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Hügelkultur as a debris management technique in forest fuel reduction treatments

A comparative productivity evaluation of a fuel reduction treatment incorporating hugels

PROJECT NUMBER: 301014884

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Disposal of woody debris and vegetative matter from forest fuel reduction treatments is a challenge and alternatives to conventional methods of pile burning and chipping are being considered. The construction of hugels is proposed as a debris management technique that would configure debris on site in a less flammable state. While flammability of piled debris (hugels) is a key consideration in the viability of this debris disposal method, the cost of the operation must also be considered.

This research design presents the development of test methods and data collection methods that can be applied in evaluating the productivity of a fuel reduction treatment that incorporates construction of hugels as a debris management tool. Comparative productivity trials will evaluate these productivity results in relation to fuel treatments that apply conventional debris disposal methods.

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1 BACKGROUND

Forest fuel treatments in the wildland-urban interface typically require the strategic removal of large volumes of vegetative fuel and woody debris to achieve the objectives and measurable fuel reduction targets defined in a fuel treatment prescription. The final disposal of removed fuel is often achieved through a pile and burn tactic.

Chipping or mulching are becoming more commonly applied techniques to convert fuel treatment residue to a less combustible state but these are not universally appropriate or acceptable practices.

While a pile and burn tactic can typically be achieved safely during winter months with snow cover, several negative consequences occur when using this approach. In winter months, when the potential for escaped fire is low, poor atmospheric venting conditions often limit smoke dispersion and air quality can be compromised. With any debris burning operation, green house gas emissions are a concern.

2 INTRODUCTION

Disposal of woody debris and vegetative matter from fuel treatments is a challenge and alternatives to conventional methods of pile burning and chipping are being considered. Hügelkultur is proposed as a debris management technique that would configure woody debris, branches, and other vegetative residue on site in a less flammable state (hugels). Objectives and desirable long-term outcomes of a hügelkultur technique are to:

1. Reduce the regrowth of flammable fine fuels in zones of created hugels. A patchwork of surface fuels created by hugels can interrupt the horizontal continuity of fine fuels such as grasses and shrubs that occurs in conventional fuel reduction treatments.
2. Create rings of beneficial habitat around each hugel that encourage or “push” the forest structure towards more fire-resistant broadleaf species.
3. Reduce the labour and equipment expense of the original fuel treatment.
4. Reduce the long-term maintenance requirements in a fuel reduction treatment.

‘Hügelkultur – “mound-culture” pioneered by an Austrian ecological farmer Sepp Holzer – aerobically decomposes woody debris into humus over years to decades’ (Bennett 2020). This technique has been recently applied in innovative agricultural settings to store excess woody debris and allow it to slowly rot in a fuel matrix including branches, logs, and finer mulches, which are typically covered with either soil or more mulch and then seeded or planted.

Hügelkulturs (hugels) are not composts. Composts are rich in nutrients and bacteria, so decompose in a matter of weeks or months and quickly off-gas a large proportion of their carbon. By contrast, nutrient-poor hugels decompose slowly over many years, and more carbon remains sequestered for much longer. Other benefits of hugels include habitat creation, and humus development for increased water retention and slow nutrient release.

The City of Rossland has contracted FPInnovations Wildfire Operations group to develop research protocols that explore the viability of applying hügelkultur as a debris management technique in forest fuel reduction treatments. To initiate this project, general research questions were proposed that would focus the research process.

A companion report has been prepared to present a research design that evaluates the flammabilty of hugels. As a complement to that report, the research design described in this document will outline test methods to evaluate the productivity of fuel treatment operations that incorporate hugel construction.

3 RESEARCH QUESTION

3.1 Productivity of Fuel Reduction Treatment Operations that Incorporate Hugels

Motor-manual fuel reduction treatment operations are generally conducted using workers with power tools. This type of fuel treatments is often one of the most expensive treatment methods. The costs of manual fuel treatments can range from $7,000/ha in lighter fuel types to over $22,000/ha in treatment operations in remote areas in winter conditions (Hvenegaard 2012). The cost of fuel treatments is variable and dependent on several factors including geographic area, fuel type, site conditions and fuel treatment prescription and methods.

Understanding the costs of fuel treatments can help to inform fuel management decisions with regard to an appropriate fuel treatment technique and debris disposal method. Productivity studies of forest fuel treatments allow researchers and fuel managers to observe treatment operations, measure treatment productivity rates and identify opportunities to increase efficiencies in the operations.

With the wide variability in environmental conditions and operational factors, it is difficult to make an 'apples to apples' comparison between two different treatment techniques. This research design will isolate 'debris management technique' as the primary independent variable in this comparative productivity study to determine how this variable influences productivity.

4 OBJECTIVES

Comparative productivity studies are conducted to evaluate the effect of manipulating a specific operational or environmental variable. This project aims to develop a research design that will compare the productivity of the same forest fuel reduction treatment technique using two different debris management techniques –

1. conventional debris disposal tactics - pile and burn technique that includes mulching of smaller debris
2. hügelkultur as a debris management tactic

5 METHODS

5.1 A Background to Productivity Studies

Forest fuel treatments are conducted at a stand level in the wildland-urban interface to reduce the potential for catastrophic loss caused by wildfire. Given the considerable expense of conducting these fuel treatments, fuels managers want to better understand the productivity and cost of commonly applied fuel treatments to prescribe cost-effective treatment techniques. With limited data available and the myriad combinations of fuel treatment options and equipment types in a diverse range of ecosystems, cost projections for fuel treatments are difficult to forecast reliably.

Similar questions and concerns regarding cost and efficiency have been addressed in harvest operations in the forest sector. Forest harvest and silviculture operational staff have collaborated with forestry researchers to address these concerns by developing data collection programs, monitoring operations, and conducting productivity studies.

Productivity studies in timber harvest operations have been conducted for over 50 years. At the inception of equipment productivity evaluations, there was a “growing need to be able to predict the expected productivity of logging machines when working under different environmental and operating conditions” (Aird et al., 1970). The Pulp and Paper Research Institute of Canada and the Forest Engineering Research Institute of Canada developed productivity evaluation methods and conducted extensive testing on harvesting machines performing different harvest operations.

Productivity studies are conducted to evaluate the cost and efficiency of equipment performing selected forest harvest operations. Productivity studies are also conducted to evaluate how a modification to an operation can impact productivity and reduce operational costs. Initially, short-term studies (one to two weeks) were conducted on new harvesting equipment to describe the technical and operating characteristics of new machines and to estimate their potential productivity under measured operating and environmental conditions. Recognizing the limitations of the short-term studies, the Forest Engineering Research Institute of Canada developed long-term data collection methods that would evaluate machinery performance capabilities under a wider range of environmental conditions (Folkema, Giguere, & Heidersdorf, 1981).

FPInnovations’ Wildfire Operations group has applied short-term data collection methods and technologies in vegetation management projects to measure productivity of equipment (primarily mulchers) conducting commonly applied treatment techniques in boreal and montane ecosites. To a lesser extent, productivity trials of motor-manual fuel treatments have been conducted to assess the performance of workers using hand tools (mechanical and manual).

5.1.1 Measuring Productivity

Why monitor operations? – 'you can't improve or manage what you do not measure' (Ryans 2014)

"The direct relationship between product output and time input is called productivity" (Magagnotti & Spinelli, 2012) and can be expressed using different metrics depending on the outcome or product of an operation. Commonly applied product outputs in harvest operations are volume and weight. Productivity metrics are, therefore, expressed as volume/time or weight/time.

The most commonly applied product output for forest fuel treatments is area. Hence, area/time is the most prevalent productivity metric, since fuels practitioners are primarily interested in treating defined areas of forest, grassland, or other wildland fuels.

Common productivity measurements are:

Productive machine hours (PMH) = the time a machine is actively working at its primary function (i.e., mulching, felling trees). PMH excludes any time delay greater than 15 minutes.

Scheduled machine hours (SMH) = the scheduled shift length. This is usually reported as monthly or yearly and is often used in machine costing formulas (Ryans, 2014). Most fuel treatment productivity studies have been conducted in winter when the duration of the shift is variable and often dictated by weather. During winter productivity studies, the shift length is taken as on-site arrival time to departure time.

Machine utilization (%) = a measure of longer-term machine efficiency, calculated as PMH/SMH.

Area/PMH is the most common productivity metric the Wildfire Operations group uses in assessing fuel treatment operations. Area is the size of the treatment area in hectares. Given the small scale of fuel treatment operations relative to harvest operations, all fuel treatment productivity data is collected from short-term studies.

Volume/time has also been used as a productivity metric. Biomass volume was calculated in a productivity study of a broadcast mulching operation in a black spruce forest stand with large variations in stem size and biomass loading within a single treatment unit. Using stand data provided by the Alberta Wildland Fuel Inventory Program (AWFIP) as inputs, biomass equations (Lambert, Ung, & Raulier, 2005) were used to calculate biomass volume processed in each subunit. Biomass volume was used to determine volume/time as one of the productivity metrics (Hvenegaard, 2019). Volume/time was also determined by measuring post-harvest debris piles and machine productivity in hazard abatement trials (Schroeder & Mooney, 2008).

5.1.2 Scales of Rigor in Data collection

At a very coarse scale, treatment cost/area is easily calculated using administrative records of treatment cost and area treated. This metric is sometimes used as rough indicator of productivity. This data is generally specific to a certain geographic area and comparisons to fuel treatments in other areas is more of an 'apples to oranges' comparison.

A more representative productivity metric uses the overall area treated divided by the number of hours that a machine works or the number of person-hours worked (area/time). Machine time can be roughly captured by recording machine start/stop times. Similarily, start and stop times for personnel with the number of personnel can be used to calculate productive person-hours.

A more accurate capture of machine time in productivity trials is achieved using a MultiDAT[1] datalogger to record machine start/stop times and delays. A GPS antennae attached to this unit will also record machine movement which can be used to calculate area. Data captured by the MultiDAT is used to determine productive machine hours.

Area/Productive Machine Hours is a metric commonly used in machine productivity trials. This can also be used in motor manual treatments to represent productive person-hours. Capturing such precise data is generally not attempted for each crew member in a motor manual treatment operations with larger crews. Generally, the same times for productive hours and rest breaks are applied to all crew members in the crew. However, it is important to record the number of crew members on each working day. On site data collection can record delays as mechanical or personal.

5.1.3 'Apples to Apples' Comparisons

With many environmental and operational variables that change from one fuel treatment operation to another, it is challenging to conduct comparative productivity trials to measure the impact of manipulating one independent variable. Many trials may be required to achieve a high level of confidence in the productivity data.

The Slave Lake Mulch Research Area (Hvenegaard and Hsieh 2014) was established to study productivity of two mulcher sizes applying different treatment methods in a boreal forest environment. With general similarities in forest stand types across the research area (mixedwood, upland black spruce and lowland black spruce), the productivity research project isolated four variables (stand type, treatment type, treatment intensity, and equipment type) to study as independent variables. In spite of the low number of replicates of each trial type, general trends were identified.

Productivity trials have been conducted during motor manual fuel treatments in fairly consistent site conditions at the Pelican Mountain FireSmart Vegetation Management Research Area[2]. The treatment area was even-aged black spruce on similar ground conditions in winter. Over four days in December 2016, Hvenegaard and Hsieh (2017) observed fuel treatment operations conducted by a four-person crew and captured daily productive hours and area treated to calculate an overall productivity rate as area/productive worker-hours (ha/PWH).

In addition, detailed timing was conducted to isolate individual tasks that are performed in a specific role (chainsaw operator, helper). Observing a specific operation within a fuel treatment

[1] MulitDAT is a device built by Castonguay Electronique that records machine working and non-working time. It has the capability to provide working time elements and details of forestry machines.
[2] For more information about the Pelican Mountain FireSmart Fuel Management Research Site, see the Canadian Wildland Fire & Smoke Newsletter.

with a detailed analysis of time spent on each task helps to identify inefficiencies of an operation that can be modified to improve performance and overall productivity.

A less formal approach to collecting productivity data was applied in a similar site at the Pelican Mountain site. The same treatment technique was applied, and the crew leader was tasked with collecting daily data that included treated area, times (travel, working, delays, breaks) and weather/site conditions. With appropriate briefings and coaching through the first day of treatment operations, this method proved to be a cost-effective data collection method.

To collect the most reliable comparative data, an optimum methodology would have the same crew conduct the same treatment technique (operational variables) in forest stands of the same stand age and density under the same weather conditions (environmental variables). To study the impact of a change in an independent variable (e.g. debris disposal method), a forest stand with consistent attributes (species, stand age and density, topography) would be subdivided into several units of similar size and stand characteristics of each unit would be measured.

Other productivity trials have been conducted during other fuel reduction treatments in varied fuel environments. These productivity studies employ an opportunistic approach to collect data as fuel treatments are prescribed. The downside of this approach is a lack of consistency in several variables (fuel environment, machinery type, and fuel treatment technique). Given these differences in environmental and operational variables, it is difficult to merge data from many dissimilar projects to produce reliable universal productivity curves.

5.1.4 Forest Stand and Fuel Inventory

In most of the productivity trials conducted by FPInnovations, the fuel treatment site had been sampled by the Alberta Wildland Fuels Inventory Program (AWFIP) crews using established data collection methods (Government of Albera 2014). Data collected through the AWFIP system was used to quantify forest stand attributes. These sampling initiatives and quantified stand attributes were invaluable in establishing similar trial sites in a comparative productivity study.

5.2 Research Design for Comparative Productivity Trials

5.2.1 Treatment Site Selection

Two treatment sites will be established and treated using the same fuel treatment prescription. On the first site, a conventional debris disposal method (pile and burn) will be applied. On the second site, a hügelkultur debris management method will be applied.

The two sites can be subunits of the same treatment unit. Ideally, the treatment subunits should have similar stand structure. Site characteristics can be evaluated to ensure consistency between the two sites. Varying degrees of rigor can be applied in the treatment site evaluations.

Aerial imagery of the two sites can identify parcels of forest with similar stand structure and the boundaries of these parcels can be defined with GIS mapping tools. With these boundaries defined, a site visit to both sites will be required to visually assess the stand characteristics and determine if there is acceptable similarity between the two sites.

A detailed stand inventory can be conducted to measure stand attributes. Species, stand density, diameter at breast height and stem height are key stand attributes that can be measured to assess similarity between the two stands. Documentation should also include ground-based imagery. If inventory plots are established, photos along each line transect should be taken as part of the sampling process. 360-degree imagery[3] is simple and easy to capture and provides good visual documentation of stand structure and surface fuels.

5.2.2 Fuel Treatment Technique

The same fuel treatment prescription with the same fuel treatment technique should be applied in both subunits. Fuel treatments are typically prescribed to increase crown spacing, increase crown base height and reduce surface fuel loading.

Defining the debris disposal methods

The construction of hugels in an experimental burn site is discussed in the companion report. Burn pile and hugel characteristics which are likely to impact moisture retention, flammability and sustained burning are discussed in the section on construction of hugels.

The size and shape of residue piles can influence potential fire behaviour. Burn piles that are constructed to dispose of residue from harvest operations or fuel treatments are designed to ignite easily, sustain burning and consume debris. Conversely, constructed hugels will be designed to be less flammable with reduced ignition potential and lower potential fire intensity. 'Haystack' burn piles in harvest blocks are constructed to allow for burning at lower fire hazard levels, promote fire spread in the pile, and to optimize fuel consumption. A taller vertical structure with good vertical continuity allows for greater fire spread with greater volume of fuel consumed on a smaller footprint.

Relative to constructed 'haystack' burn piles, oriented harvest residue piles with fuel particles aligned horizontally and reduced vertical structure are more difficult to ignite with reduced sustained burning and potential fire intensity (Hvenegaard et al. 2019). Applying these preliminary findings, a low-profile shape is proposed for the constructed hugels with branches and stems aligned to increase density and reduce air flow through the hugel. A lower profile hugel with increased contact with the ground may achieve the goals of greater moisture absorption/retention and reduced spread potential.

Four potential hugel configurations are discussed in the companion report. These are only suggestions for construction and the methods can be modified as efficiencies in the constructions methods are realized. Once a hugel construction method has been adopted in the fuel treatment operations, a standard size should be established. With standards established for construction method and size, data collection in a productivity study will be more efficient.

[3] https://www.insta360.com/product/insta360-oner_twin-edition

5.2.3 Measuring Pile Volume

The Piled Fuels Biomass and Emissions Calculator[4] allows users to calculate pile volume and material weight of different sizes and shapes of debris piles. This tool can be used to establish optimum dimensions for hugels and burn piles constructed in a comparative productivity study.

The shapes suggested as the most representative of piled debris and hugels are paraboloid and half ellipsoid, respectively. As hugels are built on site, a different shape in the calculator may be selected as more appropriate. Initial explorations of potential dimensions of each debris configuration with the volume and pile biomass are shown in Table 1.

Table 1. Example dimensions for hugel and burn pile construction.

Debris Disposal Method	Structure Type	Most Representative Shape	Dimensions (metres)			Calculated Value	
			Length	Width	Height	Volume (m^3)	Biomass (Mg)
Hügelkultur	hugel	half ellipsoid	5	2	1.5	6.02	.35
Pile and Burn	pile	Paraboloid		2.5	3	5.73	.34

The pile dimensions in Table 1 yield similar volume and biomass values. These dimensions are shown for illustration purposes. Actual dimensions of constructed piles and hugels will vary and can be input to the calculator to calculate volume and biomass more accurately.

The calculator includes an option to change the packing ratio of the machine-piled fuel. Given the desired compaction of constructed hugels, the highest compaction ratio (25%) should be selected.

5.3 Measuring Productivity of Pile and Hugel Construction

The time required to build hugels and burn piles should be documented to compare the productivity of each debris management technique. The volume of biomass captured in each technique can be determined using the Piled Fuels Biomass and Emissions Calculator. Data collection will require measuring the length, width and height of each pile and hugel to determine the volume of each individual feature

A detailed timing of each construction method will deconstruct the overall process into different tasks for each method and help to identify inefficiencies that can be addressed to improve productivity. A detailed timing of debris production/arrangement process would likely focus on two key workers (chainsaw operator and helpers moving debris). Some of the potential work activities that are anticipated as tasks in a detailed timing include:

1. Production of debris – Limbing branches, removing stems
2. Gathering and hauling debris to pile site/ hugel site

[4] https://depts.washington.edu/nwfire/piles/index.php

3. Arranging debris into piles or hugels.
4. Mulching debris (if applicable) and dispersing into treatment area or onto hugel.

5.4 Documentation

5.4.1 Productivity Metrics

Area/Overall time (ha/time) can be a somewhat more valuable productivity metric provided that the time required for each separate subunit is recorded. This metric is somewhat less coarse but extracting non-productive time elements will produce a more valuable metric.

Area/productive time (ha/PMH) will be the most representative productivity metric to represent actual working time. It will be necessary for an observer or crew leader to record delays and breaks. Scheduled working time - delays and breaks = productive working time.

Timing of hugel/pile construction will be a representative metric to assess the effective product output as a function of time (input). The following two metrics can be documented through data collection methods conducted by an observer or crew leader.

- Number of hugels or piles/productive time can be recorded by a crew leader or observer
- Processed volume/productive time can be calculated by measuring piles or hugels and using the Piled Fuels/Biomass calculator. This documentation should be conducted by an observer since it is time-consuming, and a crew leader has other responsibilities that are more critical.

The Appendix provides a template for data collection for a motor manual fuel treatment.

5.4.2 Environmental Conditions

While environmental conditions are not being documented as an independent variable in this study, these extraneous factors can be noted qualitatively. Weather conditions such as extreme heat or cold, rain or snow can have an impact on productivity. These conditions may be reflected in the number of cooling/warming breaks. Extreme working conditions generally result in reduced productivity. Site conditions such as steep slopes and slippery footing will also have an impact on productivity. Original site selection should aim for consistent topographic conditions between the two comparative productivity study sites.

5.5 Ongoing Modifications to this Data Collection Process

This proposal is a preliminary research design based on methods and documentation applied in productivity trials in previous mechanical and motor manual fuel treatments. The methods that are proposed in this research design attempt to account for potential site attributes and working conditions. However, further modifications may be required to address unknown variables in the future.

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APPENDIX: DAILY DATA COLLECTION SHEET

CREW		RECORDER	
# of WORKERS		DATE	

Daily Activities	Time	WEATHER and SITE CONDITIONS				
Start travel						
Arrive at staging area		Temperature	max		min	
Arrive at treatment site		Rain	Yes	No		
Treatment activities start		Snow	Yes	No		
Treatment activities finish		Slope (%)	0 -10	10-40	40 - 100	
Arrive at staging area		Stand density	Low	Med	High	
Travel complete						

BREAKS	DURATION	# of workers	DELAYS	DURATION	# of workers
Type of break (rest, coffee, lunch)			Type of delay (mechanical, personal)		

Number of hugels constructed	
Number of piles constructed	
Area treated	

Instructions

1. Safety or operational briefings are productive working time.
2. Attempt to create piles or hugels of similar size throughout the treatment area.
3. At the end of a working day, flag the perimeter of treated area and record a GPS track of the area treated for that day. Save track logs for transfer to project files.
4. Record only area that has been fully treated with debris in piles or hugels.
5. Daily - attempt to fully complete an area with debris in piles or hugels.
6. Please ensure that the number of workers is recorded for breaks and delays.
7. Mechanical delays include equipment repair that require more than 15 minutes; sharpening tools/chainsaws is not considered a delay.

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