MANAGING WOODY MATERIALS ON INDUSTRIAL SITES

Meeting economic, ecological and forest health goals through a collaborative approach

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RENEWABLE RESOURCES

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Disclaimer

This publication is intended to inform the discussion around using woody materials in reclamation programs. While every attempt was made to ensure the accuracy of the statements contained within this publication, reclamation plans should always be discussed with the appropriate government authority. Use of woody materials should never be used in a way that compromises other reclamation objectives such as soil placement and soil conservation.

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Executive Summary

Neat and tidy, that's the way industrial sites have traditionally been managed in the boreal forest. But this approach is increasingly being re-evaluated. Research suggests that although clearing woody materials from sites can provide short-term benefits in terms of fire control, longer-term goals like forest regeneration and biodiversity conservation are often not realized. This has prompted the Government of Alberta to explore new ways to promote enhanced reclamation of industrial sites while managing fire risks. Similarly, proactive companies are seeking new reclamation tools in order to achieve a step change in their environmental performance.

Woody materials (dead wood such as logs, branches and stumps) are a cost effective tool for realizing this step change. Research shows that the simple act of leaving woody material on reclaimed sites introduces microsites and variability. These microsites serve as critical habitat for a range of native plant species, seedlings, and microorganisms that are essential for the regeneration of forests. Woody material can also provide habitat for forest insects and mammals, and play a key role in nutrient cycles over time. Thus, woody materials represent a significant opportunity for reclaiming industrial sites (e.g., oil and gas sites).

To further clarify opportunities related to woody materials, we undertook a literature review to provide recommendations for incorporating woody material into reclamation programs. We used an integrated approach that included: 1) site visits to current in-situ oil sand operations; 2) a review of current policy and regulatory guidelines; 3) a review of scientific research; and 4) the development of a series of management implications. These steps will serve as a guide to the use of woody material, and assist with efficient planning of reclamation programs.

Our review of regulations suggests a gradual evolution in perception towards woody material. Until recently, companies were required to completely remove woody material from sites through piling and burning, as mandated by the Forest and Prairie Protection Act (FPPA). Regulations under the FPPA are designed to limit fire risks in the province, and total disposal of woody material was traditionally seen as necessary to achieve this objective. However, recent changes in the 2010 Reclamation Criteria for Wellsites and Associated Facilities on Forested Lands permit, and even encourage, the use of woody material as a reclamation tool. These new criteria balance fire risks and reclamation potential by requiring that excessive accumulation of material does not occur on sites, and that piles are not left following operations.

The recommendations in this Woody Material Review are therefore focused on defining volume thresholds and techniques that will balance fire concerns with reclamation potential. The techniques we identified for managing woody materials included: mulching, rough mulching, chunking, and using whole logs. For the purposes of this review, we focused our efforts on the two most common techniques, mulching, and utilizing whole logs.

Wood mulching

Wood mulch can present challenges for reclamation, and often provides limited ecological benefit. Thus, companies should have specific reclamation objectives when using wood mulch. In cases where wood mulch is seen as the best option, the depth of mulch should be closely monitored. Depths exceeding 3 to 4 cm are known to impede plant growth and limit plant establishment. This is because the mulch forms an insulative layer over the soil surface which leads to frozen ground conditions later in the growing season, delaying plant development.

The impact of mulch on soil nutrients is also highly variable. In many cases, mulch may pull nitrogen from the soil. This may be useful in some cases where nitrogen levels are too high; however, companies should not expect large inputs of nutrients from wood mulch. On the other hand, leachates are known to seep from aspen wood mulch; and even though they are a naturally occurring toxin used to defend trees from insects, leachates are potentially toxic to aquatic ecosystems. Thus, the use of wood mulch within close proximity to riparian features is not recommended.

The final, and potentially most important, learning about wood mulch is that it lacks the ability to form microsites. Thus, by investing more time and money into operations, companies remove some of the critical benefits that wood provides. We suggest companies only use wood mulch when they have specific objectives in mind, and that they employ rough mulching and the use of whole logs whenever possible.

Whole logs

Whole logs (non-merchantable trees, tree tops, stumps) have much benefit as a reclamation tool, and are known to enhance the recovery of forest ecosystems. The greatest benefit of whole logs is that they create microsites on the soil surface. These microsites serve as pockets of moisture, shade, and protection - features critical to the establishment of native plants and tree seedlings. Whole logs also add critical variability to industrial sites, promoting greater diversity.

In order to identify appropriate volumes of logs to be left on sites, we used the natural range of variability in deadwood volumes in the boreal forest as a guideline. Our review suggests that companies should target volumes of 60 to 100m^3/ha in their reclamation efforts. This translates into 10 to 25% coverage on sites. We also found that lowland sites typically have much lower volumes of deadwood and so volumes on these sites should fall in the range of 30 to 50m^3/ha.

Keeping logs as intact as possible (i.e., limiting machine traffic) will help ensure multiple ecological benefits, and applying a range of sizes and lengths of these logs is important as well. As for how to place the woody material back onto sites, we suggest that some woody material, particularly roots, can be admixed back into the soil layer during reclamation- as long as soil conservation objectives are still met. However, we encourage placing most of the material on top of the surface as a final step in reclaiming sites. This will help to ensure that the microsite benefits of whole logs are realized.

Wildlife and access management

Even though an extensive amount of work on access management has been completed, only a small percentage of these projects are monitored. Overall, studies suggest that single barriers, such as berms and gates at the access entrance, are not effective and often only entice recreationalists. Similarly, rolling back material on only a portion of these features (e.g., 100 metre sections) is not a deterrent. Consultant reports from Alberta, as well as over 10 years of professional experience in Saskatchewan, suggest that rolling back material along the entire length of exploration and access features is the most effective way to discourage recreational use of the lines.

Studies focused on understanding how to limit mammal use of access features also suggest that more intensive efforts, such as total rollback, are needed. Many studies have looked at 'quick fixes', such as felling trees at regular intervals along seismic lines to limit the line of sight, but have found no changes to wildlife habits. In contrast, examples from the United States that have focused on promoting long-term recovery back to a functioning forest have realized much success. It is critical that industry and government recognize the size of the challenge, and focus their energy on the long-term goal of developing a functioning forest back on these features. Monitoring programs are also necessary to learn from past experiences and find ways to continually improve efficiency and effectiveness.

Summary of Management Implications

Wood mulching

1) The benefits of wood mulching appear to be limited. Mulching should be used only on an as needed basis to meet specific site level challenges (e.g., dry, arid soils). It should not be used as a company-wide policy for disposing of woody material on wellsites.
2) In specific cases where mulching cannot be avoided, such as during seismic operations, rough mulching (removing branches but leaving logs intact) or hand felling should be used, rather than complete mulching, whenever possible so as to retain whole logs and reduce operational costs.
3) As was suggested in the Alberta Government directive for using wood mulch roads (Drivable Wood Fibre Surfaces- External Information Letter, 2008), there should be no aspen chipping residues within 30 metres of riparian sites, such as bogs, lakes, streams, and ephemerals.
4) When mulching is used, wood mulch should not exceed 3 to 4 cm in depth in order to promote effective regeneration on the sites.

Using whole logs

1) The application of whole logs is the preferred method of wood management because of the additional benefits logs provide for erosion control, moisture retention, creation of microsites, and increasing the heterogeneity on wellsites.
2) Woody material volumes of 60 m^3/ha to 100 m^3/ha, and coverage targets of 10 to 25% of the disturbed surface should be sought on upland sites.
3) Woody material volumes of 30 m^3/ha to 50 m^3/ha should be sought on lowland sites.
4) Operators should focus on keeping logs intact, and on maintaining a wide range of sizes and lengths of woody material on sites.
5) As an alternative to burning, companies should look at the economics of transporting woody materials from high to low volume sites.
6) When the time between site creation and site reclamation is significant (e.g., multiple years to decades) whole logs can be stored under soil salvage piles or in locations deemend appropriate by local Forest Officers. In addition, coarse woody material can be salvaged and stored together with surface soils.
7) Companies should develop a "Woody material plan" prior to disturbance, to facilitate regulatory approval and better manage woody material.

Using woody materials for access and wildlife management

1) All woody material along access features should be rolled back to promote vegetation re-establishment. Initial target volumes should be 60 to 100 m^3/ha, however higher volumes should be researched for their ability to achieve company objectives.
2) Look for and utilize older slash piles and other residual woody material from previous seismic operations.
3) Site preparation, such as mounding, can accelerate the establishment of native plants by trapping moisture along linear features. Operators can experiment with this technique as an access management tool.
4) Establish long-term monitoring programs that analyze animal movements prior to and following the above listed applications. Well designed and properly executed scientific experiments are the only way that practitioners will begin to advance their understanding of what works best in terms of achieving wildlife and access management objectives.
5) Focus reclamation efforts on creating real, long-term benefits to the ecosystem. Projects focused on short-term gains are likely to be ineffective.

Summary of Future Research Needs

Wood mulching

1) Can mulch be used in combination with whole logs and seed (cones) to encourage natural regeneration of upland black spruce and jack pine on sites with coarse textured soils?
2) Can the incorporation of mulch be used to reduce available nitrogen levels on disturbed sites in order to restrict growth of invasive species and promote growth of native species?
3) Can mulch be used to improve soil structure on compacted fine textured soils? (See Sanborn et al. 2004).
4) What is the variation in carbon to nitrogen ratio of different sizes and different portions of trees (tops, branches, alder and willow)?
5) What site preperation techniques may work best on older mulched sites that are not recovering/stagnant?
6) Can mineral fertilizer be used to resolve N immobilization on older mulched sites?

Using whole logs

1) How much woody material should be buried/mixed into topsoil and how much should be distributed along the surface of the sites?
2) What impact does buried woody material have on soil nutrient dynamics and soil formation?

Using woody materials for access and wildlife management

1) Additional research trials need to be developed to test how a variety of wood treatments impact recreational access and wildlife use of access features. It is critical that these studies are scientifically robust, and be published in the peer-reviewed scientific literature. Suggested treatments, at a minimum, include:
    a. Conventional roll-back of right-of-ways.
    b. Higher densities of woody materials (e.g., 150 to 250 m^3/ha) along right-of ways. This should be tested in various configurations (e.g. patches of high and low densities along the length of lines).
    c. High density of material only at start of access, conventional roll-back along the rest of the line.
2) What is the most effective configuration of wood placement on lines to control wildlife movements? Are intersections more important than other line segments?
3) Are small piles as effective on seismic lines as they are in forestry cutblocks? Is there an increased use of the line by small mammals due to piles and other slash placements?
4) Is the use of site preparation and slash placement more effective than either treatment in isolation for re-establishing vegetation and creating barriers to wildlife movement.

1.0 Introduction

Piling and burning is the conventional way of managing woody material on industrial sites in the boreal forest. But use of this technique outside of designated FireSmart zones is increasingly being re-evaluated. Reports suggest that piling and burning not only leads to a high number of human caused wildfires when not monitored properly (CAPP 2008), but that it also reduces the chances that a forest will regenerate on disturbed sites (MacFarlane 1999). As a result, finding ways to increase reclamation success has become a topic of much interest in recent years.

Leaving woody material on sites is seen as a cost-effective way of adding critical microsites and variability- factors which are known to promote growth of plants. However, there is still much uncertainty about when and how much woody material should be applied to sites. The following review outlines the scientific basis for using woody material as a reclamation tool and is designed to form the basis of woody material management programs for industrial operators within Alberta. This review is a joint effort between the University of Alberta, the Government of Alberta, and the Oil Sands Leadership Initiative (OSLI).

Through this project we sought to answer five key questions related to woody material management:

- What ecological benefits do woody materials provide?
- How should woody materials be applied to disturbed sites?
- How much woody material should be applied to disturbed sites?
- What are the risks associated with the application of woody materials?
- What do the regulations say about applying woody materials?

1.1 Background

What is woody material and why is it an issue?

Woody material (dead wood such as logs, branches, and stumps) is a critical, but often overlooked part of forests. Traditionally, it was seen to have little value and was often removed from forests following human activity (e.g., logging, clearing dispositions etc.). As a result, it was often called logging waste, slash residue, or forest residue (Brennan et al. 2005). Perceptions towards woody material, however, are quickly changing as information about its potential as a reclamation tool (e.g., Brown 2010), and its value to forests (e.g. Harmon et al. 1986, Siitonen 2001) becomes available.

The potential of woody material is particularly pertinent given recent changes to reclamation criteria for industrial sites in Alberta. In 2010, the Government of Alberta released new reclamation criteria that were designed to enhance the reclamation success of industrial sites. More specifically, these guidelines require a more natural plant community- such as the presence of woody and herbaceous plants. Although the new guidelines require companies to make significant changes to their traditional reclamation programs, they also permit companies to use innovative techniques such as the application of woody material.

As reclamation requirements continue to evolve, it is important that companies recognize opportunities to increase reclamation success on their sites. Maintaining woody material is an example of how companies can move towards successful reclamation, in a cost-effective way.

What are the benefits of keeping woody materials?

The variety of functions that woody materials serve is clear when one looks at the organisms that depend on it. For example, it is well known that a wide range of plants increase in numbers when woody materials are present (Harmon et al. 1986). Logs create shaded areas that protect plants from extreme temperatures (Gray and Spies 1997), trap moisture in the soil (Amaranthus et al. 1989), and protect tree seedlings from wind and frost damage (Harmon et al. 1986). These 'microsites' add critical variability to reclaimed sites, and can lead to increased survival of individual plants. Plants have also been shown to establish directly on woody material within forests (Harmon et al. 1986). Thus, it is clear that woody materials serve important roles in the establishment of plants on disturbed sites.

A wide range of animals are also highly dependent on woody material for habitat. In particular, fallen logs can act as shelter and food sources for mammals (marten, voles, mice, etc.), and insects (beetles, spiders, etc.). Many of these organisms are classified as saproxylic species - those that spend a portion or all of their life on woody material. Saproxylic species can represent up to 25% of the species found in a forest (Siitonen 2001). As a result of this strong link between woody material and biodiversity in forests, woody materials are often used as an indicator of biotic health (Stokland 2001). Maintaining woody materials on sites has clear benefits to forest biodiversity.

Woody materials are also an important contributor to nutrient cycling within forests. Although they are often found to pull nutrients like nitrogen from the soil in the short-term, they serve as an important long-term source of nutrients for a forest (Harmon et al. 1986). In addition, woody materials serve as habitat for critical nitrogen fixing bacteria (Stevens 1997) and mycorrhizal fungi associated with tree roots (Tedersoo et al. 2003). Logs can therefore serve as sources of mycorrhizal fungi and nitrogen fixing bacteria as the forest begins to regenerate. Thus, there are clear benefits to using woody materials as a way to develop self-sustaining nutrient cycles on reclaimed sites.

The variety of functions that woody materials play in an ecosystem is a key reason why perceptions are changing and why more people

> Mycorrhizal fungi are known to attach to roots of tree seedlings and facilitate the uptake of nutrients - improving the growth and vigor of the seedlings, and ultimately, increasing their survival.

are identifying opportunities for using them in reclamation programs. Practitioners now recognize the value of woody materials for erosion control, nutrient cycling, creation of microsites, protection of seedlings, and as habitat for a wide range of animals. These very functions are critical to capitalize on if companies are to see a step change in reclamation success.

1.2 Approach

This project consisted of four phases. Together, these phases cover as many aspects of woody material management as was deemed feasible and contribute to the understanding of woody material presented in this guide. Below we provide a brief overview of the four phases:

Site visits to current in-situ oil sands operations: A total of four sites were visited during the week of February 7th, 2011. We visited the operations of Total-Joslyn, Conocco Phillips-Surmont, Nexen-Long Lake, and Statoil-Leismer, and spoke with contractors and operators about their current techniques. These visits allowed us to develop a clear understanding of current approaches to woody material management, and to compare the different techniques between companies. The site visits also gave significant perspective to the authors of this document about construction and reclamation of in-situ operations.

A review of the scientific literature: We reviewed over 75 scientific publications to summarize the current understanding of woody material and its utility as a reclamation tool. We read publications from a wide range of disciplines including reclamation, forestry, chemistry, and biology. The results from scientific studies were summarized and used in the development of the management implications in this guide.

Development of a series of management implications: We developed a series of management implications based on the best available science and current regulations. The management implications we developed are the product of an extensive literature review, and should be used in an adaptive management framework (Figure 1.1). That is to say, the recommendations are based on our best available understanding of current information, and these recommendations should be evaluated/revised as more information becomes available. Companies should actively participate in this process by monitoring their reclamation activities and regularly adjusting their practices, so as to ensure continual improvement.

Review of government regulations: Although not presented in this review, we undertook an extensive review of government policies and regulations pertaining to the management of woody materials. This was an important step to ensure that the management implications fell within the regulatory guidelines.

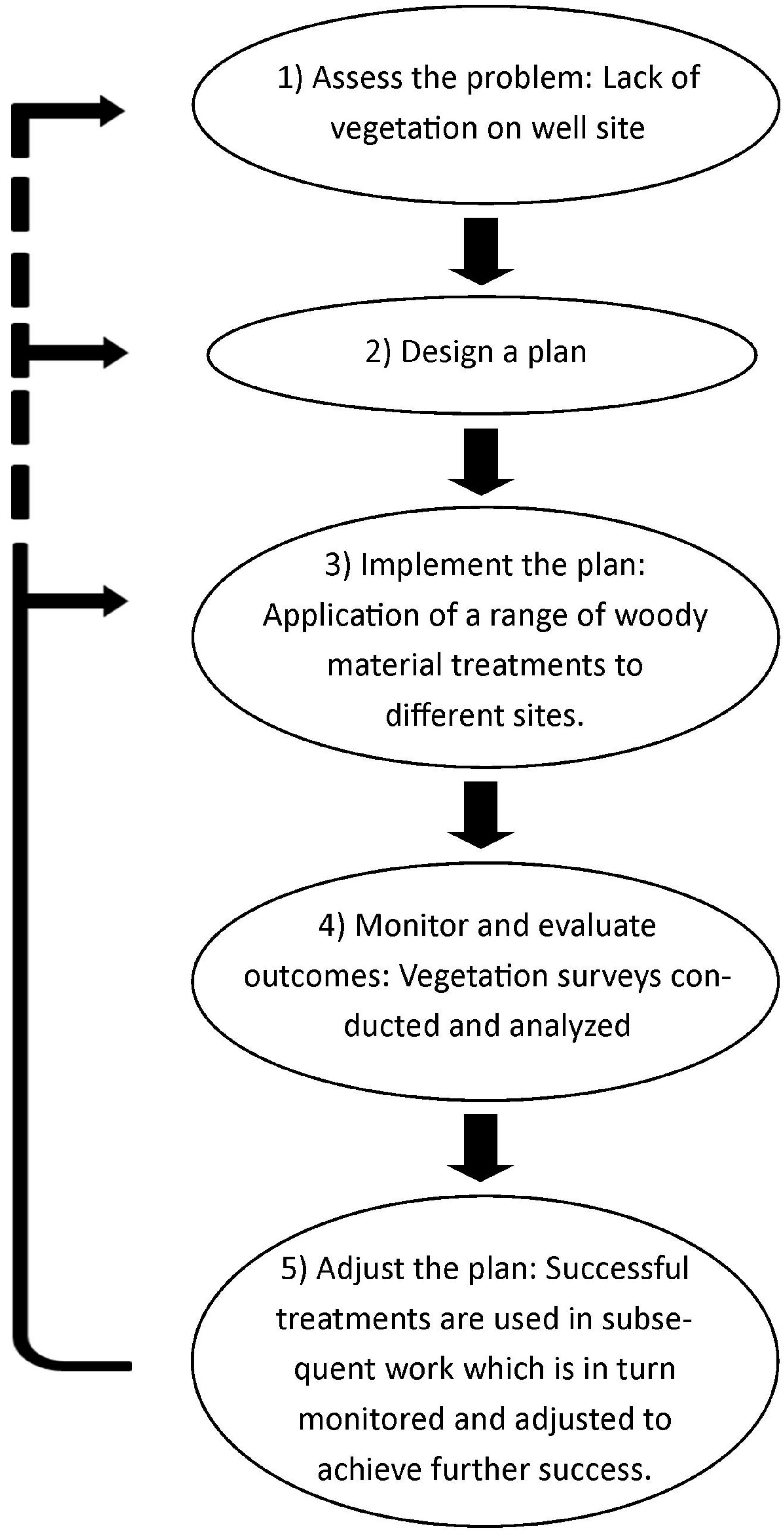

Figure 1.1: *The five steps of the adaptive management cycle. When the plan is adjusted, options exist to reassess the entire problem, redesign the plan, or implement an adjusted plan.*

Summary of Woody Material Management Techniques

Piling and burning: A conventional technique that has, until recently, been required by the Government of Alberta under the Forest and Prairie Protection Act. This method removes any and all woody material from dispositions. In some cases burning of the forest floor (duff layer) has also occured, which destroys seed sources and propagules.

Wood mulching: A recent technique that involves machines with rotating drums that mulch logs down into fine wood chips the size of large potato chips. Commonly used for seismic exploration, some companies have also opted to use mulchers on their sites as a way of minimizing fire risks.

Wood chunks: A technique which involves breaking logs into small chunks the size of fire wood. This technique has mostly been used in an experimental setting and can be considered an intermediary technique between mulching and using whole logs.

Rough mulching: A technique that uses mulching equipment but is less intensive than complete mulching. With this technique, branches are typically removed and the logs lay flat on the ground surface. This technique is often used on seismic programs and on other sites.

Whole logs: Non-merchantable trees, tree tops, stumps and other wood sources are applied directly on the disposition. Generally little effort is employed to remove branches etc. Logs are simply piled while the disposition is active, and rolled back on the site once operations are complete.

2.0 Scientific Review and Management Implications

In this section we review the current scientific knowledge about woody materials. To make the information as accessible as possible, the review is divided into three sections: 1) wood mulching, 2) using whole logs, and 3) using woody materials for access and wildlife management. These sections are intended to update practitioners on the current state of knowledge with respect to woody materials. Management implications have also been developed at the end of each section and can be used as a starting point in the use of woody materials on industrial sites. These management implications should be used in the context of an 'adaptive management cycle' (see Figure 1.1) so that results from current practices can inform future management of woody materials.

2.1 Wood Mulching

Although few studies have looked at wood mulch in the context of reclaiming industrial operations, the forest industry has conducted extensive research on the impacts of wood mulch on regeneration success. Much of this knowledge stems from the reclamation of landing decks and logging roads, disturbances which are similar in scope and impact to those of industrial projects (e.g., oil and gas sites). Here we provide a summary of the key scientific conclusions with respect to using wood mulch for reclamation.

What does the science say?

High depths impact plant growth

Given the comments we heard from oil sands operators during our field tours, it should come as no surprise that leaving behind high amounts of mulch is a major roadblock for reclamation. Many of the companies we spoke with reported a lack of regeneration on sites containing high mulch depths, and a corresponding dissatisfaction with this technique. These observations are supported by research, with many reasons for poor vegetation performance.

In terms of forest regeneration, many studies have found that when mulch is spread at depths between 4 to 10 cm, regeneration is negatively impacted (Corns and Maynard 1998, MacIsaac et al. 2003, Landhaeusser et al. 2007). The impact that mulch has on the forest soil is a major factor leading to regeneration challenges (Figure 2.1). Mulch has been shown to function as an insulative layer over the soil (MacIsaac et al. 2003). This insulation leads to frozen ground conditions that persist longer into the growing season, limiting forest regeneration. In addition, the mulch layer leads to cooler and moister ground throughout the spring, summer and fall (Corns and Maynard 1998). These changes to the soil during the growing season result in delayed emergence of trees because of cooler temperatures (Landhaeusser et al. 2007), leading to lower regeneration levels on mulched sites (Landhaeusser et al. 2007, Renkema et al. 2009).

Figure 2.1: *An example of a site that contains an extensive layer of mulch over the soil surface. Photo courtesy of I. Amponsah.*

Mulch has also been found to function as a barrier above the soil surface, making it more difficult for regenerating plants to emerge from the ground. For example, Landhaeusser et al. (2007) found a 30% reduction in saplings emerging from sites with 4 cm of wood mulch compared to sites that had no wood mulch. Similarly, MacIsaac et al. (2003) found that sites containing 6 cm of mulch had fewer trees emerge compared to sites with no wood mulch, and those that did emerge had reduced health and were more branchy. Meanwhile, in plots with only 3 cm of mulch, no negative impact was observed (MacIsaac et al. 2003). High levels of mulch can also limit the amount of mineral soil exposed, compromising natural regeneration of conifer on sites (Vic. Lieffers- Personal Communication). There is general consensus in the scientific literature that mulch levels should not exceed 3 to 4 cm.

Mulch has also been found to function as a barrier above the soil making it more difficult for regenerating plants to emerge from the ground.

Impact of mulch on nutrients is debatable

A common concern with the use of wood mulch is that it removes critical nitrogen from the soil (nitrogen sink), reducing the nutrients available for regenerating plants. While studies have shown that nitrogen can be removed from the soil, the relative impact of this removal is not clear. Corns and Maynard (1998) found that although mulch depths of up to 5 cm was serving as a nitrogen sink (i.e., pulling nitrogen from the soil), nitrogen entering the soil was still equivalent to nitrogen inputs within the surrounding forest. Thus, even though the plots with wood mulch did have lower soil nitrogen levels, the nitrogen being added to the soil through decomposition of the wood mulch was the same or greater than that in the original forest stand. Landhaeusser et al. (2007) found supporting evidence for these conclusions by showing that nitrogen run-off from wood mulch is quite high in the first three weeks following application. Finally, MacIsaac et al. (2003) found there was no significant reduction in soil nitrogen nine-years after surface application of wood mulch in forested stands. Practitioners should not expect wood mulch applied above the soil surface to add large amounts of nitrogen, but it also should not impact the nitrogen needed for regeneration.

Aspen mulch produces leachates that are potentially toxic

Multiple studies have shown that following storage of aspen logs (Taylor and Carmichael 2003) or mulching of aspen trees (Landhaeusser et al. 2007) there is a flush of chemicals from the wood. These 'leachates' are natural by-products of trees and are used as a natural defense mechanism against insect attacks when the tree is alive (Taylor and Carmichael 2003). The leachates are composed of various chemicals, including phenols, resin acids and terpenes, most of which can be toxic to living organisms.

There is evidence to support a cautious approach when applying aspen wood mulch to sites that are frequently wet and/or moist, such as lowlands.

Leachates have been tested in various contexts within upland sites and most field trials have shown they have little impact on the growth and regeneration of seedlings (Landhaeusser et al. 2007, Venner et al. 2009). Studies suggest that soils filter the leachates, thus they have little to no impact on the environment. The impact is quite different, however, in lowland sites. Taylor and Carmichael (2003) looked at the impacts of leachates within aquatic systems and found leachates from aspen mulch were in high enough concentrations to be harmful to rainbow trout and luminescent bacteria. In addition, Venner et al. (2009) was careful to specify that sites with certain hydrologic regimes, such as lowlands, may have a different response to leachates than upland sites. There is evidence to support a cautious approach when applying aspen wood mulch to sites that are frequently wet and/or moist, such as lowlands. As suggested in the Alberta Government's Industry Directive SD 2009-01: Management of Wood Chips on Public Land, practitioners should avoid mulching aspen logs when operating within 30 metres of riparian features (creeks, bogs, intermittent streams etc.), and should limit mulch application on lowland sites.

Wood mulch lacks the ability to form microsites

One of the main roles of intact woody material, emphasized throughout this review, is that it creates microsites that are beneficial for regenerating plants (Harmon et al. 1986). Wood mulch, however, does not possess this key benefit. Similarly, wood mulch has little to no value for biodiversity. Thus, by investing time and money into mulching woody material, companies are taking away many of the key attributes that make it an attractive option for reclamation. The additional costs incurred during the mulching process do not seem to produce any ecological benefits over the use of whole logs. In addition,

By investing time and money into mulching woody material, companies are taking away many of the key attributes that make woody materials an attractive option for reclamation.

companies may also have to spend additional money to remove excessive mulch and revegetate the site in order to meet reclamation goals.

How do we move forward?

Our review suggests there is little ecological value in applying wood mulch to entire leases. In fact, wood mulch placed on the soil surface creates challenges for reclamation by reducing soil temperatures and making it harder for plants to emerge and establish on sites. In addition, the possibility of toxic leachates seeping into aquatic ecosystems further challenges the utility of this technique when ecological reclamation is the ultimate goal. Mulching entire dispositions also substantially increases operational time for mulching equipment. This in turn increases exploration costs when compared to rough mulching and leaving woody materials intact. For all these reasons, intact woody materials should be used instead of mulch.

In situations such as seismic operations where using mulchers (avoidance exploration lines) is of clear benefit, rough mulching (removing branches but leaving logs intact), or hand felling should be used whenever possible. In cases where mulching is unavoidable, mulch depths should not exceed 3 to 4 cm, and aspen trees should not be mulched within 30 metres of any riparian water feature. In some cases, using low levels of mulch in combination with pine cones and whole logs may assist the re-establishment of forests on coarse textured soils where moisture is often very limiting and soil temperatures can be extremely high. Research trials should be used to further test this.

Management Implications

1) The benefits of wood mulching appear to be limited. Mulching should be used only on an as needed basis to meet specific site level challenges (e.g., dry, arid soils). It should not be used as a company-wide policy for disposing of woody materials on wellsites.
2) In specific cases where mulching cannot be avoided, such as during seismic operations, rough mulching (removing branches but leaving logs intact) or hand felling should be used, rather than complete mulching, whenever possible so as to retain whole logs and reduce operational costs.
3) As was suggested in the Alberta Government directive for using wood mulch roads (Drivable Wood Fibre Surfaces- External Information Letter, 2008), there should be no aspen chipping residues within 30 metres of riparian sites, such as bogs, lakes, streams and ephemerals.
4) When mulching is used, wood mulch should not exceed 3 to 4 cm in depth in order to promote effective regeneration on the sites.

Future Research Questions

1) Can mulch be used in combination with whole logs and seed (cones) to encourage natural regeneration of upland black spruce and jack pine on sites with coarse textured soils?
2) Can the incorporation of mulch be used to reduce available nitrogen levels on disturbed sites in order to restrict growth of invasive species and promote growth of native species?
3) Can mulch be used to improve soil structure on compacted fine textured soils? (See Sanborn et al. 2004).
4) What is the variation in carbon to nitrogen ratio of different sizes and different portions of trees (tops, branches, alder and willow)?

2.2 Whole Logs

Many research projects have looked at the role of whole logs* in reclaiming forests, and even more have looked at how whole logs affect regeneration after forest harvesting. Thus, there is much information available to base conclusions with respect to utilizing whole logs in reclamation programs. For example, the forest industry has been concerned with leaving too much woody material on harvest blocks, thus many projects have looked at maximum levels of woody materials to be left on logging sites. A significant number of projects have also documented 'natural' ranges of woody material present within intact forests, providing critical baseline values from which to develop management plans. Finally, recent projects have allowed us to understand how whole logs can be used as a reclamation tool to promote regeneration after site disturbance. Here we provide an overview of the key scientific conclusions with respect to using whole logs for reclamation.

What does the science say?

Value of woody material is in microsites, not nutrient contributions

Practitioners looking to use whole logs to add nutrients to their soils will, unfortunately, be disappointed. That's because nutrient input isn't the primary role of whole logs in a forest. In fact, research shows that logs can even function as a short-term sink (Harmon et al. 1986), thus resulting in reduced nutrient availability within soils. Over time (10 to 30 years) this woody material does become a net source of nutrients for an ecosystem (Harmon et al. 1986), albeit in small amounts (Laiho and Prescott 1999, 2004). The exact amount of the nutrients added by whole logs varies by species and location, but seems to be about 2-10% of the forests nutrient needs (Laiho and Prescott 2004). Hence, research to date suggests that whole

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* Whole logs are defined as non-merchantable trees, tree tops, stumps and other wood sources applied directly on the disposition.

logs are net contributors of nutrients over time, but very minimally so. The focus of woody material applications, therefore, should not be on how many nutrients are contributed by the logs.

The real value in applying whole logs to industrial sites is in the creation of microsites for plants to establish (Harmon et al. 1986, Amaranthus et al. 1989, Brown 2010). It is well known that heavily disturbed landscapes require microsites to promote forest regeneration (Jones and del Moral 2005, Brown 2010), and logs can do just that (Harmon et al. 1986). Research shows that logs serve as a critical source of moisture in dry ecosystems, limit soil erosion, and provide substrates for plants and tree seeds to establish (Harmon et al. 1986, Amaranthus et al. 1989). In fact, without logs on disturbed sites, the number of plant species present and the total plant cover is reduced (Brown 2010).

The real value in applying whole logs to industrial sites is in the creation of microsites for plants to establish.

An additional bonus of having logs on sites is that they can serve as a refuge for mycorrhizal fungi (Tedersoo et al. 2003), and other species that promote ecosystem function. Brown (2010) also found fewer invasive species on sites containing whole logs, a key factor in achieving new reclamation criteria within Alberta.

It is clear in the scientific literature that the presence of logs promotes plant and seedling establishment by providing critical microsites to establish on (Figure 2.2). Practitioners should capitalize on these microsite benefits by incorporating whole logs into their reclamation programs.

It is clear in the scientific literature that the presence of logs promotes plant and seedling establishment by providing critical microsites to establish on.

Figure 2.2: *An example of a reclaimed pipeline benefiting from the presence of woody materials. Photo courtesty of T. Vinge.*

How much should be applied?

The looming question about applying whole logs is how much should operators apply? To answer this, it is important to first understand how forests naturally produce woody material. Woody material is generated through two primary processes: creation of snags (dead standing trees), and creation of fallen logs. The actual amount of woody material in a forest depends on a variety of variables such as forest age, forest type, and topography. As might be expected, it is very difficult to predict specific volumes of woody material in any single stand. To overcome this obstacle, it is common for studies to report the natural range of variability for forests. This natural range of variability can be used to provide an estimate of the most likely volumes of woody material that will be encountered within specific forest stands.

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Utilizing the natural range of variability as a guideline for reclamation volumes has much potential. First, if prescriptions are based on what is naturally found in stands, it is unlikely that wood volumes will impede forest growth (Lieffers-Pritchard 2005). Second, if volumes represent the quantities naturally found in stands, the volume prescriptions for reclamation programs should be easily attained by rolling back material onto its original site.

Although studies throughout the boreal forest have reported woody material volumes ranging from 25 m^3/ha to 250 m^3/ha (Harmon et al. 1986, Densmore et al. 2004), studies specific to Alberta have suggested that woody material volumes range between 60 m^3/ha to 100 m^3/ha in stands greater than 20 years of age (Lee et al. 1997). To provide additional weight to this value, the Chief Forester of British Columbia has provided recommendations to leave 30% of the original stand volume as coarse woody material on harvested sites. Using this calculation for typical stands in Alberta's boreal forest would suggest, again, that woody material volumes in the 45 m^3/ha to 100 m^3/ha range would be appropriate. Finally, Ter-Mikaelian et al. (2008) found that mean deadwood volume within boreal forests of Ontario is approximately 65 m^3/ha on average. Given these conclusions, it is recommended that practitioners and operators apply between 60 to 100 m^3/ha of woody material to their reclaimed sites.

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This threshold of 60 to 100 m^3/ha is also within a range which should provide a balance between mitigating fire concerns on industrial landscapes and promoting ecological values. A similar review of volumes was undertaken by the United States Department of Agriculture (USDA) to determine effective woody material thresholds that maximize ecological potential while managing fire concerns. They concluded that thresholds of 50 to 150 m^3/ha provided the optimum balance between fire risk, and biological benefits (Brown et al. 2003). Thus, the threshold of 60 to 100 m^3/ha determined through our review should also provide a reasonable balance between mitigating fire risk and providing biological benefits.

Upper limit is likely quite high

Although one of the concerns with applying whole logs is that putting too much material on a site may limit regeneration, forests can withstand a large volume of material before an impact is observed. Lieffers-Pritchard (2005) looked at the effects of woody material volume on aspen regeneration in Saskatchewan, and found slash had little impact on regeneration until its levels reached 400 tons/ha (80% ground coverage). When wood volumes reach this level a large proportion of the soil is covered, restricting aspen regeneration. The woody material ranges of 60 m^3/ha to 100 m^3/ha suggested above are well below the level documented by Lieffers-Pritchard and therefore should not have an impact on aspen regeneration on reclaimed sites. Unfortunately, studies looking at spruce regeneration were not available but the professional experience and observations of the authors suggest that upper limits for spruce would also be quite high.

10% to 25% coverage as a target

Recognizing that calculating the exact volume of woody material is not feasible for operators, visual indicators are needed. Various studies have looked at the percentage of ground covered by material in natural stands and suggest that approximately 10 to 12% coverage is the natural range of variability in forested stands (Harmon et al. 1986, Clark et al. 1998). That being said, Brown (2010) conducted a study on a reclaimed oil sands mine site and found that coverage levels between 25 to 45% did not impede regeneration but rather promoted growth of native plants. We are also in the process of studying the impacts of woody material on regeneration within jack pines stands at Moose Lake Provincial Park. From this study, and through modeling wood coverage estimates from over 16,000 forestry plots throughout Alberta, we suggest that coverage levels between 10 to 25% correspond to wood volumes between 60 to 100 m^3/ha. We should, however, acknowledge that this coverage target will depend on the size of materials being applied. Smaller materials will result in greater site coverage.

Lowland sites should have ½ the volume- similar coverage to upland sites

Compilation of data from the Alberta Biodiversity Monitoring Institute shows that black spruce stands in lowland areas have about ½ of the coarse woody material volume of upland stands. This suggests that total CWD volumes on lowland sites should be between 30 to 50 m^3/ha. This corresponds well to the scientific literature which suggests lower levels of woody material in lowland sites (Harmon et al. 1986). Creation of microsites on lowland sites has been shown to be critical for re-establishing a forest, and woody

This suggests that total CWD volumes on lowland sites should be between 30 to 50 m^3/ha.

materials may play an important role in this regard. However, companies should also explore the feasibility of using site preparation techniques, such as mounding, to increase forest regeneration on difficult lowland sites. Finally, in order to mitigate fire concerns on lowland sites, operators should rough mulch wood so as to remove any branches that may serve as a fire hazard.

The more intact the better

During our site visits we saw that a large amount of the woody materials had been broken down into smaller pieces as a result of machine traffic. We were also told that much effort had gone into ensuring even coverage across the wellsite. This resulted in increased traffic over the logs, as well as increased expenses on the operator's behalf. Although distributing woody materials across the site is important, it is also important to limit the breakdown of logs via machine traffic. Studies have shown that intact woody material is very important for various plant and animal species (Riffell et al. 2011). More specifically, logs with the bark intact serve as habitat for a variety of insect and plant species (Muller et al. 2002, Jacobs et al. 2007). Thus, efforts should be made to keep wood intact and should attempt to distribute the woody materials across the site in as few passes as possible. Minimizing the machine traffic will ensure that wood is kept intact with as much of the bark as possible. Finally, new machinery should be researched to ensure the most economically feasible option is being used. New machines such as grapple forks and/or wood bundlers are being used by some companies; the feasibility of these machines should be explored.

Efforts should be made to keep wood intact and should attempt to distribute the woody materials across the site in as few passes as possible.

Variability in log sizes is critical

When it comes to the diameter and length of woody materials used for reclamation, the more variability the better. Within forests, there is a natural range of sizes, lengths, and stages of decomposition (Harmon et al. 1986). This variation is essential for biodiversity (Siitonen 2001), but it is also very important for creating microsites and promoting nutrient cycling. For example, large logs have greater coverage, and their size provides increased protection for plants from wind and frost damage (Harmon et al. 1986). Operators should therefore focus on keeping a range of log sizes, and try not to break longer logs into smaller pieces. Large logs, small logs, long logs, short logs, the presence of all of these are very important for successful reclamation.

Operators should therefore focus on keeping a range of log sizes, and try not to break longer logs into smaller pieces.

Can whole logs be mixed into the soil during reclamation?

One question which is often raised about the placement of whole logs is whether or not they can be mixed within the soil. This is a question for which there is no easy answer; however, recent research and professional experience can provide some insights. Sucre et al. (2009) found that buried wood can be an important contributor to soil structure. However, it is also well known that woody materials can pull nutrients from the soil while buried (Harmon et al. 1986). Personal observations of the authors suggest that burial of a portion of the whole logs may help to establish heterogeneity in the soil surface and enable seedling root penetration following planting of sites. Although the current uncertainty around burial of whole logs requires additional research, it is apparent that mixing stumps into the soil surface may provide some key benefits for reclaiming sites. Nonetheless, conservation of topsoil on sites ***should remain the primary goal*** and operators should ensure that incorporation of whole logs into the soil surface does not compromise this key objective.

How do we move forward?

There is substantial support for the application of whole logs during reclamation. There are many benefits that whole logs provide that are not offered by other techniques such as mulching. These benefits include: erosion control; creation of microsites; source points for mycorrhizal fungi; and most importantly increased heterogeneity.

Our review suggests that applying volumes of 60 m^3/ha to 100 m^3/ha on upland sites, and 30 m^3/ha to 50 m^3/ha on lowland sites will result in increased reclamation benefits. Most, if not all, of this can likely be obtained through the deadwood within stands prior to disturbance, as well as tree tops and stumps left following harvesting. There will, however, be instances where wood volumes are either higher, or lower than the suggested range. In order to effectively handle variability in wood volumes, the creation of a woody material plan is recommended prior to site disturbance. Such a plan will not only provide operators with the information they need on expected woody material volumes, but it will also direct them on how to handle sites which have excess or too little material. On sites with an excess of woody material, companies should explore the feasibility of moving this material to sites that are lacking material through the use of equipment such as wood bundlers (See Baxter 2010). Having a woody material plan, will ensure an adequate use of the woody materials generated after industrial exploration, and it will also greatly assist in the regulatory approval stages. Such a planning document is currently being discussed by the Alberta government ESRD.

Management Implications

1) The application of whole logs is the preferred method of wood management because of the additional benefits logs provide for erosion control, moisture retention, creation of microsites, and increasing the heterogeneity on wellsites.
2) Woody material volumes of 60 m^3/ha to 100 m^3/ha, and coverage targets of 10 to 25% of the disturbed surface should be sought on upland sites.
3) Woody material volumes of 30 m^3/ha to 50 m^3/ha should be sought on lowland sites.
4) Operators should focus on keeping logs intact, and on maintaining a wide range of sizes and lengths of woody material on sites.
5) As an alternative to burning, companies should look at the economics of transporting woody materials from high to low volumes sites.
6) When the time between site creation and site reclamation is significant (e.g., multiple years to decades) whole logs can be stored under soil salvage piles or in locations deemend appropriate by local Forest Officers. In addition, coarse woody material can be salvaged and stored together with surface soils.
7) Companies should develop a "Woody Material Plan" prior to disturbance, to facilitate regulatory approval and to better manage woody materials.

Future Research Needs

1) How much woody material should be buried/mixed into topsoil and how much should be distributed along the surface of the sites?
2) What impact does buried woody material have on soil nutrient dynamics and soil formation?
3) What influence does the size of logs have on regeneration, widlife values, and decomposition rates?

2.3 Restoring Existing Features: Access Management and Wildlife Benefits

There is considerable interest from various oil sands companies in determining how to properly decommission and/or recover linear features, such as roads and seismic lines, to protect wildlife values and limit recreational access into remote areas. Woody material is seen as a possible avenue for promoting recovery along these lines, as well as functioning as a physical barrier to reduce recreational access. Here we discuss the current science behind access management for wildlife and recreational values.

What does the science say?

Lots of application, very little monitoring

The literature is rather sparse with respect to research on decommissioning or restoring roads, and how this affects wildlife and recreational objectives. Switalski et al. (2004) found that "even after thousands of kilometres of roads have been removed, there is an alarming lack of published analysis of the effectiveness of these efforts. . .". This lack of monitoring and analysis makes it very challenging to draw conclusions about how to effectively restore linear features.

"Even after thousands of kilometres of roads have been removed, there is an alarming lack of published analysis of the effectiveness of these efforts."

Within Alberta, however, there are a few consultant reports which have focused on this topic. These studies have looked at decommissioning or blockading roads to restrict recreational access. EOS (2009) conducted a review for the Foothills Research Institute in Alberta and found the three most successful actions with respect to effectiveness were: 1) Manned gates; 2) Right-of-way re-contouring; and 3) Rollback. Similar reports by Golder (2007) and Axys (1995) ranked rollback as the most effective strategy for access management.

Complete rollback appears necessary

Although few scientific studies on access management have been completed, experience from other provinces and our personal observations suggest that complete rollback along exploration and access features is necessary. For example, the Government of Saskatchewan has, for 10 years, encouraged that all woody material be rolled back along access and drilling features. This complete rollback appears to be extremely effective at deterring recreational access and promoting regeneration, according to senior managers at the Saskatchewan Ministry of the Environment. Ad hoc experiments have also looked at rolling back material along only portions of lines as a cost saving measure; however this has been ineffective as recreationalists continue to use these features. It appears that complete rollback along the entire length of access and exploration features is the best way to manage access.

It appears that complete rollback along the entire length of access and exploration features is the best way to manage access.

Results of a rollback study within the Little Smoky caribou range in the east-slopes of Alberta suggest that the use of rollback as a reclamation technique has additional benefits of initiating forest recovery along linear features, promoting a trajectory back to a functional forest. Rollback at this study site has promoted plant and seedling establishment along linear features through the creation of microsites (Figure 2.3).

Figure 2.3: *An example of a seismic line that had woody material applied seven years prior to photograph. Note the variation in plant cover and seedling presence as a result of microsites. Photo courtesy of T. Vinge.*

Single barriers are ineffective for deterring recreational access

One of the greatest frustrations for the oil and gas industry has been the lack of success when investments are made in access management features, such as gates, berms, and pits. These actions typically have high costs and are often ineffective. For example, EOS (2009) found that single barriers at the start of roads, such as gates and berms, were the least effective measure at reducing recreational use. Scientific studies have also drawn similar conclusions about the ineffectiveness of single barriers as they are simply avoided by recreationalists who drive around them to gain access into remote areas (Figure 2.4). This is a systemic issue within Alberta that requires much greater efforts than can be discussed here.

Figure 2.4: *Example of a failed attempt at using a gate to close an area to recreational access. Photo courtesy of M. Pyper.*

With respect to woody material, piling wood at the entrances to remote areas has been suggested. Although this will create a visual obstruction, if applied on its own it is unlikely to deter access as recreationalists will quickly build paths around the wood piles. To promote effective access management, a comprehensive field study is required to better understand which combinations of features will result in the greatest deterrence to recreationalists. In the meantime, full rollback of woody material along right of ways is recommended.

Does restoration of existing features enhance wildlife values?

Another possible application of woody material is to restore linear features within critical wildlife habitat- thereby enhancing wildlife values on the landscape. For example, it is well documented that wolves capitalize on high densities of seismic lines to travel more efficiently and increase their hunting success. This presents a serious threat to caribou populations in Alberta (James and Stuart-Smith 2000). Thus, it is important to develop techniques that mitigate impacts by effectively restoring linear features. Unfortunately, there has been very little research to date about the effectiveness of woody material applications on wildlife use of linear features.

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Neufeld (2006) looked at how felling trees every 10 to 15 metres across seismic lines would impact the use of lines as a travel corridor by wolves, caribou, and other mammals in the Little Smoky caribou range. In this study, Neufeld used remote cameras to monitor lines for the presence of mammals. Despite the intensity of tree felling on individual lines, Neufeld documented no effect on wildlife use of seismic lines. This study suggests that wildlife, much like humans, are not deterred by infrequent interruptions along lines and that more intensive actions to alter wildlife use are required. The study, however, was also challenged by the large density of linear features in the area (Figure 2.5). For example, it is very hard to detect a change in wildlife use of seismic lines when, logistically, scientists are only able to close down a small proportion of the seismic lines in an area. In addition, the interplay between seismic lines, natural game trails, and wildlife movement is not fully understood. Developing a solid understanding of what techniques truly impact wildlife use of lines requires a more intensive effort to close down a higher proportion of lines. Such an effort may have a broader landscape level impact.

Developing a solid understanding of what techniques truly impact wildlife use requires a more intensive effort to close down a higher proportion of lines.

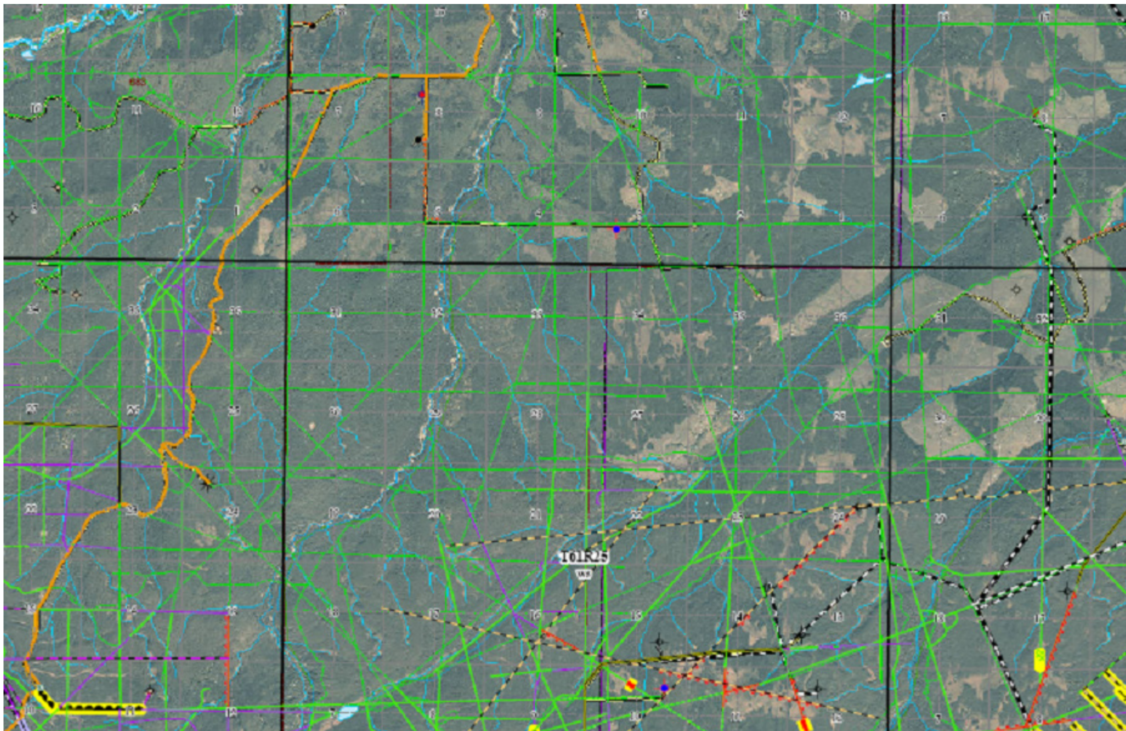

Figure 2.5: *An example land base showing the density of seismic lines in green. Wildlife research is challenged by the fact that only a proportion of these lines can be closed and monitored because of costs and logistics. Photo courtesy of Little Smoky Habitat Restoration Pilot.*

An example of one of these more intensive efforts at altering wildlife use of an area was studied in the United States. Switalski et al. (2004) found that when roads were decommissioned (removed completely) it resulted in greater use by numerous key wildlife species, including black bears. Prior to restoration, these species had otherwise avoided these areas, treating them as a fragmentation of their habitat. This study suggests that there may be some benefits to more intensive operations at restoring key wildlife habitat.

Although many efforts are designed to restore existing features and create wildlife benefits in the short-term, our review suggests that efforts will ultimately be more effective if they are applied with a long-term plan in mind. That is, it seems that efforts will be more effective if restoration actions are designed to recover linear features to forested habitat. This requires a significant change in mindset from current approaches, but it will likely produce much greater ecological benefit in the long-term. This is because many studies have tried to develop a 'quick and easy' solution for wildlife management. The reality, however, is that companies are working within an ecosystem, and that system is very complex and

It seems that efforts will be more effective if restoration actions are designed to recover these features to forested habitat.

difficult to predict. Actions need to have a long-term focus and be designed to achieve real benefits in terms of wildlife management. Recent examples suggest that actions focused on longer-term goals will be more successful at restoring key wildlife habitat (Switalski et al. 2004). That is to say, actions taken now should be evaluated based on their ability to restore the habitat along linear features.

New models are being developed for prioritizing restoration activities

For companies wishing to restore existing features to obtain conservation offsets or to enhance wildlife values, one of the most challenging questions is: which lines should be restored? Recent developments from the Foothills Landscape Management Forum of the Foothills Research Institute show much progress with respect to prioritizing and selecting lines for restoration activities. This method uses soft copy imagery to calculate various indices:

a) Trafficability: Current use by OHV's;
b) Re-vegetation: The degree to which vegetation is already establishing on lines;
c) Browse/forage availability: To define the relative amount of food available to ungulates; and
d) Line of site: to identify lines that have recovered sufficiently to reduce line of sight concerns.

Techniques such as these promote effective prioritization schemes and also assist with identifying restoration techniques suitable for candidate lines. For further information on the technique please see Greenlink (2010).

How do we move forward?

There is a large amount of uncertainty about the best way to restore existing features in order to achieve access management and wildlife objectives. The substantial lack of follow-up monitoring on many restoration projects means that many dollars have been invested in restoring disturbed forests, but the effectiveness of such investment remains unverified.

The first and most important conclusion, therefore, is that companies need to invest resources not only in testing different restoration techniques, but also in research and monitoring. Only through investments in monitoring and research will companies be able to understand what techniques are actually enabling them to achieve their objectives. This is a critical step because companies must increasingly prove success of programs to the public in order to obtain and hold their social license.

The second conclusion is that single barriers (berms, gates, etc.) are ineffective at deterring recreational access. Similarly, actions such as felling trees along lines to reduce line of sight for wildlife are not likely to be effective in reducing wildlife use of linear features. This has major implications for practitioners looking to restrict recreational access and alter wildlife use of linear features. There is likely not an easy solution for achieving recreational access and wildlife management objectives. The best solution currently available is rolling back all woody material along the entire length of exploration and access features. This technique is known to have a real benefit by providing microsites for vegetation re-establishment, and it is also known to be a deterrent for recreational enthusiasts. Thus, rollback has short-term benefits of limiting recreational access into remote areas, and long-term benefits of recovering the ecosystem- providing tangible benefits to wildlife over time.

Management Implications

1) All woody material along access features should be rolled back to promote vegetation re-establishment. Initial target volumes should be 60 to 100 m^3/ha, however, higher volumes could be explored through focused research programs.
2) Look for and utilize older slash piles and other residual wood from previous seismic operations.
3) Site preparation, such as mounding, can accelerate the establishment of native plants by trapping moisture along linear features. Operators can experiment with this technique as an access management tool.
4) Establish long-term monitoring programs that analyze animal movements prior to and following the above listed applications. Well designed and properly executed scientific experiments are the only way that practitioners will begin to advance their understanding of what works best in terms of achieving wildlife and access management objectives.
5) Focus reclamation efforts on creating real, long-term benefits to the ecosystem. Projects focused on short-term gains are likely to be ineffective.

Future Research Questions

1) Additional research trials need to be developed to determine how wood treatments impact recreational access and wildlife use of access features. It is critical that studies are scientifically robust, and get published in the peer-reviewed scientific literature. Suggested treatments, at a minimum, include:
   a. Conventional roll-back of right-of-ways.
   b. Higher densities of woody material (e.g., 150 to 250 m^3/ha) along right-of ways. This should be tested, via focused research, in various configurations (e.g., patches of high and low densities along the length of lines).
   c. High density of material only at start of access, conventional roll-back along the rest of the line.
2) What is the most effective configuration of wood placement on lines to control wildlife movements? Are intersections more important than other line segments?
3) Is the use of site preparation and slash placement more effective than either treatment in isolation for re-establishing vegetation and creating barriers to wildlife movement.

Visual Guide to Woody Material Applications

Light (25-50 m³/ha)

Moderate (100 m³/ha)

High (200 m³/ha)

3.0 Conclusion

At the start of this review we sought to answer five key questions:

- What ecological benefits does woody material provide?
- How should woody material be applied to disturbed sites?
- How much woody material should be applied to disturbed sites?
- What are the risks associated with the application of woody materials?
- What do the regulations say about applying woody materials?

Following this review, perhaps the most important message about woody material is that it is a critical component of forest ecosystems, and it should be capitalized on for use in reclamation programs. Our review found numerous benefits to the application of woody material, not the least of which is promoting enhanced regeneration on disturbed sites. Although there is a need for more research to better define volume thresholds for maximizing reclamation potential, there is extensive support for incorporating woody material in reclamation programs.

We found the following answers to the questions posed:

What ecological benefits does woody material provide?

Woody material provides a multitude of ecological benefits including: erosion control, facilitating nutrient uptake, serving as habitat for wildlife, and creating microsites for the establishment of vegetation. The most important role, in the context of reclamation, is the creation of microsites. The presence of woody material is known to create pockets of moisture, shade, and provide protection from wind and frost to growing plants. All of these functions contribute to enhanced potential for reclamation success on disturbed sites.

How should woody materials be applied to disturbed sites?

Woody materials can be applied in a number of ways; however, companies should expect different results based on the application. Mulching has recently been employed as a wood disposal technique but there are many concerns with the creation of a thick, homogenous layer over the soil surface. Mulch depths exceeding 3 to 4 cm are known to reduce the regeneration of plants in forested areas. Use of whole logs (roll back) is the preferred option for applying woody material to forested sites. Using whole logs provides many ecological benefits including: creating microsites, protection for seedlings, and habitat for biodiversity. In addition, research shows increased growth of native species when woody material is applied to sites. We therefore recommend that woody material be applied as whole logs, keeping logs as intact as possible.

How much woody material should be applied to disturbed sites?

The amount of woody material on sites is an important consideration in reclamation programs. We found that mulch depths should not exceed 3 to 4 cm in depth. With respect to whole logs, there has not been as much research on appropriate volumes. However, natural woody material levels in forested stands typically fall between 60 to 100 m^3/ha on upland sites. Additional research by the United States Department of Agriculture (USDA) suggests that woody material volumes ranging between 50 to 150 m^3/ha provide an optimum balance between fire risks, and biological benefits. Therefore, the volume threshold we suggested of 60 to 100 m^3/ha on upland sites should provide a good balance between these two often contrasting objectives. On lowland sites, woody material volumes should be half of this value (30 to 50 m^3/ha) as lower volumes are naturally found within these lowland sites.

Visual estimates of coverage for these volume estimates should range between 10 to 25% site coverage.

What are the risks associated with the application of woody materials?

Fire risk has long been a concern when leaving woody material on forested sites and this has contributed to past policies and regulations requiring piling and burning of all wood from industrial operations. However, the very act of piling and burning has also been shown to be a contributor to fire risk when not monitored appropriately.

Applying woody material should not pose a major fire risk if managed appropriately. The volumes suggested in this guide are well within the range found naturally in forests, and specific attention was given in the management implications to ensure that excessive accumulation does not occur on sites. Our estimates also fall within the range suggested by the USDA in a study they conducted which looked at defining appropriate volume thresholds to balance both fire risks, and biological benefits of applying woody material.

As an additional measure to mitigate fire concerns on industrial sites, we encourage companies to closely align their policies with the provincial FireSmart program so as to ensure fire risks are appropriately managed.

What do the regulations say about applying woody materials?

Provincial regulations have historically been designed to eliminate all woody material from industrial sites to reduce the risk of fires. However, this focus is changing with recent guidelines, such as the 2010 Reclamation Criteria for Wellsites and Associated Facilities for Forested Lands, highlighting the benefits of woody material on reclaimed sites.

Woody materials are also defined and discussed within the new Enhanced Approval Process (EAP)- further emphasizing that responsible use of woody materials is supported. Companies should consult their local forest officer, the EAP guidelines and local FireSmart criteria, in order to develop a balanced and responsible approach to woody material management.

3.1 Management Implications

Our review of the scientific literature focused on three topics: use of wood mulch in reclamation programs, use of whole logs in reclamation programs, and use of woody material for access and wildlife management. Through our extensive review, the following management implications were developed:

Wood mulching

1) The benefits of wood mulching appear to be limited. Mulching should be used only on an as needed basis to meet specific site level challenges (e.g., dry, arid soils). It should not be used as a company-wide policy for disposing of woody material on wellsites.
2) In specific cases where mulching cannot be avoided, such as during seismic operations, rough mulching (removing branches but leaving logs intact) or hand felling should be used, rather than complete mulching, whenever possible so as to retain whole logs and reduce operational costs.
3) As was suggested in the Alberta Government directive for using wood mulch roads (Drivable Wood Fibre Surfaces- External Information Letter, 2008), there should be no aspen chipping residues within 30 metres of riparian sites, such as bogs, lakes, streams, and ephemerals.
4) When mulching is used, wood mulch should not exceed 3 to 4 cm in depth in order to promote effective regeneration on the sites.

Using whole logs

1) The application of whole logs is the preferred method of wood management because of the additional benefits logs provide for erosion control, moisture retention, creation of microsites, and increasing the heterogeneity on wellsites.
2) Woody material volumes of 60 m^3/ha to 100 m^3/ha, and coverage targets of 10 to 25% of the disturbed surface should be sought on upland sites.
3) Woody material volumes of 30 m^3/ha to 50 m^3/ha should be sought on lowland sites
4) Operators should focus on keeping logs intact, and on maintaining a wide range of sizes and lengths of woody material on sites.
5) As an alternative to burning, companies should look at the economics of transporting woody materials from high to low volume sites.
6) When the time between site creation and site reclamation is significant (e.g., multiple years to decades) whole logs can be stored under soil salvage piles or in locations deemend appropriate by local Forest Officers. In addition, coarse woody material can be salvaged and stored together with surface soils.
7) Companies should develop a "Woody material plan" prior to disturbance, to facilitate regulatory approval and better manage woody material.

Using woody materials for access & wildlife management

1) All woody material along access features should be rolled back to promote vegetation re-establishment. Initial target volumes should be 60 to 100 m^3/ha, however higher volumes should be researched for their ability to achieve company objectives.
2) Look for and utilize older slash piles and other residual woody material from previous seismic operations.
3) Site preparation, such as mounding, can accelerate the establishment of native plants by trapping moisture along linear features. Operators can experiment with this technique as an access management tool.
4) Establish long-term monitoring programs that analyze animal movements prior to and following the above listed applications. Well designed and properly executed scientific experiments are the only way that practitioners will begin to advance their understanding of what works best in terms of achieving wildlife and access management objectives.
5) Focus reclamation efforts on creating real, long-term benefits to the ecosystem. Projects focused on short-term gains are likely to be ineffective.

3.2 Limitations

This review was based on the best currently available science, and the combined professional experience of the authors. Numerous research projects are currently in progress at the University of Alberta and other institutions, and thus our knowledge of the role of woody material in reclamation programs will only continue to be refined in coming years. We recommend that the information be implemented within the context of an adaptive management strategy. By adopting this adaptive management process, companies will ensure they are continually improving their programs and capitalizing on the best currently available science.

4.0 Literature Cited

Amaranthus, M. P., D. S. Parrish, and D. A. Perry. 1989. Decaying logs as moisture reservoirs after drought and wildfire. Pages 191-194 in E. B. Alexander, editor. Proceedings of Watershed 89 - a Conference on the Stewardship of Soil, Air, and Water Resources. United States Department of Agriculture, Forest Service Alaska Region, Juneau.

Axys Consultants. 1995. A compendium of physical access control measures for roads and other rights-of-way. A component of the access management initiative in Northeastern B.C.

Baxter, G. 2010. Costs and benefits of seven post-harvest debris treatments in Alberta's forests. FP Innovations.

Brennan, K. E. C., O. G. Nichols, and J. D. Majer. 2005. Innovative techniques for promoting fauna to return to rehabilitated sites following mining. Australian Centre for Minerals Extension and Research (ACMER), Brisbane Minerals and Energy Research Institute of Western Australia (MERIWA Report 248), Perth.

Brown, J.K.. E.D. Reinhardt, and K.A. Kramer. 2003. Coarse woody debris: Managing benefits and fire hazard in the recovering forest. United States Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-105.

Brown, R. L. 2010. Use of woody debris as an amendment for reclamation after oil sands mining. University of Alberta.

CAPP. 2008. Best management practices- Wildfire prevention. Canadian Association of Petroleum Producers.

Clark, D. F., D. D. Kneeshaw, P. J. Burton, and J. A. Antos. 1998. Coarse woody debris in sub-boreal spruce forests of west-central British Columbia. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 28:284-290.

Corns, I. G. W. and D. G. Maynard. 1998. Effects of soil compaction and chipped aspen residue on aspen regeneration and soil nutrients. Canadian Journal of Soil Science 78:85-92.

Densmore, N., J. Parminter, and V. Stevens. 2004. Coarse woody debris: Inventroy, decay modelling, and management implications in three biogeoclimatic zones. BC Journal of Ecosystems and Management 5:14-29.

EOS Research and Consulting. 2009. Review of strategies and tools for access management. Pp. 99 Submitted to Foothills Landscape Management Forum, Hinton, AB.

Golder and Associates. 2007. Audit of operating practices and mitigation measures employed within woodland caribou ranges. Submitted to Caribou Landscape Management Association, Peace River, AB.

Gray, A. N. and T. A. Spies. 1997. Microsite controls on tree seedlIng establishment in conifer forest canopy gaps. Ecology 78:2458-2473.

Greenlink Inc. 2010. Lineal inventory of the Little-Smoky caribou range. Pp.75 Submitted to the Foothills Landscape Management Forum, Hinton, AB.

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. Sedell, G. W. Lienkaemper, K. Cromack, and K. W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research 15:133-302.

Jacobs, J. M., J. R. Spence, and D. W. Langor. 2007. Influence of boreal forest succession and dead wood qualities on saproxylic beetles. Agricultural and Forest Entomology 9:3-16.

James, A. R. C. and A. K. Stuart-Smith. 2000. Distribution of caribou and wolves in relation to linear corridors. Journal of Wildlife Management 64:154-159.

Jones, C. C. and R. del Moral. 2005. Effects of microsite conditions on seedling establishment on the foreland of Coleman Glacier, Washington. Journal of Vegetation Science 16:293-300.

Laiho, R. and C. E. Prescott. 1999. The contribution of coarse woody debris to carbon, nitrogen, and phosphorus cycles in three Rocky Mountain coniferous forests. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 29:1592-1603.

Laiho, R. and C. E. Prescott. 2004. Decay and nutrient dynamics of coarse woody debris in northern coniferous forests: a synthesis. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 34:763-777.

Landhaeusser, S. M., V. J. Lieffers, and P. Chow. 2007. Impact of chipping residues and their leachate on the initiation and growth of aspen root suckers. Canadian Journal of Soil Science 87:361-367.

Lee, P. C., S. Crites, M. Nietfeld, H. VanNguyen, and J. B. Stelfox. 1997. Characteristics and origins of deadwood material in aspen-dominated boreal forests. Ecological Applications 7:691-701.

Lieffers-Pritchard, S. M. 2005. Impact of slash loading on soil temperatures and aspen regeneration. University of Saskatchewan, Saskatoon.

MacFarlane, A. 1999. Revegetation of wellsites and seismic lines in the boreal forest. University of Alberta.

MacIsaac, D. A., R. Krygier, I. K. Edwards, L. Kaytor, and S. Luchkow. 2003. Chipping debris disposal: Soil temperature, hardwood regeneration and nutrient relationships. Ninth year results. Page 46.

Muller, M. M., M. Varama, J. Heinonen, and A. M. Hallaksela. 2002. Influence of insects on the diversity of fungi in decaying spruce wood in managed and natural forests. Forest Ecology and Management 166:165-181.

Neufeld, L. M. 2006. Spatial dynamics of wolves and woodland caribou in an industrial forest landscape in west-central Alberta. University of Alberta, Edmonton.

Renkema, K. N., V. J. Lieffers, and S. M. Landhausser. 2009. Aspen regeneration on log decking areas as influenced by season and duration of log storage. New Forests 38:323-335.

Riffell, S., J. Verschuyl, D. Miller, and T. B. Wigley. 2011. Biofuel harvests, coarse woody debris, and biodiversity - A meta-analysis. Forest Ecology and Management 261:878-887.

Sanborn, P., C. Bulmer, and D. Coopersmith. 2004. Use of wood waste in rehabilitation of landings constructed on fine-textured soils, central interior British Columbia, Canada. Western Journal of Applied Forestry 19:175-183.

Siitonen, J. 2001. Forest management, coarse woody debris and Saproxylic organisms: Fennoscandian boreal forests as an example. Ecological Bulletins:11-41.

Sucre, E. B. and T. R. Fox. 2009. Decomposing stumps influence carbon and nitrogen pools and fine-root distribution in soils. Forest Ecology and Management 258:2242-2248.

Stevens, V. 1997. The ecological role of coarse woody debris: an overview of the ecological importance of CWD in B.C. forests. Working Paper 30. British Columbia Ministry of Forests, Victoria, B.C.

Switalski, T. A., J. A. Bissonette, T. H. DeLuca, C. H. Luce, and M. A. Madej. 2004. Benefits and impacts of road removal. Frontiers in Ecology and the Environment 2:21-28.

Taylor, B. R. and N. B. Carmichael. 2003. Toxicity and chemistry of aspen wood leachate to aquatic life: Field study. Environmental Toxicology and Chemistry 22:2048-2056.

Tedersoo, L., U. Koljalg, N. Hallenberg, and K. H. Larsson. 2003. Fine scale distribution of ectomycorrhizal fungi and roots across substrate layers including coarse woody debris in a mixed forest. New Phytologist 159:153-165.

Ter-Mikaelian, M. T., S. J. Colombo, and J. X. Chen. 2008. Amount of downed woody debris and its prediction using stand characteristics in boreal and mixedwood forests of Ontario, Canada. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 38:2189-2197.

Venner, K. H., C. E. Prescott, and C. M. Preston. 2009. Leaching of nitrogen and phenolics from wood waste and co-composts used for road rehabilitation. Journal of Environmental Quality 38:281-290.