FINAL REPORT

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Moisture content and ignition probability in chip fuelbeds along BC Hydro's Northwest Transmission Line right-of-way

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INTRODUCTION

BC Hydro's Northwest Transmission Line (NTL) runs 344 kilometres from the Skeena Substation near Terrace north to a new substation near Bob Quinn Lake. Clearing of the right-of-way (ROW) began in January 2012. In some sections the trees and shrubs were chipped and spread across the ROW. In September 2013, we conducted fieldwork along a recently cleared section to determine ignition probability and potential fire behaviour in the chipped woody debris. Data collected at that time indicated that the surface layer in the open ROW can dry quickly, making it receptive to ignition and allowing it to sustain low to moderate intensity burns (Hvenegaard 2013).

Our 2013 fieldwork was conducted after a short drying period in weather conditions up to the 75th percentile (i.e. low to moderate fire hazard conditions). However, potential fire behaviour along the NTL ROW during an extended period of drought when fire hazard is high to extreme is still a concern for BC Hydro and provincial wildfire managers. Documented observations and empirical studies of fire behaviour in masticated (i.e., chipped or mulched) fuels under high fire hazard conditions are few. As well, the fuelbed along the NTL ROW is a unique fuel environment and previous work in other masticated fuel environments may have limited application.

We returned to the NTL ROW in August 2014, and again in September 2014, to measure fuel moisture and record ignition potential under extremely dry conditions. While there we also collected fuel load data along the 1L387 ROW, which runs parallel to the NTL. The 1L387 is an older ROW cleared and maintained using conventional practises. We have already collected fuel load data along other older BC Hydro ROWs to assess potential fire behaviour (Hvenegaard and Schiks 2013) and the data we collect from 1L387 will add to that dataset. BC Hydro and provincial wildfire managers are also interested in how a fuelbed of compacted wood chips changes over time and how that affects ignition potential and fire behaviour. So, for 2014, we were trying to answer the following questions:

1. How will drought influence fuel moisture within chipped fuels?
2. How will drought affect ignition probability and potential fire behaviour in chipped fuels?
3. How does a fuelbed of wood chips change over time? How will these changes influence ignition potential and potential fire behaviour?

4. What are the differences in fuel environments and fire behaviour potential between the NTL ROW and the older 1L387 ROW?

METHODS

Study Sites

Moisture Sampling Sites

In 2013 we collected moisture samples from a single site—at Kilometre 6.5 on the South Fulmar Road. For 2014, we sampled from several sites along the ROW from structure 82-1 on South Fulmar Road to structure 103-2 near Nass Camp.

Ignition Probability Test Site

We conducted ignition probability tests south of structure 85-1 at Eider Creek (Figure 1). The fuelbed here appeared to be undisturbed since the spreading and compacting operations in July 2013. The ROW consisted of three distinct fuel zones: the open ROW (30 m wide); an adjacent buffer zone to the west (5 m wide); and adjacent standing timber to the east.

Figure 1. Eider Creek study site looking south (left) and north (right).

The open ROW (Figure 2) had no overstorey and was a continuous layer of chipped woody debris. Most of the chips were less than 1 cm in diameter. The fuelbed depth ranged from 15 to 30 cm.

Figure 2. Open ROW at the Eider Creek study site.

In the adjacent buffer zone, the surface layer consisted of leaves and grass with a small amount of woody debris. There was abundant Fireweed and the shrub layer consisted primarily of Thimbleberry, various Willow species, and Trembling Aspen saplings (Figure 3).

Figure 3. Vegetation in the adjacent buffer zone at the Eider Creek study site.

In the adjacent standing timber, the overstory was a mix of Western Red Cedar, Western Hemlock, Subalpine Fir, and Trembling Aspen. The surface layer consisted of a thick layer of twigs, leaves, and needles (Figure 4).

Figure 4. Surface fuels in the adjacent standing timber at the Eider Creek study site.

Fuel Load Data Collection Sites

The 1L387 ROW originates at Terrace, BC and runs north to New Aiyansh, BC. It is approximately 100 km long and parallels the NTL. It was cleared in the mid 1960s and is regularly maintained. We collected fuel load data at two sites along 1L387. The first was adjacent to the Eider Creek study site (Figure 5), and the second was at structure 88-1 (Figure 6).

Figure 5. Fuel load data collection site at Eider Creek on the 1L387 ROW.

Figure 6. Fuel load data collection site at structure 88-1 on the 1L387 ROW.

Weather Data Collection

The closest weather station was at Nass Camp, 14 km from the Eider Creek study site (Table 1). The British Columbia Wildfire Management Branch (BCWMB) provided us with historical and current weather data, as well as calculated Fire Weather Index (FWI) values. We used the historical data (2003–2013) to determine historical averages and them to the averages recorded for 2014.

Table 1. Study site and weather station locations.

Location	Coordinates	Elevation
Eider Creek Study Site	N 55° 09.06 W 128° 58.69	250 m (est.)
Nass Camp Weather Station	N 55° 17.30 W 128° 59.60	191 m

We also recorded temperature, relative humidity, and wind speed at each sample site and for each ignition test using a Kestrel 3500 pocket weather meter.

Fuel Moisture Sampling

We dug twenty moisture-profile pits at different sites along the NTL ROW. At thirteen sites we recorded the depth of the fuelbed and collected samples at six intervals: surface, 5 cm, 10 cm, 15 cm, 20 cm, and at mineral soil. At seven sites we collected samples at four intervals: surface, 5 cm, 10 cm, and 20 cm.

We also collected samples at the ignition probability test site at Eider Creek. We collected a sample from the surface just prior to each ignition test in each fuel zone for a total of 39 samples. We collected three additional samples from the surface layer and at 2 cm to see what variation, if any, occurred within the top layer.

Each sample was sealed in an airtight container and transported to the drying lab at the University of Alberta. Technicians weighed the samples (wet weight), oven-dried them at 100°C for 48 hours, and weighed them again (dry weight). The difference between wet weight and dry weight equals water weight. The ratio of water weight to dry weight gives moisture content and can be greater than 100%.

We had also collected moisture-profile data from four pits in 2013. That data was never presented, so we include it in this report. In those pits, we sampled at the surface and at 10 cm intervals down to mineral soil.

Ignition Probability Tests

We conducted the ignition probability tests in each of the three fuel zones (open, buffer, and timber). The ignition probability of a surface layer is determined using a match-drop test (Schroeder *et al.* 2006; Beverly and Wotton 2007; Schiks 2013). A successful ignition is when the fuels continue to burn for two minutes. The test starts by dropping a single, lit wooden match on the fuelbed. If the first try is not successful, it is repeated using two matches. If the second try is not successful, it is repeated with three matches. If no sustained burning occurs after the third try, the test is considered a failure.

We placed several numbered pin flags in a row within each of the three fuel zones on similar slope and aspect. Each hour between 13:00 and 17:00, we randomly chose a number and conducted a match-drop test at that numbered pin flag in each fuel zone.

Fuel Load Data Collection

Following the sampling protocols described in the Alberta Wildland Fuels Inventory Program Manual[1], we measured dead-and-down woody debris, regeneration (saplings and seedlings), and the shrub layer along four transects within the 1L387 ROW. Because 1L387 is narrow (30 m), we had to slightly modify the protocol for transect placement. We calculated fuel loads according to Delisle and Woodard (1988).

RESULTS

Weather Analysis

The Drought Code (DC) and the Duff Moisture Code (DMC) are numerical ratings for the average moisture content of subsurface forest fuels: the higher the value, the drier the fuel (Van Wagner 1987). The DC reflects the moisture content of deep layers 10 to 20 cm deep, and the DMC reflects the moisture content of loosely compacted layers 5 to 10 cm deep. The DC and the DMC are the best indicators of drought conditions (Lawson 1977). The Build Up Index (BUI) is a combination of DC and DMC and is a relative measure of the amount of fuel that becomes available for combustion as drying occurs (Hirsch 1996).

[1] http://wildfire.fpinnovations.ca/145/AlbertaWildlandFuelsInventoryProgramFieldSamplingManual2014.pdf

The 2014 fire season was abnormally hot and dry. Weather records from the Nass Camp weather station showed that the DC was well above the historical average for most of the fire season and approached the historical record high (Figure 7). The DC during our study was between 504 and 563, near the 2014 maximum of 570. The DMC during our study ranged from 15 to 44. The maximum DMC recorded in 2014 was 71.

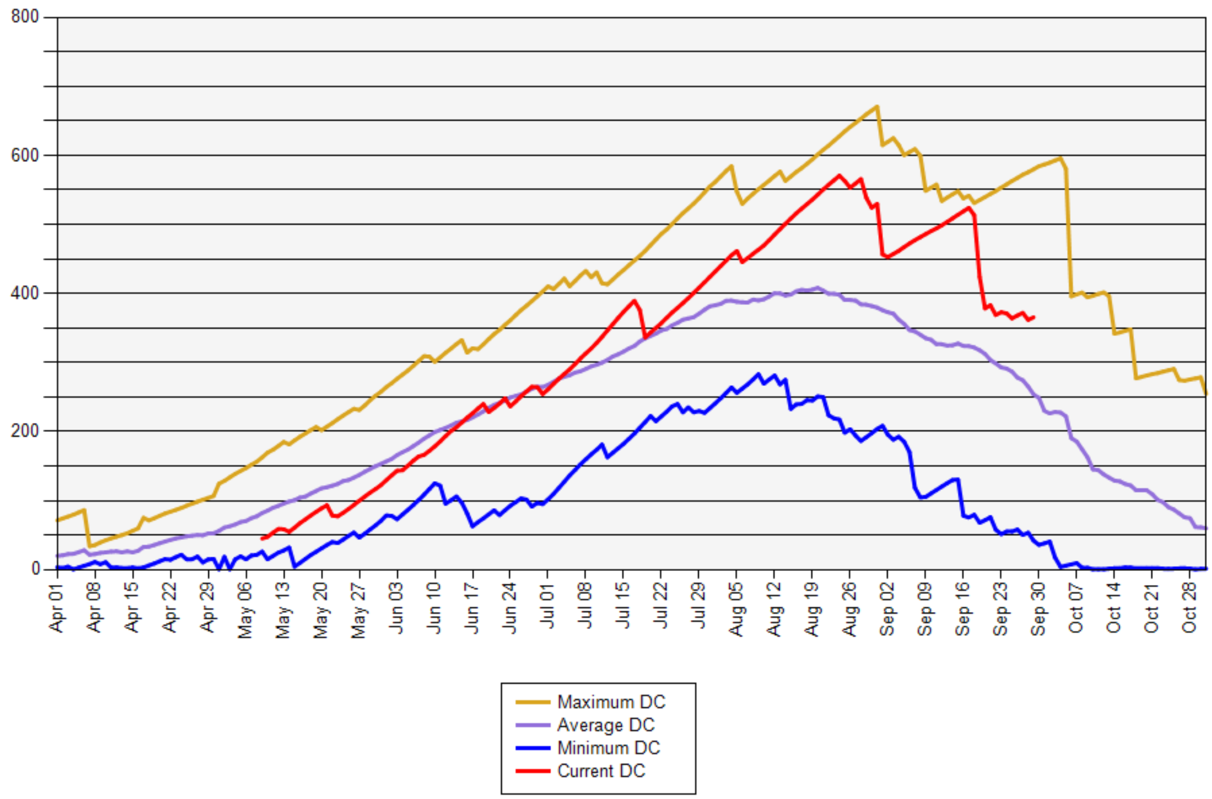

Figure 7. Drought Code daily average vs. current day for Nass Camp.
(*Based on 36 years of data. Courtesy of BCWMB*)

Table 2 compares June-to-August noon weather averages in 2014 to the eleven-year historical averages. The high FWI values and volatile wildfire conditions exhibited across Northern British Columbia in 2014 can be attributed to below average precipitation throughout the summer. Average monthly precipitation recorded at the Nass Camp weather station from June to August was 36% below the eleven-year historical average.

The average noon reading of relative humidity was 20% lower than the eleven-year average. Higher temperatures and lower relative humidity decrease the moisture level of the fine fuels and the upper duff layer (DMC) to the greatest extent.

Table 2. Historical and current noon weather readings for June to August.

Weather Parameter	2014 Jun–Aug Average	Historical Jun–Aug Average
Temperature	20.3°C	19.2°C
Monthly Precipitation	37.1 mm	57.9 mm
Relative Humidity	52.9%	66.6%
Drought Code	355	291
Duff Moisture Code	38	24
Build-Up Index	58	36

Fuel Moisture Analysis

Fuelbed Moisture Profiles

We collected our fuel moisture samples between August 25 and September 15, 2014. Table 3 summarizes the average moisture content found at each depth interval. In general, our data showed higher moisture content at lower depths. Our data from 2013 showed a similar trend.

Table 3. Average moisture profile of chip fuelbeds along the NTL ROW.

Year	Sampling Depth					
	Surface	5 cm	10 cm	15 cm	20 cm	Bottom
2014	18.23%	74.79%	136.89%	174.35%	159.34%	186.34%
2013	36.33%	58.70%	71.41%	-	80.67%	70.21%

Surface Moisture

The average moisture content of surface fuels in the open ROW was 6.41%; in the adjacent buffer it was 18.78%; and in the adjacent standing timber it was 24.89%.

The three additional samples taken at the ignition testing site from the top layer of the fuelbed showed that the moisture content at 2 cm was 2.5 to 3 times greater than the moisture content at the surface (Table 4).

Table 4. Moisture content at the Eider Creek study site.

Sample	Depth	Moisture Content
A	surface	5.3%
	2 cm	17.1%
B	surface	5.9%
	2 cm	13.5%
C	surface	6.3%
	2 cm	16.15%

Our data also showed changes in the moisture content at the surface throughout the day. Surface samples collected during the morning had moisture contents ranging from 13% to 33%, and surface samples collected during the afternoon had moisture contents ranging from 5% to 13%.

Ignition Probability

We conducted match-drop tests on September 13 to 15. We conducted 13 tests in each of the three fuel zones. In the open zone, 11 of the 13 tests resulted in successful ignitions, and in the buffer zone, 6 of the 13 tests resulted in successful ignitions. There were no successful ignitions in the timber zone. Based on these results, the observed ignition probabilities were:

- 85% in the open ROW
- 46% in the adjacent buffer
- 0% in the adjacent standing timber

At the time of the successful ignitions, the Fine Fuel Moisture Code (FFMC) was above 81.2, the wind was less than 6.9 km/h, and the moisture content of the surface layer ranged between 4.9% and 8.7%.

In the open ROW, sustained burning from the successful ignitions (up to 2 mins) resulted in flame lengths of less than 15 cm and the fire grew to less than 50 cm diameter.

Fuel Loads

The 1L387 ROW consisted primarily of deciduous regeneration and a dense shrub layer. There was a minimal amount of woody debris (i.e. slash). The density, height, and composition of the vegetation varied considerably along this ROW. For example, near structure 88-1 (Figure 8, left) we saw Mountain Alder and various Willow species up to 4 m tall, but in a southern section close to Cedar River (Figure 8, right) the shrub layer was discontinuous and much shorter (<1 m tall).

Figure 8. Vegetation in 1L387 at structure 88-1 (left) and near Cedar River (right).

The overall shrub coverage in 1L387 at the Eider Creek site (Figure 9, left) was 22.3% (97.0% Thimbleberry and 3.0% Rose). Fireweed was also present (3.0% coverage). In contrast, the site at structure 88-1 (Figure 9, right) was dominated by matted grass with an overall shrub coverage of 13.6% (72.0% Thimbleberry and 28.0% Rose).

Figure 9. Shrub coverage at the Eider Creek site (left) and the 88-1 site (right).

Table 5 summarizes the seedling and sapling density and composition on the 1L387 ROW. We found considerable variation between our two sapling density plots at the 88-1 site. The sapling density in one plot was 18750 stems/ha and the sapling density in the plot on the adjacent transect was only 1000 stems/ha (Figure 10).

Table 5. Seedling and sapling composition and density in the 1L387 ROW.

Site				Species Composition (%)				
	Class	Density (stems/ha)	Average Height (m)	Willow spp.	White Spruce	Mountain Alder	Balsam Poplar	Other
Eider Creek	Saplings	5500	1.7	27.3			72.7	
	Seedlings	1750	1.0		14.3		71.4	14.3
88-1	Saplings	9875	3.2	73.4	6.3	11.4	5.1	3.8
	Seedlings	3000	0.9			42.0	58.0	

Figure 10. Low-density saplings (left) and high-density saplings (right) at the 88-1 site.

Table 6 summarizes the amount of dead-and-down woody debris in 1L387. We classify these volumes as a light fuel load.

Table 6. Dead-and-down woody debris in the 1L387 ROW.

Size Class	Eider Creek	Structure 88-1
Fine Woody Debris (<7cm)	0.305 kg/m^2	0.003 kg/m^2
Coarse Woody Debris (>7cm)	none	none

Discussion

Fuel moisture determines the amount of fuel available for combustion and is a critical factor that influences ignition and fire behaviour. For other, more common, forest fuel environments, the Canadian Forest Fire Danger Rating System allows wildfire managers to make reliable estimates of relative fuel moisture conditions, which in turn allows them to predict and plan for potential fire behaviour. However, moisture retention in a fuelbed of wood chips is different from the fuelbeds of other forest fuel environments and predicting fire behaviour using standard fuel models may not be reliable.

Effect of Drought on Fuelbed Moisture Profiles in the Open ROW

Like other fine surface fuels, the moisture content of chipped fuels 0–5 cm deep responds rapidly to rainfall and to changes in temperature and relative humidity. It also changes diurnally, with the lowest moisture content occurring at the peak of the burning day when temperature is highest and relative humidity is lowest. A drought will have a significant drying effect on surface fuels.

The fine fuels in the deeper layers seem to act as a reservoir, accumulating moisture from fall, winter, and spring precipitation. In addition, debris at the surface acts as an insulating layer (Schiks 2014) that limits heating of lower layers, limits airflow, and limits migration of moisture to the atmosphere. The average moisture content at the 10 cm, 15 cm, and 20 cm layers was 137%, 174%, and 159%, respectively. DC calibration curves by Lawson and Dalrymple (1996) indicate that a DC of 500 equates to a moisture content of 100% in deep layers in the Coastal Western Hemlock (CWH) biogeoclimatic zone and 50% in the Interior Cedar Hemlock (ICH) biogeoclimatic zone. Our study sites along the NTL ROW technically lie within the ICH biogeoclimatic zone, but the average annual precipitation recorded by the Nass Camp weather station is almost twice that recorded at the sites used to develop the ICH calibration curve. Nevertheless, at a DC of 500 the moisture content in our samples of chipped fuel was 1.5 to 3 times greater than moisture content indicated by calibration curves for the CWH and ICH biogeoclimatic zones.

According to equations developed by Lawson *et al*. (1997) for the CWH biogeoclimatic zone, our observed DMCs of 15 to 44 equate to moisture contents of 120% to 219%. Lawson *et al*. took their samples from a depth of 7 cm. The average moisture content we observed at this level on the NTL ROW was lower: at 5 cm the average moisture content was 75%, and at 10 cm the average moisture content was 137%.

Thus, in a drought year we found that chips at the surface and below to 10 cm were drier than what the equations and calibration curves estimated and drier than what we recorded in the same region during a non-drought year. This was not surprising given that surface fuels in an open ROW are subjected to more sunlight, more heat, and more wind. But we also found that the chips in the deeper layers were wetter than estimated; wetter than what we recorded during a non-drought year; and wetter than what other researchers have recorded in other forest environments under similar drought conditions.

Effect of Drought on Ignition Probability and Potential Fire Behaviour

The surface layer of chipped fuels can quickly reach the ignition threshold. The data we have collected over the last two seasons suggests that ignition will occur at an FFMC as low as 80 and will most likely occur after 12:00 and when FFMC reaches 82. Despite the drought conditions in 2014, the ignition probability we observed in the open ROW (86%) was not substantially different from what we observed in 2013 (80%). In both years, we found that ignition occurred more frequently in the open ROW compared to the adjacent buffer and the adjacent standing timber.

FWI indices, including the FFMC, have been used effectively as a predictor of sustained ignition in several different forest fuels (Beverly and Wotton 2007). However, Schiks and Wotton (2015) found that FFMC tends to over-predict moisture content in chipped fuels and that a recalibrated version of the moisture models is needed to provide a more reliable predictor of sustained ignition.

Frandsen (1987) determined the smouldering limit for peat moss to be between 93% and 103%, and experimental burns in pine forests by Van Wagner (1972) showed that duff consumption did not occur when duff moisture content was above 134%. These types of duff fuels have lower density and higher surface-area-to-volume ratio than chip fuelbeds and would be more prone to sustained smouldering and burning. Nevertheless, if we compare these results to the moisture contents of the chip fuelbeds of the NTL ROW, smouldering may reach to a depth of 10 cm.

In a season of normal weather, more frequent rains limit the number of days in which surface fuels are available for consumption. During a drought, as seen in 2014, the number of days in which surface fuels can sustain ignition is increased. Additionally, higher average temperature with reduced relative humidity recovery as seen in 2014 would have extended the daily timeframe in which sustained ignition would be possible.

Changes in the Fuelbed Over Time

The moisture profiles for 2013 were for freshly chipped fuel. The moisture content in these pits had much less variability between the layers and was much lower than what we found in 2014. Since 2013, the fuelbeds have been subjected to fall, winter, and spring precipitation. This has added to the overall moisture reservoir in the fuelbeds, increasing moisture content considerably in 2014. The moisture held in the deep layers can migrate up to the surface during extreme drought conditions. However, any depletion of moisture will likely be replenished during periods of heavy precipitation in the fall, winter, and spring (Lawson and Dalrymple 1996).

As these fuelbeds age, the chips will decompose and become more compacted, and vegetation will eventually regrow (depending on fuelbed depth). Regeneration of the shrubs and other vegetation will reduce the relative ground coverage of chipped fuel and will increasingly shade the chipped fuel. Increased shading will reduce the drying rate of the surface layer of chipped fuel. The higher moisture content and a lower relative ground coverage of chipped fuel at the surface will reduce the ignition probability over time.

Differences between NTL ROW and 1L387 ROW

The vegetation and surface fuels measured in the 1L387 ROW were similar to what we found in the buffer zone of the NTL ROW. Our match-drop tests in the buffer zone suggest that ignition would be less probable (46%) in the 1L387 ROW. Greater shading, less abundant receptor fuels, and increased deciduous foliage reduces probability of ignition and fire behaviour potential.

Other Findings

At three of our sampling sites, the chips appeared to be more loosely deposited than at the other sites; the chips in the deep layers at these sites were much easier to dislodge. Moisture analysis of the samples collected at these sites showed lower moisture content relative to our other sampling sites. We don't have enough samples to make any solid conclusions, but we believe that loosely deposited debris would be drier due to greater aeration and could exhibit more vigorous fire behaviour. Future studies will need to determine the prevalence of these loosely compacted sites, and to confirm the differences in the moisture profile.

CONCLUSIONS

In Northern British Columbia, persistent drying during the 2014 fire season contributed to very dry forest fuels and extreme fire behaviour. Above average temperatures and below average precipitation in June, July, and August resulted in FWI values near record levels. These high FWI values suggested low fuel moisture content in forest fuels.

Our study results on the moisture profiles of chip fuelbeds in the NTL ROW were not consistent with moisture conditions indicated by the FWI values. In spite of below average rainfall in the summer of 2014, deep layers of the chip fuelbed retained moisture from the previous winter's snow pack and spring rains. We found that the DC under-predicted the moisture content of these deep fuels.

The fine fuels of the surface layer (0 to 5 cm) in the open ROW lose moisture quickly under conditions of high temperature and low relative humidity. With greater exposure to sunlight and wind, chipped debris in the ROW dries quicker than surface fuels in closed forest stands. Hence, the FFMC, which was developed through trials in closed jack pine stands, over-predicts moisture content of the surface fuels in an open ROW.

Rapid drying of the surface layer occurs even during summers with normal precipitation. However, during a drought surface fuels are available for consumption for longer time periods.

The moisture profiles from this study suggest that chipped debris in the uppermost surface fuel layer (0 to 2 cm) dries quicker and becomes more readily available for ignition than the surface fuels in other forest types. If ignition occurs, the chipped fuel in the top 5 cm is dry enough to sustain ignition and support moderate intensity fire behaviour. The moisture content at 5 to 10 cm is sufficient to support smouldering and creeping surface fire. Flaming combustion is not likely in chipped fuels deeper than 10 cm.

The results of our ignition-potential tests in 2014 were consistent with those of 2013. In both years, we showed that the open ROW has the greatest probability of ignition. Unfortunately, existing moisture models do not reliably predict ignition potential in chipped fuels. There are new models under development that should provide a better representation of fuel moisture and a more reliable predictor for ignition in chipped fuel.

The chipped fuels of the NTL ROW have been exposed to a full year of weather. The increase in moisture in the deep layers from 2013 to 2014 suggests that they will continue to retain moisture over time. Our samples from the deeper layers revealed decomposition of debris and compaction of the fuelbed. More studies are needed to determine the decomposition and weathering of chipped debris over time and how this influences moisture retention, probability of ignition, and potential fire behaviour in the chip fuelbed.

Vegetation in the ROW is currently patchy where mineral soil was exposed. Long-term monitoring will be required to evaluate the extent to which re-colonization occurs along the NTL ROW.

Our results showed that the adjacent 1L387 ROW had a lower probability of ignition and reduced potential fire behaviour. It is a much different fuel environment than the chip fuelbed. This ROW was cleared using different mechanical methods and has had over 50 years to regenerate. The rate at which the NTL ROW will change over time is not known, but with continued decomposition of the chips and regeneration of the vegetation, the NTL ROW may evolve into an environment with reduced ignition probability and modified fire behaviour potential.

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