Review

A Disturbance Ecology Perspective on Silvicultural Site Preparation

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Abstract: Silvicultural site preparation methods are used as planned disturbances for counteracting soil and vegetation constraints, as well as facilitating successful tree regeneration and growth. Understanding the possible effects of silvicultural site preparation on the ecosystem and evaluating site preparation as an ecological disturbance can help guide the selection and application of site preparation techniques for forest management goals. This review evaluates silvicultural site preparation techniques that are commonly used in boreal mixedwood ecosystems as agents of ecological disturbance by comparing the effects of each technique on the area disturbed and the degree of biomass modification, and then ordering them along a disturbance severity gradient. With a strong emphasis on the numerical estimation of the spatial footprint of different disturbances, broadcast burning typically has the highest disturbance severity, followed in order by broadcast herbicide use, mixing, plowing, disc trenching, mounding, scalping, and inverting. The evaluation of disturbance severity of various silvicultural site preparation techniques while using the proposed framework is feasible, in which quantitative assessments of area disturbed and biomass modification could be collected and assessed in most managed forests.

Keywords: boreal mixedwood ecosystems; disturbance footprint; disturbance severity; ecological disturbance; mechanical site preparation

1. Introduction

Silvicultural site preparation techniques are planned anthropogenic disturbances that are designed to aid in the regeneration and establishment of a new stand of trees. The main goal of any silvicultural site preparation is to create a beneficial environment for tree regeneration and growth, which may include favorable germination spots for seeds [1], successful seedling survival and establishment [2,3], and a reduction in realized competition [4]. To accomplish this, many methods can be applied in order to improve soil conditions (such as low or excessive moisture, low nutrient availability, and compaction) and control competing vegetation [1,2]. The disturbance of soil and vegetation can create a favorable microclimate for tree establishment [5,6] and it can influence the species composition and the structure of the future forest [7]. Silvicultural site preparation has the potential to mitigate the effects of climate change on early plantation growth in boreal forests by promoting tree establishment and growth, as well as promoting microclimate conditions for vegetation establishment [4].

The efficacy of site preparation depends on appropriately aligning potential methods with the specific site conditions, tree species, competing vegetation, climate, and the desired silviculture

objectives. Improper site preparation can negatively affect the chemical, physical, hydrological, and biological properties of the soil, and result in a failure to achieve management objectives [3]. Site preparation may also create unfavorable growing conditions when applied incorrectly or on an inappropriate site or ecosystem [1,3]. Thus, it is important to select the appropriate site preparation method that will minimize any undesired impacts on the ecosystem.

Although widely recognized as an anthropogenic disturbance, silvicultural site preparation techniques are commonly not examined through the lens of disturbance ecology. Understanding the possible effects of silvicultural site preparation on the ecosystem and recognizing site preparation as an ecological disturbance can help to select the best option for different forest management goals. For example, a forester managing a forest for ecological restoration may opt to apply a site preparation technique with little area disturbed and/or little biomass modification. Moreover, the study of site preparation techniques from a disturbance ecology perspective can help direct attention to the biological and ecological legacies [8] that are associated with site preparation activity.

Disturbances are typically characterized by their frequency, intensity, and severity [9]. Frequency is the temporal scale at which disturbance occurs, whereas intensity is a measure of the force of the disturbance [9]. Severity can be defined as the amount of biomass loss or the degree of change in ecosystem structure or function caused by a disturbance [9]. The quantification of disturbance severity provides a framework for evaluating, comparing, and predicting the results of any natural or anthropogenic disturbance [10]. Roberts [11] evaluated clear-cuts and partial cuts with scarification while using a disturbance severity model [10] but did not explore different kinds of silvicultural site preparation. An assessment of the disturbance severity of a range of silvicultural site preparation methods can provide insight into the suitability of site preparation options for various land management goals and their underlying ecological impacts.

The objective of this paper is to explore silvicultural site preparation techniques as agents of ecological disturbance. We focus on eight types of site preparation treatments—prescribed burning and herbicides, plus six types of mechanical site preparation (MSP), namely mixing, plowing, disc trenching, mounding, scalping, and inverting—that are commonly used today in boreal mixedwood ecosystems [1,4]. Mixed forests of white spruce (*Picea glauca* [Moench] Voss) and trembling aspen (*Populus tremuloides* Michx.) in northwestern Canada are typically clear-cut logged, followed by site preparation to offset the effects of cold wet soils and vigorous competition from species, such as trembling aspen and bluejoint (*Calamagrostis canadensis* [Michx.] Beauv.), in order to promote establishment of nursery-grown seedlings of the preferred crop tree, white spruce. Other site preparation techniques, such as motorized-manual screefing, are practiced elsewhere in the world, but they are not treated here. Specifically, we (1) review the general effects of the selected site preparation techniques on soil conditions and seedling performance, (2) propose a framework for evaluating site preparation disturbance severity at the cutblock/stand level, (3) analyze site preparation techniques while using our proposed framework with the objective of ordering them along a disturbance severity gradient, and (4) identify research needs and recommend future work.

2. Silvicultural Site Preparation Techniques

2.1. Prescribed Burning

Prescribed burning can be used to prepare sites prior to planting in order to remove organic materials from the area [12,13]. However, prescribed burning requires planning during the harvesting, as it requires a continuous cover of slash to carry the fire, it is limited seasonally by weather and fuel conditions, and may intensify competition problems when undesired or invasive vegetation is adapted to fire or invades after fire [14,15]. In addition, the use of prescribed burning has declined in response to concerns regarding air quality [12]. Even though the use of prescribed burning has decreased in some areas, it is still used in boreal mixedwood ecosystems, especially in remote locations for the establishment of conifer plantations.

2.2. Herbicide

When employing the chemical site preparation method, which involves the use of systemic herbicides, the two main objectives are to control competing vegetation by reducing its abundance before planting or seeding and to control competing vegetation during the early stages of tree seedling establishment [16,17]. Where the objective of site preparation is not vegetation suppression alone, herbicides may be used in combination with MSP and burning methods [12,18–20]. A broad-spectrum herbicide is sometimes used in order to kill and dehydrate the vegetation prior to the use of broadcast burning, in a technique that is known as “brown and burn”. The selection of the chemical treatment involves determining which registered herbicide (e.g., those with glyphosate or 2, 4-D amine as active ingredients) would be the most effective on the identified target species [16]. The use of herbicides is greatly constrained by concerns regarding impacts on non-target organisms (especially non-target plants [21], aquatic animals, cyanobacteria [22], and human health [22]). Although sometimes applied in spot treatments for crop tree release, herbicide applications for site preparation are almost always applied in a uniform broadcast manner, usually by aircraft.

2.3. Mixing

Mixing consists of incorporating the surface organic layer into the underlying mineral soil, which leaves the nutrients of the organic layers immediately available to germinants or planted seedlings. Mixing methods can be divided in three categories: coarse mixing, fine mixing, and spot mixing [1,23]. Coarse mixing is accomplished while using disc implements that heap clods of surface organic and mineral soil layers into a bed. This method provides slight control of competing vegetation, but it provides benefits where low soil temperatures and/or high soil water tables inhibit seedling growth [1]. Fine mixing is usually used on sites with high potential for competing vegetation, so a high-speed rotating implement is required to chop propagating plant parts small enough to control resprouting [1,6,23]. Spot mixing is usually recommended for sites where mixing is biologically suitable, but where stumps, slash, or other obstacles impede the use of strip mixing implements [23]. This method is also prescribed on sites where minimal soil disturbance is required [1,6].

2.4. Disc Trenching

Disc trenching exposes mineral soil in continuous strips. Disc trenching can produce three different planting positions: the trench position for dry sites, hinge position for medium-moist sites, and berm position for moist sites [1]. The trench profile can be adjusted depending on the objective by changing the disc angle. A disc angle that runs more parallel to the direction of travel produces a deeper, narrower trench, and a disc angle that runs more perpendicular to the direction of travel produces a wider trench [1,23].

2.5. Mounding

The main purposes of mounding are to create elevated planting spots [2,23]. Spot mounding is an intermittent form of mounding, which removes vegetation and the surface organic layer and results in inverted or mixed soil on top of an organic surface or bare center. Mounds may be composed of mixed surface organic matter and mineral soil, or of mineral soil capping on top of a largely undisturbed organic layer. Deep planting is usually applied in order to protect roots from being exposed to weathering of the mound surface subsequent to planting [1,23].

2.6. Plowing (Ploughing)

Plowing consists of creating continuous elevated berms [1,2]. In some regions it is listed as continuous mounding because it creates elevated planting spots on ridges [2], while, in other regions, planting is done in the furrows. Ripper plows are modified standard ripper teeth, on the back of a tractor, and they are specifically designed for tilling wet ground when it is frozen [1]. The most common

plow design is a double mouldboard, which attaches to the ripper shank of the tractor. The ripper teeth dig into the soil, while the plow attachment displaces soil on either side [1].

2.7. Scalping

Scalping, which is also known as patch scarification, creates patches of mineral soil exposed in a systematic pattern by removing the surface organic layer to expose the underlying mineral soil. Planting spots are usually below the original ground level [2], but different planting spots may be chosen, depending on site conditions (e.g., moisture regime of the site [23]). On most sites, seedlings are recommended to be planted on the shoulder of exposed mineral soil, adjacent to the inverted humus [1]. Seedlings may be planted in the bottom of the scalp on dry sites. The depth of scarification has to be appropriate for the site. Scalping that is too shallow may not be sufficient for controlling vegetation if competing roots are not removed. If scalping is too deep, the planting spot may become waterlogged, especially on a wet site or during wet periods [1,6,23].

2.8. Inverting

Inverting consists of turning the surface organic layer over; the inverted organic layer may be covered with mineral soil (mineral soil cap). Inverting is sometimes listed as one of the mounding techniques, although the planting spot normally is not significantly elevated [2,24]. On some sites, seedlings can have a problem with frost heaving following site preparation by inversion [23,25]. For instance, in Ontario, frost heaving in hand-simulated inverted humus mounds has been severe enough to cause concern regarding the suitability of such planting spots [23,25].

3. Effects of Silvicultural Site Preparation Techniques on Soil Conditions and Seedling Performance

Silvicultural site preparation techniques differ with regard to the type and amounts of soil disturbance that they induce and the concomitant ecosystem impacts. Ballard [26] evaluated the effects of forest management on forest soils and found that there can be both positive and negative impacts. The sensitivity of the site to short- and long-term degradation must be considered when selecting from among silvicultural site preparation options [1]. Site preparation techniques, such as herbicide application and prescribed burning, tend to cause less disturbance to the soil than mechanical practices [17], and they could be an option where MSP would pose a risk to sensitive soils or to water quality.

Many boreal forest ecosystems have a highly developed organic layer that overlies mineral soil [27]. Cold temperatures, short growing seasons, and high soil moisture decrease the decomposition rates of organic matter, resulting in the accumulation of a thick surface organic layer [28], which insulates the undisturbed soil beneath. In unprepared soil (i.e., with no site preparation), the humus layer (H horizon) may remain cool on warm days as the litter and fermentation layers (L and F horizons) act as insulation [27]. Exposed mineral soils warm faster than the undisturbed soil beneath the organic layers [23]. Therefore, MSP methods increase soil temperature by exposing mineral soils in a manner that varies with soil color [29]. In addition, removing shading from vegetation by herbicide, prescribed burning, and MSP methods also promotes the warming of the soil surface.

The increase in soil temperature as a result of site preparation treatments can provide benefits to tree seedlings, especially at high latitudes and high elevations [30,31]. Increasing soil temperature is, in many cases, beneficial for plants in general, because roots grow faster in warm soil than in cold soil [23]. Spruce (*Picea* spp.) seedlings, for example, show minimal growth at soil temperatures under 10 °C [32]. Warm soil can also facilitate water uptake, and it can decrease frost damage to seedlings through re-radiation of heat energy [23,33]. For example, in scalped soils, seedling roots that are stimulated by the increased soil temperature may quickly grow beyond the scalped area, reaching the nutrients in the surrounding undisturbed layers [2,23]. In inverted soils, roots reaching the mineral soil beneath the inverted layers have access to an enhanced supply of moisture [6,23]. Because

transpiration from the soil horizons under organic layers is reduced when vegetation is controlled, moisture accumulates beneath these organic layers [23].

Soil disturbance that is caused by MSP techniques can also enhance seed survival and germination during natural regeneration or direct seeding of a number of tree species [34,35]. Seeds and small seedlings may suffer desiccation in the organic layer, thus their contact with mineral soil can facilitate water uptake [2] and enhance seed and seedling survival [36]. MSP may also increase biodiversity because it tends to improve conditions for seed germination of a number of woody and herbaceous species [2].

Silvicultural site preparation techniques have the potential to significantly affect nutrient dynamics [37,38], either positively or negatively. For example, the mixing technique may risk releasing too much of the nutrient reserves of a site in the first few years after treatment, resulting in the long-term depletion of nutrients. Nutrients not taken up by plants may be lost to the ecosystem through leaching or erosion [23]. Prescribed burning can increase short-term (<5 years) availability of nutrients in the soil [13], but it may cause longer-term nutrient deficiencies [39]. Unlike the MSP techniques, herbicides can indirectly affect soil properties. Vegetation reduction by herbicide treatment tends to help retain available soil moisture [40], and there may be significant nutrient losses by leaching, increased daytime temperatures, decreased nighttime temperatures, and increased microbial activity [41].

Mechanical site preparation has been shown to cause reductions in available phosphorus (P) as well as reduced nitrogen (N) and carbon (C) in surface soils [38] if the forest floor is displaced. A study that was conducted in Alberta indicated that fifteen months after different MSP methods, treated sites have either reduced or unchanged concentrations of total N and C, available P, and mineralizable N in the surface mineral soil, as compared with harvested sites with no site preparation [42]. Although many studies indicate that nutrient pools may be affected by MSP [42,43], few studies have shown that MSP has negatively affected the long-term productivity of crop trees [2]. Piatek and Allen [44], for example, indicated that the nutrients lost during MSP had no noticeable effect on foliage production when measured 15 years after planting.

Silvicultural site preparation can lead to deep soil disturbances, depending on the intensity [2]. Most MSP techniques can cause soil erosion if not carefully implemented and adapted for the specific climate and site characteristics [45]. Excessive soil disturbance can result in further soil erosion, compaction, removal of nutrients beyond root systems, or even landslides [1]. The risk of soil erosion is increased when mineral soil is exposed by MSP (especially on slopes), and nutrients can be exported from a site in solution or by mass transport [46]. Alcázar et al. [45] showed elevated levels of soil erosion on areas where MSP treatments exposed the mineral soils. At sites where there is a risk of soil erosion, low fertility, and low soil organic matter, harvesting and MSP in combination with wet weather can cause soil compaction and erosion, with effects on site productivity (i.e., tree survival and growth) [47]. Disc trenching has the risk of accelerating erosion if running across the contours of a slope. Beasley et al. [48] compared the storm flow and sediment losses from mechanically and chemically prepared sites in southwest Arkansas over a four-year period. In contrast to MSP effects, they found that chemical site preparation using herbicides had no significant effect on sediment loss. Prescribed burning can have a major effect on surface soil erosion if it removes much of the forest floor over large areas of the cutblock [13].

Most research to date on silvicultural site preparation methods and plant performance has been conducted utilizing a few conifer tree species with the goal of increased productivity in traditional plantation forestry or during restoration [12,24]. In general, studies indicated improved seedling performance on sites with site preparation as compared to untreated sites. A study conducted in Sweden showed that, after 18 growing seasons, higher levels of Norway spruce (*Picea abies* [L.] Karst.) seedling survival were found following soil inversion (77% for normal intensity and 76% for high intensity) in comparison with mounding (67%) and control (i.e., no scarification, 57%) [34]. The difference in the seedling height between these scarification treatments and control corresponded

to a time gain of approximately four years of growth after 18 years [34]. Powelson et al. [12] in British Columbia indicated a greater white spruce growth response to MSP and herbicide treatments when compared to untreated sites over 30 years.

Studies indicate that herbicide site preparation results in better crop tree growth when compared to MSP, particularly on mixedwood sites where hardwoods and shrubs compete with planted conifers [49,50]. For example, a study on black spruce (*Picea mariana* [Mill.] BSP) establishment indicated that the largest stem volume with the lowest vegetation indices was recorded under chemical site preparation as compared to the scarification site preparation methods [49]. Moreover, chemical site preparation can be more effective in improving early conifer performance than when chemical brushing is used after planting [25]. Chen et al. [51] showed that planting trees after herbicide treatments resulted in increased crop tree and stand volume for both container-grown jack pine (*Pinus banksiana* Lamb.) and black spruce, but not bareroot black spruce.

Seedling responses to silvicultural site preparation vary among tree species [36] due to their physiological differences (e.g., tolerance to drought and flooding). Therefore, the choice of silvicultural site preparation methods needs to take the desired species or species composition and its expected responses into consideration. For example, seedlings of species that are intolerant to flooding [e.g., whitebark pine (*Pinus albicaulis* Engelm.), ponderosa pine (*Pinus ponderosa* Dougl. ex P. & C. Laws.), and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco)] are expected to have better performance when placed on the elevated spot, rather than the pit resulting from mounding.

4. Assessment of Area Disturbed and Biomass Modification of Silvicultural Site Preparation Techniques

The assessments of the percentage of total disturbed area were based on the typical application of each site preparation technique, whether it follows a systematic pattern of spot treatments, a continuous pattern, or the entire cutblock/stand [1,52] (Table 1). The analysis of the degree of biomass modification was based on which pre-existing organic materials are consumed, dislocated, or otherwise disrupted by each technique [1,13,16,23,52] (Table 1). The biomass considered includes living materials (e.g., understory vegetation), any organic materials left by previous vegetation (e.g., woody material, roots and rhizomes, and dead foliage), and forest floor (i.e., surface organic layers, LFH).

Biomass modification was inferred from general principles, as quantitative measurements are largely absent from the literature. Consequently, a simple ordinal score was assigned in order to represent the degree of biomass modification that is associated with each site preparation technique, ranging from 0 to 6, where 6 is the highest degree of biomass modification. We assigned a disturbance severity index from 0 (non-existent) or 1 (low) to 3 (high) for modifications to the residual biomass (e.g., living materials and organic materials left by previous vegetation) and the forest floor (Table 1). The biomass modification ordinal score corresponds to the sum of the disturbance index of the residual biomass and forest floor. For example, the justification for broadcast burning being assigned an ordinal score of 6 is that the organic material that was left by previous vegetation and the forest floor were both 3, while the herbicide treatment was assigned an ordinal score of 4.5 that was based on a high impact on the residual biomass (3), but a lower impact on the forest floor (1.5).

Table 1. Attributes of eight site preparation techniques commonly used in boreal mixedwood ecosystems.

Site Preparation Technique	Total Area Disturbed	Principal Effect	Biomass Modification (Effect/Disturbance Index)		Summed Score (0 to 6)
			Living Material and Organic Materials Left by Previous Vegetation (Scored 0 to 3)	Forest Floor (Scored 0 to 3)	
Broadcast burning	Whole area 90%–100%	Kills all aboveground vegetation, variable consumption of organic matter	Consumed, charred, or scorched, some incorporated into soil organic matter/3	Consumed or scorched, much incorporated to mineral soil/3	6
Herbicide (broadcast)	Whole area 90%–100%	Kills most of the dominant vegetation	Not removed from area treated, but understory vegetation (shrubs and herbs) mostly killed/3	Not directly affected, but a prolonged pulse of litter from killed vegetation is added/1.5	4.5
Mixing (coarse or fine)	Continuous pattern 50%–75%	Incorporation of the forest floor into the underlying mineral soil	Vegetation and fine/medium woody materials are chopped and mixed with soil/2.5	Mixed with mineral soil and organic materials derived from previous vegetation /2.5	5
Plowing	Continuous pattern 30%–65%	Exposure of mineral soil, organic material buried	Dislocated or buried in area treated/2	Dislocated or buried in area treated/ 2.5	4.5
Disc trenching	Continuous pattern 25%–50%	Exposure of mineral soil planting area	Dislocated within area treated/2	Dislocated within area treated/2	4
Mounding	Systematic pattern (of plantable spots) 15%–35%	Exposure of mineral soil planting spots	Dislocated within spots treated/2	Dislocated within spots treated/2	4
Scalping	Systematic pattern (of plantable spots) 10%–30%	Exposure of mineral soil planting spots	Dislocated from spots treated/1.5	Dislocated from spots treated/1.5	3
Inverting	Systematic pattern (of plantable spots) 10%–30%	Exposure of mineral soil planting spots by turning the forest floor upside down	Not removed from spots treated but moved from above ground to below ground as soil organic layers are turned upside down/1	Not removed or dislocated, but turned upside down/1	2

For drawings of the different MSP techniques and machines involved, refer to Von der Gönna [1] and McMinin and Hedin [23]. Von der Gönna [1] outlines the range of surface areas disturbed by different MSP techniques.

5. Disturbance Severity Analyses

Many studies have discussed disturbance severity [53,54], but with a focus on its effects on the dominant tree layer. Roberts [10] proposed a three-axis model of disturbance severity as an extension of a single-axis model of Oliver and Larson [53], with each of the three major vertical layers in the forest ecosystem (forest canopy, understory vegetation, forest floor, and soil) on a separate axis. The model has been used in order to evaluate a wide range of natural disturbance types [10] and evaluate clear-cuts and partial cuts with scarification [11].

Building on the work of Roberts [10], we have also adapted Oliver and Larson's [53] definition of disturbance severity to apply to the eight types of site preparation at the cutblock/stand level (i.e., the area harvested and treated by silvicultural site preparation). It is presented in the form of a simple two-dimensional framework, with one axis being the percentage of the total area disturbed and the other axis being the degree of biomass modification (Figure 1).

Figure 1. A two-dimensional framework for evaluation of site preparation disturbance-severity at the cutblock/stand level applied to eight site preparation techniques commonly used in boreal mixedwood ecosystems. The vertical axis is the percentage of the total area disturbed, with vertical bars representing the typical ranges of disturbed areas reported, and the horizontal axis is the degree of biomass modification (as per Table 1).

Broadcast burning is interpreted to have the highest disturbance severity, followed in order by herbicide, mixing, plowing, disc trenching, mounding, scalping, and inverting, based on the percentage of total area disturbed and degree of biomass modification of each technique (i.e., the two-dimensional framework) (Figure 1). Because broadcast burning and herbicide site preparation are designed to cover the whole area, not just plantable spots, they have a greater percentage of total area disturbed and typically result in higher degree of biomass modification when compared to MSP techniques. The organic materials of the entire cutblock are consumed or modified by broadcast burning; thus,

the amount of biomass loss by these techniques is higher than the other techniques. Herbicide site preparation also kills most of the dominant vegetation, eventually killing the root systems of plants, but it does not remove the organic material left behind, and may even result in a pulse of new litter as foliage dies and falls to the ground.

Because of the physical impact of the MSP techniques, much of the living understory vegetation is also expected to be killed in the disturbed spots. However, because MSP methods are either applied in a systematic or continuous pattern instead of across the whole cutblock, they result in a lower degree of modification to the cutblock's biomass than broadcast burning or herbicide. Although displaced, rhizomes, stolons, and root stocks of many species eventually resprout [55]. Mixing has the highest percentage of area that is disturbed of mechanical disturbance (50%–75%) and a higher degree of biomass modification than the other MSP techniques, because the organic materials that are left by the harvested trees, understory vegetation, and the organic matter are chopped and incorporated into the mineral soil.

Plowing, disc trenching, scalping, and mounding all remove the organic materials that are left by harvested trees and organic matter from the areas treated, but plowing has the greater percentage of area disturbed (30%–65%), followed by disc trenching, mounding, and scalping. Although both scalping and mounding are applied in a systematic pattern, mounding is expected to have a higher ground area disturbed than scalping, because mounding displaces the organic layer in order to create an adjacent elevated planting spot. The lower severity that is assigned to inverting reflects its low percentage of area disturbed (10%–30%) combined with the fact that it turns the organic layer upside down, leaving the organic materials disrupted but in place in the spots disturbed.

The two-dimensional framework (Figure 1) allows for the evaluation of disturbance severity of each site preparation method at the cutblock/stand level and provides an ordination of the techniques along a severity gradient. This ordering of site preparation techniques gives strong emphasis to the numerical estimation of the spatial footprint of these anthropogenic disturbances. Depending on land management goals or the concerns of particular natural resource management disciplines (e.g., carbon sequestration, biodiversity protection, and soil conservation), alternative degrees of emphasis might be placed on the fate of residual biomass (e.g., as long-lasting black carbon [56]) or on the widespread maintenance of soil health [57].

Taking these ideas forward from a conceptual ordering to an empirically based ordination that builds on our conceptual framework of disturbance severity is feasible. This framework could then incorporate quantitative assessments of area disturbed, biomass loss and alteration, and forest floor/soil disruption, which could be evaluated across a variety of boreal mixedwood cutblocks that have just undergone site preparation, and that could also be applied to forest operations in other parts of the world. Statistical multivariate ordination of disturbance severity using proportional area affected, biomass disrupted, and other factors, such as carbon emissions and wildlife habitat value, could also be undertaken.

6. Conclusions

Silvicultural site preparation effects on forest ecosystems can vary according to site conditions and management objectives. Selecting a suitable silvicultural site preparation method requires an understanding of the possible effects on forest ecosystems, on planting spot microclimates, and the potential for enhanced tree growth and carbon sequestration. Many studies in boreal ecosystems have concentrated on evaluating the effectiveness of silvicultural site preparation techniques in promoting successful tree regeneration, but there is still a need to study the effects on a wide range of additional species, under different site conditions, and their potential for ameliorating the effects of timber harvesting, site degradation, and climate change. To this end, there is value in looking at site preparation techniques through the lens of disturbance ecology. A preliminary conceptual assessment indicates that broadcast burning appears to have the highest severity, followed in order by herbicide, mixing, plowing, disc trenching, mounding, scalping, and inverting, but other perspectives

and statistical analyses are also possible. Future studies could apply the proposed two-dimensional disturbance severity framework and further elaborations of this approach to empirically evaluate additional site preparation techniques and operational forest management effects in forests around the world.

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