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EVALUATING A SELECTIVE HARVEST OPERATION AS A FOREST FUEL TREATMENT:

A CASE STUDY IN A MATURE DOUGLAS-FIR FOREST IN CENTRAL INTERIOR BRITISH COLUMBIA

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This report is not restricted.

ABSTRACT:

The City of Quesnel, B.C. has applied an innovative selective harvesting technique in a mature Douglas-fir forest stand with the objectives of maintaining biodiversity and reducing fuel-load buildup and consequent wildfire threat. FPInnovations researchers monitored and documented the harvesting operations and measured machine productivity to evaluate the cost-effectiveness of the operation.

To support the assessment of fuel-load reduction, FPInnovations' Wildfire Operations group conducted pre- and post-harvest fuel-sampling activities to evaluate changes in forest fuel components.

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BACKGROUND

Study site

The Community Wildfire Protection Plan developed for the City of Quesnel, B.C. prioritized areas with hazardous forest fuels that pose a wildfire threat to values in the community. Fuel Management Treatment Unit (FMTU) 14A was identified as a high priority area (Figure 1).

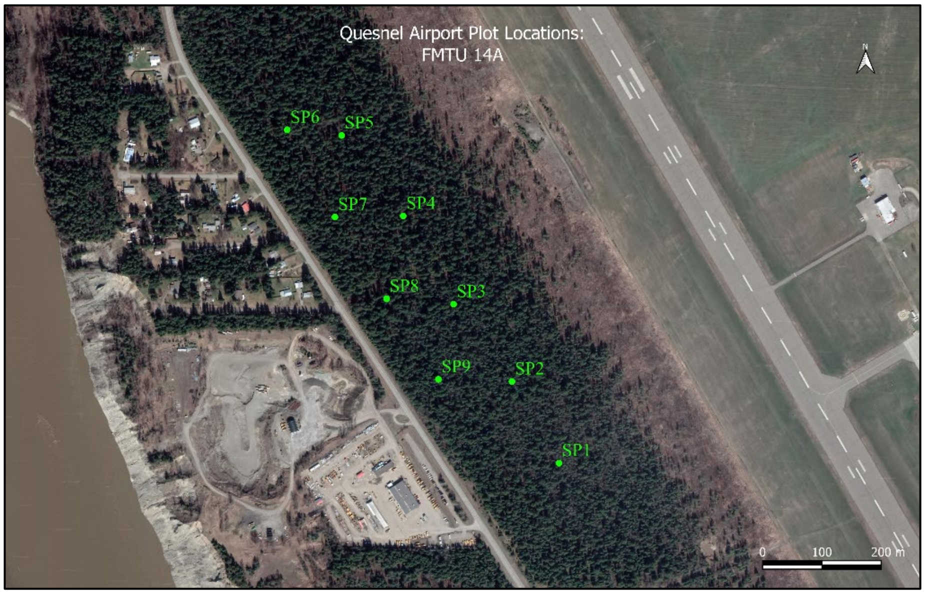

Figure 1. Fuel Management Treatment Unit 14A is a 29-ha parcel adjacent to the Quesnel airport to the northeast and residential and industrial structures to the southeast. The locations of sampling plots (SP) are indicated on the photo (image captured from Google Earth).

Fuel treatment prescription and execution

The fuel management prescription[1] for FMTU14A was developed with the overarching goals of:

- maintaining a forested ecosystem; and
- improving the overall resilience of the local forest ecosystem by reducing surface fuel debris and restructuring the forest stand.

This strategy was achieved by applying a "thin-from-below" partial harvest operation and a "semi-mechanized" surface fuel cleanup with the following specific objectives:

- retention of large conifers (> 40 cm diameter at breast height)
- removal of a component of remaining stems in all diameter classes
- removal of dead, dying, and suppressed conifers
- retention of all deciduous stems
- pruning of all trees up to 3 m in height

[1] Courtesy of Forsite Forest Management Specialists

During the harvest operation, an Ecolog® 550D harvester was used to fell and process merchantable stems and gather and pile debris and non-merchantable stems in a separate pile (Figure 2). Aggressive cleanup operations following the harvest operation included removal of debris with a forwarder (Figure 3) and semi-mechanized cleanup of any remaining dispersed debris using a hand-fed mulcher mounted on a skidsteer machine (Figure 4). Details of these operations and productivity results will be documented in a forthcoming FPInnovations publication.

Figure 2. Ecolog harvester.

Figure 3. Removal of piled harvest residue.

Figure 4. Final cleanup with hand-fed mulcher.

OBJECTIVES

FPInnovations researchers collaborated on this project using a two-pronged research approach. Firstly, the Forestry group measured machine productivity and analyzed the overall cost of the harvesting operations. Secondly, the Wildfire Operations group supported the research project by providing a forest stand characterization, which included fuel sampling, data compilation, and conversion of data into practical tools that can be used by fuels managers.

This report focuses on pre- and post-harvest inventories to evaluate changes in forest fuel loading. The specific objectives of this project were as follows:

- Inventory forest fuels prior to harvest operations and following harvest and debris removal operations.
- Quantify changes in overstory structure and surface fuel loading.
- Evaluate potential fire behaviour in pre-harvest and post-harvest fuel environments.
- Establish baseline fuel inventories that can be compared to future changes in fuel loading.

METHODS

Pre-harvest fuel sampling activities were conducted during the last week of September 2019, and the same sampling activities were conducted post-harvest in the last week of May 2020. During the pre-harvest fuel sampling activities, nine sampling points were established (Figure 1), and a permanent steel marker was set at each plot centre.

Overstory attributes within an 11.28-m fixed radius plot at each sampling point were sampled to inventory the species, diameter at breast height (DBH), live crown base height (LCBH), height, and health of each stem. Further processing of the plot data yielded forest stand data (Appendix A). Crown closure and crown fuel loading were calculated using FuelCalc BC.[2]

Surface fuel loading was sampled along four 25-m transects from each plot centre using the line intersect method (Van Wagner 1982). The data were input into a line intersect calculator[3] in a spreadsheet format to calculate loading of fine woody debris components by size class (MacRae et al. 1979) and coarse woody debris. Pre-harvest depths of duff and litter were measured along the four transects associated with each plot. Photos of vegetation (shrubs, grasses, herbs) in the surface fuel layer were also taken.

A Canon 5D Mark II camera with a Rokinon 8-mm circular fisheye lens was used to take 360-degree photos at two sampling points (SP1 and SP3) for illustrative purposes only. At the current time, fuel load data are not available based on this process.

To assess the fuel treatment's capacity to modify fire behaviour and reduce the potential for crown fire initiation, we used the Critical Surface Intensity Worksheet in the British Columbia Wildfire Service (BCWS) suite of Tools for Fuel Management.[4]

[2] https://www2.gov.bc.ca/gov/content/safety/wildfire-status/prevention/vegetation-and-fuel-management/fire-fuel-management/fuel-management/fuelcalcbc

[3] https://www2.gov.bc.ca/gov/content/safety/wildfire-status/prevention/vegetation-and-fuel-management/fire-fuel-management/fuel-management

[4] https://www2.gov.bc.ca/gov/content/safety/wildfire-status/prevention/vegetation-and-fuel-management/fire-fuel-management/fuel-management

RESULTS

Overstory structure

The prescribed treatment for retention of larger stems and partial removal of smaller trees resulted in the following general trends in changes to forest stand structure:

- reduction in stem density, basal area, canopy closure, and canopy fuel loading
- increase in mean diameter at breast height, mean stand height, and mean live crown base height

Changes in specific stand attributes are shown in Appendix A. An increase in mean DBH with a minor decrease in basal area suggests that the prescription for retention of larger stems was achieved. This was also evident from data sheets that detailed the removal of specific stems from each sampling plot. As prescribed in the fuel management prescription, dead and dying and suppressed conifers were removed, while deciduous stems were retained (Figure 5).

SP2 North pre-harvest

SP2 North post-harvest

Figure 5. Reduction in overall stem density due to removal of less viable conifers.

Surface and ground fuels

Pre-harvest fuel inventory data (Appendix B) show there were large volumes of coarse woody debris (CWD) (≥ 7 cm diameter) in the form of large-diameter fallen stems on the forest floor in most sampling plots. Salvage of these large stems during the harvest operations resulted in a large reduction of sound and rotten CWD.

A general trend resulting from most harvest operations or forest fuel treatments (mechanical or manual) is an increase in fine woody debris (FWD) (0–6.99 cm in diameter). An increase in FWD often occurs when residual branches and needles from the delimbing processes accumulate and are not disposed of by burning or physical transfer for processing (Figure 6). In the prescription for this fuel treatment area, a cleanup of FWD was identified as a critical component of wildfire risk reduction, and appropriate standards and processes were identified and implemented. Following the cleaning operations, the overall increase (from pre-harvest conditions) in FWD across the treatment area was 2.6 t/ha (0.26 kg/m^2). The average FWD load across the treatment area was 7.3 t/ha (0.73 kg/m^2).

SP9 North pre-harvest SP9 North post-harvest

Figure 6. Minor accumulation of residual branches and other FWD following cleanup operations.

Both the duff layer and litter layer in the treatment area are thin, with depths of each ranging between 1 and 3 cm. Post-harvest observations indicated there was minimal disturbance of the surface vegetation and ground layers in areas where access trails were created. Harvested areas adjacent to the access trails showed little change in vegetation (Figure 7).

Figure 7. Minimal disturbance of the ground layer along an access trail and the vegetation adjacent to the access trail.

Imagery

The following 360-degree panorama images illustrate most forest stand attributes and surface fuel elements:

SP1:
https://cdn.pannellum.org/2.5/pannellum.htm#panorama=https%3A//i.imgur.com/d3qq52V.jpg&autoLoad=true

SP3:-
https://cdn.pannellum.org/2.5/pannellum.htm#panorama=https%3A//i.imgur.com/TINcWEq.jpg&autoLoad=true

DISCUSSION

Forest fuel characterization

The pre-harvest and post-harvest forest fuel environments in the FMTU14A treatment area are not clearly represented by any of the fuel types characterized in the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992). Most conifer fuel types in the FBP System do not include mechanisms that can account for any modifications to the fuels due to harvest operations or fuel treatments.

The open Douglas-fir overstory with high crown base height and discontinuous understory are predominant characteristics suggestive of the C-7 (Ponderosa Pine–Douglas-fir) fuel type. However, the surface layer observed in the treatment area is not consistent with the perennial grasses and needle litter that are typical of the C-7 surface fuel layer.

The C-3 (Mature Jack or Lodgepole Pine) fuel type has overstory characteristics (mature stems with high crown base height) shared with those of the treatment area. However, other fuel environment descriptors of the C-3 fuel type such as the greater stem density, sparse conifer understory and deeper organic layer (~10 cm) are not consistent with the fuel characteristics observed in the treatment area.

Currently, the treated area is a poor fit to the C-7 fuel type, but over time it may trend toward a medium fit with a regeneration of grass fuels in the more open stand. C-3 is also a poor fit with the treated area and will overpredict rate of spread because of the greater stem density and diameter class.[5]

Without a clear representative fuel type, fire behaviour in this fuel environment is difficult to confidently predict using the FBP System unless a fire behaviour analyst has extensive experience in observing fire behaviour in fuels in this environment and assigning a surrogate fuel type as a predictor of fire behaviour. Alternative approaches that use innovative tools for predicting fire behaviour in areas of modified fuels are required.

[5] M. Lees, Wildfire Prevention Officer, British Columbia Wildfire Service, personal communication (August 28, 2020)

Evaluating fuel treatments

Agee and Skinner (2005) introduced fuel management principles within the context of treating forests to "be more resilient to wildfire". These principles are commonly subscribed to in vegetation management programs (Partners in Protection 2003) and are detailed further in fuel treatment prescriptions with specific fuel treatment targets. The principles of fire resistance for dry forests include:

- reduction of surface fuels
- increase in height to live crowns
- decrease in crown fuel load or density
- retention of large trees of resistant species

While application of these principles in fuel treatments can be subjectively evaluated, pre- and post-treatment measurements of the fuel components can be applied in appropriate fuel management tools to quantify the extent to which a treatment meets the prescription's objective measures.

In most fuel treatment prescriptions, modifications to the surface fuel layer and ladder fuels are prioritized as fuel treatment strategies to reduce the potential for sustained ignition and crown fire initiation (Province of British Columbia 2020). A measurable target for prescribed treatments is a surface fuel reduction that will achieve a reduction in potential fire intensity to a level of 2000 kW/m or less. When the critical surface intensity is less than 2000 kW/m, reduction in the surface fuel loading in conjunction with an increase in crown base height should result in the predicted fire intensity being less than the critical surface intensity. Fire intensity should be calculated using 90th percentile Fire Weather Index conditions.

The Critical Surface Intensity Worksheet[6] developed by BCWS aids users in predicting the likelihood of surface fire transitioning to crown fire under specified conditions. This tool uses foliar moisture content (FMC) and height to live crown base as inputs to determine the critical surface intensity required to initiate crown fire. We used the pre- and post-harvest median crown base height for the overall treatment area and an FMC of 95% (standard FMC in drought conditions) as inputs to the worksheet.

Surface fire intensity is calculated using the weight of available surface fuel and rate of spread as inputs. The surface fuel component generally consists of fine woody debris, grasses, and shrubs. In FMTU14A, the most predominant surface fuel was woody debris. Other vegetative components, because of their low height and sparse coverage, were deemed to make relatively little contribution to overall surface fire behaviour.

To determine fire intensity, the worksheet uses Byram's (1959) formula (I = Hwr), where:

I = fire intensity (kW/m)
w = weight of available fuel (kg/m^2)
r = rate of spread (m/min)
H is an assumed constant value (300) for the low heat of combustion; 18,000 kJ/kg is divided by 60 so that rate of spread can be expressed in m/min rather than m/sec (Hirsch 1996).

The average fine woody debris loading across the treatment area was used as the weight of available fuel. FWD is considered the most active contributor to fire intensity during the active flaming stage, while CWD and deep organic

[6] https://www2.gov.bc.ca/gov/content/safety/wildfire-status/prevention/vegetation-and-fuel-management/fire-fuel-management/fuel-management

layer contributions are more commonly associated with the smouldering (glowing combustion) stage of fire behaviour (Alexander 1982).

The 90th percentile Fire Weather Index conditions were determined by using the BCWS percentile calculator.[7] The mean Fine Fuel Moisture Content, Initial Spread Index, and Buildup Index values for the Quesnel area[8] are 92.8, 10.6, and 113.0, respectively.

Two rate of spread scenarios were developed by applying these Fire Weather Index values in REDApp[9] to the C-7 (Ponderosa Pine–Douglas-fir) and the C-3 (Mature Jack or Lodgepole Pine) FBP fuel types. This yielded spread rates of 3.6 and 6.8 m/min, respectively. The calculated critical surface intensity and predicted fire intensity values for these fuel types at the 90th percentile are shown in Table 1. These rate of spread scenarios are hypothetical based on the assigned FBP fuel types and do not reflect observed or documented fire behaviour in this fuel environment. For other localized predictions in other fuel environments, consultation with local experts will help determine an appropriate rate of spread to be used in the fire intensity equation.

Table 1. Potential for crown fire initiation at 90th percentile conditions

Sampling phase	Median live crown base height (m)	Critical surface intensity (kW/m)	Average total fine woody debris load (kg/m²)	Fire intensity (kW/m)		Crown fire initiation
				Rate of spread = 3.6 m/min	Rate of spread = 6.8 m/min	
Pre-harvest	8.1	3656	0.46	497	938	No
Post-harvest	9.4	4570	0.73	788	1489	No

Despite an increase in fine woody debris post-harvest, the fire intensity generated in the surface fuel layer is still below the critical surface intensity and below the 2000 kW/m threshold. An extension of this process will involve using the heat intensity equation to establish a threshold surface fuel loading that would increase the fire intensity beyond the 2000 kW/m level and trigger a re-treatment operation.

Beyond this evaluation of the potential for crown fire initiation in the FMTU14A treatment area, other less quantifiable impacts of the fuel treatment should also be considered. Retention of large-diameter stems with little change in canopy closure maintains a shaded fuel break (Agee et al. 2000), which has positive impacts such as limiting solar radiation and wind flow at the surface level (Whitehead et al. 2008) and reducing moisture loss in surface fuels (Wotton and Beverly 2007).

The thinned understory and increased visibility through the stand will allow for quicker detection of spot fires in the treatment area (Ault, Baxter, & Hsieh 2017) and safer access/egress and more efficient suppression operations for firefighters (Moghaddas and Craggs 2007).

[7] Predictive Services Unit Percentile Calculator: https://wps-web-prod.pathfinder.gov.bc.ca/percentile-calculator/
[8] Mean values from the BCWS Nazko and Benson weather stations
[9] Universal Fire Behaviour Calculator: https://redapp.org/

Ongoing fuel monitoring

Given the easy access to the treatment unit, ongoing monitoring can be quickly achieved through an informal subjective assessment, whereas detailed fuel sampling will require a greater time commitment (1–2 days).

With reduced competition from a thinned understory, favourable conditions are created for producing a thriving surface vegetation layer, and this fuel layer should be the focus of ongoing fuels monitoring. The volume of the shrub, herb, and grass components is difficult to evaluate; however, the photoload sampling technique (Keane and Dickinson 2007) provides a methodology that is designed for a similar forest fuel environment. Photoload sequences that illustrate varying ranges of fuel loadings in shrubs and grasses will be useful for quickly assessing vegetation loading and monitoring ongoing changes in this fuel layer.

Monitoring changes in the volumes of surface vegetation and debris will help in better understanding the nature and extent of vegetation regrowth and debris accumulation/decomposition over time. With this understanding and documentation of temporal changes in the fuel environment, it will be easier to establish fuel treatment maintenance plans and re-treatment triggers in other similar treatments. Ongoing monitoring and assessment of fuel loading will be important for determining the optimum timing of re-treatment (Province of British Columbia 2020).

CONCLUSION

An innovative selective harvesting technique was applied in a mature Douglas-fir dominated forest with the overarching fuel treatment goals of maintaining forest resilience and reducing wildfire threat to adjacent values. The thin-from-below treatment strategy coupled with salvage of large stems on the ground was successful in maintaining a healthy and resilient overstory of mature and fire-resistant stems while removing a large volume of coarse woody debris.

Aggressive debris removal operations using machinery and stand cleaning by hand crews were successful in reducing post-harvest debris loading and increasing the height to live crown fuels, which had a positive outcome of limiting surface fire intensity and the potential for crown fire initiation.

The fuel treatment prescription with selective harvest operations and cleanup operations was developed to meet the forest and fuel management objectives in the mature Douglas-fir forest stand of FMTU14A. Other forest fuel treatments in other ecosites will require different forest management objectives and strategies that apply site-specific treatment tactics. The critical surface intensity tool used to evaluate the potential for crown fire involvement in this treatment unit is one of several tools that can be used to evaluate fuel treatment effectiveness. Other tools may be more applicable in different fuel treatments in other fuel environments.

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APPENDIX A: CHANGES IN FOREST STAND STRUCTURE FROM PRE-HARVEST TO POST-HARVEST

Plot ID	Sampling phase	Stems/ ha	Mean DBH (cm)	Median DBH (cm)	Max DBH (cm)	Mean ht (m)	Median ht (m)	Max ht (m)	Mean LCBH (m)	Median LCBH (m)	Min LCBH (m)	BA (m^2/ha)	CC (%)	CFL (t/ha)
SP1	Pre	1100	18.15	15.25	47.00	17.37	17.15	28.90	10.10	9.00	3.2	35.35	70	11.70
	Post	750	19.53	15.50	47.00	18.79	20.10	28.90	9.74	8.95	3.2	28.27	60	10.50
SP2	Pre	1400	13.89	8.75	70.00	11.27	9.05	34.70	4.83	2.25	1.0	51.99	65	16.70
	Post	400	27.43	15.00	70.00	19.29	13.85	34.70	9.07	8.65	5.8	41.99	50	13.20
SP3	Pre	275	38.38	44.00	57.70	23.66	27.40	33.10	9.52	11.00	1.0	38.47	70	13.70
	Post	200	43.21	49.95	57.70	24.79	28.05	31.50	9.84	9.40	3.0	33.59	60	11.30
SP4	Pre	250	38.59	41.05	58.50	28.75	30.55	36.60	12.61	13.90	7.9	32.05	45	12.00
	Post	150	44.10	45.35	58.50	32.82	34.80	36.60	13.78	13.55	11.9	24.34	35	9.15
SP5	Pre	450	20.14	11.45	72.30	14.94	11.15	38.20	7.57	5.70	1.5	27.60	40	9.34
	Post	175	26.70	18.20	72.30	18.80	18.40	38.20	10.11	10.80	3.0	18.62	25	5.45
SP6	Pre	300	37.73	38.40	67.00	26.21	29.70	39.10	12.05	11.25	1.0	43.59	55	14.70
	Post	225	47.03	51.00	67.00	31.67	33.00	39.10	15.36	17.20	6.1	42.84	50	14.00
SP7	Pre	475	31.79	27.50	80.00	26.33	31.10	37.60	9.57	9.40	2.9	50.17	60	19.00
	Post	200	45.00	43.00	80.00	32.45	33.25	37.60	11.68	10.20	6.0	36.89	45	12.30
SP8	Pre	625	22.53	18.00	63.00	17.81	14.65	35.80	7.41	6.90	1.3	35.38	60	13.90
	Post	350	28.49	25.00	63.00	21.54	21.80	35.80	9.25	7.45	3.0	29.17	50	9.81
SP9	Pre	650	28.50	17.50	96.00	18.99	18.00	38.60	9.22	9.20	1.0	70.79	70	21.60
	Post	475	34.03	20.00	96.00	21.80	19.50	38.60	10.68	10.60	3.0	66.60	65	19.40

Sampling phase = pre-harvest, post-harvest
DBH = diameter at breast height
Ht = height
LCBH = live crown base eight
BA = basal area
CC = crown closure
CFL = canopy fuel load

APPENDIX B: CHANGE IN WOODY DEBRIS LOADING FROM PRE-HARVEST TO POST-HARVEST

Plot ID	Sampling phase	Fine woody debris (t/ha)						Coarse woody debris (t/ha)			Overall (t/ha)
		0.00–0.49 cm	0.5–0.99 cm	1.00–2.99 cm	3.00–4.99 cm	5.00–6.99 cm	**Total**	Sound	Rotten	**Total**	
SP1	Pre-harvest	0.01	0.25	0.71	1.42	1.81	4.19	8.98	6.88	15.87	20.06
	Post-harvest	1.08	0.85	2.08	1.45	2.51	7.97	2.67	4.91	7.57	15.54
	Change	**1.07**	**0.60**	**1.37**	**0.04**	**0.71**	**3.78**	**-6.32**	**-1.98**	**-8.29**	**-4.52**
SP2	Pre-harvest	0.35	0.37	1.75	0.95	1.78	5.20	6.03	44.23	50.25	55.45
	Post-harvest	1.06	0.66	2.09	2.25	4.99	11.04	3.80	2.65	6.45	17.48
	Change	**0.71**	**0.28**	**0.34**	**1.30**	**3.22**	**5.84**	**-2.23**	**-41.58**	**-43.81**	**-37.97**
SP3	Pre-harvest	0.18	0.44	2.84	0.95	0.99	5.40	20.43	10.34	30.76	36.16
	Post-harvest	1.23	0.75	3.79	0.00	0.84	6.62	5.60	10.57	16.16	22.78
	Change	**1.06**	**0.31**	**0.95**	**-0.95**	**-0.15**	**1.22**	**-14.83**	**0.23**	**-14.60**	**-13.39**
SP4	Pre-harvest	0.10	0.39	3.06	0.43	0.00	3.97	31.84	55.92	87.76	91.72
	Post-harvest	1.13	0.37	3.08	0.67	1.04	6.28	0.93	4.09	5.02	11.30
	Change	**1.04**	**-0.02**	**0.02**	**0.24**	**1.04**	**2.31**	**-30.91**	**-51.83**	**-82.74**	**-80.43**
SP5	Pre-harvest	0.08	0.05	1.18	0.11	0.20	1.61	60.89	19.76	80.65	82.27
	Post-harvest	0.70	0.79	3.76	1.00	1.25	7.49	4.56	8.10	12.66	20.15
	Change	**0.63**	**0.74**	**2.57**	**0.89**	**1.06**	**5.88**	**-56.34**	**-11.66**	**-68.00**	**-62.12**
SP6	Pre-harvest	0.07	0.26	2.41	1.62	0.60	4.96	20.69	11.03	31.72	36.68
	Post-harvest	0.71	0.41	2.44	0.78	0.63	4.96	0.82	12.26	13.09	18.04
	Change	**0.63**	**0.14**	**0.02**	**-0.84**	**0.03**	**-0.01**	**-19.87**	**1.24**	**-18.63**	**-18.64**
SP7	Pre-harvest	0.48	0.36	3.68	1.16	0.00	5.67	31.44	39.49	70.92	76.59
	Post-harvest	0.57	0.66	4.47	2.48	0.63	8.81	6.55	4.08	10.63	19.44
	Change	**0.10**	**0.31**	**0.79**	**1.32**	**0.63**	**3.14**	**-24.89**	**-35.40**	**-60.29**	**-57.15**
SP8	Pre-harvest	0.16	0.40	1.76	0.76	0.59	3.66	24.18	46.97	71.15	74.81
	Post-harvest	1.19	0.61	2.35	0.99	0.83	5.96	2.23	13.72	15.95	21.90
	Change	**1.03**	**0.21**	**0.59**	**0.23**	**0.25**	**2.30**	**-21.96**	**-33.25**	**-55.21**	**-52.91**
SP9	Pre-harvest	0.35	0.93	1.33	2.87	1.58	7.06	4.62	5.70	10.32	17.38
	Post-harvest	0.95	0.50	1.84	1.89	1.04	6.22	1.79	0.00	1.79	8.01
	Change	**0.60**	**-0.43**	**0.51**	**-0.99**	**-0.53**	**-0.84**	**-2.83**	**-5.70**	**-8.53**	**-9.37**
FMTU14A Average	Pre-harvest						**4.63**				**54.56**
	Post-harvest						**7.22**				**16.81**
	Change					**Fine woody debris**	**2.59**			**Coarse woody debris**	**-37.75**

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