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FACTORS CONTRIBUTING TO SPONTANEOUS COMBUSTION OF SLASH AT SKID SITES

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Factors contributing to spontaneous combustion of slash at skid sites

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Executive summary

The problem

In recent years, there have been several instances of forestry residue piles (“birds’ nests”) self-combusting in skid sites across New Zealand. This has renewed the interest of Fire and Emergency New Zealand in further understanding the conditions leading to spontaneous combustion at skid sites. These unintended slash pile fires can be difficult and costly to suppress, and they can threaten valuable assets such as forestry and neighbouring lands.

The project

Scion undertook a research study for Fire and Emergency New Zealand investigating the factors contributing to spontaneous combustion of forestry skid sites. The findings from this study will help to inform industry best-practice guidelines for minimising, isolating or eliminating the risks associated with spontaneous combustion of slash piles.

There were three parts to this study:

1. Identify the factors that contribute to unintended slash fires due to spontaneous combustion.
2. Review industry guidelines and literature to identify good practice slash management that can reduce the occurrence of skid site spontaneous combustion fires.
3. Provide best practice suppression techniques to manage slash pile fires.

Key results

The common factors associated with the spontaneous combustion of slash at skid sites.

The study produced a literature review, compiled a database of known slash pile fires and consulted with forestry and fire sectors to investigate what is causing these fires. The common factors identified include:

- The size of material in the pile appears to have a role, with the presence of fine material being key to increasing the risk of spontaneous combustion.
- Sufficient green plant material in the pile to initiate the heat-generating decomposition process.
- If soil is mixed into the pile, which provides bacteria that can promote the decomposition process. Soil also promotes prolonged smouldering and restricts air movement in a similar manner to excess fines in the pile (inhibiting ventilation).
- Large pile size, especially at depth/heights greater than 3metres.
- Our modelling from the database of known forestry spontaneous combustion events indicates fires tend to occur under moderate fire conditions, rather than extreme conditions.
- Fires tend to occur following rainfall and high humidity.
- Pile moisture content is important, with moisture promoting microbial growth and enhancing the oxidation processes.
- Limited ventilation can increase the amount of oxygen and moisture in the pile.
- Foreign objects (e.g. metal or oily rags) can act as a catalyst for ignition.

Best practices for managing forestry slash piles to reduce the risk of fires starting and spreading.

We have identified the best practices based on collating knowledge from survey and interview responses, as well as wider literature. The consensus around best management practices recommends the following.

- Minimise slash created:
 - Have a slash recovery or reduction management plan in place, especially for mechanized harvesting where more slash is created.
 - Delimb in the cutover rather than on the landing where possible.
 - Avoid fine material in the slash piles.
- Build piles in stable areas to limit cracks forming and allowing air and moisture to enter the pile. Avoid gullies or steep slopes.
- Construct benches and/or trenches to limit slash movement and create 10 m cleared fire breaks around piles (this aids ease of suppression in the event of a wildfire).
- Slash pile size and composition:
 - Keep slash piles under 3m in height.
 - Avoid compacting the pile if possible.
 - Keep free of soil and don't let inorganic objects be placed in the pile, especially wire rope and oily rags, etc.
 - Try to limit the amount of fine materials in the pile as these reduce void spaces and increase the possibility of heating.
 - Ensure water does not drain into the piled material.
 - Avoid placing new slash onto old piles.
- Management of pile after harvesting:
 - Identify high risk slash piles that have potential for spontaneous combustion.
 - Regularly monitoring of internal pile temperatures is recommended.
 - Deconstruct the pile at the end of processing and spread slash over the area.
 - Drag slash that has been pushed over the edge back up onto the landing.
 - Where safe to do so, burn the slash pile.
 - If it is not possible to completely remove the pile, then try to open the pile and reduce height to under 1m in height for long term composting.
 - Avoid building new skid sites using material from old slash piles.

Best techniques for suppressing skid site fires.

Based on survey and interview responses, we have identified several clear, but opposing, strategies and tactics employed to best suppress slash fires at skid sites:

- Open the pile up and dampen down with water / foam (or water additive).
- Open the pile and spread material out over landing site and extinguish with water / foam (or water additive).
- Cap and leave to burn out.
- Burn the pile until there is no combustible fuel remaining.
- Do nothing and monitor, if safe to do so (e.g. based on sufficient clearance from adjacent fuels or forecast weather conditions/time in season).

The interviews revealed that each region prefers one or two of the tactics suggested above. It became apparent that there are no typical skid site or 'birds' nest' fires. What situation applied at one fire cannot be totally applied to another across the country or in the same region. There isn't a standard recommendation on what is the best practice, but we have identified the best strategies and tactics employed and have compared the various options. We recommend that there needs to be flexibility with strategies and tactics, as there are several environmental and social factors to consider when suppressing a slash fire.

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Introduction

The Problem

Lately, there has been renewed interest about spontaneous combustion of slash at forestry skid sites. Slash pile fires threaten key valuable assets such as forestry and neighbouring lands. Suppression of these fires can be challenging and time-consuming, making it a costly exercise. In recent years, there have been several instances of forestry residues self-combusting at skid sites across New Zealand. Discussions with both forest and fire managers suggest that these fires are becoming more common.

The project

The purpose of this study was to investigate the probable causes of fires in slash piles (“birds’ nests”) on forestry skid sites. This report identifies the potential factors and possible solutions to mitigate the risk of spontaneous combustion of slash pile fires. The objective of the study was to summarise the following:

- Objective 1: Identify the common factors linked with spontaneous combustion of slash stored at forestry skid sites.
- Objective 2: Identify the measures how forestry manages the risk and prevents further spread of these slash fires.
- Objective 3: Identify the best techniques to suppress slash fires.

The key findings for each of the three objectives are summarised in the results section (pages 13 – 17), followed by the in-depth summary of the analysis for each objective.

Background

What is a skid site?

A skid site is a term used by the forest industry to refer to a location within a forest where they process felled trees. Trees are extracted from where they grow and processed into logs on a landing or skid site before being loaded onto trucks. Processing tree stems into logs generates woody debris at the skid site. The forest industry refers to this waste material as ‘slash’. Over time, the skid site can accumulate large amounts of organic material such as leaves, branches, stumps and roots. To keep the site tidy, this material is pushed into piles or over the edge of a slope. The stacked slash in piles or below the skid site on a slope is often referred to as a “bird’s nest”.

What is a skid site fire?

Logging slash is a potential fire hazard, and over the years there have been numerous instances of fires occurring at skid sites in New Zealand. A skid site fire can occur from either natural, accidental or intentional causes. The main causes of fires in exotic plantations are arson, escaped burns, forestry operations, spontaneous combustion, vehicles and campfires. Combustion of slash at a skid site can originate from either a heat source on the surface or deep below the surface of slash. Fires that begin on the surface of slash usually start from an external heat source such as a spark from equipment operations or embers from a wildfire. Flaming combustion begins at the surface/top of the pile and then may work its way downwards. However, fires that begin under the surface of slash are generally not linked to an external heat source and are most likely the result of spontaneous combustion.



Image 1. Example of a skid site fire caused by spontaneous combustion (P. Houston, 2016).

What is spontaneous combustion?

Spontaneous combustion is the combustion of a material that occurs in the absence of 'forced ignition'; that is, without a spark or a flame (Buggeln & Rynk 2002). If heat builds up or smouldering occurs, it may go undetected for long periods of time. We define the spontaneous combustion of slash as sub-surface fires, where heat has built up within the pile, buried below the surface of slash, sufficient to cause the ignition of the piled woody material. The heat is generated by the decomposition of organic material within the pile. Flaming combustion can occur when certain environmental conditions line up to cause the fire to break through to the surface of the pile.

Key conditions that lead to spontaneous combustion in piled organic materials are biological activity, relatively dry materials or dry pockets, large well-insulated piles with limited air flow, and time for temperature to build up (Rynk 2000). It is a complex process involving several factors, including slash pile structure, composition, size, and conducive environmental conditions.

The process of spontaneous combustion outlined below draws largely on literature referring to piles of 'yard trimmings' (a mix of vegetative and woody material) and wood chip piles containing wood and bark chips and slash (Frandsen 1993; Pyne et al. 1996; Buggeln & Rynk 2002; NWCG 2016).

The process of spontaneous combustion

Initial heating phase

The accumulation of heat generated within a pile depends on the balance between the rate of internal heat production and the rate of heat loss to the external environment. When more heat is generated than lost, the pile starts to heat up. Heat is generated through oxidation processes,

which create a self-generating heating process which increases the internal temperature of the pile. When temperatures are below 90°C, microbial oxidation is the likely main driver in the initial heating phase. However, if there is sufficient green plant material in the pile, then plant cell respiration can also be a significant contributing influence or even initiate the heat generation.

Moisture within the pile also plays an important role as it promotes microbial activity and facilitates the oxidation processes. Moisture also has a moderating effect on the temperature in the pile via wetting, evaporation, diffusion and convection until all the water has been removed, usually when temperatures reach around 70-90°C.

Although abiotic oxidation processes are considered a minor contributor in the initial heating phase, the presence of plant oils and resins can facilitate abiotic oxidation during this phase and inhibit the biological oxidation processes. Conifers are an example of a plant group that contains high levels of resins as well as other volatiles (e.g. terpenes) in the live green needle foliage, which are released (volatilised) as they decompose. At the end of the initial heating phase, the internal temperature of the pile has risen to around 70-90°C. At this temperature, the heat has killed the microbes, the biotic oxidation processes have stopped, and the free water has evaporated.

Secondary heating phase

If air is still flowing into the pile, then the abiotic oxidation of plant chemicals will continue a self-perpetuating process of increasing temperatures creating faster reactions and increasing oxygen demand (Figure 1). This process can continue until the oxygen runs out or ignition temperatures are reached.

However, if the heat within the pile increases under oxygen-starved conditions, another heat producing process is initiated – pyrolysis. Pyrolysis is the thermal decomposition of a substance by the action of heat under oxygen-starved conditions. Pyrolysis products include char, gaseous compounds, and sometimes bio-oil and tar. Slow pyrolysis occurs over long periods of time and may be initiated as the internal pile temperature increases above 35°C. Once temperatures reach beyond 90°C, fast pyrolysis may be initiated, perpetuating the self-heating process. Without moisture, heat transfer is mainly via conduction and convection.

During this secondary phase, whether chemical oxidation or pyrolysis will be the dominant heat-generating process will depend on the temperature and oxygen levels within the pile.

Smouldering can also occur during this phase. Smouldering is a slow, low-temperature, flameless process that is typically an incomplete combustion reaction. Smouldering is a complicated process that includes combustion (requiring oxygen) and pyrolysis.

Spontaneous combustion

When the heat within the pile reaches a critical temperature, thermal ignition (spontaneous combustion) will occur (Figure 1), igniting the surrounding material. In large piles of organic materials, with limited available oxygen, spontaneous combustion usually leads to a smouldering fire, generally at temperatures between 150° to 200°C.

Continuous pyrolysis into unburned material creates a smouldering wave ahead of the combustion zone that spreads throughout the pile. If a smouldering pile collapses, introducing oxygen, then flaming combustion can occur.

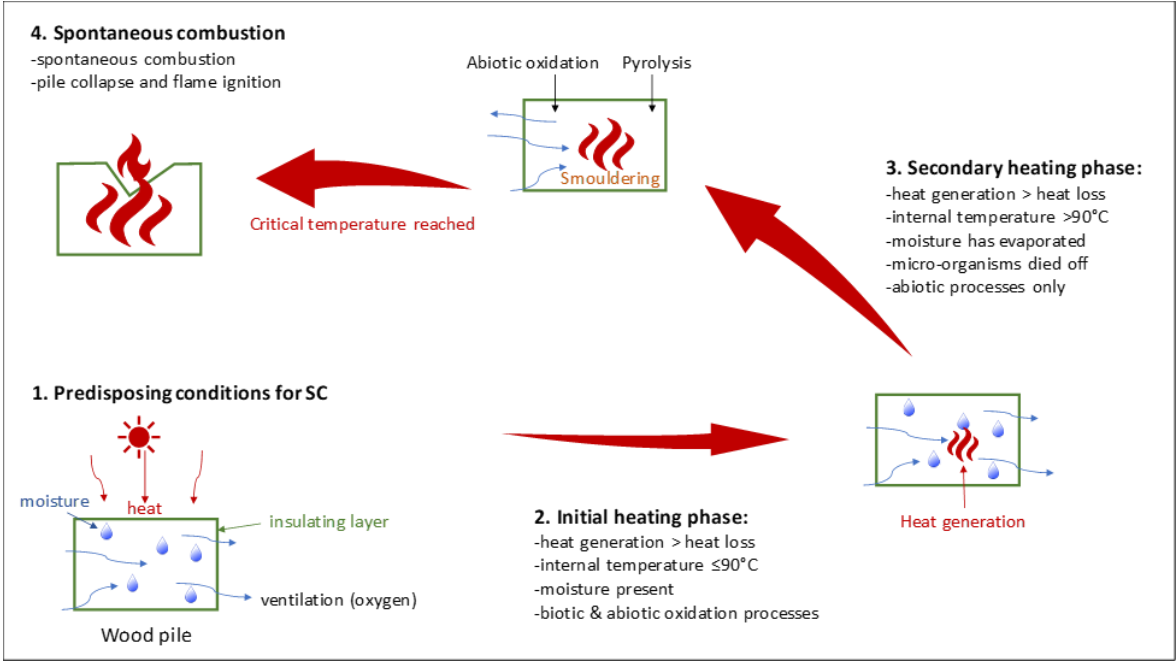


Figure 1. Outline of the spontaneous combustion (SC) process in a vegetation pile. Author generated figure based on information from literature (Frandsen 1993; Pyne 1996; Buggeln & Rynk 2002; NWCG 2016).

Materials and methods

The objective of this study was to identify the factors that contribute to unintended slash pile fires and evaluate how forest industry practices may influence the occurrence of unintended slash fires. This was achieved by undertaking a literature review, surveying and interviewing forest and fire managers, and analysing data collected from investigation reports.

Literature review

We reviewed industry guidelines and international literature to summarise the following:

- Known factors that cause skid site fires.
- Forest industry guidelines or best-practice for managing residues around landings/skid sites for fire purposes.
- Best practice fire suppression strategies and tactics for fires in skid piles.

We collected and summarised a total of 35 articles through the literature search, and from direct requests to fire investigators and international scientists. The search terms used included: skid, landing, fire, burn, slash pile, harvesting residue, spontaneous combustion/ignition, wildfire, fire risk, hazard, management. The search sites included: Google Scholar, WorldCat Discovery, Google and firesearchinstitute.org

We identified that there was limited literature on the spontaneous combustion of slash at skid sites. From what we have found, the spontaneous combustion of skid sites doesn't appear to be a significant issue internationally. There is plenty of information about wildfires and slash pile fires or burns on skids/landings, but they are usually not linked to spontaneous combustion.

Analysis of incident reports

Data collection

We identified several factors from the literature search and feedback from forestry and fire managers. From this we collected information for each of the known reported skid fires to build a database. There was a total of 36 fires for which data were collected, with only 30 having enough information for analysis.

We compiled the database using information gathered from forest and fire managers, ICAD reports, investigation reports, survey and interview responses, and personal communications. The format of the database is currently in an Excel spreadsheet containing general information on the fires (date, location, etc.), as well as several environmental categories that we understand to affect fire occurrence and behaviour.

We evaluated the main fire weather factors for each of the fires: air temperature (°C), relative humidity (%), wind direction, wind speed (km/h), rainfall (mm); along with the fire weather codes and indices: Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), Drought Code (DC), Initial Spread Index (ISI), Buildup Index (BUI) and Fire Weather Index (FWI).

Weather data leading up to each fire was downloaded from the closest or most representative weather station using the Fire Weather System database. Weather stations ranged from 5 – 28 km away from the fire location. The weather data contained hourly records of the following weather variables: air temperature, relative humidity, wind direction, wind speed, precipitation, FFMC, DMC, DC, ISI, BUI and FWI.

This data was analysed on a national scale rather than a regional scale due to the limited number of fires for each region obtained. Continued collation of wildfires using the form (Appendix A1) would allow for a larger database and analysing at a regional scale to identify trends, similarities and differences that may not appear at the national scale.

Data analysis

Collected data were used to try and identify the common factors that resulted in the spontaneous combustion of slash stored at forestry skid sites. The full list of common factors identified and investigated are listed in the results section (Table 1). Because some fires had data missing for fuels and terrain factors, numerical data analysis focused on the weather variables, and other factors were described qualitatively.

Data processing was performed using the R analysis package (R Core Team 2019). The hourly data was converted to daily by extracting 12:00 NZST records from the hourly data for all the variables except precipitation. Precipitation for each day was calculated by adding up all the hourly precipitation from and not including 12:00 NZST the previous day up to and including 12:00 NZST the current day. These daily values are shown in the Appendix B.

To compare weather conditions between fires, different summary metrics were calculated. These included: days since rain, last precipitation amount, and mean of all variables over 1 day, 7 days and 30 days. Since wind direction is a circular variable with 0 and 360 indicating the same direction, the mean wind direction was calculated using the mean function from the circular package (Agostinelli & Lund 2017).

The weather data is multi-faceted, and it is difficult to visually compare the multitude of variables between all the fires. One solution for visualizing such high-dimension data is to use dimensionality reduction techniques such as non-metric multidimensional scaling (NMDS). NMDS compresses multi-dimensional data into two dimensions while attempting to represent the dissimilarity between fires as closely as possible. The distance between points was calculated using the Bray-Curtis dissimilarity statistic. Clustering was performed using the k-means function from the 'factoextra' package (Kassambara & Mundt 2020).

Forestry survey on slash management

We sent out a short SurveyMonkey™ questionnaire to the New Zealand forestry sector. The NZ Forest Owners Association (NZFOA) assisted with the distribution of this survey for input from forestry managers and skid site supervisors. The survey had a total of 38 questions and took approximately 20 minutes to complete. The list of questions can be found in Appendix C. A summary of findings is found in Table 3.

The survey investigated:

- How slash piles are constructed (when, where and how large), and various means of managing slash on site.
- The features of skid sites and slash piles that resulted in spontaneous combustion.
- How many spontaneous slash fires have occurred on skid sites in the past five to ten years.
- How any slash fires have been dealt with, and any lessons learned by the companies around managing slash piles, and slash pile fires that occur.
- Any further fires to add to the database developed in phase 1.

We received a total of 30 survey responses from various forestry companies across the country, including:

- City Forests
- EOL Gisborne
- Forest Management Ltd
- Hancock Forest Management
- Juken NZ
- Mangatu Blocks Incorporation
- Ngāi Tahu Forestry
- Ngutunui Forestry Partnership
- NZ Forest Managers
- OneFortyOne
- PF Olsen Ltd
- Port Blakely Ltd

- Rayonier Matariki Forests
- Timberlands Ltd
- Wilton Colliery Farm

Forestry and Fire interviews on best suppression techniques

We interviewed forestry and fire managers who have been involved in fighting skid site fires. The purpose of the interviews was to capture information on best practice suppression techniques to manage skid site fires.

A total of 30 forestry and fire managers across the five Fire and Emergency New Zealand (FENZ) regions were identified as key contacts for the interviews. Sixteen semi-structured interviews were conducted, and each took approximately 30 minutes to one hour. In total, thirteen questions were asked about the suppression of skid site fires (see Appendix D).

Those interviewed had varied experience with fighting forestry fires across the country (between 10 – 48 years). Organisations interviewed included:

- Forest Protection Services
- Ernslaw One
- Rayonier
- Timberlands
- OneFortyOne
- Juken NZ
- Wenita Forest Products
- FENZ staff, 2-3 from each of the 5 regions.

Results

Summary of key findings:

1. Common factors associated with the spontaneous combustion of slash.

- We have summarised the fire environmental factors that affect a fire's behaviour in Table 1 of the results. It reveals the factors that increase the risk, information gaps and where further research is required.
- There is limited national and international literature on this topic.
- The literature review appears to concur with the interviewees and the findings from the database analysis.
- Information on the Terrain and Fuel factors were hard to collate from known fires. Typically, this information was not recorded and would take time to fully collate. Weather factors were available for each fire that had a location, start date and time.
- The weather analysis of the database compiled showed that:
 - Each of the five regions appeared to have a problem with spontaneous combustion of slash at skid sites.
 - These fires occur at any time of the year, there is no specific month or season the fires tend to occur in.
 - The fires are occurring under moderate fire weather conditions as opposed to extreme conditions.

Factors that increase the risk of spontaneous combustion.

- A mix of woody material and fresh foliage in the pile.
- High amounts of fine material (a few large pieces present a lesser hazard than many small pieces, even if the slash load is the same).
- The moisture content of the pile is greater than 20%.
- The pile is 1.0 m or greater in height (deeper slash and larger piles are more prone to spontaneous combustion).
- Soil is mixed into the pile (provides bacteria and soil promotes prolonged smouldering).
- The pile must be sufficiently porous to allow air (oxygen) to permeate through the pile, but of sufficient depth and compaction to provide an insulating layer to trap generating heat.
- Warm external environmental conditions:
 - After periods of warm humid days. Warm days reduce the rate and amount of heat loss from the pile, aiding the build-up of internal temperatures, shortening the time to potential spontaneous combustion.
 - High air temperatures.
 - After a period of rain followed by a period of hot and dry weather.
 - Pile location on the sunny side of the slope (west and north facing slopes).
- High relative humidity.
- Windy conditions.
- The pile is facing the prevailing wind direction.
- Pieces of metal/wire rope left in the pile.
- Harvesting and wood processing practices that increase the amount of small/finer material left in slash piles.

Factors that decrease the risk of spontaneous combustion include:

- Cooler external environmental conditions. Cooler days increase the rate of heat loss from the pile, prolonging the time to ignition.
- Ventilation in slash piles enhances drying and low moisture content, creating an unfavourable environment for the existence of micro-organisms (but can also increase spontaneous combustion risk, as above).
- Very high moisture content, restricting access to oxygen, limiting both biotic and abiotic oxidation processes. These conditions favour microbes that thrive in oxygen-deprived environments and there will be minimal heat-generation.
- Piles containing high amounts of large pieces of wood, with fewer fine materials.
- Small piles (more difficult to build up and retain heat).

Table 1. Summary table identifying common factors across the various methods of intel gathering on the spontaneous combustion of slash at skid sites.

FACTORS	COMMENT
<u>FUEL VARIABLES</u>	
Tree species	Survey/interview findings indicate that timber species do not affect spontaneous combustion. Combustion occurred with single or mixed species present. No evidence in the literature review to date.
Chemical contents	The literature suggests that the presence of plant oils and resins can facilitate heating. Unknown if sugars from the spring flush also play a role.
Size of vegetation	Literature and survey/interview findings indicate that high amounts of fine material increase the risk of combustion.
Age of material	Literature and survey/interview findings indicate that fresh material are contributors. Green material (chips, branches and leaves) in the pile can contribute to ignition as they decompose.
Moisture content	Survey/interview findings indicate spontaneous combustion occurs when the moisture content is greater than 20%. No evidence in the literature review to date.
Slash compression	Literature and interview findings indicate compaction of slash and soil can act as an insulating layer and trap oxygen and heat.
Slash/pile depth	Literature and interview findings indicate that piles taller or deeper than 3m increased the chance of combustion.
Contaminates	Literature and survey/interview findings indicate that the presence of other objects act as catalysts and increase the chance of ignition.
<u>TERRAIN VARIABLES</u>	
Site location	Evidence from interviews suggest sites that are located at the top or head of a gully increase the risk by allowing for greater air movement and oxygen to encourage combustion. No evidence in the literature review to date.
Shape of terrain	Survey/interview findings indicate location of sites on steep slopes or flat ground does not influence spontaneous combustion. No evidence in the literature review to date.
Slope aspect	Evidence from interviews suggest piles that face the sun (west and north facing slopes) and exposure to prevailing wind increase the risk. No evidence in the literature review to date.
Soil type	Evidence from interviews suggest capping with loose aerated soil increases the risk, as it allows oxygen to penetrate and the skid to continue to smoulder. Capping with clay soil can create an air-tight seal to reduce the risk. No evidence in the literature review to date.
Capped with soil	Evidence from interviews suggest that capping reduces airflow but increases the chance for heat to build up. However, a small hole in the cap can allow oxygen and moisture into the pile, which increases the risk of combustion. No evidence in the literature review to date.

FACTORS	COMMENT
<u>WEATHER VARIABLES</u>	
Season / Time of the year	The database analysis revealed spontaneous combustion of slash occurred in all months of the year.
Climate	The literature suggests that warm days aid the build-up of internal temperatures, shortening the time to potential spontaneous combustion. Anecdotal evidence from the survey and interviews indicate that combustion typically occurs after a period of rainfall followed by warm weather (either dry or humid).
Fire weather	Analysis of the database revealed that these fires tend to occur during low to moderate fire weather conditions, rather than under extreme conditions.
Temperature	The analysis revealed that air temperatures were typically on the cool side, between 13 °C and 19 °C.
Humidity	The analysis revealed that humidity was typically high, between 60% and 80%, especially 1 to 7 days prior to combustion (first noticing).
Rainfall	The analysis revealed that the presence of moisture is important, but in low amounts. Usually after a few days of light rainfall (less than 10 mm).
Wind speed	Interview findings revealed that these fires occurred on windy days. The analysis revealed that wind speeds were generally between 3 and 18 km/h and was important on the day of first noticing.
Fine Fuel Moisture Content (FFMC)	Values were in the Low to Moderate range, most commonly between 50 and 78, especially 1 to 7 days before ignition.
Duff Moisture Code (DMC)	Values were in the Low to Moderate range, usually between 1 to 30.
Drought Code (DC)	Values were Low to High, typically between 2 and 300.
Buildup Index (BUI)	Values were Low to Moderate, typically between 1 and 25.
Initial Spread Index (ISI)	Values were Low, typically 1 to 4.
Fire Weather Index (FWI)	Values were Low, typically 0 to 5.
<u>GENERAL</u>	
Harvesting type	Interview findings suggest that mechanisation has increased the amount of small/fine material at skid sites. Further investigation could reveal if this plays a major role.
Time since logging	Forest managers observed that the seasonal timing of harvesting and then composting time seem to play a role. Piles typically ignited in slash material between 2-4 months up to 2 years old.
Pile usage	Interview findings suggest that double decking or layering fresh material on top of old material could be a contributor.
Pile size/skid site type	The literature suggests that small piles would decrease the risk, as it is more difficult to build up and retain heat. Survey and interview findings revealed that the size of the pile did not matter, combustion occurred in small and large piles with pile depth a more important factor (see Fuels above).
Pile temperature	The process may be initiated as the internal pile temperature increases above 35 °C. A rule of thumb amongst many respondents was that if surface temperatures were below 50 °C, then they were typically considered of no concern. Whereas a temperature of 50 – 60 °C is a good indicator that there is something hotter below the surface. Temperatures greater than 70 °C indicated burning was occurring below the surface.
Presence of gas	The use of a photoionization detector (PID) gas analyser to determine if vapour venting out of the slash pile was either methane or carbon monoxide. If carbon monoxide is measured, it will indicate that it is burning; if methane is present, it indicates decomposing.

2. Best practices for managing forestry slash to reduce risk of fires starting and spreading.

The consensus from the literature review, survey responses and interview findings suggest the following practises reduce the risk of spontaneous combustion.

Consider the following during the planning phase:

- Develop a slash management plan.
- Build piles in very stable areas/firm ground (to prevent cracks forming and allowing air and/or moisture in).
- Avoid steep gullies and north or west facing slopes.
- Construct benches and trenches for slash movement.
- Construct a 10m fire break around the skid site.

Consider the following activities during the harvesting and processing phase:

- Keep slash pile dimensions small and keep piles under 3m deep/high.
- Avoid blading the slash to minimise the amount of soil mixed into the pile.
- If soil is present in the piled material, separate the soil from slash.
- Limit the amount of fine materials in the pile.
- Separate foliage and branches from log offcuts.
- Delimb in the cutover rather than on the landing.
- Allow green foliage to cure (red appearance) before piling.
- Avoid compaction by reducing heaving machinery traveling or working on slash heaps.
- Avoid contaminates entering the slash pile.
- Ensure water does not drain into slash piles.
- Contain slash to the landing, in small piles on the hard-compacted surface.

Consider the following activities after harvesting:

- Identify slash piles that have the potential for spontaneous combustion.
- Establish a regular monitoring programme to monitor for steam, smoke, pile temperature or changes in the soil cap.
- Deconstruct the slash pile at the end of harvest and turn into smaller piles.
- Where safe to do so, burn the slash pile.
- Deconstruct the pile and spread slash over the area.
- Drag slash that has been pushed over the edge back up onto the landing.
- Reduce the pile height to less than 3m deep/high (ideally 1m or less).
- Open the pile, to aid drying and create a habitat less favourable for micro-organisms.
- Avoid placing new slash on old piles.
- Chip the slash and remove off the landing.
- Cart slash to other areas in the forest.

3. Best techniques for suppressing slash fires.

Based on survey and interview responses, we have identified several clear, but opposing, strategies being employed for suppressing fires within slash piles. There wasn't a clear preference for which of these strategies was 'best'. It became apparent that there are no typical slash pile fires. What is applied at one fire cannot be totally applied to another across the country or in the same region. The decision to employ a strategy and tactic was based on recognising social and environmental factors.

Tactics employed to suppress slash fires at skid sites:

1. Open the pile up and dampen down with water or water / foam.
2. Open the pile and spread material out over landing site and extinguish with water or water / foam.
3. Cap and leave to burn out.
4. Burn the pile until there was no combustible fuel remaining.
5. Do nothing, and monitor.

Objective 1: In-depth analysis of the common factors associated with the spontaneous combustion of slash

Literature and industry consultation on common factors

As noted by Quintiere et al. (2012), spontaneous ignition as a cause can be easily missed by an investigator because the signs of spontaneous combustion are difficult to detect and are usually destroyed by the fire. In addition, there is a lack of information on the symptoms of spontaneous combustion. It is a complex process and many factors promote it, so how to assess its likelihood is difficult. Predicting the time to ignition remains a challenge due to the many factors involved and possible compounding combinations. Initial material composition and moisture conditions, along with variable weather conditions in the field, all interact to control the rate of pile heating and thus the length of time to ignition.

We searched literature on the fire environmental categories that we understand to affect fire occurrence and behaviour. The literature identified several common factors that increase the likelihood of a pile to spontaneously combust (Frandsen 1993; Schnepf et al. 2009; Howitt 2015; NWCG 2016) or decrease the risk of combustion (Frandsen 1993; Buggeln and Rynk 2002).

Feedback from forestry and fire managers during the survey and interviews also helped further identify parameters that are likely to increase the risk of spontaneous combustion. The literature review findings appear to concur with what managers reported and the findings from the database analysis.

Fuel factors

Species

This factor has been identified as a knowledge gap based on little evidence from the literature and anecdotal evidence from forest and fire manager observations. An interesting comment noted that if mixed pine and eucalyptus slash were buried together you will often get combustion. On the other hand, forestry managers have also experienced combustion with just single species (i.e. *Pinus radiata*). Therefore, we suspect species does not play a major role.

Volatile compounds

Different wood and plant materials will have different tendencies for spontaneous combustion, especially if containing volatile compounds. Pine resin experimentally added to a sawdust sample reduced the critical temperature required to induce spontaneous combustion. Lower ignition temperatures have been reported in wood high in lignin. Anecdotal evidence also notes that material composed of Manuka slash will likely spontaneously combust when the pile heats up to around 70°C.

The presence of plant oils and resins are suggested to increase the chance of spontaneous combustion. Conifers are an example of a plant group that contains high levels of resins as well as other volatiles (e.g. terpenes) in the live green needle foliage, which are released (volatilised) as they decompose.

Size of material

The size of material appears to have a role (needles, stems, roots, stumps, chipped wood, etc). The literature indicates that the presence of smaller sized slash – tree crown foliage, small chips and fines are contributing to the likelihood of spontaneous combustion. This is also supported by observations from forestry and fire managers. Piles that contain high amounts of larger pieces of wood material would decrease the risk.

However, chip piles store more heat than slash piles because of reduced ventilation and insulation from the closely packed chips, reducing the flow of heat to the surface of the pile. Large pieces of wood cannot pack together so well.

This is also echoed by the survey and interviews findings where fine material appears to cause the problem. Many large deep heaps contain fine fuels, such as chips, branches and needles. Heat build-up occurred with the fine material beginning to compost.

What we also understand is that debris composition in slash piles can be extremely variable. It can be influenced by felling and extraction methods, and log prices.

Age of material

The age of material (fresh/old) appears to play a key role. If there is enough green plant material in the pile, then plant cell respiration can be a significant contributing influence or even the initiating process in heat generation. It is suggested that fresh foliage, branches and fine chip/bark could increase the heap temperatures over the first 1-2 weeks. The additional moisture from fresh foliage is also likely to play a part (refer below).

In Oregon and Washington, Frandsen (1993) estimated the age of chip piles containing some slash material and foliage to be 10-24 weeks old when they ignited. Interview findings revealed that it is often not the freshest skids that cause the most problems, but those between 18 months to a few years old.

The time of year that the slash piles are created can also influence the time to ignition. Fine fuels generated in late winter or early spring can dry and be highly combustible in the summer and early autumn when fire danger is highest (Schnepf et al. 2009).

Moisture content

The literature indicates that moisture content, which must be present either from green material or added by rain, plays a key role.

Forest managers found that moisture content was critical; typically spring and autumn created the right conditions, however winter was too wet and summer too dry. Anecdotal evidence (from the survey and interviews) suggests that spontaneous combustion occurs when the moisture content is at a certain percentage. The survey response gave an average of 50% on a scale from 1-100%. It was also suggested when the moisture content of the pile is greater than 20%.

Slash compaction

The literature indicates that the pile must be sufficiently porous to allow air (oxygen) to permeate through the pile, but of sufficient depth and compaction to provide an insulating layer to trap generating heat. Good ventilation in slash piles, that enhances drying and low moisture content, will create an unfavourable environment for the existence of micro-organisms and reduce the chances of spontaneous combustion.

Pile depth/height

The literature indicates that deeper and larger slash piles are more prone to spontaneous combustion. This concurs with forest and fire manager observations. Typically, material height or depths greater than three metres increased the chance of spontaneous combustion. The amount of heat being generated inside slash piles 6m to 8m deep can be surprising for forest and fire managers.

Contaminants

The literature indicated that pieces of metal/wire rope left in the pile play a role, which also concurs with forestry and fire manager interview findings. Observations today indicate that this behaviour (common years ago) has reduced drastically as foreign objects are not typically found in current slash fires these days. Only 13% of survey responses indicated that such objects (including skidder rope, straw lines, drums, metal waste) were present. A greater proportion of respondents have had slash fires occurring on sites without foreign objects, suggesting other factors now play more important roles.

Terrain factors

There was no literature or database evidence to indicate which terrain variables either contribute or inhibit spontaneous combustion of slash. We have identified the following information gaps:

- The shape of the terrain (flat or slope).
- Slope aspect.
- Soil types.
- Capping.
- Location in the terrain.

Anecdotal evidence from interviews suggest that:

- Piles that face the sun and are exposed to prevailing wind are at risk.
- Southerly aspects are typically cold and damp, the northerly aspects can get warm dry northwest winds. Combustion is likely if you push material onto the NW facing slopes, and if they get moisture to start decomposition, then dry out.
- Piles that experience thermal heating from the sun (i.e. face west and north) will increase the internal temperature of the pile.
- Sites that are at the top or head of a gully increased the risk by allowing for greater air movement and oxygen to encourage combustion. Sites in a gully are also prone for water to run into the pile, further accelerating the decomposition process.
- Siting the skid at the chute will provide more air into the lower sections of the pile.
- Soil mixed into the pile can increase the decomposition rate. Delimbed material often pushed up into large piles (e.g. by dozers) receives inoculations of soil bacteria which can lead to elevation of the pile temperature.
- Compression of the material and capping reduces airflow and increases the chance for heat to build up.
- Capping with clay soil can create an air-tight seal for best results. In contrast, capping with loose aerated soil is a poor choice, as it allows for oxygen to penetrate and allow the pile to continue to smoulder.
- However, clay soils hold moisture and increase the chances of combustion, whereas well drained soil (sand) will not.
- Note though that under extended dry conditions, a clay cap can crack and open up the pile to increased airflow and oxygen, and also to moisture from rainfall, etc., increasing the likelihood of ignition.

Weather factors

Season

The literature findings indicate that the time of year that the slash piles are created can also influence the time to ignition. Fine fuels generated in late winter or early spring can dry and be highly combustible in the summer and early autumn when fire danger is highest (Schnepf et al. 2009).

The literature findings appear to contrast with those interviewed and the database analysis. The database analysis revealed spontaneous combustion of slash occurred in all months and seasons.

Climate leading up to fire

The literature suggests that warm days reduce the rate and amount of heat loss from the pile, aiding the build-up of internal temperatures, shortening the time to potential spontaneous combustion. Anecdotal evidence from the survey and interview findings also concurs with literature findings. Forest managers typically observed skid fires after a period of:

- Prolonged dryness followed by rainfall.

- Hot and dry weather with recent rainfall.
- Warm and humid days.
- Higher than usual humidity.
- High winds.

Humidity and Rainfall

There is evidence from the literature that moisture in the pile plays an important role in microbial processes, where a higher moisture content promotes microbial growth. There is experimental evidence that moisture also enhances the oxidation processes. Water will also have a moderating effect on the temperature in the pile via wetting, evaporation, diffusion and convection until all the water has been removed, usually when temperatures reach around 70-90°C.

A very high moisture content restricts access to oxygen, limiting both biotic and abiotic oxidation processes. These conditions favour microbes that thrive in oxygen-deprived environments but there will be minimal heat-generation.

This concurs with what was identified in the weather analysis (see next section, p. 22). Rainfall and high humidity seem to play a key role in these fires.

Other weather factors

Results on weather factors are in the database analysis presented in the next section (see p. 22).

Other factors

Harvesting and processing type

Current harvesting and wood processing practices are likely to increase the amount of small/finer material left in slash piles. From the survey, fire starts typically occurred where the processor worked (potentially compacting the slash and soil). Others note that mechanisation typically created a lot of fine materials (bark, delimbed branches and twigs) at the skid.

Time since harvesting/logging

Forest managers observed that the seasonal timing of harvesting and then composting time appeared to play a role. The survey indicated that these fires are occurring on piles no longer being constructed, where the majority were no longer having fresh slash added to the pile. The types of piles that ignited ranged between 2-4 months of age, up to 2 years old. It was suggested a timeline of harvesting and mechanisation type be developed to monitor if there is an increase or decrease in the number of fires associated with these factors.

Pile usage

The survey and interviews also indicate that a mix of woody material and fresh foliage in the pile are contributors. However, the “double decking” of slash with new fresh material being added on top of dry old material appears to contribute to composting as noted by several responders. The layering of slash and capping with soil is also recommended to build up the site. However, sandwich layers of dirt and slash can make fire suppression prolonged and difficult.

The following questions were raised by interviewees for future consideration on the effects of spontaneous combustion:

- Whether harvesting stopped and then started after a period (because of holidays)?
- Whether the pile is used more than once (creating deeper material)?
- Does the addition of fresh slash on top of old slash play a role?
- Does the amount of area harvested to the skid play a role?

Pile size and shape

The literature suggests that small piles would decrease the risk, as it is more difficult to build up and retain heat. The critical temperature to induce spontaneous combustion is also influenced by

the pile size. A critical pile size refers to the minimum dimensions of a pile of material that may theoretically undergo spontaneous combustion under ambient conditions (conditions of the surrounding environment). For example, the larger the pile, the lower the critical temperature for spontaneous combustion. Tall piles with a narrow base have a greater potential for heat loss, due to the chimney effect, compared with a shorter pile with a broad base and a flatter top. Other factors include the surface area to volume ratio and the insulation properties of the pile.

The survey identified that in recent years, as compared to historically, most fires have started in mainly smaller piles rather than larger super-skids. From the survey, skid site piles ranged in volume between 300 m³ and 1800 m³ of material.

Pile temperature

Frandsen (1993) suggested that there was the potential for spontaneous combustion in piles if the internal temperature was at or above 70°C.

This also concurs with observations from forest and fire managers. Observations of internal pile temperatures above 50-60°C indicate that there is a risk of combustion. Indications of spontaneous combustion potentially occurring were:

- Vents that open in the piles were greater than 70°C.
- Smoke rising from the pile.
- Steam seen from the pile on a cold morning.
- Measuring methane or carbon monoxide (decomposing or burning respectively).

Database analysis

The raw data graphed for each of the fire weather variables shows that there were no clear patterns in the weather data (See Appendix B, Figure B1). Box and whisker plots were created to visually summarise the data and identify mean values and any signs of common themes (Figure 2 below). The data was displayed to compare the weather variables averaged over the day, week and month leading up to each fire.

Basic analysis of this data shows that these fires tend to occur during low to moderate fire weather conditions, rather than under extreme conditions. Typically, spontaneous combustion occurred when:

- Air temperatures were on the cool side, humidity is high and wind speeds were low.
- Moisture was present, but in low amounts. Usually, after a few days of light rain fall (less than 10 mm).
- Fine Fuel Moisture Code (FFMC) and Duff Moisture Code (DMC) values were in the low to moderate range, with low to high Drought Code (DC) values.
- Buildup Index (BUI) values were low to moderate.
- Initial spread index (ISI) and Fire Weather Index (FWI) values were low.

Below is a summary of the weather variables observed in Figure 2 (min, max and mean values can be found summarised in Appendix B, Table B 1):

- Mean temperature values were generally between 13°C and 19°C.
- Mean relative humidity was between 60% and 80%.
- Mean wind speeds were generally between 3 and 18 km/h.
 - One fire had a mean daily wind speed as high as 70 km/h.
- Total daily precipitation was mostly below 5 mm.
 - Six fires had daily precipitation between 5 mm and 30 mm.
 - One fire got as much as 47 mm during the pre-ignition day.

- Precipitation usually occurred either the day before, typically under 3 days before.
 - One fire event occurred 12 days after rain.
 - The last precipitation amount was generally less than 8 mm (but could be as high as 47 mm).
- Mean FFMC values were most commonly between 50 and 78.
 - Some fires had mean FFMC during the pre-ignition day as high as 90.
- Mean DMC values were usually between 1 and 20.
- Mean DC values were typically between 2 and 300.
- Mean ISI values were generally between 1 and 4.
 - Some fires had ISIs as high as 18.
- Mean BUI values were between 1 and 25.
 - Some fires had BUIs on the pre-ignition day as high as 133.
- Mean FWI values were between 0 and 5.

To further identify any patterns in the data an ordination was created, which condensed the weather variables into a 2-dimensional plot (Figure 3). This non-metric multidimensional scaling (NMDS) analysis examined multiple weather variables to determine how different the conditions at fire events were from each other. At the same time it indicated if a weather variable significantly contributed to these overall differences between fires.

- Points located closest together on the plot are most similar, and points furthest apart are very different.
- The blue arrows show the environmental variables that were not involved in the arrangement of the fires but do have a correlation with the arrangement.
- The black arrows show weather variables that contributed to differences between fires, and Table 2 shows all weather variables and their corresponding p-values.
 - A p-value below 0.05 indicates that a given variable varied a lot from fire to fire.
 - A p-value above 0.05 indicates that the variable did not differ much between fires.

Results from NMDS (see Figure 3):

- Fires on the left generally occurred earlier in the year and fires on the right happened later in the year.
- The data shows that there is not a clear time of the year or season in which these fires are occurring.
- These fires did not seem to occur during a specific season (i.e. spring, summer, winter or autumn), with fires being reported in all seasons. This contrasts with the literature findings.
- There are three distinct polygons (or clusters) that were grouped together by a k-means algorithm.
 - Summer to mid-autumn fires (group A).
 - Autumn to early winter fires (group B).
 - Winter to spring fires (group C).

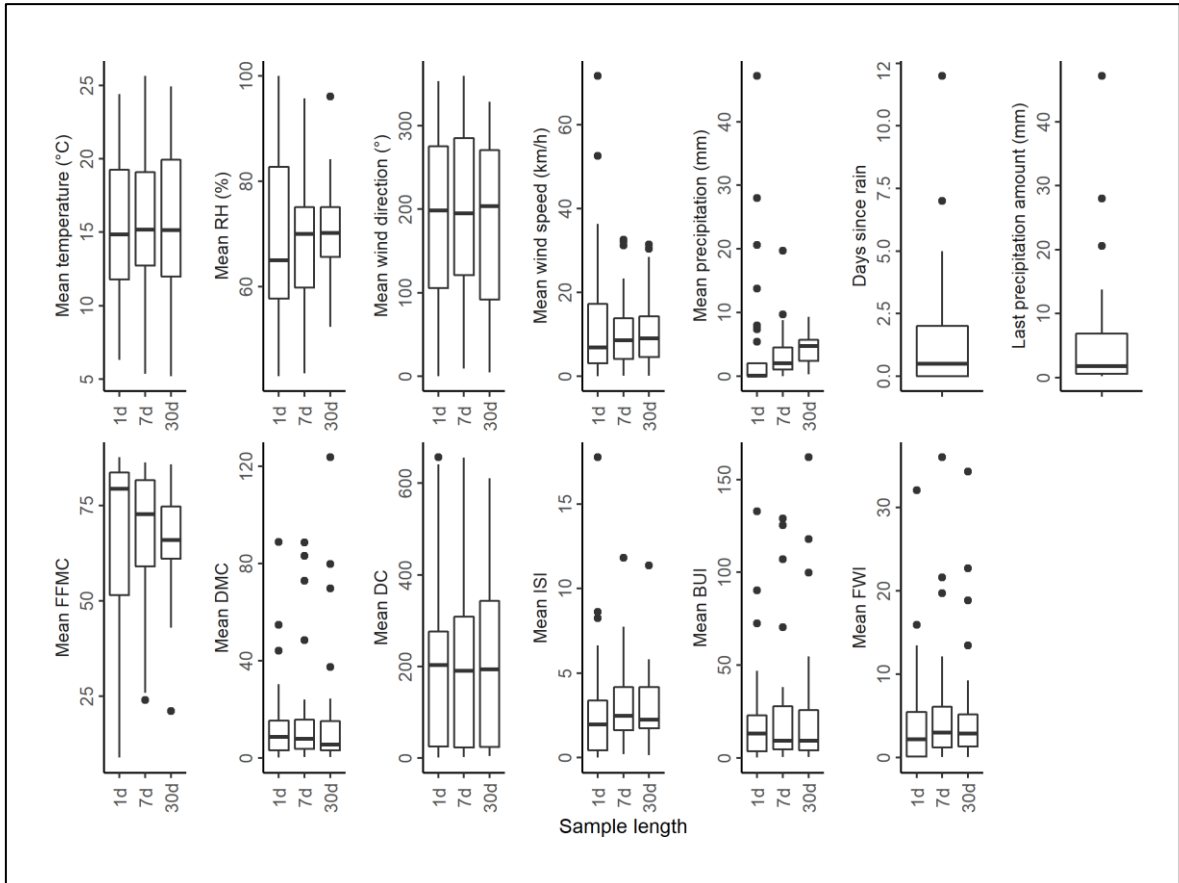


Figure 2. Boxplots of variables averaged over 1 day, 7 days and 30 days before each ignition.

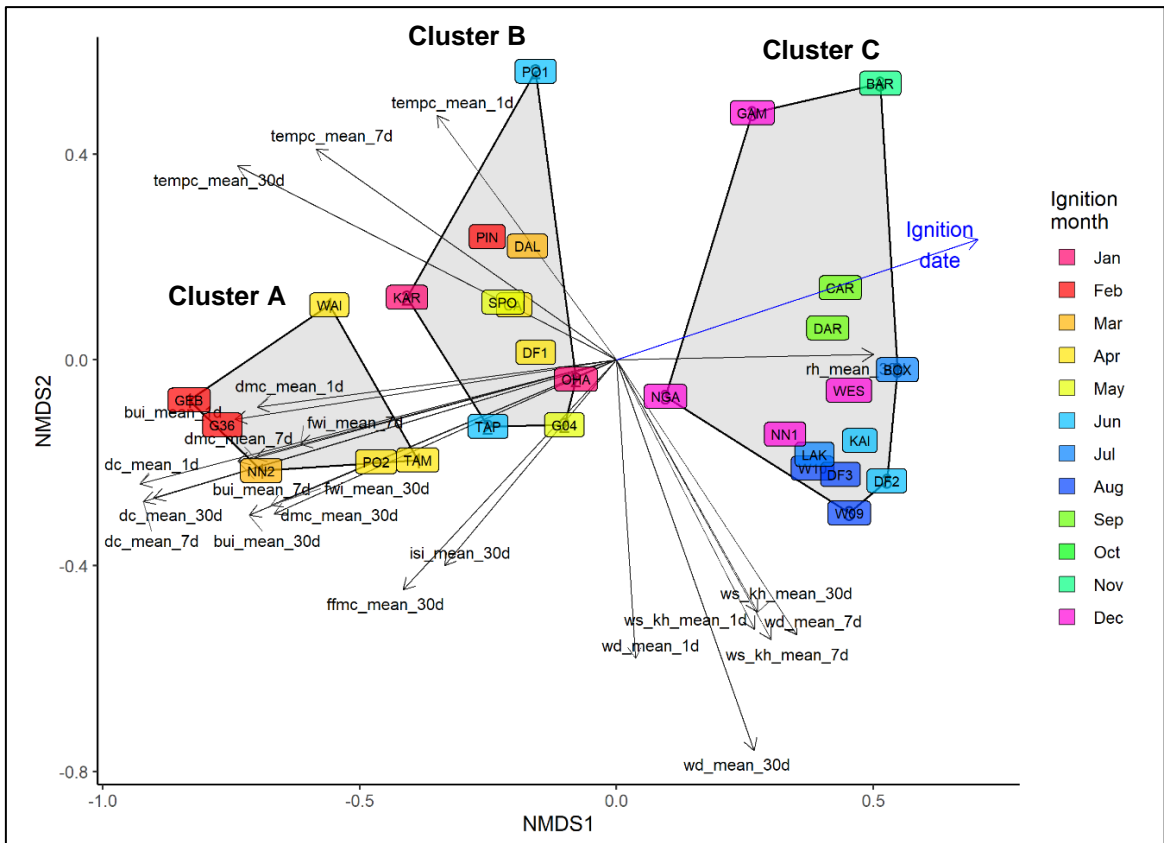


Figure 3. NMDS (a dimension-reducing technique) showing which weather variables significantly contributed to the distribution of points on the graph. Each of the 30 fires have been coloured by the month in which the ignition occurred.

Table 2. Variables with a p-value below 0.05 significantly contributed to the distribution of fires on the ordination in Figure 3; meaning that differences in these variables are well reflected in the distance between points. Blank entries indicate a p-value above 0.05 and were similar between fires.

Weather variable	1 day p-value	7 day p-value	30 day p-value
Mean temperature	<0.05	<0.05	<0.05
Mean RH			<0.05
Mean wind direction	<0.05	<0.05	<0.05
Mean wind speed	<0.05	<0.05	<0.05
Mean daily precipitation			
Last precipitation amount			
Days since rain			
Mean FFMC			<0.05
Mean DMC	<0.05	<0.05	<0.05
Mean DC	<0.05	<0.05	<0.05
Mean ISI			<0.05
Mean BUI	<0.05	<0.05	<0.05
Mean FWI		<0.05	<0.05

We re-analysed the cluster data from Figure 3 to see if there were any similarities or differences in the weather for each cluster for the month leading up to ignition (Figure 4). The box plots show that:

- Cluster A (summer to mid-autumn fires) – seems to have the most flammable conditions: high temp, low RH, high FWI indices and codes.
- Cluster B (autumn to early winter fires) – seem to have moderate fire weather conditions.
- Cluster C (winter/spring) – is the least “flammable” with mild fire weather conditions.
- It seems that for all of the clusters the weather conditions are moderate rather than on the extreme end.

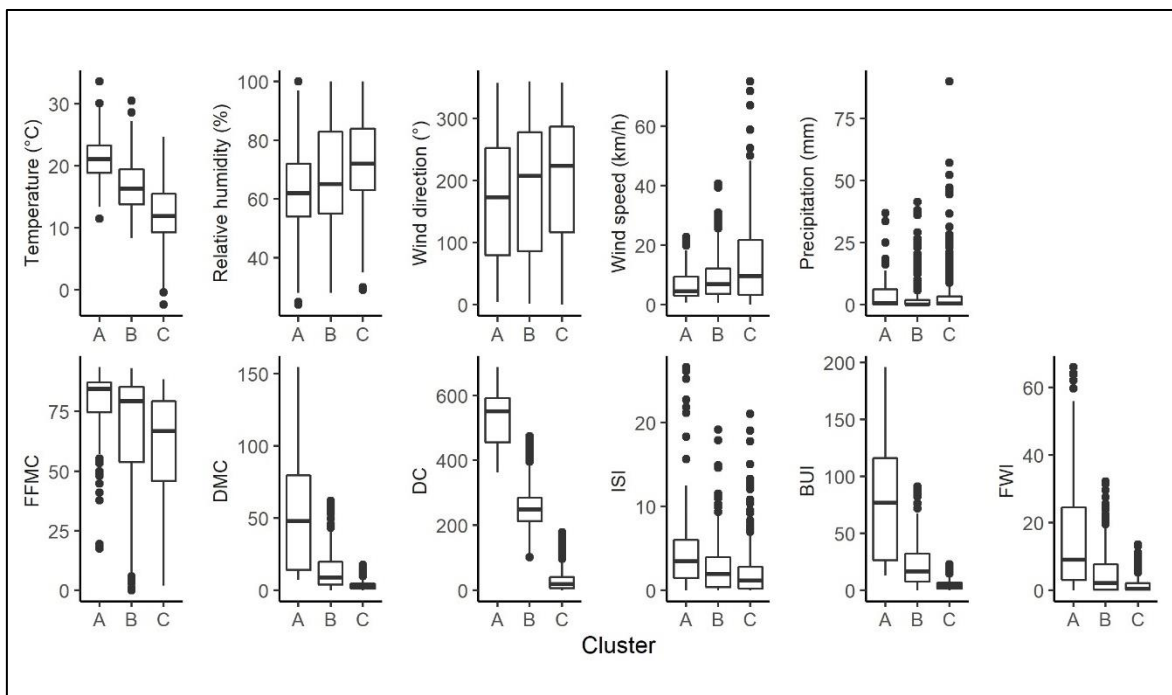


Figure 4. Conditions during the month leading up to ignition by cluster.

Objective 2: Survey and literature findings on how forestry manages the risk of slash fires.

Forestry practices have changed over the last 15 years. Felled trees used to be delimited on site, where the fine material stayed. Modern practices involve extracting felled trees to a central point (landing or skid site) where the logs are processed prior to loading onto trucks for transport. This process creates excess woody debris or slash (branches, bark, small wood chips and log offcuts that are not millable). To make room on the landing, the build-up of slash is often heaped into large piles or pushed off the slope below the skid site, into a bird's nest. The piles of slash may be capped with soil or even mixed with soil as machinery blades the skid site to keep the area tidy. Over time, these piles could become susceptible to spontaneous combustion.

Management of slash according to the literature

A survey by Hall (1998) on logging residues at landings found that stem wood was the largest component of the residue regardless of whether the stem was delimited at the landing (66% of total residue) or at the stump (80% of total residue). Regardless of the delimiting method, most of the branch material was left on the cutover.

Most forestry sites operate 2-3 slash piles per landing, and these piles are generally created during the harvesting operation. One forestry manager noted that their forest estate may have up to 200 skid sites in operation at any time. Most of the forest managers we spoke with (87%) managed slash by piling at a skid site or landing. This makes slash piles very prevalent amongst forests within New Zealand; however, incidence of skid fires is very low (probably only 0.1% - 0.3%) of all those skids in operation (personal comment from respondent).

Other key methods for slash management included leaving slash in the forest, spreading slash over the landing site, or continually pushing slash waste over the edge of the landing. Most slash piles are of a consistent age – 74% of the respondents were not adding new materials to older slash piles. The slash piles are usually left to decompose on site – 87% of responses state slash is managed via composting, often for more than 10 years. Very few piles are chipped or transported off site once harvesting is completed. Note that international literature suggests chipping/grinding/mulching the slash has the potential to increase the risk of spontaneous combustion unless the material is scattered or removed from the site.

Piles on the landing are typically of low density, with wood volume of 20% - 25% of total pile volumes, the rest being air space (Hall, 1998). Large pieces of wood cannot pack together well. This is a partial reason why slash piles are not usually associated with spontaneous combustion (Frandsen 1993). From our own survey and interviews, the piles that caught fire at sites usually contained a lot of fine materials or chip (60% of the piles that ignited) compared to those with mainly crown foliage materials (40% of piles that ignited).

Forestry managers that were interviewed stated that the skid slash/debris composition can be extremely variable depending on regional wood flow, residue extraction, terrain, felling and extraction methods. The residue also depends on the percentage of stem breakage during extraction, and whether there is a facility to take residues (chip, firewood, pulp mill) nearby.

Compacting piles to make them denser (on the assumption that dense piles fail to heat) isn't fool proof and may backfire. Compaction of fines might reduce oxygen penetration, but it may lead to heat generation by fast pyrolysis (Frandsen 1993; Buggeln & Rynk 2002; Schnepf et al. 2009; NZFOA 2018; FOA 2018; Wright et al. 2019).

The NZ Forest Owners Association (NZFOA) has a non-regulatory Forest Practice Guide on Managing Processing Slash on Landings (Forest Owners Association, 2018) designed to minimise risks. It is not yet known how this guidance is being used in practice, but there are indications that guidelines are being followed based on interview responses and email correspondence.

The NZFOA website is the best place for finding the latest Forest Practice Guides, including:

- Managing Processing Slash on Landings: https://docs.nzfoa.org.nz/site/assets/files/1509/6-1_harvest-slash_managing-processing-slash-on-landings-2-0.pdf
- NZ Forest Road engineering manual: <https://docs.nzfoa.org.nz/live/nz-forest-road-engineering-manual-operators-guide/earthworks/forming-the-landing/>
- Forest fire risk management guidelines: <https://nzfoa.org.nz/resources/file-libraries-resources/standards-and-guidelines/670-forest-fire-risk-management-guidelines/file>
- New Zealand Environmental Code of Practice for Plantation Forestry: <https://www.nzfoa.org.nz/resources/file-libraries-resources/codes-of-practice/44-environmental-code-of-practice/file>

Over the years, several managers and companies have changed their slash management practises following numerous skid site fires. At least one company has created a skid risk assessment form (See appendix A2), which is not routinely used on all skids, but for times when the fire weather makes them concerned. High risk skids that have been operational in the last two years are highlighted based on the parameters in the risk assessment table. There is potential to expand on this form, to create a risk matrix similar to the one used for Hazard Removal Assessments that FENZ have developed and can be found in fire plans.

The literature search and interview correspondence revealed the following management practices to minimise the risk of sustainable combustions of slash piles:

Planning phase:

- Develop a slash management plan.
 - Especially for skids likely to have high volumes of slash.
 - Identify and plan for the placement of processing slash, and where appropriate incorporate slash benches as part of the landing design and construction.
- Avoid west facing.
- Avoid filling steep gullies.
- Only build piles in very stable areas/firm ground.
- Slash to sit on flat benches.
- Design slash to be benched to a maximum of 3m high.
- Consider fire threat if piles were to ignite.
- Consider fire suppression materials on site – clay for capping and distance to water.
- Calculate slash placement area required.
- 10m flat fire break and working bench to be constructed on exterior edge of slash bench.
- Create slash benches to prevent slash movement and stop any material on fire rolling downhill into adjacent forest/cutover.

Harvesting and processing phase activities:

- Keep the skid site size small.
 - Where practical, maintain heap heights (involving foliage, branches and fine chip) under 3m depth/height.
 - This is thought to keep the critical internal temperature of the pile below 60-70°C.
 - Otherwise, it may require skid modification or transport away.
- Minimise soil by separating soil from slash in bird's nests during harvesting operations.
 - Minimise blading as a method to clear slash from skids to make a tidy clean landing.

- Try to limit the amount of fine materials in the pile, as these reduce void spaces and increase the possibility of heating.
 - Avoid spreading fine material or bark/wood chips, as this will reduce air circulation and increase the temperature in the slash heap.
 - Delimb in the cutover rather than on the landing where possible, so that less slash accumulates on the skid site.
- Separate foliage and branches from log offcuts
 - Finer waste will decompose faster, the larger off cuts will take a long time to burn out when these are dry enough to ignite.
- Allow green foliage to cure (when discoloration in foliage is apparent, i.e. red slash appearance). This may reduce the initial respiration minimising the stimulus for bacterial metabolism in heat generation.
- Minimise machinery travel over the slash heap, this will prevent compaction and associated reduction of ventilation and heat escaping.
 - Loosely stacked piles with plenty of void space allows more ventilation, reducing the piles ability to store heat.
- Remove rubbish offsite (especially oily rags, wire rope and other metal objects).
 - Avoid contaminates from entering the slash pile as these can act as a catalyst for ignition.
- Monitor operations to ensure slash build up is not becoming an issue.
 - No Waratah (bark fines).
 - Limit fine branch material by delimiting in the bush or cutover.
 - Don't mix large wood and fines/dirt (skid sweeping to different slash bench).
 - Push slash periodically to storage extremity rather than extending skid over top.
- Ensure water does not drain into the slash pile/bird's nest.
- Contain slash to the landing and avoid slash spilling over the side of the hill; leave small areas of debris piled up on the hard-compacted surface, where it is stable.
 - Preventing spill over of slash improves the productive replanting area.
- There are conflicting responses about using a skid site more than once. If doing so, care needs to be taken with managing slash.
 - Often the build-up of slash can be deep, so it is not recommended.
 - A fire could trigger in the decomposing material from the first usage, and the layers of slash from the next logging crews and soil can make it difficult to put the fire out.

Management of pile after harvesting:

- Undertake slash pile assessment to identify piles with the potential for spontaneous combustion.
- Establish a monitoring/surveillance programme. In high risk periods, monitor with an infra-red camera. Monitor the internal temperature of high-risk piles.
 - Monitor slash temperature, or for steam or smoke regularly.
 - Use machine down-time to pull some material out of the stack and test temperature by hand.
 - Check to see if the stack steams when in the morning.
 - Check to see if there is a smoky smell in the air.
 - Check with temperature probes or thermal cameras to detect heat build-up near the surface on landings. Inform if temperatures are between 50-70°C. Temperatures at or over 70°C indicate likely combustion.

For piles identified as high risk, the options include:

- Open the pile, to aid drying and create a habitat less favourable for micro-organisms. Spread out the slash to increase contact with the soil to aid decomposition. Excavators or other machines with a grapple are preferable to a bulldozer because they can lift, separate and pile the slash and collect less soil.

- Reduce the pile height to less than 3m to reduce insulating properties or remove the pile if necessary. If possible, reduce the pile height to 1m or less.
- Chipping, grinding or mulching the slash has the potential to increase the risk of spontaneous combustion, unless the material is scattered or removed from the site.
- Deconstruct the pile at the end of processing and spread slash over the area:
 - Drag slash back up onto landings that has been pushed over the edge.
 - If it is not possible to completely remove the pile, then try to open the pile and reduce height for long term composting to under 1m in height.
 - Do not build new skid sites on top of old slash piles.
- Deconstruct the slash pile at the end of harvest and turn into smaller piles that can be burnt:
 - Where safe to do so, burn the pile to prevent spontaneous combustion. Burning slash can be an effective option to reduce the amount of slash in a bird's nest if carefully managed.
 - Fire supervision and resources are required onsite when burning.
 - Protect any sensitive areas from burning (e.g. with firebreaks).
 - A fire permit and burn plan are typically required. Consider any other regional requirements around air quality and the environment.
 - Minimise the amount of slash in piles that are to be burnt, as larger piles with higher slash amounts are more difficult to burn, can smoulder for days/months and may provide an ignition source into the next fire season.
 - Burning poses a risk in dry and windy environments, and burning debris can also roll downslope.

The best slash pile management options according to the survey findings (Table 3), additional interviews and the literature include:

- Keep slash pile height under 3m. This could be difficult to manage on steep slopes or at the edge of a skid.
- No new slash to be placed on old piles.
- Dragging of slash that has been pushed over the edge back up onto landings at the end of harvest.
- Create slash benches to prevent slash movement and stop any material on fire rolling downhill into adjacent forest/cutover.
- Delimb in the cutover so less slash is accumulated on the skid site.
- Blade off processor pads to reduce slash build up.
- Only build piles in very stable areas/firm ground.
- Avoid foreign objects from entering the slash pile, especially metal.
- Chip slash and then remove off the landing.
- Cart slash to other areas in the forest – often covered / buried / compacted.
- Deconstruct the slash pile at the end of harvest and turn into smaller piles that can be burnt.
- Use of NZFOA Forest Practice Guide section 6.1 (FOA, 2018).

Table 3. Summary of safety precautions taken to reduce the risk of spontaneous combustion and further spread of fire identified from survey responses.

Actions	% who do this
Slash pile height restricted (usually to <3m)	44%
Bury piles with earth and cover, sometimes compact also	25%
Rake out contents over skid site once harvesting is complete (i.e. processor slash)	19%
Formal risk assessment undertaken	19%
Spread out slash as much as possible	19%
Redistribute into smaller piles once pile gets too big	13%
No foreign objects (esp. metal) in pile	13%
Open the heap up mechanically to check internal condition	13%
Keep out green waste from entering old piles	6%
Ensure pile is built on firm dry ground	6%
Keep slash clean	6%
Don't mix branches and soil	6%
Maintain a bare earth perimeter	6%
Check piles following rain and after significant downtime (e.g. after Xmas break)	6%

Objective 3: Best practice suppression techniques to suppress slash fires.

This section summarises how forestry and fire managers fight skid site fires, started from either spontaneous combustion or from other heat sources.

Survey findings

The survey findings show that several actions are taken by forest companies when noticing slash at a skid site is spontaneously combusting or is on fire:

- Open pile up and spread out over the site using excavator (e.g. a sealed road or clay).
- Water applied.
- Call FENZ for advice.
- Call 111 if additional suppression is required.
- Create a firebreak around the pile.
- Let it burn out – cut a hand line for larger piles where spreading out isn't feasible.
- Use Class A foam – on the pile.
- Cover it with earth – cap.
- Spread out pile into thin layers of less than 2 m thickness.

The survey also highlighted several clear but opposing strategies being employed for suppressing fires within slash piles. There wasn't a clear preference for which of these strategies was 'best'.

1. Open the pile up, and dampen down with water.
2. Spread pile material out over landing site and extinguish with water and/or foam.
3. Cap and leave to burn out.
4. Burn the pile until there was no combustible fuel remaining.

We explored these strategies in further detail by interviewing representatives from forestry companies and fire managers. The interview questions placed emphasis on when they might employ each strategy and the parameters of the skid site that would determine whether each option was suitable or unfavourable. It became apparent that there are no "typical" birds nest fires. What you applied in one fire cannot be totally applied to another.

Interview Findings

We interviewed a total of 14 forestry or fire personnel across each of the five regions. They have a previous background in forest and rural fire management, working for the forest industry, Department of Conservation, City Council or Rural Fire Authority (during the National Rural Fire Authority era). Today they continue to work in either the forest industry or Fire and Emergency New Zealand. The years of experience the interviewees had with fighting forestry wildfires (including skid site fires) ranged between 3 - 45 years (Table 4). We have summarised the responses to interview questions with regards to:

- The strategies and tactics used to suppress a skid site fire.
- If more than one tactic, when would they employ each one.
- What types of resources were preferred for suppression.
- What technologies were used during suppression (mop-up and monitoring phase).

Table 4. Summary of interviewees by region and experience.

Region	Industry	Number interviewed	Years of wildfire experience	Years of skid site fires experience
Region 1	Forest	2	38 - 42	20
	Fire	1	15	8
Region 2	Forest	2	30 - 40	30
	Fire	0	n/a	n/a
Region 3	Forest	1	20	15
	Fire	1	45	35
Region 4	Forest	1	21	20
	Fire	2	25 - 35	18 - 25
Region 5	Forest	2	42	30
	Fire	2	13 - 36	3 - 20
Total		14	13 - 45	3 - 35

Suppression strategies and tactics

The way a skid site fire is suppressed is a little different depending on whether it has started from spontaneous combustion or from another heat source from above the surface. If the fire has started from an external heat source (such as a wildfire moving across the landscape), fighting the fire is typically done by putting it out initially with water and then using an excavator to pull back the top layer of slash that is burning and extinguishing it fully.

If the fire started internally, these types of fires can be dangerous, because as they burn the pile can collapse. There are several opposing strategies and tactics used to fight these fires. Depending on the strategy and tactics chosen, the suppression operation can be long, arduous and expensive.

The strategy is to first contain the fire and then to put it out or let it burn. Usually, during winter there is low fire risk, so some regions have a “let it burn” strategy; during summer, the fire risk is generally higher, and “putting out fire for good” is the main strategy.

Tactics are how you are going to do the job. Tactics are chosen based on decisions around the fire location, size of the skid, number of skids involved, the terrain (slope steepness), soil type, resources available, access, weather forecast, time of the year (season), receptive unburnt vegetation, distance to water supply, cultural and environmental constraints, and neighbouring values at threat.

Creating a plan B ensures that there will be no surprises if a break out occurs. Skid site fires on top of a hill can have burning rolling material that can cause a problem. Skid site fires situated on a ridge can also throw embers aloft with increasing winds and start new fires. It also depends on how receptive the surrounding fuels are; for example, if the cutover has been sprayed with a desiccant to aid later burning or for weed control, or if the forest floor under nearby tall standing timber will likely have low moisture content from prolonged drought.

If the fire is likely to spread from the skid and threaten values, it is advisable to take a more aggressive approach. The best approach is to first contain the fire, to prevent the fire spreading further and to reduce the risk of new fire starts in neighbouring trees or cutover. Once this is dealt with, then you can then deal with the source of the fire. If there is more than one skid site burning, prioritise the most serious one first, and then record which ones you have extinguished on maps.

Mop-up is one of the most important phases of fire suppression. Any remaining burning material may rekindle making any previous efforts worthless. There are two types of mop-up, dry and wet, which involves scraping, digging, stirring, mixing, separating and turning.

In no particular order, the following is a summary of the interview responses of forest and fire managers on the various tactics used around the country. Each tactic chosen has pros and cons associated with it, and are considered the best approach for different reasons.

1. **Fighting fire with fire**

In the NZ Forest Service era, foresters would deliberately light the slash to reduce the fuel loading and make it easier for replanting the next forest. Valuable lessons have been learnt over the years with burning material rolling downhill and the construction of fire breaks and/or trenches. Today, the preferred option for some is to use fire to further speed up the process. However, this option is harder to undertake for other regions that regularly experience strong winds and have dry climatic conditions.

Fighting fire with fire is considered the cheapest and quickest option with less smoke produced over time. This method is suitable if there is a lot of slash sitting above ground, or not buried within mixed layers of slash and dirt.

This tactic involves lighting from the top and letting it burn out. A handline or firebreak is cut around the skid or pile to contain it, and the skid fire would be managed with a fire crew to monitor the weather and keep an eye on the burn. Depending on the fire risk and danger, helicopters on standby can also be used. Another risk is the wind; if the weather forecast is not favourable, a strong wind can increase the chance of new fires starting and spreading. A preventative method is to set up sprinklers on the surrounding unburnt vegetation (if dry enough for fires to start easily) to reduce the risk of any new fire starts from spot fires caused by wind-borne embers.

Pros	Cons
Quick and cheap.	Not advised during high fire danger.
Less smoke over a period time.	Create trenching if on steep slopes to prevent rolling material.
Reduces risks to firefighters and machinery operators.	Resources needed onsite and also on standby to stop any break outs.
	Sight of smoke and flames concern public.
	If not following a burn plan prescription, an escaped fire could threaten neighbouring forest and lands.

2. **Let it burn itself out (do nothing and monitor)**

This tactic typically occurs in autumn/winter or with low winds and low fire danger. If a skid site is ignited from a spark or spontaneous combustion, and is not a threat, then letting it burn while being under observation can be a sensible approach. However, this technique is considered too risky in areas that regularly experience strong winds and have dry climatic conditions where burning piles can flare-up or reignite many days, weeks or even months later.

During the spontaneous combustion phase, burning inside a heap can cause the material to collapse and affect any existing cap, allowing more oxygen into the pile. A hole the size of a cell phone is enough to let oxygen into the heap and re-ignite the fire. This venting can result in intense heat and could result in material rolling down the hill or embers being transported in the wind. When you get a vent, this is when it becomes most risky for any neighbouring slash to catch on fire. Over time, the burning residue can fall in on itself and eventually burn itself out.

This method involves:

- Evaluating the likelihood of a fire starting and spreading in adjacent areas, and determining if the burning pile(s) can be left to burn.

- If the neighbouring vegetation is green (or not receptive to ignition), and the forecast weather is looking favourable, then the pile can be left to burn-out but should still be closely monitored over time.
- Cut a fire break around the skid or pile to contain the fire.
 - A trench or bench should also be cut around a skid pile on the face of a hill, using bulldozers and/or excavators. The trench will stop burning material rolling downhill starting new fires in adjacent slash or tall/standing timber.

The decision to let burn depends on:

- If there is no risk to neighbouring unburnt vegetation and other values (farmland, conservation areas, cultural sites or other structures).
- Time of the year and fire danger levels.
 - Fires burning in March/April, or into the winter months, may be allowed to burn, as there is less threat over winter.
 - In the height of summer, the decision to let a skid fire burn needs to be more carefully considered. There is the risk that once the cap breaks down, you could have embers being transferred out of the pile (either from convection or rolling material downhill) into logging slash or unlogged forest.
- The makeup of the pile.
 - If the pile contains many layers of slash buried by layers of dirt, you will likely have to revisit the site as the fire burns into each lower layer of material.
 - If the fire is deep seated or burning into any larger woody material present (e.g. logs, stumps), it may cause issues as conditions start to dry out.

Managed risk examples:

This option was considered suitable when there was no risk of spread (from forecasted weather) over the holidays / long weekend that followed ignition of a skid pile. The site was monitored by a 2-person crew with pressurised water on site. The following day, when more resources were available, a thermal camera was used to identify where the hot areas were, and the skid was pulled apart by heavy machinery (effectively splitting the skid in half into burning and unburnt material). The warm/burning material was spread out and wet down.

During the Pigeon Valley wildfire in February 2019, large sawdust and bark heaps were left to burn, as there was little chance of a fire spreading further due to the burnt ground around the heaps. During COVID-19 restrictions in the month of March 2020, the decision was also to let it burn for skid sites in the North and Sound Island to reduce the number of personnel in contact with each other.

Pros	Cons
Cheap. Only labour costs (monitoring).	If pile isn't burnt cleanly, can combust again later.
Ability to dig into clay created the perfect fire pit, to seal it up if having difficulties.	Can smoulder away for months, potentially years (depending on volume of slash and if it involves deep-seated burning).
	Not advised during high fire danger. Avoid allowing it to burn during summer.
	The presence of strong winds can fan the fire and result in escapes.

3. Trenching and Capping

Another technique is to bury burning material. This is done using a trenching and capping method. This method is typically carried out when the volume of material can make it very difficult to pull

apart, or on steep slopes where it is difficult to get in and break open the pile. The suppression cost can be in the region of \$30,000 - \$50,000 (if carrying out direct attack and without the use of aircraft).

This method involves:

- Creating a trench or bench around the skid pile on the face of a hill, using bulldozers and/or excavators. The trench will stop burning material starting new fires in fresh slash or tall/standing timber.
- Water and foam are applied at the top of the pile to keep the heat down. Water can also be applied on the surface and around a skid, to prevent any further surface spread until the area is capped.
- Smouldering or flaming material is then smothered by adding more soil to rebuild the cap.
- It is then a monitoring exercise, regularly checking on the fire to ensure the cap remains intact and that the fire has not broken out again. This can carry on into the next fire season, or for up to 12 - 18 months.
 - Monitoring should occur on a regular basis, initially every week, then monthly.
 - The status of the cap should be checked and may require additional soil added if it slumps/caves in or breaks down further.
 - The area should also be fenced off where the slash is believed to be on fire, with warning signs in place that underground is unstable and to keep away.
 - Avoid putting further slash on top.

Monitoring is generally carried out by forest managers and staff/contractors just keeping an eye on the site. If they are concerned, a thermal camera can be run over the top, with a surface temperature of 50–60°C being a good indicator that there is something hotter below the surface.

The forestry or management company needs to monitor it every few days in the first instance, then weekly to ensure that the cap of the fire is not breaking down, or that fire isn't finding its way to the surface. As the cap breaks down, you could have material finding its way down hill into a new fuel source. To reduce the chance of new fires starting or injuring crews working below, further fire breaks can be constructed to stop roll-outs from the skid.

Most skids have a trench/stump collector below the skid slash. This is a large trench dug 3 – 4 m wide, with a bank/bench of soil. This stops slash moving down slope and provides support to collect rolling slash. Another option is to split off the slash that isn't on fire, to contain the burn area, then cap that portion with soil. The burning slash can be pushed down onto the bench, wet down and capped with soil.

Managing the risk

In some regions this technique is the preferred option, for others it is not employed. There is still the risk of material smouldering underground for years, and that could find its way out. In some cases, capping of the skid fire initially stopped it due to starving the fire of air/oxygen. However, in other cases, it just delayed the time for when the crews had to come back and put it out. A good example of the latter is the Mt Allan fire, near Dunedin (23/02/2010), where a capped super skid re-ignited 18 months following the original wildfire. If a skid pile bursts, a lot of debris and embers can scatter downhill. Mix this with wind, and new fires can run up and across the hill.

A lesson learned over time is the importance of the cap construction. It can be challenging to suppress a fire if you don't have the right soil type. Capping with clay soils can create an air-tight seal for best results. Capping with loose aerated soil is a poorer choice, as it allows oxygen to penetrate and the skid fire to continue to smoulder. For some regions, it can be prohibitively expensive if there isn't ready access to clay soil types locally to create a cap. If some sites are built on very steep slopes with loose rock or shallow topsoil, creating a cap with heavy clay can be problematic as it can more readily slump away.

Pros	Cons
A good technique if the site is considered unsafe.	You'll never know if and when it's 100% out because it is buried.
Good technique if the site is on difficult terrain (steep slopes).	There is still the risk of objects smouldering underground, and it can re-ignite a few months to several years later.
Capping technique requires less time and resources compared to pulling the skid apart and extinguishing. Therefore, is the next cheapest option following burning out.	Is a risk for personnel or machines to break through the crust/cap.
Capping a skid fire with clay soil can help develop an air tight seal therefore helping suppress the fire.	Using loose aerated soils (e.g. sandy soils) increases chance of oxygen fuelling the fire.
	For some regions, it can be prohibitively expensive if there isn't clay soil locally to make it economical to cap.
	Requires monitoring and surveillance for signs of smoke, steam, and disturbance of the cap.
	A hole the size of a cell phone may be big enough to let in enough oxygen to cause a flare-up or escape from embers.
	If the cap or soil begins to slump, it allows moisture and air to get into the pile and continue to gather heat. If the cap breaks down further, material could roll down the hill.
	Depending on time of the year and prevailing weather and fire danger conditions, could threaten neighbouring forest and land from an escape fire.

4. Pulling the skid apart

This tactic is undertaken if the fire is burning deep below the surface (as opposed to burning on top of the slash). This method involves breaking the pile up and extinguishing it as you go. It is considered dirty mop-up requiring crews and heavy machinery, and a lot of water is used with or without surfactants (Class A foam or soap) which aid penetration of the water into the fuels. If the volume of slash is small, then it is easy to pull a skid apart and dampen down with water, and the cost won't be as much. However, if it is a large skid fire, the suppression effort can be extremely slow, require a lot of water to extinguish and be very expensive. However, it is the only tactic that ensures the fire is completely out.

The terrain can also have an impact on how you attack the skid fire. If the skid fire is in a steep area, you'll have to dig it from the top. But if the fire is on a gentle slope, and not very big, it can be dug out from the bottom.

This method involves:

- Knocking the heat out of it, using water or water with a surfactant.
- Identifying or creating a safe area that burning material will be spread out onto (either the landing or a road surface).
- Creating a fire break around the area and, if necessary (e.g. on slope), a trench or bench to catch rolling material.

- Care needs to be taken with this method before opening the pile. A mitigation plan needs to be in place, as once the skid site is open, more oxygen is available, and the fire can flare up.
 - Opening the pile increases the rate of burning / intensity and increases the chance of ember transfer.
 - Choose a day that does not have strong winds forecast.
 - Some managers open up the skid to see where it was burning and to concentrate their efforts.
- Opening the pile with heavy machinery; this is typically best done by excavators.
 - Ensure that the machinery operator is not at risk by keeping the heat down with water.
- A combination of excavating the burning material and extinguishing using crews on hoses wetting down the material.
 - Two hoses can be run off an appliance or dam; the first hose is to keep the heat down on the skid fire, the second hose is for wetting down material that is spread out onto a hard surface.
 - As you excavate, spread the contents out on the hard surface, to either let it burn out, or wet it down.
 - Each bucket load removed needs to be fully wet down. Ensure the material is cold before more is pulled out from the skid. This can be done with a thermal camera, or by using the back of a hand as a heat sensor.
 - You don't want to shift a heat source from one location and move it to another where it could set fire to other material.
 - It is critical to keep the heat down and not run out of water.
 - It is critical to have a continual water supply, pumping from an adjacent stream or pond. An ideal set-up might include a 20,000-litre dam and hose lines or bulk water tanker(s) to keep it full as required. Some managers have employed 3-5 tankers to keep a continued water supply.
- Continue to dig out the pile until cold earth is seen.

Pros	Cons
If the skid is not very deep, pulling it apart is likely the best option.	The length of time and cost to put a fire out depends on the size of the skid, volume present, how compacted it is, how far the fire has spread, and the size of machinery used. Some responders said that they have spent \$200,000 on resources (heavy machinery, tankers and helicopters).
If you have good access, you can chip away at it, piece by piece.	The terrain and depth of burning can impact how easy it is to get heavy machinery in. If it's situated on steep slopes, then it is much more difficult to get in and break up the pile, and unstable skids can make it unsafe for machine operators.
Trenching is a recommended action to prevent further spread of a fire if one was to start. It stops objects rolling down hill and starting new fires.	The slash fire can become more active / aggressive once more oxygen gets in with opening the pile, vents forming, or if the pile collapses.
This tactic can be applied to other types of heaped vegetative material (i.e. saw dust).	Can create a problem with ember transfer once you open the pile (airborne embers or material rolling downhill).
Use water with foam can further increase effectiveness and penetration into the piled material.	Some locations have environmental and/or cultural constraints with use of surfactants. This can mean that penetration is poorer if using water alone.

Pros	Cons
A fire pond is useful if present.	Must have a constant water supply established before opening the pile. A lot of water is required to extinguish the fire. Some have stated that 100,000 L of water can be used per day.
Once mineral earth reached, it is completely out. If cleaned out completely, it's guaranteed the fire has been extinguished.	Transporting water to the location can be challenging for some areas.

5. Flooding

This tactic can be employed to prevent putting people or machinery at risk, especially if fighting larger heap fires (e.g. bark or sawdust dumps). It could be used in conjunction with another tactic, as a means of dampening down unburnt vegetation to prevent ember transfer and further surface fire spread into adjacent cutover, as well as saturating the burning pile.

This method involves either:

- Setting up sprinklers from a water supply for up to several weeks.
- Using peat/duff probes to apply water deep into the ground.
- Opening the pile with heavy machinery, flooding with water, and mixing everything up “like a slushy”.

If a local water supply is present, there is no need to truck it in (to keep the costs down).

Issues:

Squirting water over the surface for a short amount of time is not effective. The water will not penetrate deep down to where it is burning underneath, it will only put the fire out on the surface.

Pros	Cons
Use this method to prevent putting people at risk, especially for large dumps.	You'll never know if/when it's 100% out because it is buried, and the fire can re-ignite.
If a local water supply is present (e.g. a fire pond or farm supply) there is no need to truck water in. This can significantly reduce the cost.	Depending on the method used, and size of the pile and volume of slash, it can be a time-consuming process and a lot of water used. One person advised they pumped water into a large burning dump over a 2-week period and the fire still did not go out.
	Costs will increase with the number of resources used (especially heavy machinery) as opposed to setting up sprinklers.
	Not appropriate if there are issues with a limited water supply. The fire can re-ignite.
	Using helicopters increases the cost significantly and is not as effective to get water to penetrate deep into the pile.
	Transporting water to the location can be challenging in some areas.
	Excess run-off can occur on slopes due to the large amounts of water being used, potentially

Pros	Cons
	causing erosion or slash material to move downslope.

Types of resources

The most critical elements of the suppression effort when dealing with burning slash piles require an excavator and bulldozer working in tandem with a ground crew wetting down. Excavators were the most frequently mentioned resource used in skid site fires (Table 5). Excavators were used to pull apart piles and gain access to the seat of the fire. Water tankers were used to supply the suppression effort, which used portable dams and waterway equipment. Bulldozers were used but mentioned less frequently than excavators. Occasionally helicopters were used for suppression, and less frequently fire appliances and hand tools to get to the seat of the fire.

Table 5. Type of resources used to suppress skid site fires.

Resource	Times mentioned
Excavator	17
Tanker	13
Portable dams, pumps and foam	9
Bulldozer	7
Helicopter	6
Fire appliance	3
Ground crews with hand tools	2
Peat probe	1

Heavy Machinery

Machinery is key, regardless of the tactics being employed (extinguishment, capping etc.). Large excavators (20 tonne minimum) were generally used. These were equipped with grapple or root rake attachments, to allow the dirt to fall away from the combustible material. An excavator can pick up large logs due to the bucket with a “thumb” attachment. A land prep machine with a rake on the front of it instead of a bucket can also be used to shift logs and turn material over. Sometimes the excavator provided was too small for the job, which limited the work, and soon required replacing with a larger unit.

Bulldozers were used less often than excavators, due to being prone to burying material instead of removing it. However, they were sometimes used to good effect in conjunction with an excavator to push the material around after the excavator had removed it.

Another consideration with machinery is the cost of getting them to site. Often the locations are remote and there may be reluctance to commit the equipment. A common theme from the interviews was to spend money up front to save in the long run. Some forest and fire managers noted they were lucky if earth works gear was available on site or locally.

The effectiveness of machinery was well summed up by one respondent, where initially they pumped water onto it over a 2-3 week period with no success. Then the pile was opened with machinery (22t excavator and D6 dozer), wetting down the material as it was pulled out, and the pile was finally extinguished over 1.5 days.



Image 2. Example of an excavator with root rake (B. Janes, FENZ. Packhorse Hut, Gebbies Pass).



Image 3. Example of a bulldozer (R. McNamara, FENZ. Lunar Rd Skid Fire, North Bank, 2014).

Ground crews (people)

The number of fire crew required on site depended on the scale of the fire(s) and the time of the year (high or low fire danger). Based on the interviews, somewhere between 3 to 10 people were used to operate the waterway equipment. If the threat of escape was high, additional resources might be required to stamp out any escapes as the skid site is opened. Regardless of the number of crew, a constant rotation was recommended to ensure people were always on site to deal with any flare ups.

Several mentions were made of the need to have supervisors on site to monitor crews, weather and make decisions on the strategy. Another common theme mentioned was the need to use a firefighter's senses (smell, sight, hearing and touch), and there can be an over reliance on thermal cameras.

- **Sight includes:** White ash is a serious indicator of high heat. Sometimes heat waves can be seen in your view. Smoke in the canopy or at ground level is another sign. Steam following a short spray from a hose. Stump holes or old root balls completely consumed may hide pockets of hot material in the root system that need digging up.
- **Smell:** the smell of smoke as you approach smouldering fuels will smell different to the burnt vegetation surrounding.

- **Sound:** cracking and popping sounds of a fire can sometimes be heard as you approach.
- **Touch:** to find heat, experienced fire fighters can feel the fireline to ensure that all of the material close to the line is out. This is done carefully using the back of an ungloved hand.



Image 4. Example of ground crews, fire appliances and hoses to dampen down the fire (R. McNamara, FENZ. Waikakaho Skid Fire, 2014).

Water and Foam

While machinery is key, the use of water is critical and preferably used with a surfactant (e.g. Class A foam, or a hydroblender with soap capsules). A common theme from the interviews was the need for a continuous supply of water. This could be from a static water source (e.g. fire pond, river, stream, etc.) or via bulk water tankers and portable dams (e.g. 20,000L). The supply of water needed to be sufficient to keep the machinery working. This includes the waterway equipment to deliver the water from the water source to the fire, with appropriate volume or pressure pumps.

It was noted that use of Class A foam with water was more cost-effective than water alone, and several noted that using water alone was ineffective as it would just turn to steam. However, sometimes surfactant use was restricted due to cultural or environmental reasons (if near waterways or if the run-off will get into a waterway).

The foam mixture employed would depend on what the strategy was; e.g. trying to knock the heat out of the fire to open up the site, suffocate the fire or extinguish it. If penetration into the fire was desired, the foam mixture needs to be weak, otherwise it will form an insulation layer over the area. If wanting to suffocate the fire, a high-density foam (equivalent to shaving foam) should be used to help stop air getting to the fire. To take the oxygen away, a 2% - 3% concentration mix is needed to make a slurry so that it will stick and not run away. Either way, you need to look at what material, how much and how deep it is burning, and decide on the best way to deal with it and adapt the foam percentage accordingly.



Image 5. Example of foam used during suppression (Otago Rural Fire Authority).

Aircraft

A common theme from the interviews was that helicopters were ineffective for skid site fires. They were sometimes used for initial attack to stop the spread of the fire, or possibly held on site if there was an elevated risk from ember transfer or high values at risk. They were also occasionally used in initial stages for water transport if the area was remote and water supplies were not yet set up.



Image 6. Example of aircraft used during the suppression phase (R. McNamara, FENZ. Waikakaho Skid Fire, 2014).

Monitoring

Monitoring during the suppression and mop-up phases are exclusively done by sight, smell, hearing, touch and infrared/thermal cameras. Investigating for signs of heat is best done during the early hours of the morning (about 0600 hrs) where signs of heat can be easily picked up from the surrounding cool earth before the ground surface heats up from solar radiation. Monitoring starts off as regular/constant daily checks, for the first two weeks. Checks are then phased out over time from every 2nd day, to weekly and then monthly, until the forest owner is sure the fire is completely out.

Manual checks involved visiting the site on foot and placing the back of an un-gloved hand on the ground feeling for any signs of heat. The smell of burning, sounds of crackling and visual signs of smoke can also be picked up from ground visits. Another visual cue was signs of disturbance on the surface of soil-capped skid sites, where cracking, caving in or even heat and gases escaping from cracks were an indicator of combustion still occurring.

Thermal infra-red cameras were the most mentioned monitoring method, followed by experienced personnel using the manual methods identified above (Table 6). Thermal cameras were also useful for monitoring signs of heat over large areas and/or multiple skid sites. These cameras can be used from either in the air with helicopters or Unmanned Aerial Vehicles (UAVs), or handheld cameras with ground crews. A few respondents have used a metal rod to drive into the slash pile to detect heating of the rod through conduction to touch. One respondent mentioned the possibility of using satellite (IR) imagery.

The fire is considered extinguished when there is no heat detected with an IR camera or visual and manual observation identifies no presence of heat. A few fire managers stated the fire was not considered extinguished until they had dug down to mineral earth and found no burning material. Two other managers would, if they could, burn the pile until there was no combustible fuel remaining.

Table 6. Resources and technologies mentioned as being used during the suppression, mop-up and monitoring phases.

Resources and technologies	Times mentioned
Infrared / thermal camera	27
Back of hand, eyes, ears, nose	22
Drone / UAV	7
Metal rod	3
Dig to mineral earth	3
Satellite imagery	2
Weather stations	2
Fire as a tool	2

Thermal cameras

A common theme among all interviews was the use of thermal cameras, with some using them more extensively than others. Many noted the advancement of the technology over recent years and would consider using them if required. Thermal cameras were used at multiple stages; to identify possible areas before an outbreak of fire, during the operational phase and during the monitoring phase after a fire.

Many people noted caution with the use of cameras as they are only giving surface temperatures. Rules of thumb amongst many respondents were that surface temperatures below 50°C were typically considered of no concern, whereas temperatures greater than 50-70°C was considered as a trigger indicating burning below the surface.

Thermal cameras generally discussed were handheld (most commonly used), attached to a UAV (used extensively by some) or handheld from a helicopter (not often used now as UAVs are more prevalent). Satellite infra-red imagery was mentioned by few, as a tool to identify general areas of heat, that would then be inspected in person.

Although thermal cameras were discussed, a common theme reinforced was that you can't rely just on thermal cameras. You need to use all your senses (smell, sight, hearing and back of your hand to feel heat coming off the ground), and the thermal camera is just another tool that can help.

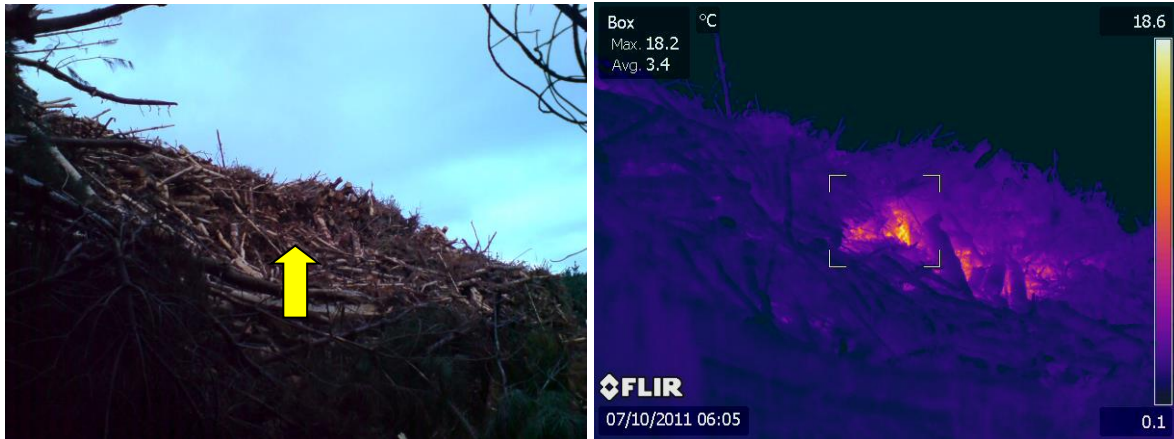


Image 7. Example showing thermal imaging and heat in a slash pile. The DOC FLIR 620 high resolution thermal camera was used to scan a super-skid of concern. Temperatures ranged between 20–60°C, indicating the early stage of organic decomposition (B. Janes, FENZ).

UAVs

The use of UAVs for thermal or aerial imagery was extensive in some locations. Benefits include checking over large areas to identify the areas of interest and concentrate resources. They also offer the ability to compare imagery over time to monitor the effectiveness of the suppression, or build-up of heat that may lead to a fire. They are also often used for identifying hot spots during mop up.

Other techniques:

Temperature probes

Heat probes (e.g. metal stakes or excavator bucket) were often previously used to identify the build-up of heat below ground. This technique was still sometimes used, but in many instances had been replaced by thermal cameras.

New heat probe technology, currently undergoing development and testing, has the capability to measure the internal temperature of piles by combining a long rod with a thermocouple temperature sensor. It has the potential to be used to remotely monitor and transmit pile temperature data during the different phases involved in spontaneous combustion of skid piles – during the heat build-up phase, once ignition has occurred, and following suppression to ensure the fire remains out.

Weather stations

Monitoring of on-site weather was often discussed, with particular attention given to tracking RH and temperature. A rule of thumb mentioned was that if the RH was less than 60%, then there was an increased chance of a fire happening outside the burn area. The use of portable weather stations was suggested and, if used, these should be installed quickly on site.

Gas analysers

The use of PID gas analysers (photoionization detector) was also mentioned. These are handheld devices which can produce instantaneous readings for gases associated with combustion. This was used to measure the gas content from vapour escaping from cracks in the soil cap. If the crack was releasing methane, it was a sign that decomposition was occurring within the pile. If the crack was producing carbon monoxide, it was a sign that combustion was occurring underneath.

Conclusion and Recommendations

This study produced a literature review, compiled a database of known slash pile fires, and consulted with forestry and fire sectors to investigate what is causing forestry skid site fires and how best to suppress them. The lessons learned from this study can be applied to minimise the risk of fire starts in slash stored at skid sites, and to better extinguish these fires when they occur.

Fire occurrence

Typically, fires originating outside of forests on neighbouring lands present the largest risk to plantation forests. However, the full scale of the problem is currently not well understood. We do not have a good appreciation of the true number of forestry fire incidences around the country, because most small fires are dealt with directly by forestry companies and go largely unreported. Skid site fires were previously captured by fire investigation reports when a claim was made on the firefighting fund. Now skid site fires are only logged through the 111 system when fire personnel are required to attend for suppression.

Slash pile fires appear to occur more often than commonly thought in New Zealand. Anecdotal evidence from one forest company indicated that 200 skid sites are being used on an annual basis, but that the incidence of skid fires within this area was very low, involving only approximately 0.3% of these skid sites. However, from our survey findings, 17 out of 26 respondents (65%) indicated that they had a slash pile fire occur in the last 10 years, with three quarters of these fires having occurred within the past 5 years. The majority (88%) of those fires were attributed to spontaneous combustion of the slash material.

There is not a lot of information on the topic of spontaneous combustion fires in production forests in the international literature. It is possible that some forest fires that have lightning listed as the cause may have actually been started by spontaneous combustion, but this can be difficult to prove (Armstrong 1973). Kourtz (1967) found that almost one-third of fires whose causes are attributed to lightning occur in dry snags, a material which could be susceptible to the processes involved in spontaneous combustion. As noted by Quintiere et al. (2012), spontaneous ignition as a cause of a fire can be easily missed by an investigator because the signs of spontaneous combustion are difficult to detect and are usually destroyed by the fire. In addition, there is a lack of information on the symptoms of spontaneous combustion in forest fuels in comparison to that of other piled organic materials, such as compost or hay.

Common factors associated with spontaneous combustion of slash at skid sites

A review of the literature revealed limited knowledge on the common environmental factors involved with the spontaneous combustion of forestry slash material stored at harvesting skid sites. A database was then built using information gathered from surveys, interviews and fire incident reports. To date, the database lists a total of 36 skid site fires and contains several environmental categories that we understand to affect a fire's behaviour. The information gathered was to identify where in the country these fires typically occur, how often they are occurring (is it a regular thing, or only occasional), and when they occurred (in a specific season or under certain fire weather conditions).

The information gathering phase was difficult. Fire investigation reports (a key requirement by the National Rural Fire Authority (NRFA) during the cost recovery phase) did not typically exist for fires in commercial forests. At the time, little documentation occurred because fighting these fires was a cost absorbed by the forest industry. It was also difficult to obtain information on fires older than 10 years, as key contacts have often retired or moved on.

Therefore, there was limited information available to identify what are the common factors associated with spontaneous combustion of slash stored at skid sites, and certainly not enough to

develop a predictive model. As a result, we focused on the analysis of weather conditions, which had the most complete dataset collated from the number of fires we had dates and times for.

This analysis revealed surprising results, including that these fires tend to occur during low to moderate fire weather conditions, rather than under the extreme conditions that one might expect. It also highlighted that rainfall and humidity play a key role in spontaneous combustion, which concurs with observations from forest and fire managers. It also highlighted that these fires occurred across the country and in all months of the year. This contrasted with what was previously thought about their seasonality being mostly during the months of spring and autumn.

Further research

With limited real-world evidence or literature on all of the three fire environmental factors, it is difficult to identify which factors play more of an important role than others. We have identified several knowledge gaps and recommend continuing to collect information on skid site fires as they occur. A reporting form has been created for forestry and fire managers to complete and send in (refer to Appendix A1). This will increase the number of fires in the database and, in future, allow for better identification of trends with other non-weather environmental factors.

A deeper scan of the literature could address some of the knowledge gaps and reveal the parallels with the spontaneous combustion of hay, sawdust pits/piles, bark dumps and even landfill refuse. These lessons could also help reduce spontaneous combustion fires in other woody biomass and vegetative residues stock-piled for large scale and long-term storage (e.g. for bioenergy fuels or wastes from essential oil extraction).

The weather data was only analysed on a national scale due to the limited number of fires for which data was obtained. In the future, if a bigger database is collated, it would allow for analysing at a regional scale and identifying trends, similarities and differences that may not appear at the national scale. We suspect differences in weather patterns and soil types will become apparent across different regions of the country.

Field trials could also be undertaken to monitor thermal activity (heat build-up). This would include documenting the fire environmental conditions (using the form in the appendix A1), setting up portable weather stations, and using thermocouple temperature measurement probes. The monitoring could include several skid sites across a forest area and across different regions of the country, various ages of skid piles (newly formed and older), and inserting temperature probes at various pile depths. This would help build a much better understanding of the processes involved, as well as the environmental factors contributing to increased risk of spontaneous combustion of slash piles at forestry skid sites.

Best practices for managing forestry slash to reduce the risk of fires starting

With a bit of planning, these types of fires can be avoided in the future. From the interviews, it is clear that industry is following guidelines and adjusting their practises as contributing factors are identified. Fire managers have not found metal contaminants buried in the slash at several recent fires following identification of their role in promoting ignition of slash piles. However, the fact that fires are still occurring at these sites indicates that there are still other factors at play. The literature review and interviews have revealed practical steps for forest managers to prevent, minimise, eliminate or monitor heat build-up in woody residues, along with useful risk assessment forms (Appendix A2 and A3) developed by industry to identify at risk sites.

The next steps could involve deciding if further guidance on slash management is needed by either updating the current guidelines on slash management practices (based on any gaps in the current guidelines) and/or establishing a more formal code of practise to minimise or eliminate the risk of future self-combusting slash fires.

We suspect that the difficulty of extinguishment of fire in forestry slash piles will change over the years with changes in forestry practises. Old practises included felling and delimiting trees in the bush. A sawyer/tree feller would also cut the log into lengths in the cutover which were then transported to the skid. With the arrival of more mechanised felling, the entire tree is now hauled to a central location and delimited. In the last 4 – 5 years, technology has changed with some

companies using delimiting machines to trim trees on site and therefore reducing slash and fine material building up at the skid site. Therefore, moving forward, we expect to see less skid site fires with a change in practises.

Best practice fire suppression techniques to manage slash fires

Based on the survey and interview findings, there are several clear but opposing strategies and tactics employed to deal with fires in forestry slash piles across the country. These are chosen based on decisions around the fire location, size of the skid, number of skids involved, the terrain (slope steepness), soil type, resources available, access, weather forecast, time of the year (season), nearby receptive unburnt vegetation, distance to water supply, cultural and environmental constraints, and neighbouring values at threat. It became apparent that there are no typical skid site fires, and what applied at one fire cannot be directly applied to another.

Maintaining relationships

If the forest owner or management company has requested help or advice from Fire and Emergency New Zealand to deal with a skid site fire, it is important to work closely with the forest company or contractor right from the beginning (this also applies to a forest or wildfire in the area). It is likely the forest company needs to continue operating in the area, and the tactics may need to be adjusted to allow logging to continue. It can be near fatal economically for a forest owner to halt logging for a length of time, as there are downstream issues if you hold a boat in the port waiting to export logs. Some situations can allow for harvesting operations to remain on-going in one area of the forest while suppression occurs in another. The sooner a skid site fire is under control, the sooner it can be handed back to a forest company.

Costs

Sub-surface slash fires can be difficult, time intensive and costly to fully extinguish during the drier parts of the year. Foresters, fire managers and the insurance industry have been surprised, at times, by the frequency and cost of fighting these types of fires across the country. The costs associated with suppressing even relatively small skid site fires can range from \$30,000 up to \$200,000 and more.

Depending on the tactics chosen, the cost of extinguishing a skid site fire can be expensive and time consuming. The costs associated depend on:

- The numbers and types of resources required. These can include helicopters, tankers (depends on water availability and potential need to ferry water in rather than pumping), ground crews, and heavy machinery (excavators and bulldozers).
- The number of days of suppression, which can range between two to five days up to two weeks or more.

Acknowledgements

Thank you to all the forest companies and Fire and Emergency New Zealand staff for taking the time to provide their insights into the survey and interviews. Many thanks are also extended to the NZ Forest Owners Association for distributing the survey questions on our behalf.

We also express our gratitude for the time taken by forestry managers, contractors and fire managers who provided information on skid site fire incidents, reports, photographs and their insights on causes and best suppression strategies and tactics.

We greatly appreciated the international scientists that provided links to grey literature on the spontaneous combustion of forestry harvesting residues or knowledge of reports and publications or other contacts that weren't available publicly online.

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Appendix A1. Form for skid site fires

Please fill out the following form to further build a database to identify the common factors on spontaneous combustion of slash at skid sites. Answer as much as you can.

Factors	Description
ICAD/report number	
Contact details	(name, email, number)
Confidence that it is spontaneous combustion?	(high/low) <ul style="list-style-type: none"> spontaneous combustion (smouldering/burning below) or has it been lit from a heat source on the top of slash?
Date noticed Time noticed	
What did you notice	(signs of combustion: smoke, flames, gases, cracks, heat, etc)
Terrain factors:	
Location of fire	(GPS co-ordinates or kml pin drop)
Flat or Slope	
Slope aspect	(N, S, E, W facing slopes)
Head/top of a gully?	If on steep terrain, where is it located? Is it exposed to wind, or wind channelled to aerate it further?
Soil type	(clay, sandy etc)
Skid capped with soil	(Y/N)
Skid compressed	(Y/N)
Fuel factors:	
Tree species	(single (Radiata), or a mix of species)
Type/size of vegetation	(needles, stems, roots, stumps, chipped wood, etc) (fine or large size material)
Moisture content of vegetation	
Time since logging Age of material	(how fresh/old was the pile contents, green material/dry/grey/red material)
Age of skid site Pile usage	(was it still being added to, over a length of time? Was it a fresh site, or was it no longer in use?)
Non-organic material added	(Y/N) (describe, e.g. wire rope etc)
Size of the pile/skid	
Pile depth	
Weather factors:	
Nearest weather station	
Climate leading up to fire	(What did you notice before the fire, i.e. several weeks of warm weather, then rainfall etc...)
Further comments:	

Appendix A2. Example Site Risk Assessment Template

Consider the risk factors and decide whether the risk is Low, Medium or High.
Identify any remedial work that may be undertaken to reduce the risk. Transfer the information to the "Skid Fire Prevention Schedule" form.

Skid: _____

Features	Description	Risk Factor (Y/N)
Fire threat	Dwellings within 1km	
	Third party assets downwind/uphill	
	Proximity early/mid rotation crop	
Ignition risk	West facing	
	No flat storage bench	
	Slash estimated greater than 3m	
	Slash not pulled back	
	Signs of rubbish buried in slash	
	Large volume of slash concentrated in small area	
	Cracking present across slash heap	
	Significant amounts of soil in slash	
	Slash pushed into a 'chimney' type gulley	
	Steaming or 'smoking' in early morning	
	Heat can be felt emanating from slash	
	Odour present downwind of slash pile	
Suppression factors	Clay available for capping	
	Water point nearby	
	Brigade within 10km	

Recommended Remedial work: _____

Low – do nothing

Medium – check on change of season

High – regular checking

Appendix A3. Form for Skid Fire Prevention Schedule

ID	Ignition Risk	Fire Threat	Water availability	Predominant Face/ Aspect	Fines / Dirt proportion	Compacted	Depth of Slash	Estimated Volume Slash	Temp Monitoring	Cap material	Recommended action	Notes (history ie Waratah)
Super skid example	High	Low	Bad						2 weekly Nov- March	Medium	Monitor the cap	Delimbed/Waratah

Appendix B. Common Weather Factors Analysis

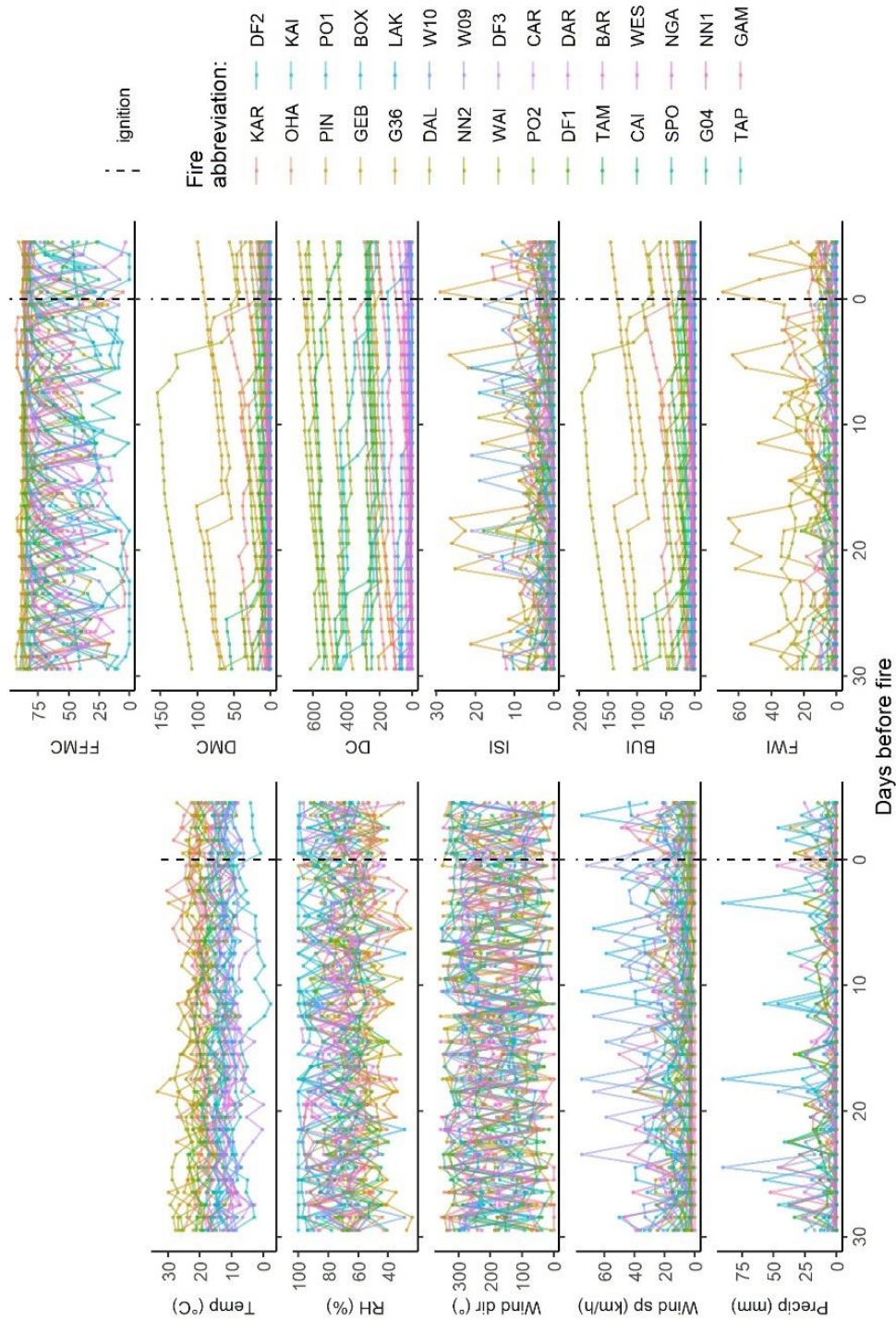


Figure B 1. These line graphs show the raw daily fire weather readings during the last 30 days before ignition. Each coloured line represents an individual fire from the database.

Table B 1. Summary table of the weather variables (min, max & mean) observed in the box and whisker plots (see Figure 2).

Variable	Min (across fires)	Max (across fires)	Mean (across fires)
Mean temperature (1d)	6.3	24.4	15.49
Mean temperature (7d)	5.37	25.64	15.78
Mean temperature (30d)	5.21	24.93	15.7
Mean RH (1d)	43	100	70.47
Mean RH (7d)	43.57	95.71	68.7
Mean RH (30d)	52.4	96.07	69.5
Mean wind direction (1d)	0	353	184
Mean wind direction (7d)	8.94	359.45	205.47
Mean wind direction (30d)	4.62	328.15	177.95
Mean wind speed (1d)	0	71.64	13.58
Mean wind speed (7d)	0.11	32.5	11.28
Mean wind speed (30d)	0.13	31.36	11.25
Mean precipitation (1d)	0	47.2	4.61
Mean precipitation (7d)	0	19.74	3.65
Mean precipitation (30d)	0.32	9.33	4.27
Days since rain	0	12	1.63
Last precipitation amount	0.2	47.2	5.86
Mean FFMC (1d)	8.81	87.73	66.19
Mean FFMC (7d)	23.97	86.35	68.19
Mean FFMC (30d)	21.08	85.82	65.99
Mean DMC (1d)	0.1	88.88	14.17
Mean DMC (7d)	0.27	88.74	16.3
Mean DMC (30d)	0.28	123.83	16.87
Mean DC (1d)	0.84	656.87	212.49
Mean DC (7d)	2.09	655.69	214.4
Mean DC (30d)	4.42	611	208.69
Mean ISI (1d)	0	17.76	2.86
Mean ISI (7d)	0.21	11.81	3.09
Mean ISI (30d)	0.14	11.36	2.94
Mean BUI (1d)	0.15	132.83	22.69
Mean BUI (7d)	0.38	128.89	25.08
Mean BUI (30d)	0.56	162	25.24
Mean FWI (1d)	0	32.06	4.34
Mean FWI (7d)	0.05	36.03	5.52
Mean FWI (30d)	0.04	34.33	5.46

Table B 2. p-values contributing to the spread of the NMDS and not contributing (which means they are similar across all fires). High P values (above 0.05) did not significantly contribute to the differences between fires (see Table 2).

Weather Variable	Different/ similar between fires	p-value	Weather Variable	Different/ similar between fires	p-value
Mean temperature (1d)	different	0.005	Mean FFMC (1d)	similar	0.855
Mean temperature (7d)	different	0.001	Mean FFMC (7d)	similar	0.306
Mean temperature (30d)	different	0.001	Mean FFMC (30d)	different	0.003
Mean RH (1d)	similar	0.322	Mean DMC (1d)	different	0.001
Mean RH (7d)	similar	0.333	Mean DMC (7d)	different	0.001
Mean RH (30d)	different	0.017	Mean DMC (30d)	different	0.001
Mean wind direction (1d)	different	0.003	Mean DC (1d)	different	0.001
Mean wind direction (7d)	different	0.003	Mean DC (7d)	different	0.001
Mean wind direction (30d)	different	0.001	Mean DC (30d)	different	0.001
Mean wind speed (1d)	different	0.002	Mean ISI (1d)	similar	0.341
Mean wind speed (7d)	different	0.004	Mean ISI (7d)	similar	0.214
Mean wind speed (30d)	different	0.007	Mean ISI (30d)	different	0.013
Mean daily precipitation (1d)	similar	0.691	Mean BUI (1d)	different	0.001
Mean daily precipitation (7d)	similar	0.453	Mean BUI (7d)	different	0.001
Mean daily precipitation (30d)	similar	0.337	Mean BUI (30d)	different	0.001
Last precipitation amount	similar	0.664	Mean FWI (1d)	similar	0.072
Days since rain	similar	0.94	Mean FWI (7d)	different	0.001
			Mean FWI (30d)	different	0.001

Appendix C. Forestry Survey Questionnaire

Participant Information Sheet

Skid site slash combustion questionnaire

Slash has been recognised as a potential fire hazard and there have been several instances of fires self-combusting in skid sites in New Zealand. These unintended slash fires can be difficult and costly to suppress and threaten key valuable assets such as forestry and neighbouring lands.

The questions we ask in this questionnaire are mainly about how slash piles are constructed at your skid sites; and parameters of slash pile fires that have occurred on your skid sites within the past five years. We are also wanting to assess the relative management practices relating to slash piles, even if you have not had a fire occur within this timeframe.

The survey will take around 15-20 minutes to complete, and there is no liabilities associated with taking part in this survey.

The findings from this study will help with informing industry best-practice guidelines for minimising, isolating or eliminating the risks associated with these types of fires.

Participation is voluntary and you have the right to withdraw before you complete the survey without any penalty. All data collected in the survey will be kept in secure facilities or in password protected electronic form. They will only be used for the purpose of this research.

If have any questions about the research or would like a summary of the results of the project, you can contact Veronica Clifford (veronica.clifford@scionresearch.com) or Karen Bayne (karen.bayne@scionresearch.com)

Survey Questions

Logging skidsite slash fires

Logging Slash Piles - Introduction

1. Tell us about yourself

Company Name:

Your Name:

Your role in the company:

2. Over the past 10 years, how many slash pile fires have occurred at your company skid sites?

None More than 10

1-5 I am not sure

6-10

3. And how many of these fires were due to spontaneous combustion ?

None

1-5

6-10

More than 10

I am not sure

4. Have you noticed any typical weather pattern in the lead up to these fires?

(e.g. a week or two after heavy rain with warm temperatures?)

Yes No

Logging skidsite slash fires

Slash management at the skid site

5. Are you currently moving harvesting slash into piles on a skid site or landing?

Yes [Go to Qu17](#)

No

Logging skidsite slash fires

About your slash piles

6. Over the past 12 months, besides piles, how else have you managed your harvesting slash? (Check all that apply)

- Logging slash has been scattered on skid sites / landings
- Logging slash has been left in the forest (i.e. not brought onto landing)
- Logging slash has been removed from the skid sites/ landings shortly after harvesting (i.e. not piled or scattered for a time)
- We only use slash piles
- Other (please specify)

7. If you are currently piling slash onto the skid site/ landing, please estimate:

Average number of piles produced per skid site/ landing

Average volume of each pile (m³) or provide the maximum height and diameter of an average pile

Where are the piles usually located on the skidsite/ landing (in the North; East; West; South)

8. Do your slash piles contain any of the following non-wood components?

	Yes	No	I don't know
Metal	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Glass	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fuel oil	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Wire rope	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

9. Please indicate the usual composition of the slash piles:

	Low proportion in pile	Medium proportion in pile	High amounts in pile
Soil component	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fine wood component (sawdust; chip; dried needles)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Larger wood component (Branches; Stems; Logs)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

10. Are you adding new slash to older piles at your skid sites/ landings?

- Yes
 No
 I don't know

11. What are the long term plans for slash piles currently on your skid sites/ landings?

Please indicate the proportion of piles that will be managed in this way (should sum to 100%)

Chip or mulch	<input type="text"/>
Fuelwood (hogwood; firewood)	<input type="text"/>
Composted	<input type="text"/>
Burned	<input type="text"/>
Transported/disposed off site as is	<input type="text"/>
Other use	<input type="text"/>

12. How long are most slash piles left on the skidsite/ landing for?

- less than 1 year 6-10 years
 1-2 years longer than 10 years
 3-5 years

13. Do you build harvesting waste slash into piles:

- Continuously throughout the year
 A few times a year
 Once a year
 Seasonally (please specify months)

14. Does your organization monitor slash piles for risk of spontaneous combustion?

Yes

No

[Go to qu 17](#)

Logging skidsite slash fires

Monitoring your slash piles

15. Which of the following actions are taken?

- Temperature check on interior of pile
- Moisture content check of interior of pile
- Visual assessment of pile
- Infra-red camera
- Other (please specify)

16. What other safety precautions are taken to manage the risk of smouldering combustion or pile reignition?

Logging skidsite slash fires

Actions if a fire breaks out

17. If a slash pile catches fire, what actions are taken to suppress these fires?

Logging skidsite slash fires

Best management practices

18. Has your organisation implemented any best management practices and/or guidelines for managing slash piles? If so, please indicate what these were:

19. Do you have any previous experience in managing a slash pile fire?

- Yes [Go to Qu 21](#)
- No

20. Can you recommend someone who has experience with slash pile fires?

Name

Email address

Cell phone number

Logging skidsite slash fires

Your past experiences

21. Have you had a slash pile fire occur within the past 5 years?

- Yes [Go to Qu 22](#)
- No [Go to Qu 36](#)

Logging skidsite slash fires

Please tell us about the skid site and pile where the fire occurred:

22. How large was the skid site

- Super Skid
- Smaller size skid site or landing

23. How long had the skidsite been operating at the time of the fire?

24. Where was the skid located (Please indicate to best of ability:)

GPS

Forestry road address

Forestry compartment number

25. What aged stand was being felled?

26. How large was the pile that ignited? Please estimate

Maximum height of pile (m)

Depth of pile (m)

Volume of pile (m3)

Age of pile

27. Was the slash capped with :

Soil

Other material (please specify)

28. If so, how deep was the capping material; was it compacted by heavy machinery?

Depth of capping material:

Compaction?

29. Was the slash pile:

Still being added to with new slash

No longer being constructed

30. What type of vegetation was in the slash pile?

Mostly crown

Mostly stems/ logs

Mostly roots and stumps

Mostly chip and small particles

31. How dry was the pile?

Very dry; dusty Very wet; waterlogged

32. How long after pile was constructed was smouldering detected?

33. How did you detect the smouldering?

34. What do you think might have been the main cause(s) of the pile ignition?

35. How long did it take for the fire to be brought under control?

Logging skidsite slash fires

36. Do you have any learning or recommendations for handling future slash pile fires? (What to do differently, what worked, what didn't?)

37. Would you be willing to have someone contact you to discuss in greater detail your experiences with slash pile fires? If so, please provide your details:

Ph number:

Email address:

Best time of day to contact you:

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Further thoughts

38. Is there any other information regarding slash pile fires that you believe would be a valuable addition to our study? Please outline this below:

Thank you for your assistance and contribution to this research study.

Appendix D. Interview Questionnaire

Interview participation information sheet

Participant Information Sheet

PROJECT: LOGGING SKIDSITE SPONTANEOUS SLASH FIRES

PURPOSE

The purpose of the project is to identify the main reasons that slash pile fires can spontaneously ignite at skid sites, and the best measures to prevent this from occurring or to suppress those that do occur. It is primarily a scoping exercise to determine safer management options for slash in the New Zealand commercial forest industry. The purpose will be accomplished through knowledge-sharing interviews (via phone or skype in lieu of face to face interactions) with key experts and those experienced in slash fire management within the forest harvesting and rural fire sectors. The research is being conducted by the Rural Fire Research Group, Scion, Christchurch.

WHAT IS INVOLVED?

Scion is interviewing key stakeholder groups that have experience with slash management, or slash fires on logging sites. As someone with a vested interest, your views are very important to our research and will help to identify any potential causes and possible solutions to mitigate future slash fire risk. Semi-structured interviews will be conducted and will take approximately 30-40 minutes.

CONFIDENTIALITY

Interviews will be recorded on digital recording equipment and later transcribed if consent is provided to allow us to better analyse the information. Your individual responses will remain confidential to the research team, and your name will not be linked to the transcription document or subsequent reports/papers. We are interested in the aggregate responses amongst different types of stakeholders and between different groups of people.

Electronic recordings and transcripts will be held in a secure data location on a SharePoint and will only be available to project team members. Information will be stored for five years following the project completion (30 June 2020) and then archived, following prescribed protocols.

PARTICIPANT RIGHTS

Your participation in this study is entirely voluntary. You have the right to:

- i. Decline to participate or to not answer any particular question
- ii. Withdraw from the study at any time during your participation
- iii. Withdraw permission to use the data collected at any time during the two-week period following your participation
- iv. Ask any questions about the study at any time during participation
- v. Provide information on the understanding that your name will not be used

CONTACT

If you have any questions about this research, or for further information, please contact:

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Interview Questions

Q1. What region are you based in?

Q2. How many years of experience do you have in fighting forestry fires?

- *Managing fire full time or part time?*
- *Number of fires*
- *Fireline days actively managing forest fires?*
 - *managers with the same number of years could have dramatically different experiences.*

Q3. Do you have any experience in fighting skid site fires? (Yes/No)

If yes, how many years of experience do you have with suppressing skid site fires?

Q4. How many skid site fires have you attended?

Q5. What was your role in the suppression effort?

- *What roles have you performed in fire suppression;*
- *What roles have you performed on active forest fires?*

Q6. Thinking back to skid site fires you've attended, did anything stand out to you as surprising or unique during the suppression effort?

Q 7. What strategies and tactics did you use to suppress a skid site fire?

- Did some techniques work better than others?
- What techniques worked well?
- What techniques didn't work so well?
- Did you have flareups again, or re-ignition weeks, or months later.
- If you had the opportunity, how might you fight this fire differently next time?
- For each method you tried, how much did it cost in terms of resource time/effort and money? (short/prolonged, easy/difficult, cheap/expensive)

Below are some of the strategies that could be used:

- *let it burn, create a deep wide fire break around it*
- *open it up to cool with heavy machinery*
- *not aerating by injecting water,*
- *apply water only – how much (surround and drown? Light soak)*
- *use different foam rates*
- *benching*
- *capping*
- *what other methods could be used not outlined above?*
- *What worked well, didn't work so well, what would you do differently next time*

Q8. What type of resources did you use to suppress the skid fires?

- *What worked well, didn't work so well, what would you do differently next time*

Below are some of the types of resources typically used:

- *Man power/Ground crews – hand tools (shovels, Pulaski's, water under pressure + with additives (soap, foam) – use of hoses or probes*
- *Heavy machinery (what types i.e. excavator, bull dozer)*
- *Aircraft, helicopters with buckets, or fixed wing aircraft, use of additives (retardants, soaps, foams)*
- *Mostly combinations of above*

Q9. Explore when they might employ each strategy (site conditions etc.) and what parameters of the pile (i.e. skid site size, slope or on flat, soil type, heavy material – logs/stumps) make each option more or less suitable?

(refer to their strategies talked about in Q7)

Some of the common strategies for pile extinguishment that came out of the survey findings:

- *Do nothing/monitor*
- *Dig out/extinguish (open it up and put water on it OR spread material over landing site)*
- *Trench and cap (and let it burn out)*

Q 10. What technologies have you used at these skid site fires?

(monitoring the skid site before it starts, during a fire and after a fire)

Examples could include:

- *bang a metal pole and leave it for a while, pull it out to feel hot how*
- *use of IR (infrared) cameras*
- *Use of satellites*
- *Use of UAVs*
- *Other, please list*

Q 11. How do you monitor the skid fire during the active suppression phase?

- *(This is where there are signs of flaming and smoking)*
- *Crew on standby or using a drone with IR camera*

Q 12. How do you monitor the fire during mop-up phase?

- *(This is where there little/no signs of flaming, but still have smouldering and smoke present)*

Q 13. How do you know that the fire is completely out? (are you using tools or technology to ensure its no longer hot)

- *Did you monitor the fire or leave this to forestry companies to sort?*
- *If yes, how often did the monitoring take (daily, weekly, monthly).*
- *How do you confirm that the skid fire was fully out?*

Q 14. Additional question, can leave this out if running out of time:

We are building a database of skid site fires where spontaneous combustion of the slash was the cause. Do you have any records of these types of fires to help us build a collection to identify the common factors that lead to combustion?

If Yes, we need the following information:

- *What date/time was it was first noticed (heat, smoke or flames)?*
- *Location for this skid site? GPS co-ordinates*
- *Size of the pile/skid*
- *How deep was the pile?*
- *Was it capped with soil?*
- *Was it compressed?*
- *What was the rough species in this*
- *What type of wood/vegetation was in the pile? (needles, stems, roots, stumps, chipped wood, etc)*
- *How fresh/old was the slash in the pile*
- *Was it still being added to or was it no longer in use?*
- *Was the pile dry or wet*