an effective predictor of sapstain. This was probably because sapstain fungi and fire risk variables are influenced by different biological and physical parameters. However it was established that sapstain is not likely to become significant until daily mean temperatures exceed 21°C. Appreciable sapstain, affecting 10 per cent of disc cross-sectional area, is therefore unlikely to develop anywhere in New Zealand during winter. Once this daily temperature is exceeded significant sapstain generally develops within one to two months. Faster or slower development may sometimes occur though, apparently influenced by stem moisture content, with higher moisture content delaying development.

Background

Storms in *Pinus radiata* plantations are unpredictable and costly (Moore et al., 2013). Apart from the direct damage they cause, additional losses follow as sapstain and other forms of degrade develop before all the sound timber can be recovered. A means of anticipating when sapstain will appear would greatly assist forest managers overseeing salvage operations after windthrow has occurred.

After-effects of a storm in a central North Island pine plantation, May 2011

Is it possible to predict the rate of sapstain development in damaged trees from daily weather data in the same way that fire danger forecasts are provided as a guide to fire risk? Just as wood burns more readily when it dries, so is sapstain hastened by a reduction in wood moisture content. This is because the fungi that cause sapstain are aerobic, requiring oxygen for growth, and are therefore unable to colonise water-saturated wood from which air is excluded.

A series of studies was conducted between 2008 and 2011 investigating the progression of sapstain in windthrown pine stems in different parts of New Zealand. These were undertaken by Scion in collaboration with the University of Canterbury. Results have been published in detail in two research papers (McCarthy et al., 2010, 2012) and summarised in a popular article (Hood and McCarthy, 2012).

The second of these studies was conducted at six locations distributed throughout the country. At each location, trees were felled and left on the forest floor to simulate windthrow. Felling was undertaken in summer and winter at all locations and also in spring and autumn at one selected location. Trees were assessed periodically after felling by cutting discs along each stem, and over 2,000 discs were taken from more than 450 trees. Samples were weighed and dried to evaluate moisture content and the discs were scanned to determine the percentage cross-sectional area affected by sapstain.

Sapstain in radiata pine discs cut during the second study showing 13 per cent (left) and 100 per cent (right) of the cross-sectional area affected. Brown staining associated with colonisation by decay fungi is also treated as sapstain

Discs prepared and photographed by Kane Fleet and Rod Brownlie, respectively.

Values were calculated for each location and felling season of the time from felling until sapstain became significant i.e. affected 10 per cent of disc cross-sectional area. The period it took to reach this threshold was found to vary greatly between locations and felling times, as shown in Figure 1, demonstrating that sapstain is indeed influenced by climate and season.

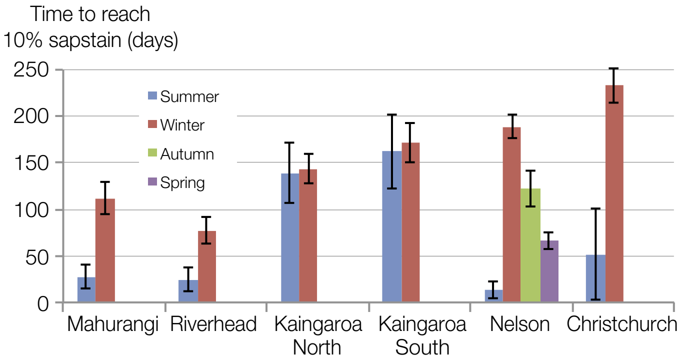

Figure 1: Time from felling for radiata pine stems to develop significant sapstain for different seasons of felling at six locations throughout New Zealand. Error bars are standard errors. After McCarthy et al. (2012)

The objective of the present investigation was therefore to examine relationships between sapstain and weather data. This was achieved by comparing the sapstain data from the earlier study with weather and fire risk data obtained for each location. The aim was to see if such weather data might be useful in predicting how soon sapstain appears following windthrow.

Methodology

Daily weather data covering the period of the study were downloaded from http://www.nrfa.org.nz/fire_weather/weather/Archive.asp (now http://fireweather.nrfa.org.nz/) for climate stations near each location. These data included temperature, rainfall and the fire risk index Drought Code, which is generated daily from weather data using a formula that includes moisture state, rainfall and evapotranspiration (Van Wagner, 1987; Briggs et al., 2005).

The Drought Code was selected as the most appropriate index since it applies to slow drying forest fuels and takes into account deep organic duff layers as well as large logs. A value of 200 is high, while 300 is extreme. The other fuel moisture indices were judged less suitable, being applicable to faster drying organic matter at surface and intermediate depths and not inclusive of large downed wood.

The relationship between the daily Drought Code values and sapstain was analysed in two ways. First, the average value of the Drought Code over the period from felling until significant sapstain became evident (i.e. affected 10 per cent of disc cross-sectional area) was calculated for each location and felling season. A regression model for predicting the time for sapstain to become evident from the mean daily Drought Code over this period was then fitted. It was expected that sapstain develops more rapidly at higher average values of Drought Code, meaning that this regression model would provide a useful tool for predicting sapstain development.

Second, the cumulative sum of daily Drought Code values was calculated for each location and felling season over the period from felling until sapstain became evident. It was hoped that analysis would reveal a threshold for this cumulative value, which could be used to predict when sapstain is likely to be significant.

Another variable considered was the maximum temperature during the period of sapstain development. The aim of this analysis was to identify if there is a threshold temperature value below which sapstain does not develop.

Results and discussion

Times for sapstain to become significant along with mean and cumulative Drought Code values are shown for each location and felling season in Table 1. These demonstrate that the fire risk index Drought Code is not useful for predicting how quickly sapstain develops. There was only a weak and statistically non-significant relationship between the time for sapstain to develop and the average Drought Code value ($R^2 = 0.11$).

Also, the cumulative sum of daily Drought Code values over the period between felling and when significant sapstain developed varied greatly, ranging from 1,000 to 51,000, and was clearly unhelpful for predicting sapstain.

Table 1: Time for sapstain to develop and mean and cumulative sum of the fire risk index Drought Code (DC), over the period between felling and when sapstain became evident (affecting 10 per cent of disc cross-sectional area) for each location and felling season

Location	Felling season	Time for sapstain to develop (days)	Mean DC[1]	Cumulative DC sum
Mahurangi	Summer	27	317	8,560
	Winter	112	81	9,092
Riverhead	Summer	25	461	11,533
	Winter	77	54	4,138
Kaingaroa North	Summer	139	274	38,085
	Winter	144	120	17,217
Kaingaroa South	Summer	162	185	30,040
	Winter	171	87	14,904
Nelson	Summer	14	74	1,030
	Autumn	122	121	14,722
	Winter	189	45	8,513
	Spring	66	40	2,668
Christchurch	Summer	52	521	27,100
	Winter	233	221	51,448

[1] The respective adjacent fire weather stations, in order of location, were Mahurangi Forest, Woodhill, Goudies, Matea, Western Boundary and Bottle Lake

Table 2: Temperature and moisture content in relation to appearance of significant sapstain (affecting 10 per cent of disc cross-sectional area) for each location and felling season

Location	Felling season	Highest daily mean temperature before sapstain developed (°C)	Number of days with temperature > 21°C before sapstain developed	Number of days from 1st temp > 21°C to sapstain development	Moisture content six months after felling (%)
Mahurangi	Summer	29.8	22	26	96
	Winter	36.3	13	57	110
Riverhead	Summer	24.2	23	25	106
	Winter	25.8	1	1	91
Kaingaroa North	Summer	24.2	15	60	149
	Winter	26.9	17	48	167
Kaingaroa South	Summer	27.0	10	66	170
	Winter	26.5	22	85	137
Nelson	Summer	22.9	2	2	40
	Autumn	21.7	1	1	91
	Winter	28.6	25	53	84
	Spring	24.3	9	27	34
Christchurch	Summer	27.1	15	45	83
	Winter	22.0	57	180	100

Besides summing all values, tests were made of cumulative daily Drought Code values above various thresholds but these proved to be no more useful.

This analysis suggests that the weather factors affecting fuel drying and fire hazard are not precisely the same as those influencing the growth of sapstain fungi in wood. For instance, it is possible that the establishment and growth of the fungal colonies that cause sapstain may still occur even when overall moisture content is comparatively high if there are zones of drier wood within stems. Sapwood dries from the outside during summer, but may re-wet peripherally during autumn and winter (Schroeder and Buck, 1970). The predictive data may not be sufficiently sensitive to allow for such internal variation.

The next analysis considered the effect of temperature on the rate of sapstain development. It was found that sapstain never became significant until there had been at least one day with a mean temperature greater than 21°C, as shown in Table 2. This temperature therefore appears to be a threshold below which significant sapstain is unlikely to develop, possibly because fungal activity slows when it is cooler.

As daily winter temperatures greater than 21°C are extremely rare for most parts of New Zealand, sapstain is generally unlikely to develop in winter anywhere in the country. In this study, even at the two most northerly locations in the warmest region, stems felled in winter did not develop significant sapstain until November (Riverhead) or December (Mahurangi).

Sapstain does not necessarily appear though as soon as daily temperatures of 21°C are exceeded. The number of days with mean temperature greater than 21°C before sapstain developed varied from one day (Riverhead winter and Nelson autumn) to 57 days (Christchurch winter) (Table 2). The elapsed time from the first day with mean temperature >21°C, and the development of significant sapstain, was generally in the range of one to two months (Table 2). However at Nelson, sapstain mostly developed less than one month after the first occurrence of a daily mean temperature >21°C, while at Kaingaroa the elapsed time was generally two to three months.

At Christchurch, trees felled in July and in January both developed sapstain in the following March. For the summer-felled trees this was only one-and-a-half months after the first occurrence of a daily mean temperature >21°C, but for winter-felled trees it was six months after the first occurrence (Table 2). Clearly, the high daily temperatures that commonly occur in spring and early summer at this location were not sufficient to trigger the development of significant sapstain.

The observations in the preceding paragraphs suggest that variables additional to mean daily temperature may improve the explanation of when sapstain is likely to develop. A further factor that may be implicated is the moisture content of the felled stems. It was noticeable that moisture content was particularly low at Nelson. This was perhaps partly because of small stem diameters, where sapstain developed most rapidly after the temperature threshold was exceeded (Table 2). Conversely, the moisture content of stems was high at Kaingaroa where sapstain developed more slowly. This suggests that a high moisture content may slow, but not completely halt, the development of sapstain after the 21°C temperature is exceeded. Finally, rainfall did not show a relationship with sapstain.

Conclusion

Fire weather indices are not promising as a means of predicting the appearance and rate of development of sapstain in fallen radiata pine stems. Apparently the drying of fuel and the growth of sapstain fungi in wood are affected by factors that are not exactly the same. Nevertheless, the analyses presented in this paper have provided useful information.

Sapstain in fallen radiata pine stems is unlikely to be significant until daily mean temperatures exceed 21°C. Once this daily temperature is exceeded, after the passing of winter and the arrival of spring, appreciable sapstain generally develops within one to two months. However faster or slower development can sometimes occur, apparently influenced by stem moisture content, with higher moisture content slowing development.

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