ENFO410 Independent Project Report

Investigating the Conditions that Affect the Burn Time of Radiata Pine Slash Piles.

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Abstract

Forestry slash is an unavoidable byproduct of forestry, and in more recent years, slash has become a problem for the industry. Although forestry slash has benefits it also has its draw backs if left unmanaged. One way to manage forestry slash is through burning. When done well burning can clear off slash in a controlled manner.

This study investigated the variables that could affect the burn time of slash piles. This was done at two different study sites. Located in the southern North Island, the first trial was in Te Namu Forest and the second was in Craig Dean Forest. From each forest 4 piles were investigated. Measures were derived for pile size, fuel contents (fine, medium, and heavy), and weather. These variables were also compared to Fire Weather Index components to see if further explanation for the burn time of the piles could be made.

Although some of the piles are still burning there were some key findings from this research. It was found that the size of the pile did not relate to the burn time as larger piles extinguished before smaller piles. Fuel content showed to be a stronger predictor of burn time as the piles with larger heavy fuel contents are still burning. High rainfall events such as one where 44.2mm of rain fell in day could impact the burn time of the piles. These were also backed up by the Drought Code (DC). The DC only dropped below 100 into the range where heavy fuels are easy to extinguish in the last five days of the trial. Before that heavy fuels were moderately to extremely difficult to extinguish.

Forest managers can utilise the finding from this report to determine how long piles may burn for and what factors influence this. Forest managers can then plan any burns they might do to factor in the contents of the pile, any significant rainfall events, and the DC.

Acknowledgements:

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1 Introduction:

Forestry slash is an unavoidable byproduct of forestry, and in more recent years, slash has become a problem for the industry. Slash is “any tree waste left behind after commercial forestry activities” ("NES-CF," 2017). Slash can be tree stumps, roots, branches, bark, slovens, logs and other organic material. This material is either transported offsite, piled up on the skid or left just off the side of a skid on a slash bank and it can be a considerable proportion of the volume harvest. In 2017, the average clearfell yield was reported to be $555m^3/ha$ ((Forest Owners Association, 2025)). Harvey (2022) found that an average bulk volume of 170 m3/ha of slash is piled up at landings after clear-fell harvesting has been completed. This means that left-over slash averages roughly 30% of the yield harvested from forests.

Although forestry slash has benefits, such as providing habitats for terrestrial and aquatic plants and animals, nutrients for the soil, and protection from rain for new crops, it can also be a risk (Ministry for Primary Industries, 2024). These risks include debris flow which can lead to property and infrastructure damage, environmental damage, and spontaneous combustion. Slash can be a hindrance not only to planting new trees but also to the development of those trees. Where slash is piled up off the sides of landings and skids, seedlings are not usually planted due to these areas being dangerous and challenging to access.

There are many ways to manage slash. The US Department of Agriculture Forest Service has suggested solutions such as scattering or burning slash in place, piling and burning slash, shredding then scattering slash, and chipping and hauling slash away (Groenier, 2008). In New Zealand, slash can be taken away and used for biofuel production, mulched, chipped and placed alongside landings or roads for erosion control, or burnt. This report will be looking at fire as a slash management option. Specifically, the burning of slash sitting on slash banks or piled up (“birds’ nested”) on the sides of landings.

This report will begin with a literature review on the use of fire for land preparation in New Zealand, examining the factors that affect the duration and effectiveness of slash burns. This will also cover the methods available for measuring and analysing these factors. The objective of this study will be stated, followed by the methodology. This methodology includes a description of the site conditions, along with an explanation of the fire management practices that will be used to ignite each pile safely. The results will be presented and then discussed in detail, after which a conclusion will be drawn.

2 Literature Review:

History of Fire Use for Land Preparation:

Fire has been used in New Zealand as a land clearance method for the last 1,000 years since the arrival of the Polynesian people (Pearce et al., 2008). It is thought that Māori had decreased forest cover from about 80% when they first arrived to 50% by the time that Europeans arrived (Pearce et al., 2008). Prior to the 1990's fire was used as a method for weed control, slash management through broadcast burning of cutovers, and for the control of wilding pines (Richardson, 1993). Fire was also used then as a land preparation tool on terrain that machinery could not operate (Richardson, 1993). However, around the early 1990s, the use of fire as a land preparation tool decreased due to concerns about the loss of organic material, smoke pollution, and costs (Richardson, 1993). Therefore, these practices had been reduced by larger forest companies in New Zealand at the time.

Although fire is a helpful tool for slash management, there are some drawbacks to the method. Such drawbacks are an ineffective fire that can burn too hot and intensely, leave behind partially burned material, remove too much litter and topsoil, and can burn uncontrolled into areas that were not supposed to be burned. Done well, this practice can clear off any unwanted material, such as slash and weeds, cleanly and in a controlled manner. (Forest Industries Training, 2005). However, the difficulties associated with controlling fires, particularly as workforces decreased and forest managers became less familiar with fire has meant that the use of fire for managing slash residues has decreased over time. Burning is recognised as the alternative managers turn to when other methods such as storing slash in positions where it is unlikely to be mobilised (Spinelli et al., 2018) transporting for chip wood or biomass are not viable (Barker et al., 2025; Spinelli et al., 2018; Udali et al., 2024). Cost analysis has also shown that costs of burning are invariably higher than expected (Barker et al., 2025).

For all the negative press, authors also recognise that burning slash has its place (Barker et al., 2025; Spinelli et al., 2018; Udali et al., 2024) and as new regulations push forestry companies in New Zealand to eliminate slash from positions in which heavy rain events could see that slash mobilised, fire is making a comeback. That is bringing back into focus what we do know and do not know about how to burn safely and cost effectively. The emphasis in New Zealand research over the last few decades has been on protecting the plantation resource from wildfire (Pearce et al. 2008). While various authors make recommendations on how to burn effectively (e.g., Barker et al., 2025) recent improvements in tools for describing slash piles (e.g., Harvey, 2022) to enable more effective prediction of fire behaviour have not yet been incorporated into research practice. A key recommendation of Barker and their colleagues (2025) in their assessment of the costs and constraints of forest residue disposal by pile burning is that more research is required to improve understanding and efficiency of pile burning practices. The purpose of this research study is to start to fill that gap.

Fire Life Cycle:

Fire requires three elements: oxygen, heat, and fuel. If one of these elements is removed, fire cannot be created or maintained. . Oxygen from the air allows combustion to occur. Heat from a flame, spark, or friction starts the combustion process, and fuel is the material that burns (Forest Industries Training, 2005).

Fire has three main phases. Pre-ignition is the first stage where solid fuels are heated, dried and partially volatilised. Then, the flaming combustion of the gases, and finally, the smouldering or charcoal phase (Sullivan & Ball, 2012).

In the pre-ignition phase, the fuel is heated by heat transfer from adjacent fuels that are either already burning or hot or from an ignition source such as a flame or spark (Sullivan & Ball, 2012). From here, the unbound water found in or around the fuel starts to evaporate. Then any extractives in the fuel start to evaporate into gas, and pyrolysis of the solid fuels starts to occur (Falk, 2012).

The second phase is the flaming combustion phase. Any gases produced during pre-ignition are ignited and oxidised, which is when flames are generated. This is the phase in which fires achieve their maximum heat. Typical wildfires can produce temperatures from 400 to 1,000℃ (Falk, 2012).

The last phase is the charring or smouldering phase. This occurs when combustion becomes incomplete due to char residue cooling below the ignition temperature (Sullivan & Ball, 2012). This process will continue until the fuel no longer gives off enough gas to support flames, and will smoulder until fully extinguished if not impacted upon to burn again (Falk, 2012).

Factors that Affect Fire:

Many factors influence how efficiently a fire burns, such as the moisture content of the fuels, the types of fuel present, the size and arrangement of the fuel, and what direction it faces. The following points will discuss these factors.

Fuel Moisture

Fuel moisture, also known as moisture content, refers to the amount of water present in the fuel. Wood is a porous material that contains air, water, and other wood substances. As a result, the weight of wood is not constant. Wood can lose or gain moisture due to environmental conditions such as those stated above. There are two states of water found in wood. The first state is absorbed or free water, which is found in the cell lumens or intercellular spaces. The second state is adsorbed or bound water within the cell walls (Walker, 2006).

Free water is the first to be removed while drying. Once all the free water has been removed from the wood, that piece is now at the fibre saturation point. The fibre saturation point is when the cell walls are fully saturated with bound water or when the cell wall is completely swollen with water. The fibre saturation point is found at 25 to 35% moisture content (Walker, 2006). The remaining bound water in the cell walls can remain within the wood even under very low humidity levels. This means energy (>20 kJ/mol) is required to break the bonds between the water and cell walls to completely dry the wood (Walker, 2006).

Fuel moisture can significantly affect burning efficiency. If the fuel is very moist, energy must first be used to dry it out before it can be converted into a gas for combustion. This increases the duration of the pre-heating stage and the initial energy required to ignite the fuel (FENZ, 2019).

There are many ways to measure moisture content. Most of these measures only work over a narrow range of moisture contents. However, the oven drying method is suitable for all types of moisture content. This method limits the size of the samples, as they need to fit inside the oven. This means that the samples selected must reflect what the moisture content of the pile is likely to be. This method involves measuring the samples' weight while wet, then drying them in an oven at 105 °C. The samples are weighed every 4 hours until there is a weight change of less than 0.2% over 24 hours (Mikulová et al., 2014). This method is simple and suitable for any starting moisture content. However, this method does limit the size of the sample.

Fuel Types

Fire and Emergency New Zealand (FENZ) categorise fuels into three types: fine, medium and heavy/coarse fuels (Figure 1). These fuel sizes link to the Fire Weather Index (FWI), which classifies sizes for both above and below-ground material.

Fine fuels are usually the first to ignite. They carry fire rapidly and can pre-heat surrounding fuels. They lose moisture easily and ignite easily. Fine fuels include grasses, fallen leaves, pine needles, and small twigs (FENZ, 2019).

Medium fuels include scrub, branches, young trees, manuka, gorse, and coastal vegetation. These fuels require more time to dry out and will not ignite until after the leading edge of the fire front passes. Medium fuels produce hot fires that spread rapidly (FENZ, 2017).

Heavy/coarse fuels are large, dense, woody, or deep organic materials. They are hard to ignite, but once they are on fire, they are hard to extinguished. Heavy fuels will produce high-intensity fires. Heavy fuels include stumps, logging slash of mature trees, wind-felled trees, and native trees (FENZ, 2017).

Fuel density		Description
Fine fuels		These are fuels that lose moisture easily and dry out quickly. Dry fine fuels ignite easily and can carry a fire rapidly. In most cases fires start in light fuel and spread to other fuel types. Examples are grasses, fallen leaves, pine needles and small twigs.
Medium fuels		These require more time to dry out and are too large to start a fire by themselves. Medium fuels produce hot fires. Examples are scrub, branches and young trees.
Heavy fuels		These are usually difficult to ignite. Once on fire heavy fuels produce high intensity fires and are difficult to put out. Examples are stumps, logging slash of mature trees, native forest and peat.

Figure 1: Description of fuel types (FENZ, 2017).

Pile Composition

FENZ (2019) notes that fires spread through four main vectors. The first is through radiation, where rays from burning vegetation travel in all directions to heat the unburnt vegetation near it. The second method is conduction. Different substances conduct heat at different rates. Wood is a poor conductor of heat compared to substances like metal. The following method is through convection. As the fire gets hotter, the air around it starts to heat. The heated air rises and can pre-heat fuels above the fire. This rising air can also carry ash, embers and small pieces of burning fuel. The final method is ember transport. This is where embers are transported by the wind, convection columns or by rolling downhill and can ignite dry fine fuels.

The shape and size of the pile can affect how the fire spreads. Fire spreads much faster vertically than horizontally (Forest Industries Training, 2005). This means that taller piles will burn faster due to the pre-heating of materials through radiation and convection. Compared to piles spread out flat, the fuels are only heated through radiation. Piles that are more spread out will naturally dry out faster than those piled high. This is because the spread-out pile has a larger surface area for natural drying than taller piles with more fuel inside, which are not drying out as effectively. Therefore, taller piles tend to be wetter.

The arrangement of the fuels can increase their rate of combustion. A pile with lots of airspaces will burn faster up to a point than a pile with few airspaces. The airspaces increase airflow through the pile, allowing combustion to happen faster (Forest Industries Training, 2005).

There are many ways to measure the size of a pile. One such way is the ground-geometric method. This method uses similar shapes to determine the gross volume of a pile. There are seven geometric shapes that a pile can be compared to, and each shape has its volume formula (Casey, 2015). This method is only good if the pile is on flat ground so that a reliable height can be measured and has well-defined edges to the pile for accurate width and length measurements. Another method is using a laser rangefinder to define the pile shape. This method uses a laser to mark perimeter and height points along the outside surface of the pile from a known location. These points can create a triangular irregular network (TIN), and the volume can be calculated from that model. This method is more accurate than the ground-geometric method but requires a clear perimeter around the pile to measure the laser points (Casey, 2015). The last method uses photogrammetry. Photos are taken of the pile and then used to construct a point cloud. The point cloud can then be converted into digital elevation models (DEMs), and the pile's volume can be calculated using a ground datum (Riedinger & Harvey, 2021). This method can be used on any terrain. This method is very accurate, provided the photos have a low ground sampling distance (GSD), which is how much area is covered in each image pixel.

Fire Weather Index:

The FWI is made up of six numerical ratings. Three fuel moisture codes: fine fuel moisture code, duff moisture code and drought code. There are also three fire behaviour indices: initial spread index, buildup index and fire weather index. The fuel moisture codes provide ratings on the dryness of each of the fuel types. The fire behaviour indices provide ratings for various aspects of fire behaviour, including rate of spread, amount of fuel available to burn, fire intensity, and difficulty of control. The FWI system uses inputs such as temperature, relative humidity, wind speed, and 24-hour accumulated rainfall to calculate its indices (Clifford & Anderson, 2009). Figure 2 shows how these codes and indices are used to build up the FWI.

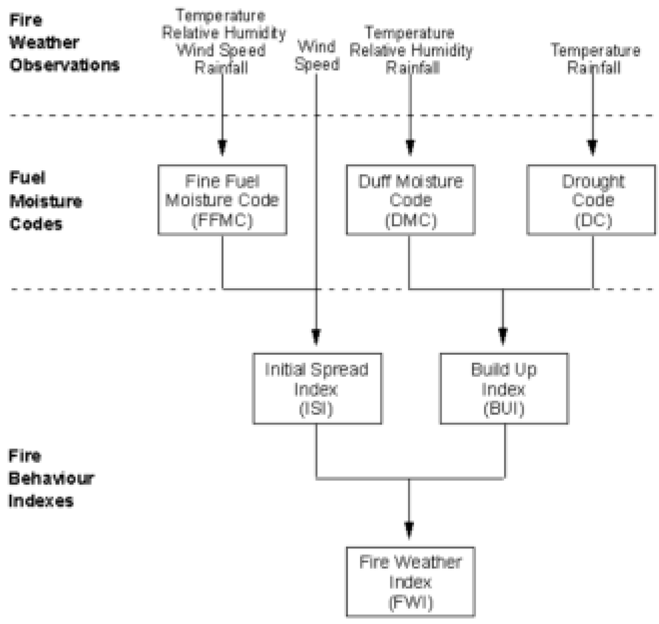

Figure 2: Structure of the FWI system.

Fine Fuel Moisture Code

The fine fuel moisture code (FFMC) is a rating of the moisture content of surface litter found at depths of 0-50mm and other fine fuels. Some examples of fine fuels are dead pine needles, small twigs and cured grass on the forest floor. Fine fuels are susceptible to all four weather inputs because they have small diameters and a larger surface area-to-volume ratio. The fine fuels have a time lag of two-thirds of a day or 16 hours to reflect the rapid change to fuel moisture levels. It has a rainfall threshold of 0.6mm, meaning that rainfall below this level will not affect the FFMC. Ignition of these fuels will not easily occur at values under 70. While values above 92 are where fine fuels will be highly susceptible to ignition (Clifford & Anderson, 2009).

Duff Moisture Code

The duff moisture code (DMC) is a numerical rating of the moisture content of loosely compacted organic layers, for depths of 50-100mm, and of medium-sized dead woody material with diameters of 50-300mm. Due to these fuels having deeper layers and being larger in size, they take longer to dry out. The DMC has a rainfall threshold of 1.5mm and a time lag of 15 days. For DMC values below 30, fuels are unlikely to go through a complete burn, and values above 40 indicate that burning in these layers will be intense and complete (Clifford & Anderson, 2009).

Drought Code

The drought code (DC) represents the moisture content in deep organic layers found 100-200mm below the surface fuel layer. The DC indicates the likelihood of deep-seated burning in the deeper organic layers and large woody material with diameters greater than 300mm, such as logs and branches. The DC has a rainfall threshold of 2.9mm and a time lag of 53 days. Values below 100 indicate that it is easy to extinguish deep materials and logs, while values over 300 mean that these materials are extremely difficult to extinguish (Clifford & Anderson, 2009).

Fire Behaviour Indices

The first of the fire behaviour indices is the Initial Spread Index (ISI), which combines wind speed with the FFMC to show the expected rate of fire spread. These values range from 0-16+, where values from 0-3 show a slow rate of spread and values over 16 represent extremely fast rates of spread. The second of the indices is the buildup index (BUI). The BUI is a combination of the DMC and DC to indicate how much fuel is available for burning. This index can show if there could be difficulties with controlling and extinguishing fires. Values for the BUI range from 0-60+. the FWI combines the ISI and BUI to show fire intensity and to indicate general fire danger. Low fire intensities have values of 0-5, while extreme intensities are values over 30 (Clifford & Anderson, 2009).

3 Objectives:

Given that there appears to be little documented evidence of the relationship between different factors known to impact burn time of slash piles, this study aims to analyse different factors by investigating the weather leading up to the burns, fuel moisture content, and the size of the piles. The results will help inexperienced forest managers and owners to understand how long it could take for slash piles to burn completely.

4 Method:

Forest 360 and Ernslaw One had plans to conduct slash pile burns as part of their harvesting cleanup. This research project collected its data alongside these operations.

All piles were ignited using a flammable napalm. During the burn, all piles were left untouched to burn naturally unless they needed to be controlled, at which point Forest 360 or Ernslaw One would decide what to do. Preventative measures such as water tanks and pumps were onsite, and the slash piles had a 24-hour watch in place. The piles were then monitored daily until Forest 360 or Ernslaw One decided it was no longer required.

Site Description:

Part of the trials were conducted in Craig Dean Forest North owned by Forest 360 (Figure 4). However, only four of the piles were investigated as they were all less than a year old. This is the age range that forest managers are normally dealing with as they want to be replanting the area within a year of it being harvested. Craig Dean Forest is located near Hunterville in the southern North Island (Figure 3). The piles investigated were 6, 9, 10, and 11 (Figure 4). The second location where data was collected is Te Namu Forest. This forest is also located near Hunterville (Figure 6). The piles that were looked into at the location have been circled (Figure 5). Both of the forests have large cutover areas and steep slopes. The landings where slash is kept within the forest are all on the tops of ridges or next to steep slopes, meaning that slash banks have been constructed to hold any slash pulled up to the landings.

Figure 3: Location of Craig Dean Forest.

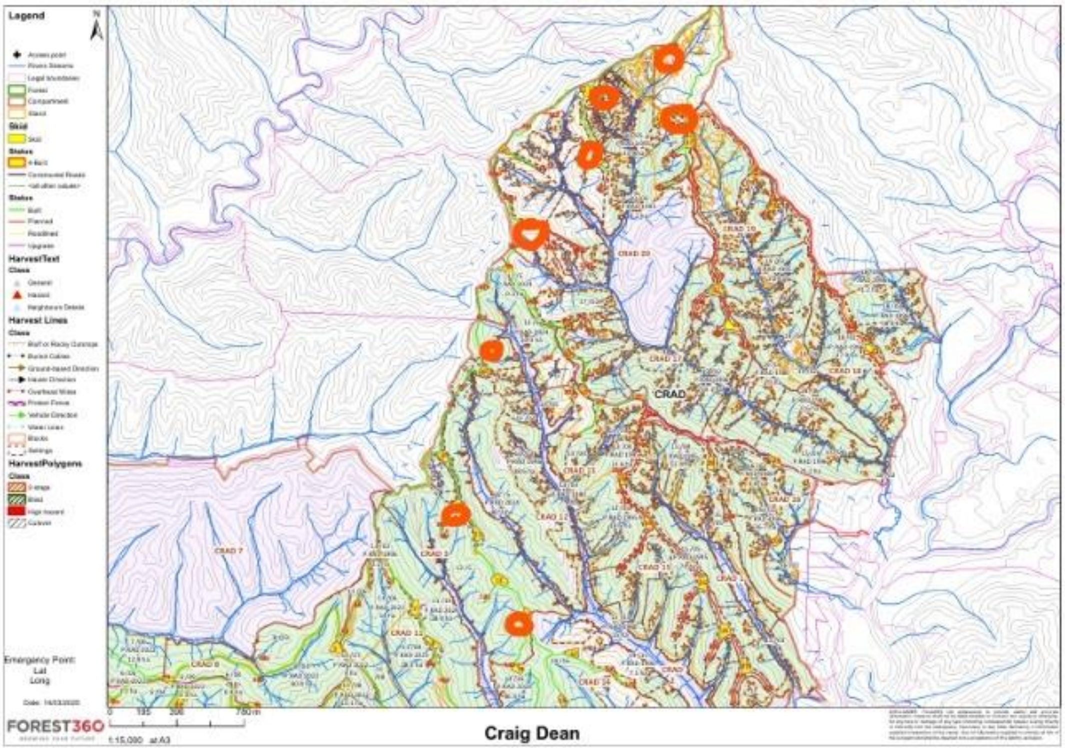

Figure 4: Slash pile locations within Craig Dean Forest.

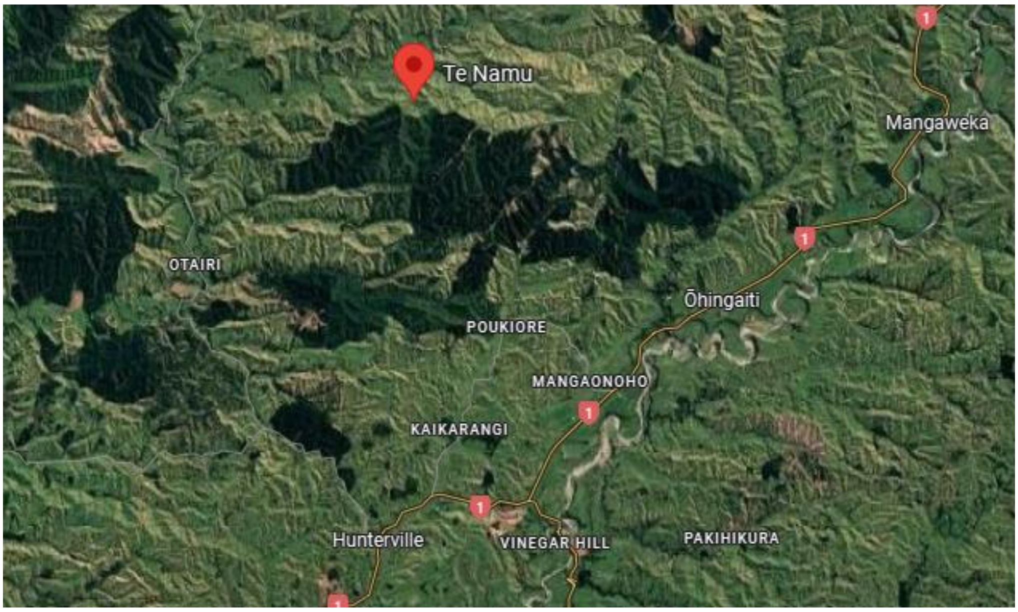

Figure 5: Location of Te Namu Forest.

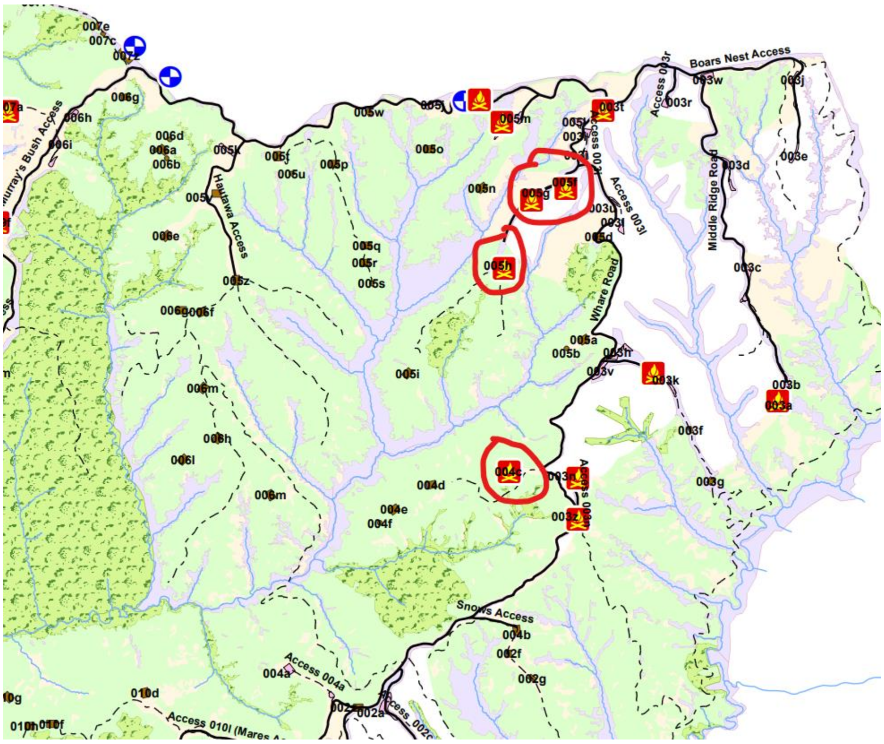

Figure 6: Slash pile locations within Te Namu Forest.

Pre-Burn Preparation:

A drone was used to take photos of the piles. The drone did two flyovers. The two fly overs were initially done to see if either method produced better images but, in the end, both sets of images were combined and used at the same time. The first was a preprogrammed flight with a ground sample distance (GSD) of 1.5cm and an overlap of 80%. The drone flew straight lines over the top of the pile and then did one lap around the perimeter. The next flyover was manually directed. The GSD and overlap are unknown for this flight, but the GSD is smaller than the preprogrammed flight as the drone flew closer to the piles to capture more detail. First, a lap around the outside of the pile was done, and then the drone did subsequently smaller circles until it reached the centre. This process was done for the piles before and after the burns.

During Burn Data Collection:

A Kestrel portable weather station was used to measure the weather factors affecting the burns. Kestrels can be mounted on a tripod and feature additional attachments, such as a wind vane for measuring wind direction. The Kestrel is capable of measuring 11 different weather factors. The factors being measured for this investigation were wind speed, relative humidity, and air temperature. The Kestrel was set up to record the weather during the initial days of the burn, the day of the burn, and the day after. The Kestrel was placed in a shady spot so that the sun did not affect any temperature readings, and away from any smoke so it did not affect any other readings. The Kestrel was programmed to take readings every 15 minutes for air temperature (°C), relative humidity (%) and wind speed (km/h). This data was then uploaded to an Excel sheet where average temperatures, relative humidities and wind speeds were calculated.

Post Burn Data Collection:

For the weeks and months after ignition, the average air temperature (°C), relative humidity (%), rainfall (mm), and wind speed (km/h) were recorded daily using a weather station located inside Te Namu Forest. This information was used to see if the weather might significantly impact the burning length.

Data of the piles were collected weekly. Photos of each pile were taken and recorded in an Excel spreadsheet with the ongoing status of each pile, whether it is still burning or not, along with the date the pile was checked.

For this paper, the definition of fully extinguished is when the ground is cold to the touch, the fire is fully extinguished. This data was recorded until the piles had extinguished or until the 17th of September.

From each pile, three wood samples were collected and weighed onsite for their initial starting weight. These samples were placed in an oven at 102°C and weighed daily until the weight of the samples stopped decreasing and became stable.

Data Analysis:

Pile contents

The drone photos were used first to categorise the fuels found in the piles. The categories are based on the FENZ fuel classes of fine, medium, and heavy fuels (Figure 1). The photos were imported into ArcGIS Pro. Polygons were drawn around the different fuel types. The areas of the polygons were then added up based on the fuel types. These totals were then converted into percentages of fine, medium, and heavy fuels within each pile.

Pile size

The second use of the drone photos was to create 3D models of the piles. Using Agisoft Metashape, a dense point cloud was created that was then used to create a digital elevation model (DEM) and orthographic of the piles. The DEM and orthographic were then imported to RoadEng10. Points of interest were located for both the before and after models of the piles, which were then used to shift the piles into alignment with each other horizontally. Then the DEMs were converted into triangular irregular networks (TIN) models, and contour elevation lines were created. These contour lines were then used to shift the models vertically to line up with each other. After both the horizontal and vertical shifts had been completed, a surface boundary was placed around the pile, and using the surface/volume calculation within RoadEng10, the volumes of the piles could be determined.

Moisture content

The moisture content of the piles was calculated using the oven drying method. Three wood samples were taken from each pile. These samples were weighted onsite for an initial weight reading. They were then sealed up in a container and taken back to the School of Forestry, where they were weighed again before drying in the oven. The scales used have an accuracy of 0.1% weighing to the nearest gram. The samples were then dried at 103 degrees until they had a consistent weight over three days. Equation 1 shows how moisture content can be calculated from these weight differences. Where m1 is the original weight and m2 is the weight after drying.

$$MC = \frac{m_1 - m_2}{m_1} \times 100\ (\%) \qquad [1]$$

5 Results:

As of the 17th of September, piles 6, 10 and 11 are still burning. On the 7th of July, all Te Namu Forest piles were reported extinguished. As well as Pile 9 in Craig Dean Forest on the 18th of July.

Pile Size and content:

The largest pile was 5 from Craig Dean Forest, with a volume of 2,633m^3, while the smallest pile, 3, was from Te Namu Forest at 900m^3 (Table 1). Craig Dean Forest had the larger pile sizes, with an average of 1,973m^3. In comparison, Te Namu Forest's piles were smaller, averaging 1,390m^3.

Table 1: The volume of material burnt in each pile.

Craig Dean	Pile 6	Pile 9	Pile 10	Pile 11
	1,581m^3	2,128m^3	1,511m^3	2,633m^3
Te Namu	Pile 1	Pile 2	Pile 3	Pile 4
	1,200m^3	960m^3	900m^3	2,500m^3

The contents of the piles could only be analysed for Craig Dean Forest due to the availability of drone photos (Table 2). The majority of the piles consisted of heavy fuels, ranging from 63% to 75% with an average of 70.25%. Fine fuels were the second most prevalent fuel in the piles, ranging from 17% to 24%. The lowest were the medium fuels, making up an average of 9% of the total fuels.

Table 2: Percentage of fine, medium, and heavy fuels present in each pile.

Craig Dean	Pile 6	Pile 9	Pile 10	Pile 11
Fine	17%	24%	22%	19%
Medium	8%	13%	6%	9%
Heavy	75%	63%	72%	71%

From the pile sizes, it is hard to determine if they are a major contributor to the burn time, as two of the three largest piles are extinguished (piles 4 and 9) while smaller piles 6 and 10 are still burning. Most of the piles are made up of heavy fuels, which are the logs, stumps and deep fuels. These are the fuels that burn the longest. Pile 9, which has been extinguished, had the lowest proportion of heavy fuels at 63% and the highest amount of fine fuels at 24%. While the other piles, which are still burning, had larger percentages of heavy fuels.

Initial Moisture Content:

From the oven dry method, the average moisture contents of samples from each pile are in Table 3 below. Pile 3 in Craig Dean Forest had the highest moisture content at 45.6% while pile 2 in that forest had the lowest at 28.7%. The Te Namu Forest piles had a closer moisture content, ranging from 30-40%.

From Table 3 the initial moisture content of the piles is not a good indicator of how long the piles will burn for. This is due to pile 9 having the highest moisture content but being the first pile to be extinguished in Craig Dean Forest. This is further confirmed by the Te Namu Forest piles having higher moisture contents that piles 6 and 11 which are still burning. It was expected that piles with lower moisture contents would extinguish first as having dryer fuels would allow the fuels to be consumed faster.

Table 3: Average moisture contents of the samples from the day of burning.

Craig Dean	Pile 6	Pile 9	Pile 10	Pile 11
	28.7%	45.6%	41.2%	29.3%
Te Namu	Pile 1	Pile 2	Pile 3	Pile 4
	32%	30%	36%	40%

Weather:

Since the first burning in Te Namu Forest on the 3rd of June till the 17th of September, 263mm of rain has fallen. Since the piles in Craig Dean were ignited later, the total rainfall is less at 234mm. One month into the burns on the 3rd of July, the highest amount of rainfall was recorded at 44.2mm (Figure 7).

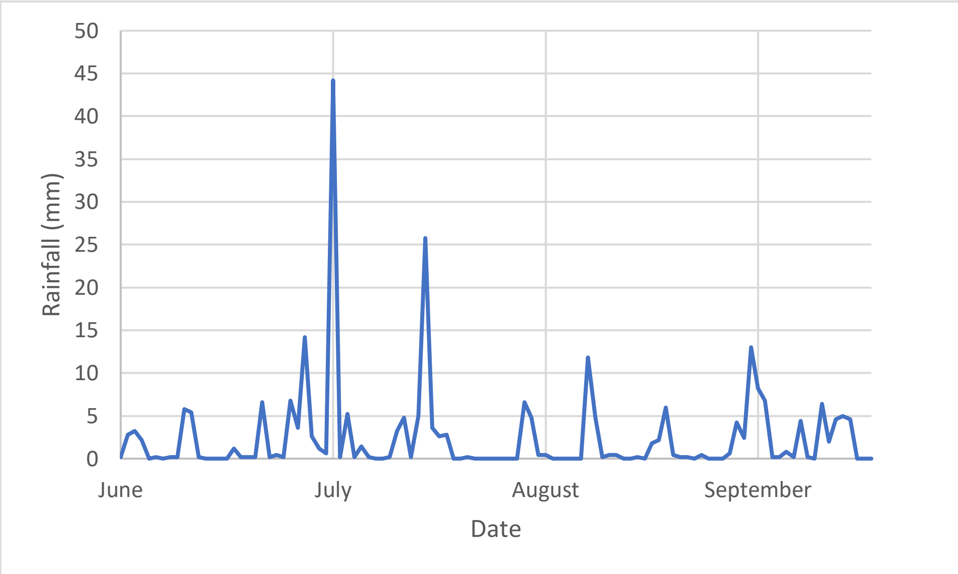

Figure 7: Rainfall recorded from Te Namu Forest since burning.

The wind speeds varied day to day, with a highest wind speed of 25.4 Km/h and a low of 4.3km/h (Figure 8). The average wind speed across the recorded period was 9.5km/h.

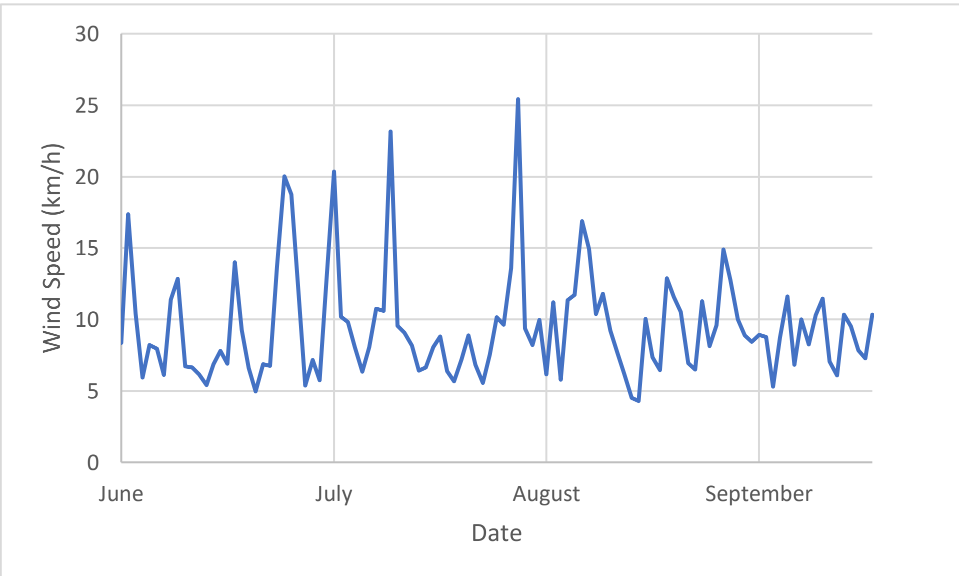

Figure 8: Wind speeds recorded in Te Namu Forest since burning.

The humidity in Te Namu Forest did not vary much; most of the data ranged between 68% and 96% with the exception of the 25th of July, when the humidity dropped to 33% (Figure 9).

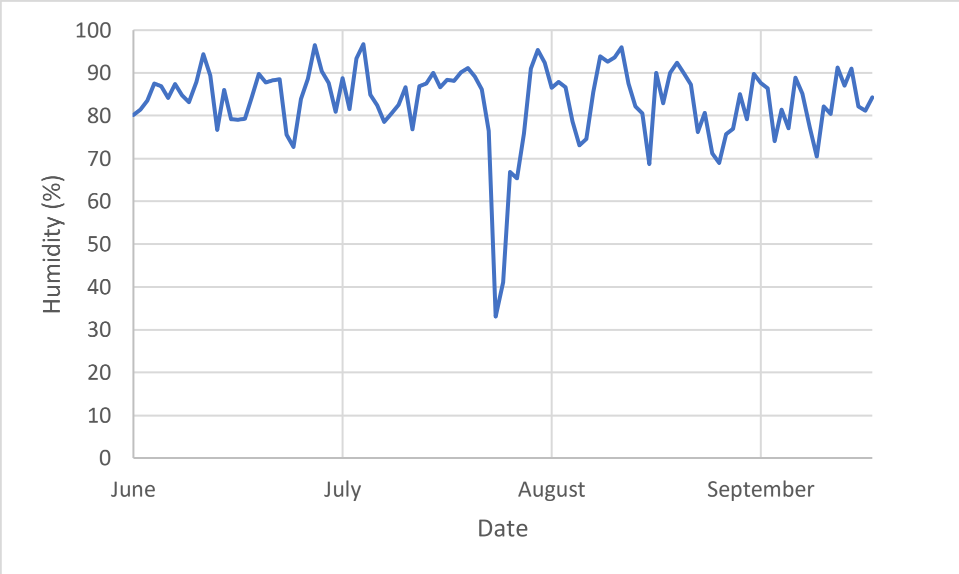

Figure 9: Humidity recorded in Te Namu Forest since burning.

The temperature recorded in Te Namu Forest changed daily, with some variations being significant. The largest daily change occurred between the 4th and 5th of July, where the temperature dropped from 13.1 to 5 °C (Figure 10). Overall, the average temperature was 8.1°C for the forest, with a maximum recorded temperature of 13.2°C and a minimum of 3.1°C

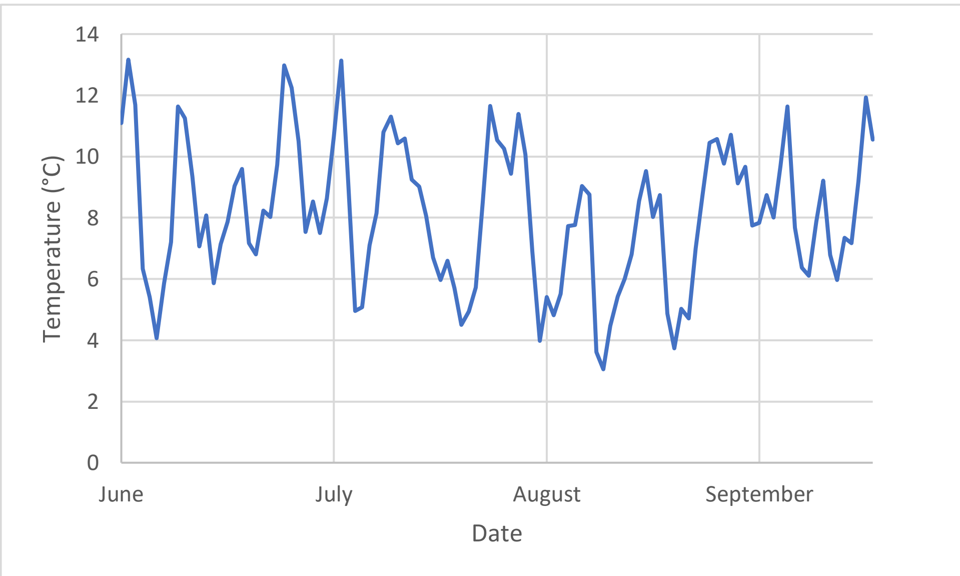

Figure 10: Temperature recorded in Te Namu Forest since burning.

Fire Weather Index:

The FFMC fluctuated significantly due to its short time lag of 16 hours, making it highly susceptible to changes in weather conditions. The minimum value of 8.8 sits within the range of 0-74, which is where fine fuels are difficult to ignite and flame easily (Figure 11). The maximum value of 85 indicates that these fine fuels are easy to ignite, as this range falls within the 85-88 range. On the burn day for Te Namu Forest, the FFMC was 81.4, while it was 81.1 for Craig Dean Forest on its burn day. These values both sit within the 75-84 value range, which is where fuels are moderately easy to ignite. Since fine fuels are small, they easily go through complete burning and will do so quickly, so these fuels are the determinant of how a fire initially spreads. The ISI is governed by the FFMC and wind speed. This relationship can be seen in Figure 11 as when the FFMC changes, so does the ISI. The ISI shows how fast a fire may spread on a given day. For the Te Namu Forest burn day, the ISI was 2.7, which indicates that the rate of spread will be slow. For Craig Dean Forest, the ISI was 3.6, which means that the rate of spread could be moderately fast.

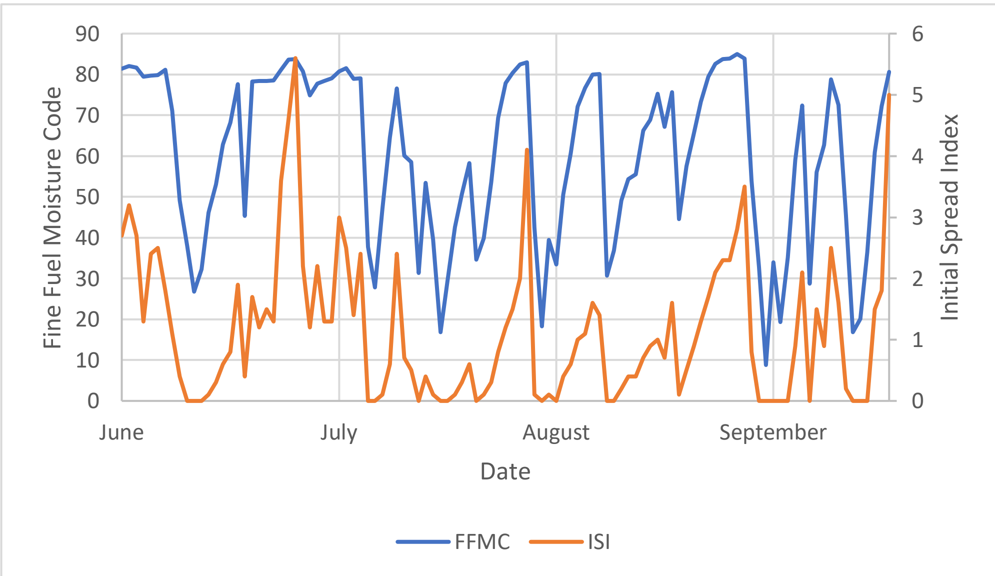

Figure 11: Daily FFMC and ISI ratings for Hunterville.

Initially, when Te Namu Forest did their burns, the DMC was high with values above 50, indicating that fuels would undergo intense and complete burning (Figure 12). This dropped one week after the burning to less than 10, which is where the burning of the medium fuels is limited. When the Craig Dean Forest burns started, the DMC was down to 2.8. This meant that getting the logs to ignite initially was challenging, and the burning of the fuels limited, potentially resulting in incomplete combustion, where consumed material could be left behind. Since these medium fuels make up on average only 9% of the pile's content (Table 2), the burning of these fuels is likely to have been impacted by the burning of other fuels, such as the heavy fuels that burn for longer and with greater heat and intensity.

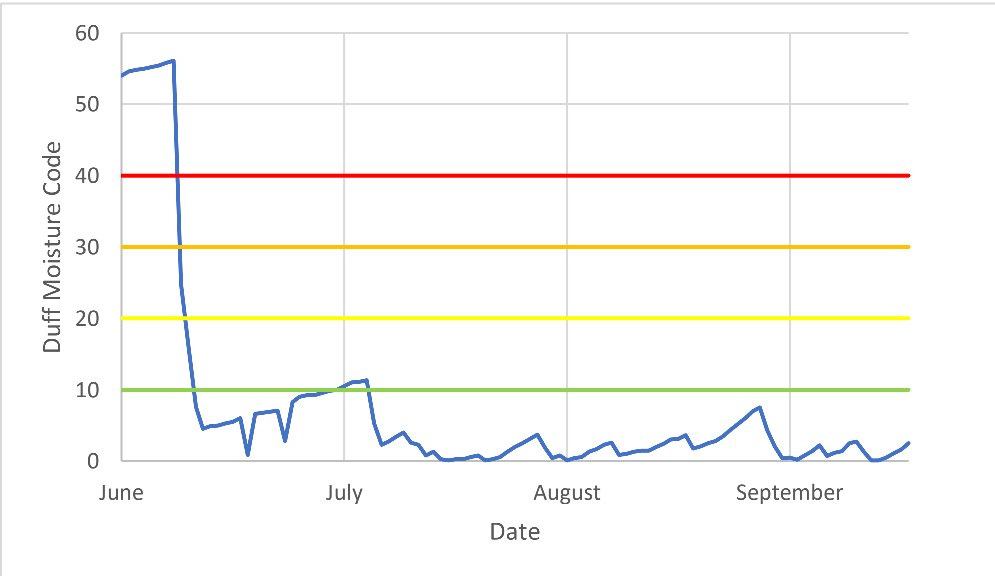

Figure 12: DMC values for Hunterville.

At the start of the burning, the DC was very high with a maximum value of 597.5 (Figure 13). The values above 300 indicate that it would be extremely difficult to extinguish, which is where the data was from the 3rd of June to the 8th of July. From the 8th of July to the 16th of July, the DC was between 251 and 300. In this range, deep and heavy fuels would be difficult to extinguish. The next range is 176 to 250. This is where the code was for the longest time (17th of July to 30th of July). This is where deep and large fuels are difficult to extinguish. The code stayed in the next range from the 31st of July to the 10th of September, before dropping below 100 into the final range. This final range is from 0 to 100 and is where deep material and logs would be easy to extinguish. Due to the deep and heavy fuels making up the majority of the pile's contents it is likely that this is why the remaining piles have not been extinguished yet.

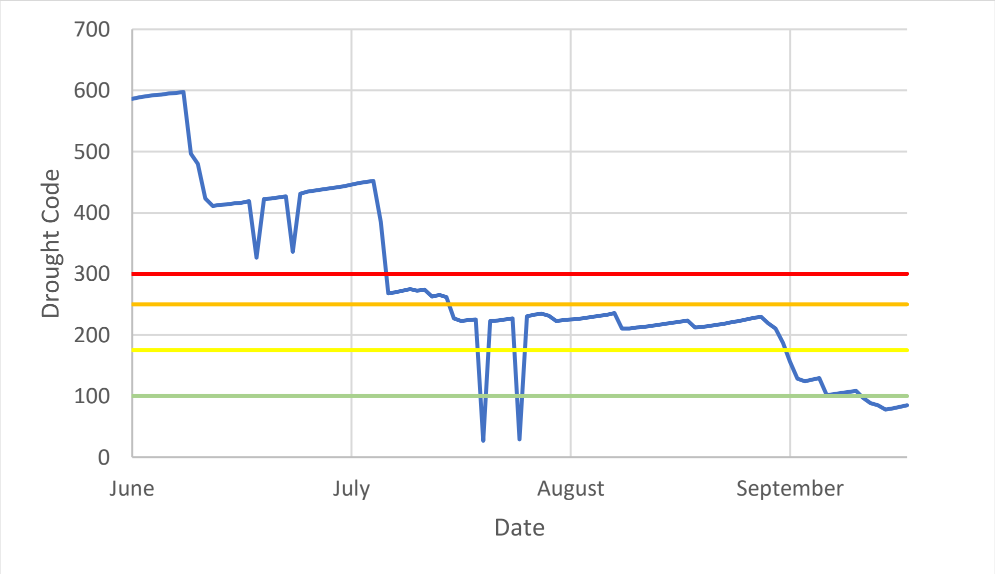

Figure 13: Daily DC values for Hunterville.

The Buildup Index indicates how much fuel is available for burning. Towards the start of the Te Namu burn period, from June 3rd to June 10th, the values exceeded 80, indicating extremely high fuel availability on those days (Figure 14). However, most of the days the piles have been burning have had values below 15 indicating that there has been low fuel availability, which means that fuels may have higher moisture contents and will need to preheat to become available for burning.

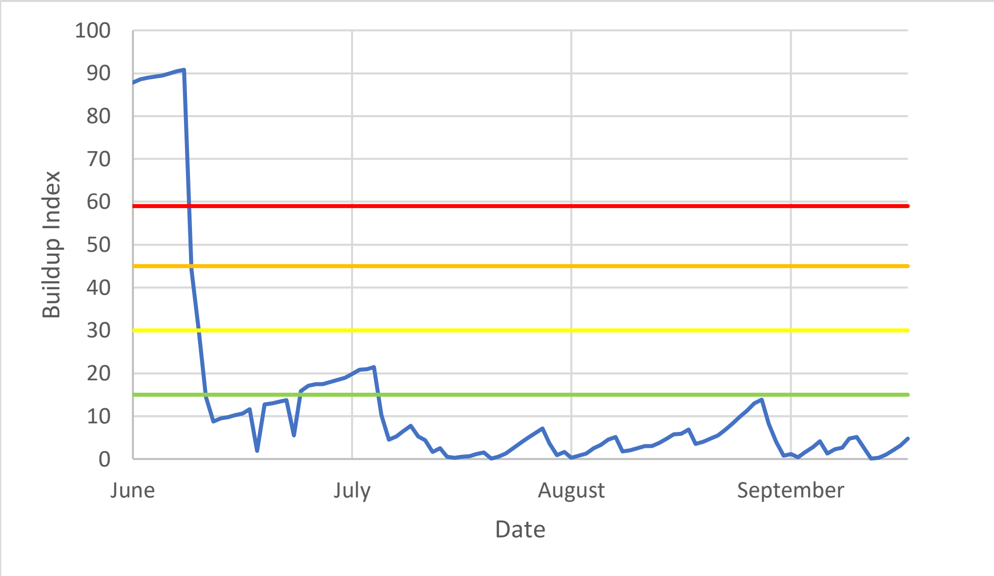

Figure 14: Daily BUI values for Hunterville

For the duration of the burns, the FWI was at either a moderate fire intensity with values between 6 and 12 or low fire intensity with values of 5 or less, except on one day (4th of June), where the FWI was high (Figure 15). Since the Te Namu Forest burns were ignited on the 3rd of June, when the FWI was at 11.3, the intensity of these fires was expected to be moderate. While on the 25th of June, when the Craig Dean Forest piles were ignited, the FWI was at 2.7, which is low.

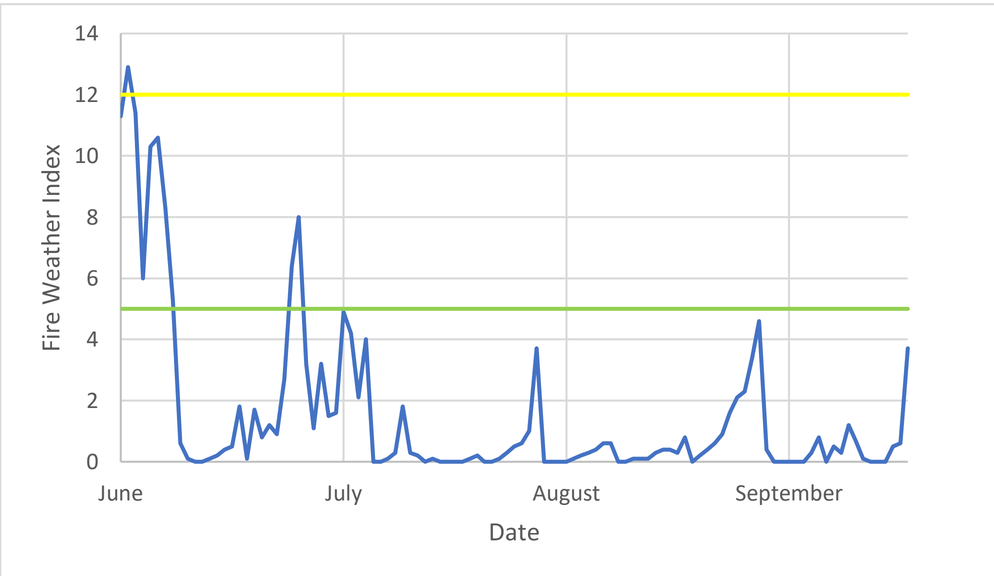

Figure 15: Daily FWI values for Hunterville

6 Discussion:

Although the piles are still burning, characteristics such as pile size, initial moisture content, wind speed, FFMC, and ISI do not appear to correlate with the burn time of the piles. However, there are still some indicators of what factors have impacted burn time in this instance such as pile contents, rainfall, humidity, temperature, DC, BUI, and FWI. The composition of fuel content was a better indicator of burn time than the size of the piles, as the piles with larger amounts of deep and heavy fuels are still burning compared to those with lower concentrations. While having a larger pile did not seem to indicate a longer burn time due to larger piles being extinguished before smaller piles.

Rainfall could also be a determinant of burn time, as four days after the maximum rainfall of 44.2mm, the piles in Te Namu Forest were recorded as extinguished. While having high humidities and low temperatures for the duration could slow down the burning, which is reflected in the DC and BUI decreasing.

Having high DC values has prolonged the duration of the burns, as having the deep and heavy fuels makes them difficult to extinguish, which means they burn for longer. External factors, such as rain, would have a difficult time getting to the heat sources to dampen and cool these fuels down. Te Namu Forest started with higher codes for DMC, DC, BUI, and FWI, which could explain why those piles burned through and extinguished faster than the piles in Craig Dean Forest, which had much lower codes at the time of burning.

There were two limitations to this study, one of which was that drone imagery was only available for Craig Dean Forest and not Te Namu. This meant that the pile sizes for Te Namu are not as accurate as the measurements for Craig Dean. Not having the drone photos for Te Namu meant that only pile contents could be determined for Craig Dean. So only comparisons on pile contents could be drawn from the Craig Dean piles. From the drone images that were captured for Craig Dean Forest the before and after images did not have matching alignments. This meant that manual adjustments had to be made and this means that there is some error in the determined piles sizes.

The other limitation of this study that could be researched further was the definition of extinguished. Determining a definition of extinguished beyond "Dig it up, pour water over it and use the back of your hand to check there is no heat left" (FENZ, 2022) would be very useful. As the trials were done in different forests each person had different interpretations to what extinguished was despite having the definition above. Te Namu Forest piles were confirmed extinguished after they had planted new trees in the black despite smoke still being present in photos, meaning that the soil still might be hot in places. If there were a more definitive way of determining what extinguished is, then there would be less variation between results.

7 Conclusion:

The objective of this research project was to analyse the different factors that affect the length of time slash piles burn. To try and achieve this, drone images of the piles were captured. The images were used to create 3D models to determine the size and contents of the piles. Weather data was captured from within the forest, and Fire Weather Index variables were collected for the area. Although some piles are still burning, the definition of extinguished was interpreted differently in each forest. From the variables captured, it could still be determined that the pile size did not seem to affect the burn time, while fuel content did.

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