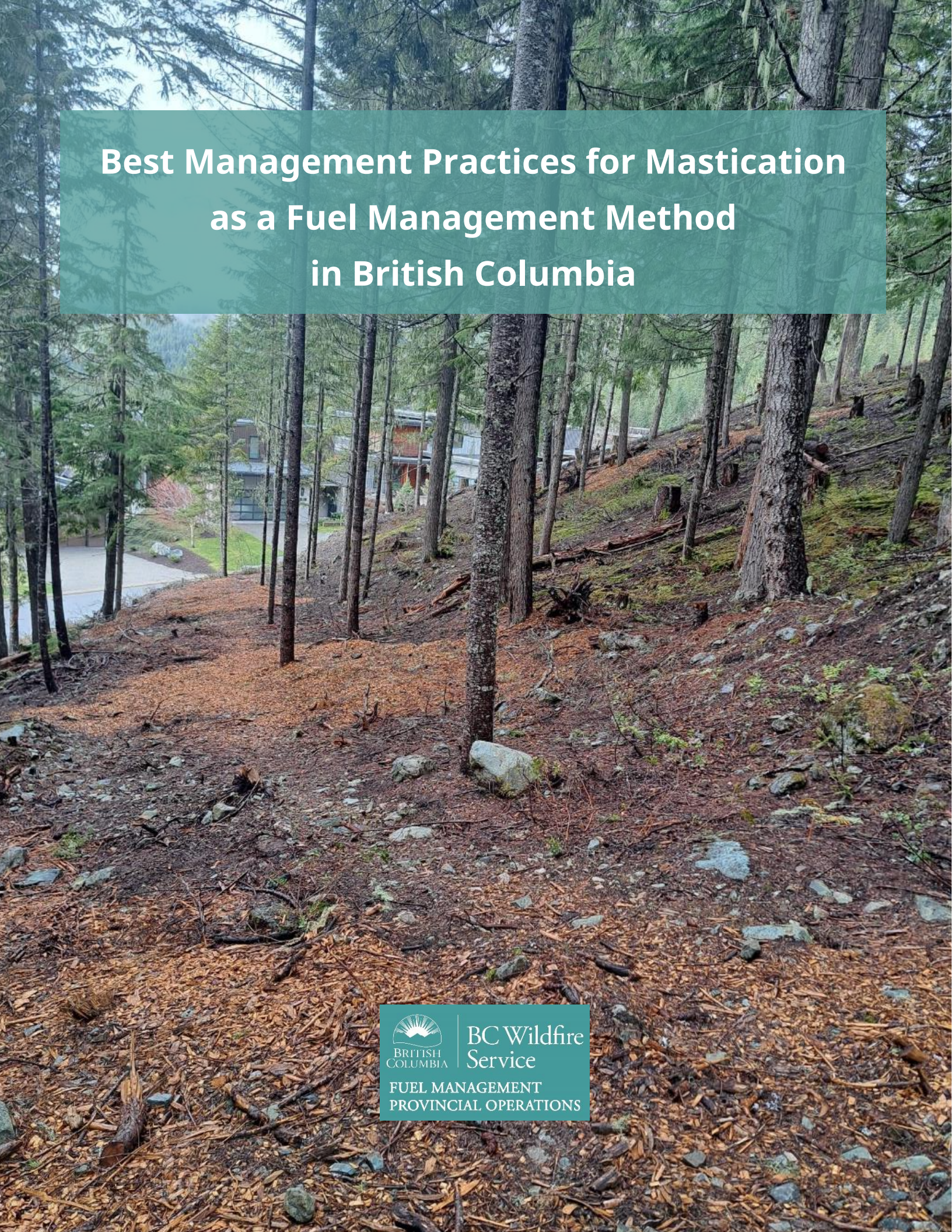
Best Management Practices for Mastication as a Fuel Management Method in British Columbia



BRITISH COLUMBIA | BC Wildfire Service

FUEL MANAGEMENT
PROVINCIAL OPERATIONS

Table of Contents

Table of Figures

Legal Notice

Disclaimer

This document contains material to assist a person in determining their fuel treatment and implementation requirements. It is intended as a guidance document. Users must refer to the Wildfire Act, Regulations, and the Open Burning and Smoke Control Regulation (OBSCR) for further detailed language regarding their statutory obligations.

Warranty

While every effort has been made to ensure the accuracy of the information herein, no warranties of any kind are made as to the precision or longevity of the contents. Readers are advised to refer directly to the wording of the legislation and regulations and obtain legal advice from their own sources. This information is provided as a public service by the Ministry of Forests and BC Wildfire Service (BCWS). This document and all the information it contains are provided "as is" without warranty, whether express or implied. All implied warranties, including, without limitation, implied warranties of merchantability, fitness for a particular purpose, and noninfringement, are hereby expressly disclaimed.

Limitation of Liabilities

Under no circumstances will the Government of British Columbia be liable to any person or business entity for any direct, indirect, special, incidental, consequential, or other damages based on any use of this information or any other document or material to which this document is linked, including, without limitation, any lost profits, business interruption, or loss of programs or information, even if the Government of British Columbia has been specifically advised of the possibility of such damages.

All Rights Reserved

Questions or Concerns?

For more information, please contact the Intellectual Property Program by:

- Email: ipp@mail.qp.gov.bc.ca
- Fax: (250) 356-0846

Acknowledgements

This document was made possible by Shifting Mosaics Corporation and their team members:

- Dr. Sonja Leverkus PhD RPF
- Dr. Mitch Greer PhD
- Alexis Jorgensen MSc
- Carolyn B. Brochez MNR RPF
- Dr. Derek Scasta PhD
- Dr. Gillian Leverkus PhD
- Georgina Preston MSc
- Tara Boag
- Hunter Bohn

As well as input and guidance from the project team:

- Steven Hvenegaard (FPInnovations)
- Pete Laing RFT (BCWS)
- Kara Froese (BCWS)
- Morgan Boghean RFT (BCWS)

Definitions

The vocabulary surrounding the process of mulching, chipping, and/or mastication and the resulting product (mulch, chips, etc.) is inconsistent across the literature, with different terms often being used interchangeably. In this document, the following terminology is used:

Mastication: The use of machinery to process woody vegetation and litter into smaller pieces, generally as a method of fuel treatment.

Masticated matter/mulch: Woody vegetation and litter that has undergone the process of mastication.

Chip size: The size of individual pieces of masticated matter.

Chip shape: The shape of individual pieces of masticated matter.

Introduction

Mastication, the use of machinery to process woody vegetation and litter into smaller pieces, has been suggested as a fuel management method in BC. Mastication removes ladder fuels and alters fire behaviour. It does not directly remove fuel but may be a valuable tool in areas where other treatment types, such as prescribed fire, are not feasible due to site conditions or local opposition.

This document is intended to provide forest managers with a summary of best management practices for integrating mastication as a fuel management method. The considerations discussed below apply to projects from the Wildland Urban Interface (WUI) to remote areas. This document is not intended as a comprehensive guide of all information and recommendations related to fuel management. This document was developed based on an extensive review of published scientific literature which can be viewed here.

Figure 1: Forest stands after mastication treatment. Images from Hvenegaard and Hsieh (2015) and Hvenegaard et al. (2016) (used with permission).

Figure 2: Open meadow before (left) and after (right) mastication. Images from Hvenegaard and Hsieh (2015) (used with permission).

Interaction of Mastication with Wildfire

Fire has been observed moving from crown to surface and having lower spread rates in masticated fuelbeds, though these results are not consistent across all studies. Research suggests that prescribed fires over masticated fuel have decreased crown scorch and may have reduced overstory mortality depending on fire residence time and soil heating.

Mulched fuelbeds tend to smoulder, potentially releasing higher levels of smoke and particulate matter, meaning that a treated area may burn longer than other fuel types. This allows for soil heating to a point that may be lethal to roots or soil microbes. In such cases, local fuel loading may rebound quickly after fire due to the death and subsequent collapse of standing trees.

When it comes to fire suppression, masticated fuelbeds offer advantages. The removal of ladder fuels makes the area more accessible for suppression actions. However, large quantities of water may be required to extinguish smouldering fires and the fuelbed may ignite or reignite relatively easily if exposed to firebrands. Firebrands have been known to travel several hundred meters or more. Therefore, attention must be paid to prevailing wind speed and direction when planning mastication treatments.

There may be ways to increase the effectiveness of mastication in the event of an approaching wildfire. A combination of retardant drops, sprinkler use, and planned ignitions around a treatment area have been used to bolster treatments in the past. Refer to the Kenow Fire and Logan Lake Fire case studies by FPInnovations for more information (Ault and Hvenegaard 2019, Hvenegaard 2023) (for full document information, see Suggested Reading on pg. 19).

Planning Your Project

Objectives

Managers should establish their objectives for a treatment program before making decisions regarding methods or equipment. Objectives should be both verifiable and measurable, allowing for the evaluation of project success and tracking of site conditions over time.

Fire Behaviour

There are numerous questions to answer before determining the appropriate fuel management method for a site. What are the goals in terms of fire behaviour? Do you want to create a linear fuel break that can act as a defendable space for firefighters? Or a larger fuel management zone? Do you want to slow the spread of ground fire or prevent crowning? Answering these questions will assist in determining the best methods to implement. Other considerations related to fire behaviour include:

- Vulnerability of standing trees to windthrow after thinning, potentially increasing fuel load.
- Potential drying of surface fuels due to increased ground-level winds and solar radiation after canopy thinning.
- The speed and type of vegetation recovery (fuel buildup) after treatment.
- Potential fire escape routes from inside to outside of the treated area.
- Mitigation of short-term risks elevated by fuel treatment.

Environment and Culture

Mastication can have several environmental impacts beyond vegetation removal. Managers should establish objectives for the appearance and ecosystem health of a site after mastication before planning treatment methods. There exist many important ecological and cultural values across the province to consider when planning fuel management methods.

Some environmental and cultural considerations relating to mastication may include:

- The number and pattern of standing trees to be left on site and their vulnerability to windthrow - Note that at least 7m x 7m spacing between trees may be required to accommodate most mastication equipment (Harrod et al. 2009).
- Nearby waterbodies that may be impacted by leachate and/or erosion resulting from treatment activities
- Disturbance, compaction, and/or hydrophobicity of soils
- Potential spread of invasive plants into the treatment area
- Potential impact of the treatments on wildlife forage and habitat including species at risk
- Potential influences on and interactions with cultural values such as traditionally and medicinally used plants or berries and culturally important locations
- Potential smoke release due to prolonged smouldering of masticated fuelbeds

Use of Masticated Material

Revenue may be generated on mastication projects through the sale of the resulting mulch. Masticated material may be used as biofuel in both suitable industrial plants and certain types of home boilers, or other types of bioproducts depending on the local market. Chips may be used for vermiculture. Managers should investigate if there is interest and infrastructure to utilize mulched product in their area, and how it would need to be processed to make this possible. Masticated material should not be used for landscaping purposes.

Site Conditions

The specific conditions of a fuel management site will determine the practicality and best methods for mastication. Forest managers should, at the least, identify the following during a primary site assessment:

- **Slope**
  Mastication equipment will only function safely up to a certain slope, commonly ≤40% (Jain et al. 2018).

- **Topography**
  Different equipment will be required for relatively even sites compared to those with diverse topography. Topography influences the moisture and hydrology of the site.

- **Soils**
  Managers should consider whether soil is sensitive to compaction or erosion from mastication activities. This will influence equipment choice and the number of passes acceptable over a particular location.

- **Moisture and hydrology**
  Masticated material will generally decompose more rapidly on wet sites. In wetter locations, masticated material is expected to remain moist longer in the case of drought or fire, influencing combustibility. In addition, moisture influences soil stability, with wetter soils potentially at higher risk for compaction.

  Managers should identify surface water bodies on site and potential drainage paths to other locations. Mulched material may release leachate into the aquatic environment. Liu et al. (1996) suggest that piles of wood residue (such as mulch) in areas containing fish-bearing streams should be kept more than 100m from the nearest surface water and not within floodplains. They recommend locating piles more than 300m from drinking water wells and 15-30m from a property line.

- **Size of treatment area**
  Area for treatment will influence the size and amount of equipment and resources required for the project.

- **Site location in relation to other treatment areas**
  The spatial arrangement of treatments related to each other may influence treatment efficacy and eco-cultural values across local and landscape scales.

- **Size and density of fuels for mastication**
  The more fuel on site, the more time and equipment will likely be required, and the more masticated matter will be left over. Fuel size and density influence equipment

requirements relating to size, processing power, and maneuverability.

- **Vegetation type**
  The species of vegetation to be masticated can have direct effects on both regeneration and the potential environmental impacts of mastication. For example, some species regenerate through relatively thick layers of masticated matter or are of greater concern for releasing leachate than others.

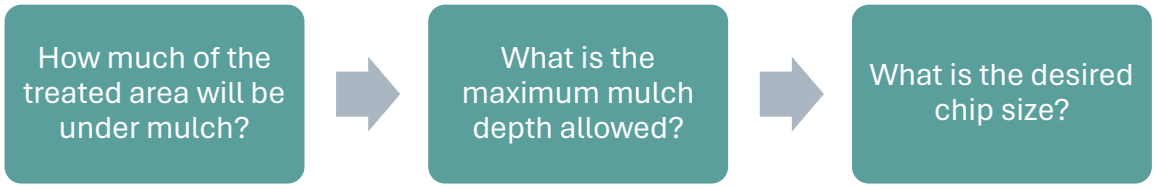
  It is important to identify invasive species in or around the project area and consider the potential impact of mastication on their introduction or spread. If there are invasive species nearby, managers should develop a control plan including preventative activities such as cleaning equipment before it enters the treatment site.

- **Bark beetle or other forest pathogens**
  Managers should consider whether bark beetle outbreak is a concern in the project area as bark beetles may be attracted by the smell of masticated material. Trees will likely be more vulnerable to a variety of pathogens if damaged by mastication equipment. Transporting masticated material out of the project area may lead to the spread of pathogens to other forest stands.

- **Other environmental or archeological concerns**
  Mastication projects will be subject to the legal requirements for factors such as species at risk, fish-bearing waterbodies, and archaeological sites. Managers should identify the probability of such values occurring in or around their treatment area and proceed accordingly.

Considerations for the Masticated Fuelbed

Critical Mulch Considerations



While it is generally recommended that as much mulch be removed from the treatment site as possible, managers should be cognizant of coarse woody debris requirements when planning their project (Chief Forester's Guidance on Coarse Woody Debris Management Wildfire Mitigation Treatments, Government of British Columbia 2022).

Biomass may be removed prior to mastication via logging or other activities. Leaving mulch on site can result in negative consequences such as suppressing plant regeneration and releasing leachates into nearby waterbodies. Although fuel is modified, it will likely decrease the efficacy of mastication as a fuel management method if left on site. If removal of all mulch is not feasible, there are several factors to be considered: amount, depth, and chip size of remaining mulch.

How much of the treated area will be left under masticated material?

The proportion of the treatment area you intend to leave covered with masticated material will depend on the desired environmental and fire behaviour objectives. There is limited research on the ideal layout of mulch on a treatment site. However, heterogeneity, with a mix of covered and uncovered areas is recommended. This provides a variety of microenvironments for plant regeneration and wildlife habitat. Managers should also consider clearing areas to disrupt fuel continuity in case of ignition.

In addition, removing chips from around the base of trees, provided it can be done without significant root damage, is recommended as it may decrease both mortality in the case of fire and bark beetle attack on residual trees. See Jain et al. (2012) for a more detailed discussion of the potential patterns of masticated material left on treatment sites.

What is the maximum depth of masticated material allowed?

The depth of masticated matter covering the ground will directly influence plant regeneration, fuel loading and resulting fire behaviour. Wolk et al. (2020) suggests that a depth of 7.5cm may hinder plant growth, and a depth above approximately 5cm may depress tree growth. However, the impact of mulch depth will depend on local site conditions, including the species being

masticated. Kreye et al. (2014) is a good reference for further information about the influence of mulch depths across different treatments.

In addition to mulch depth, another consideration is the depth of mastication into the forest floor. Will only surface vegetation be processed, or will mastication reach into the underlying soil? The latter will create greater soil disturbance and increase wear and tear on equipment.

However, mixing masticated material with mineral soil may speed decomposition and decrease flammability of the fuelbed.

What is the desired chip size?

Mastication can be done to coarse or fine levels. In the former, masticated fuels include many large pieces. Coarse-level treatments discussed in Lyon et al. (2018) sectioned trees into approximately 0.5m lengths. Fine level treatments process the fuelbed into relatively even, small fuel fragments and tend to take more time and resources. Processing fuels into coarse versus fine matter may also be referred to as low versus high intensity treatment.

Chip size will influence plant regeneration, decomposition, compaction rate, and potential for use of masticated matter as fuel or other bioproducts. It will influence fire behaviour if the fuelbed is ignited. If planning to use chips as fuel, managers should determine the chip size and shape requirements for related local infrastructure.

If left on site, it is generally recommended that smaller chips be produced as they tend to decompose rapidly and provide better conditions for plant regeneration than larger chips. Smaller chips are likely to compact more quickly than larger chips, potentially decreasing their flammability. However, smaller chips tend to ignite more easily and burn more quickly than coarse material, so ideal chip size will depend on specific objectives and site conditions.

Figure 3: Example of coarse (left), medium (middle), and fine (right) mulched fuelbeds.

Equipment

Various equipment is available for mastication and what is best for your project will depend on site characteristics such as slope and topography. However, there are a few general considerations when choosing mastication equipment. Jain et al. (2018) is an important resource to review. Using mastication equipment can lead to problems such as fuel spills and other issues. Operators should have the necessary training and supplies to mitigate these issues.

Operator Skill

Operator skill is often cited as more important than equipment type in terms of project results. A skilled operator will increase mastication efficiency and lower costs, and they are more likely to achieve project objectives. Less post-treatment work may be required to achieve results such as the desired amount, depth, and pattern of cover. A skilled operator can minimize environmental impacts of a project through factors such as taking fewer passes over a treatment area.

Stationary vs. Mobile

Stationary equipment includes a chipper or masticator, which remains in place. Secondary equipment is required to transport fuels to the masticator. The use of stationary equipment makes it easier to collect masticated material either for piling or transport. It may be the better choice when the intention is to transport mulch off site for storage or use as biofuel. However, the requirement for separate transportation and mastication equipment may increase project costs. The use of stationary equipment increases vehicle traffic on site, as machines move back and forth to the masticator, with related disturbances such as soil compaction.

Mobile equipment travels around a site masticating as it goes. The initial treatment costs may be lower as fewer pieces of equipment are required. The use of mobile equipment may be favorable in areas with sensitive soils as it requires less vehicle traffic. However, mobile equipment tends to spread masticated matter around a site and leaves greater depths of mulch around tree stumps. Further cost, equipment, and disturbance may be required post-treatment to remove masticated matter or relocate it into the desired pattern.

Drum vs. Disk Masticators

Figure 4: Examples of a drum shaft masticator (left) and disk shaft masticators (right). Images from Hvenegaard and Hsieh (2014) and Steve Hvenegaard. (Used with permission).

Mobile mastication is typically performed by an excavator or skid steer with a specialized masticating attachment. Two types of attachments are available for either machine: drum (horizontal shaft) masticators or disc (vertical shaft) masticators.

Skid steers are well-suited for working at ground level on mild slopes and level topography, while excavators are more maneuverable, can work on steeper slopes, and have greater reach. The drum masticator uses a spinning cylinder covered in cutting teeth to shred material. While drum masticators are considered slower than disk masticators, they produce a finer-sized masticated material. They can masticate both trees and brush and throw debris in a predictable path.

A disk masticator uses a circular flywheel with cutting teeth to remove material. Disc masticators cut faster and can be used to masticate larger trees, but produce coarser material, leave messy stumps, and eject material greater distances. Disc masticators generally require greater operator skill but less maintenance than drum masticators. Both mastication head types can be attached to excavators or skid steers. However, the increased power demands of a horizontal drum masticating head require a larger machine and, consequently, more ground disturbance potential.

In conclusion, it is critical to understand the capabilities of various masticating machine configurations and your site requirements before finalizing site plans or prescriptions. Dialogue with potential contractors is encouraged to better understand available machines and capabilities.

Other Equipment Considerations

- **Wheels or tracks**
  Wheeled equipment may be more maneuverable but tracked equipment tends to create less soil disturbance and is more suitable where soils are wet or prone to compaction. Tracked vehicles may be preferable on steeper terrain.

- **Cutting head attachment**
  Managers should consider whether to have their cutting head boom mounted. This will allow masticators to process fuels in locations where the full machine cannot access due to rough topography or other factors. There are many options for specific types and specifications of cutting heads.

- **Horsepower**
  Higher horsepower is required for processing larger trees and often results in smaller chip size. However, increasing horsepower generally equates to larger machines or cutting heads and higher costs.

- **Size**
  The size of equipment directly influences reach and maneuverability. Smaller machines are generally expected to be lower cost and more maneuverable, which may make them ideal for densely vegetated areas or locations where a relatively high number of residual trees are desired. They may be necessary in areas where roads do not support the use or unloading/loading of large equipment. However, larger machines are required to process larger trees. A longer reach may be required to remove fuels higher up or in locations where the full machine cannot access.

Post-Treatment Plan

Figure 5: Ignition of a coarsely mulched fuelbed. Image from Hvenegaard (2020) (used with permission).

Mastication Followed by Prescribed Fire

Prescribed fire can be an effective way to remove masticated matter from a treatment site. Reductions in fuel load from mastication followed by prescribed fire, particularly in conifer forests, can be sustained for 10 to upwards of 20 years. Prescribed fire requires less vehicle traffic within the treatment unit than activities such as raking and may create more regular and predictable fuelbeds depending on treatment methods and site characteristics. However, managers should consider the potential for mortality of residual trees due to root damage from soil heating resulting from potentially longer fire residence times in masticated fuelbeds.

There is a balance between community safety from wildland fire and the potential short-term impacts from prescribed fire smoke. Managers must complete a prescribed fire burn plan, which includes particular attention to communications, smoke management, and mop-up plans. A strong communications plan will outline how the community, public, and surrounding residents or industry will be advised of the timing of ignition, and it will allow for feedback and comments to be taken into consideration during a prescribed fire operation. A mop-up plan will discuss resources available and timing for dealing with smouldering and potential reignition of masticated matter should full consumption of fuels not be achieved.

Smouldering fires may expose field personnel and neighbouring communities to smoke or fine particulates until the fuels have been fully consumed. A smoke management plan will discuss the considerations made to venting, wind direction, and other indices prescribed to minimize

short term impacts from smoke to the surrounding area. Category 4 Resource Management Open Fires (Cat. 4 RMOF) are not prohibited under the Emergency and Disaster Management Act (EMA). While Cat. 4 RMOF are not regulated under the Open Burning Smoke Control Regulation, it is important that everyone implementing a prescribed fire considers smoke management as one of the highest priorities for consideration and mitigation particularly in the WUI. In some cases, short-term smoke impacts may be necessary to increase community safety from wildfires. Managers should have a clear communications plan for informing neighbouring landowners and tenure holders about such activities and to address concerns and to provide clean-air alternatives.

As time since mastication increases in more mesic sites (2-5 years since mastication), fuel becomes increasingly challenging to burn due to woody plants and other vegetation growing through the masticated layer. Compaction of the fuelbed occurs through time and can also influence flammability. Therefore, it is recommended that prescribed fire occur as soon after mastication treatment as possible. The fuel moisture codes (Fine Fuel Moisture Code, Duff Moisture Content, and Drought Code) may assist managers in determining the best timing for applying prescribed fire.

Another consideration related to prescribed fire is the potential influence on invasive plants. Soil heating from increased residence time in mulched fuelbeds may damage or kill invasive species on site. However, certain invasive species, such as cheatgrass (Bromus tectorum) are well adapted to fire and burning may encourage invasion. Managers should consider the abundance and type of invasive plants in the area and the potential interaction of fire with these species before deciding whether to burn a mulched fuelbed.

Alternatives to Prescribed Fire

If prescribed fire is not feasible, there are other options for removing masticated material from site. Chips may be raked into piles or baled for transportation. If using stationary equipment, mulch can be directly loaded into trucks or piles during mastication. Another option is to remove biomass from an area before mastication via logging. Even if masticated matter is intended to be left on site, post treatment piling or moving of the chips should be used to create a patchwork of covered and uncovered areas. If raking masticated matter into piles for burning is an option, equipment should have a suitable head attachment to avoid problems such as mixing snow into piles.

Post-Treatment Monitoring: Fuel Load, Soils, Vegetation, Wildlife

Managers should develop a detailed monitoring plan for the treatment site covering both fuel loading and environmental objectives. It is recommended that monitoring plots are established in treated and untreated areas for comparison. The most effective monitoring plan will cover the

site for several years allowing for both evaluation of project success and detecting when fuel levels have recovered to the point that further treatment may be required. Eco-cultural values for consideration may include but not be limited to the presence or absence of wildlife and culturally and medicinally used plants and berries, preservation of areas of cultural significance, amongst others.

Knowledge Gaps

Mastication as a fuel management method is a relatively new process in BC and it is associated with several knowledge gaps. Forest managers should be aware of these uncertainties when planning their project and know that the recommendations within this document may change as further research becomes available. Some important research needs related to mastication include:

- **Effectiveness of mastication as a fuel treatment across different fire indices and fuel types**
  Though a significant amount of research has been performed on mastication, the resulting information will not necessarily hold for all forest types and fire indices in BC. Purposeful burning of masticated fuelbeds while monitoring the resulting fire behaviour will help assess the effectiveness of mastication as a fuel treatment under varying conditions across the province.

- **Mastication and the environment**
  Wildlife, traditionally used plants, invasive species, soil nutrients and carbon sequestration, leachate, and soil microbiology. There are several theses and grant report documents available considering one or more of these topics.
  However, increased scientific exploration and publishing is recommended to gain a better understanding of the potentially complex interactions between mastication and ecological and cultural values and areas of interest.

- **The ideal pattern of masticated matter**
  Further exploration of the influence of the pattern of masticated matter left on site and what is optimal for fuel treatment and wildlife objectives would be beneficial.

- **Baling or other methods of chip removal**
  Another potential research endeavour for BC is to investigate different methods for removing masticated material from treatment areas, such as baling systems (e.g.

Gyrotrack-bioenergy baling system as discussed in (Blackburn and Keddy 2018)).

- **Engagement with on-the-ground personnel**
  It is recommended that there be review and engagement with those currently doing mastication related projects on the ground in BC. There is much expertise that exists with licensees and others involved in the forest industry and the wildland fire and fuel profession which will not be captured via literature review.

Should mastication be used in BC?

Mastication with chip removal and post-treatment plans that are implemented may be an option as a fuel management method in the WUI in BC. Chip management and post-treatment follow-up, including monitoring are critical factors for the potential success of mastication projects. Mastication with all chips left on site and no post-treatment is not recommended (with potential exceptions for wet sites with low volumes of masticated material). Such masticated areas pose environmental concerns and do not remove fuels from the location.

Mastication with removal of all or part of the resulting mulch may be a viable option in areas where other treatment types, such as prescribed fire, are either unsafe or subject to strong social opposition. This may be particularly common in the WUI, making mastication a valuable tool in such areas. Use of mastication prior to prescribed fire may be beneficial for a variety of reasons including the removal of ladder fuels and the potential for creating a consistent fuel type for managers.

Ultimately, the suitability of mastication as a fuel management method in BC will depend on specific site conditions and objectives, cost-benefits, including confirmed funding for short term follow-up and long-term monitoring balanced with eco-cultural values, the positive/negative interactions between mastication and those values, and the prioritization of mastication appropriate areas in relation to wildfire risk in the WUI and across the surrounding landscape. In short, it depends.

Summary Table 1: General Recommendations for Mastication

Subject	General Recommendation	Reference

Equipment	**Stationary vs mobile**
	• Stationary equipment if:
	  ○ Plan to remove mulch from site mechanically.
	  ○ Soils are relatively stable/resilient to compaction.
	• Mobile equipment if:
	  ○ Planning to remove mulch from site via prescribed fire.
	  ○ Soils are sensitive to erosion or compaction.
	
	Horizontal vs vertical shaft cutting head
	• Vertical shaft if:
	  ○ Tree diameter is only up to 15.2 – 20.3cm (6-8”).
	  ○ Terrain is rough or uneven.
	• Horizontal shaft if:
	  ○ Terrain and slope are relatively even.
	  ○ Tree diameter up to 76.2cm (30”) if boom mounted. (NOTE: felling and bucking trees >20cm in diameter prior to mastication is recommended to decrease processing times)
	
	Wheeled vs Tracked Equipment
	• Tracked equipment if:
	  ○ Soils are wet or sensitive to compaction
	  ○ Project is on relatively steep terrain
	• Wheeled equipment if:
	  ○ Soils are not wet or sensitive to compaction.
	  ○ Dense vegetation, complicated terrain, or other factors require the use of a machine with greater maneuverability.
	Machine Size
		(Harrod et al. 2009, Jain et al. 2018, Mitchell and Smidt 2019)

	• Smaller machines if:
	  ○ Site conditions require relatively high levels of maneuverability (e.g., complicated terrain, dense vegetation).
	  ○ Soil is sensitive to compaction.
	  ○ Site access does not accommodate larger machinery.
	• Larger machines if:
	  ○ High levels of horsepower are required (e.g., if processing large diameter trees).
	  ○ A long reach is required to reach tall trees or access areas where a full machine can't travel.
	  ○ Access to site is suitable for large machinery.
	  ○ The terrain and vegetation will not seriously hamper movement of large machines.	

Ground cover of masticated material: proportion and pattern	Recommend the removal of mulch from site either via prescribed fire or mechanically.
	• IF left on site:
	  ○ Uneven pattern, with some uncovered areas to allow for variable vegetation response.
	  ○ Move fuel at least 22.8cm (9") from the base of trees if possible without root damage.
	  ○ Build fuel breaks into the masticated fuelbed to slow or prevent fire spread if ignited.
		(Frame 2011, Jain et al. 2012)

Masticated material depth (if left on site)	Lower depths are generally more favourable for plant regeneration and decrease burn severity in the masticated fuelbed. • < 5cm to allow for regrowth of trees. • < 7.5cm regrowth of other plants. NOTE: this will vary depending on which species are present.	(Gray et al. 2010, Young et al. 2013, Wolk et al. 2020)
Chip size	• IF mulch to be removed from site: ○ Ideal size is dependent on intended end use. • IF mulch to be left on site:	(Reed et al. 2020, Pickering et al. 2022).

	○ Suggest fine particle size to aid decomposition NOTE: smaller chips may be subject to quicker compaction and ignite more easily	
Treatment Depth	• IF mulch to be removed from site: ○ Process surface vegetation only to minimize soil disturbance. • IF mulch to be left on site: ○ Mixing mulch with mineral soil may help decrease flammability and speed decomposition. ○ NOTE: This may decrease machine efficiency and have negative environmental impacts.	(Brochez and Leverkus 2022)
Residual Tree Spacing	• A minimum of 7m x 7m spacing between trees is required for effective use of most mastication equipment. • Use best practices for preventing windthrow in thinned stands.	(Schroeder 2006, Harrod et al. 2009)
Mulch pile location and leachate considerations	To mitigate impacts from leachate, mulch piles should be: • >100m away from the nearest surface water and not within a floodplain if there are fish bearing streams nearby. • >300m away from a drinking water well. • 15 - 30m from a property line.	(Liu et al. 1996)
Bark beetle considerations	If your treatment will take place in an area at risk of bark beetle attack: • Perform treatments during times of relatively low beetle activity, such as late summer, fall, or winter. • Ensure that residual chips are removed from around the boles of trees as soon as possible after treatment. • Consider using treatments that promote drying and decay of monoterpenes in slash prior to mastication. • Design treatment units to minimize the amount of edge per unit area. • Consider using low intensity treatments, as bark beetle attack may increase with treatment intensity.	(Fettig et al. 2006)

Prescribed fire on masticated fuelbeds	Schedule prescribed fires as soon after the mastication treatment as possible to minimize fuel compaction. Plan for relatively long clean up and mop up times post-fire to cover potential smouldering and reignition.	(Kobziar et al. 2013)

Summary Table 2: Considerations for BC Forests

Terrain/Forest Type	Considerations & Recommendations	Reference
Mountainous Terrain	• Vertical shaft equipment may be better for rough or uneven terrain. • Mastication equipment may only be functional at slopes < 40%, or specialized equipment may be required. • Tracked vehicles may be preferable on relatively steep terrain. • Complex topography may cause a variety of different microenvironments across your site. Consider potential variation in fire behaviour, moisture levels, and drainage.	(Jain et al. 2018, Mitchell and Smidt 2019)
Dry Forest	• Masticated material will likely decompose slowly, acting as a fuel source and revegetation suppressant for many years. • Plan to remove material from site either via burning or mechanical means. • Bark beetles may be attracted to the smell of masticated material.	(Fettig et al. 2006, Gray et al. 2010, Morrow and Hvenegaard 2016, Keane et al. 2018)
Rainforest	• Often on steep or mountainous terrain (see above). • Tracked machinery may be more suitable for projects in wet or sensitive soil, though can damage trees boles and roots while turning.	(Marshall et al. 2008, Harrod et al. 2009, Brockway et al. 2009)
Boreal	• Trees are commonly smaller than in coastal or more southern areas. • There are large areas of soft or waterlogged soil (muskeg). • Tracked machinery may be more suitable for projects in wet or sensitive soil.	(Marshall et al. 2008, Brockway et al. 2009, Hvenegaard 2017)

	• Many areas have thick organic layers, so mixing mulch with mineral soil may not be feasible. • Consider semi-mechanized treatment combining mulching and hand thinning and limbing to control costs.	

Recommended Reading

Most of the papers below are linked to this document. Additional searches can be completed with the Google Scholar Database.

Ault, R., and S. Hvenegaard. 2019. Case study - Kenow Fire - Alberta, 2017: Structure protection in Waterton Lakes National Park. FPInnovations.

A case study of the efficacy of sprinkler systems in protecting property and bolstering existing fuel treatments in the case of wildfire.

Battaglia, M. A., M. E. Rocca, C. C. Rhoades, and M. G. Ryan. (n.d.). Measuring mulch fuelbed loads.

A guide to efficiently measuring fuel loads in masticated fuel beds. The method was used in a later project (Battaglia et al. 2010) and determined to be effective.

Blackburn, K., and T. Keddy. 2018. Innovative biomass recovery – feedstock characteristics of the biomass produced by the gyro-trac bioenergy baling system. Info Note, FP Innovations.

Discussion of a potential baling method for masticated matter removal.

Gray, R. W. 2011. The effect of mechanical mastication and prescribed fire on stand structure and potential fire behavior in Joseph Creek, Cranbrook, BC. R.W. Gray Consulting Ltd.

An example of a mastication project in southern British Columbia. With stand structure, fuel chips sizes, modelled fire behaviour, example photos etc.

Harrod, R. J., D. W. Peterson, N. A. Povak, and E. K. Dodson. 2009. Thinning and prescribed fire effects on overstory tree and snag structure in dry coniferous forests of the interior Pacific Northwest. Forest Ecology and Management 258:712.

Guide for choosing mastication equipment. Specifically addresses mastication around tall and large diameter trees.

Hvenegaard, S. 2023. Wildfire/fuel treatment encounters: Assessing fuel treatment effectiveness A case study at Logan Lake, British Columbia. Technical Report, FPInnovations.

A case study of using aerial operations and purposeful burns to bolster the effectiveness of existing fuel treatments during wildfire.

Jain, T., C. Heffernan, A. Saralecos, and R. Kinyon. 2020. Is mastication right for your site? Science-based decision trees for forest managers. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Jain, T., P. Sikkink, R. Keefe, and J. Byrne. 2018. To masticate or not: Useful tips for treating forest, woodland, and shrubland vegetation. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

US Forest Service guides for mastication projects. Include useful tables and decision trees for determining whether to masticate, what equipment to use, and other considerations

Marshall, D. J., M. Wimberly, B. Pete, and J. Stanturf. 2008. Synthesis of knowledge of hazardous fuels management in loblolly pine forests. U.S. Department of Agriculture, Forest Service, Southern Research Station.

Has a list and descriptions of factors that should be considered when planning mechanical fuel treatments (including mastication) such as slope, different fuel types, and cost.

Morrow, B., and S. Hvenegaard. 2016. BC Hydro Northwest Transmission Line wildfire hazard assessment and mitigation strategy. Contract Report, Northwest Transmission Lines.

Discusses wildfire mitigations strategies for masticated fuel beds.

Spencer, S., and D. Röser. 2017. Best management practices for integrated harvest operations in British Columbia. Special Publication, FPInnovations.

Includes guidelines for increasing and extracting low-quality fibre from British Columbia forests.

Literature Cited

Ault, R., and S. Hvenegaard. 2019. Case study - Kenow Fire - Alberta, 2017: Structure protection in Waterton Lakes National Park. FPInnovations.

Battaglia, M. A., M. E. Rocca, C. C. Rhoades, and M. G. Ryan. 2010. Surface fuel loadings within mulching treatments in Colorado coniferous forests. Forest Ecology and Management 260:1557–1566.

Blackburn, K., and T. Keddy. 2018. Innovative biomass recovery – feedstock characteristics of the biomass produced by the gyro-trac bioenergy baling system. Info Note, FP Innovations.

Brochez, C. B., and S. E. R. Leverkus. 2022. Assessing the feasibility of meeting target fuel loadings for wildfire reduction in north-central British Columbia. Journal of Ecosystems and Management 22:18 pp-18 pp.

Brockway, D. G., K. W. Outcalt, B. L. Estes, and R. B. Rummer. 2009. Vegetation response to midstorey mulching and prescribed burning for wildfire hazard reduction and longleaf pine (Pinus palustris Mill.) ecosystem restoration. Forestry 82:299–314.

Fettig, C. J., J. D. McMillin, J. A. Anhold, S. M. Hamud, R. R. Borys, and C. P. Dabney. 2006. The effects of mechanical fuel reduction treatments on the activity of bark beetles (Coleoptera: Scolytidae) infesting ponderosa pine. Forest Ecology and Management 230:55–68.

Frame, C. 2011. Reducing fuels through mulching treatments: What are the ecological effects? Technical Report, U.S. Joint Fire Science Program.

Government of British Columbia. 2022. Chief Forester's guidance on coarse woody debris management wildfire mitigation treatments.

Gray, R. W., J. Przeczek, and R. Harrod. 2010. Reducing fuel hazards using mechanical mastication in the wildland-urban interface. BC Forest Professional 17:18–19.

Harrod, R. J., D. W. Peterson, N. A. Povak, and E. K. Dodson. 2009. Thinning and prescribed fire effects on overstory tree and snag structure in dry coniferous forests of the interior Pacific Northwest. Forest Ecology and Management 258:712.

Hvenegaard, S. 2017. Fire behaviour in Jack pine/black spruce forest fuels following mulch fuel treatments: a case study at the Canadian Boreal Community FireSmart Project. Technical Report, FPInnovations.

Hvenegaard, S. 2019. Mulching productivity in black spruce fuels: productivity as a function of treatment intensity. Technical Report, FPInnovations.

Hvenegaard, S. 2020. Fuel Treatment intensity and fire behaviour: Experimental fires in mulched fuels at Pelican Mountain. Technical Report, FPInnovations.

Hvenegaard, S. 2023. Wildfire/fuel treatment encounters: Assessing fuel treatment effectiveness A case study at Logan Lake, British Columbia. Technical Report, FPInnovations.

Hvenegaard, S., and R. Hsieh. 2014. Productivity assessment for a Lamtrac LTR8300T mulcher: a case study at a fuel treatment near Gregg Lake, Alberta. Project Report.

Hvenegaard, S., and R. Hsieh. 2015. Productivity assessment of a Lamtrac LTR8290Q mulcher: a case study at two forest fuel re-treatments near Hinton, Alberta. Project Report, FPInnovations.

Hvenegaard, S., D. Schroeder, and D. Thompson. 2016. Fire behaviour in black spruce forest fuels following mulch fuel treatments: a case study at Red Earth Creek, Alberta. Technical Report, FPInnovations.

Jain, T., M. Battaglia, H.-S. Han, R. Graham, C. Keyes, J. Fried, and J. Sandquist. 2012. A comprehensive Guide to Fuel Management Practices for Dry Mixed Conifer Forests in the Northwestern United States. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Jain, T., P. Sikkink, R. Keefe, and J. Byrne. 2018. To masticate or not: Useful tips for treating forest, woodland, and shrubland vegetation. Page RMRS-GTR-381. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ft. Collins, CO.

Keane, R. E., P. G. Sikkink, and T. B. Jain. 2018. Physical and chemical characteristics of surface fuels in masticated mixed-conifer stands of the U.S. Rocky Mountains. Technical Report, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Kobziar, L. N., A. J. Long, W. C. Zipperer, and J. K. Kreye. 2013. Characterization of masticated fuelbeds and fuel treatment effectiveness in southeastern US pine ecosystems. Technical Report, U.S. Joint Fire Science Program.

Liu, S., M. Nassichuk, and S. Samis. 1996. Guidelines on storage, use and disposal of wood residue for the protection of fish and fish habitat in British Columbia. Environment Canada and the Department of Fisheries and Oceans.

Marshall, D. J., M. Wimberly, B. Pete, and J. Stanturf. 2008. Synthesis of knowledge of hazardous fuels management in loblolly pine forests. U.S. Department of Agriculture, Forest Service, Southern Research Station.

Mitchell, D., and M. Smidt. 2019. Costs of mechanical fuel reduction treatments. Pages 1-7 in. S. L. Manzello, editor. Encyclopedia of Wildfires and Wildland-Urban Interface (WUI) Fires. Springer International Publishing.

Morrow, B., and S. Hvenegaard. 2016. BC Hydro Northwest Transmission Line wildfire hazard assessment and mitigation strategy. Contract Report, Northwest Transmission Lines.

Pickering, B., J. Burton, T. Penman, M. Grant, and J. Cawson. 2022. Long-term response of to mechanical mastication in south-eastern Australia. Fire 5.

Reed, W. P., J. M. Varner, E. E. Knapp, and J. K. Kreye. 2020. Long-term changes in masticated woody fuelbeds in northern California and southern Oregon, USA. International Journal of Wildland Fire 29:807–819.

Schroeder, D. 2006. Considerations for mitigating windthrow due to forest fuel treatments. Forest Engineering Research Institute of Canada, Wildland Fire Operations, Western Division.

Wolk, B. H., C. S. Stevens-Rumann, M. A. Battaglia, C. Wennogle, C. Dennis, J. A. Feinstein, K. Garrison, and G. Edwards. 2020. Mulching: A knowledge summary and guidelines for best practices on Colorado's Front Range. Colorado State University.

Young, K. R., B. A. Roundy, and D. L. Eggett. 2013. Plant establishment in masticated Utah juniper woodlands. Rangeland Ecology & Management 66:597–607.