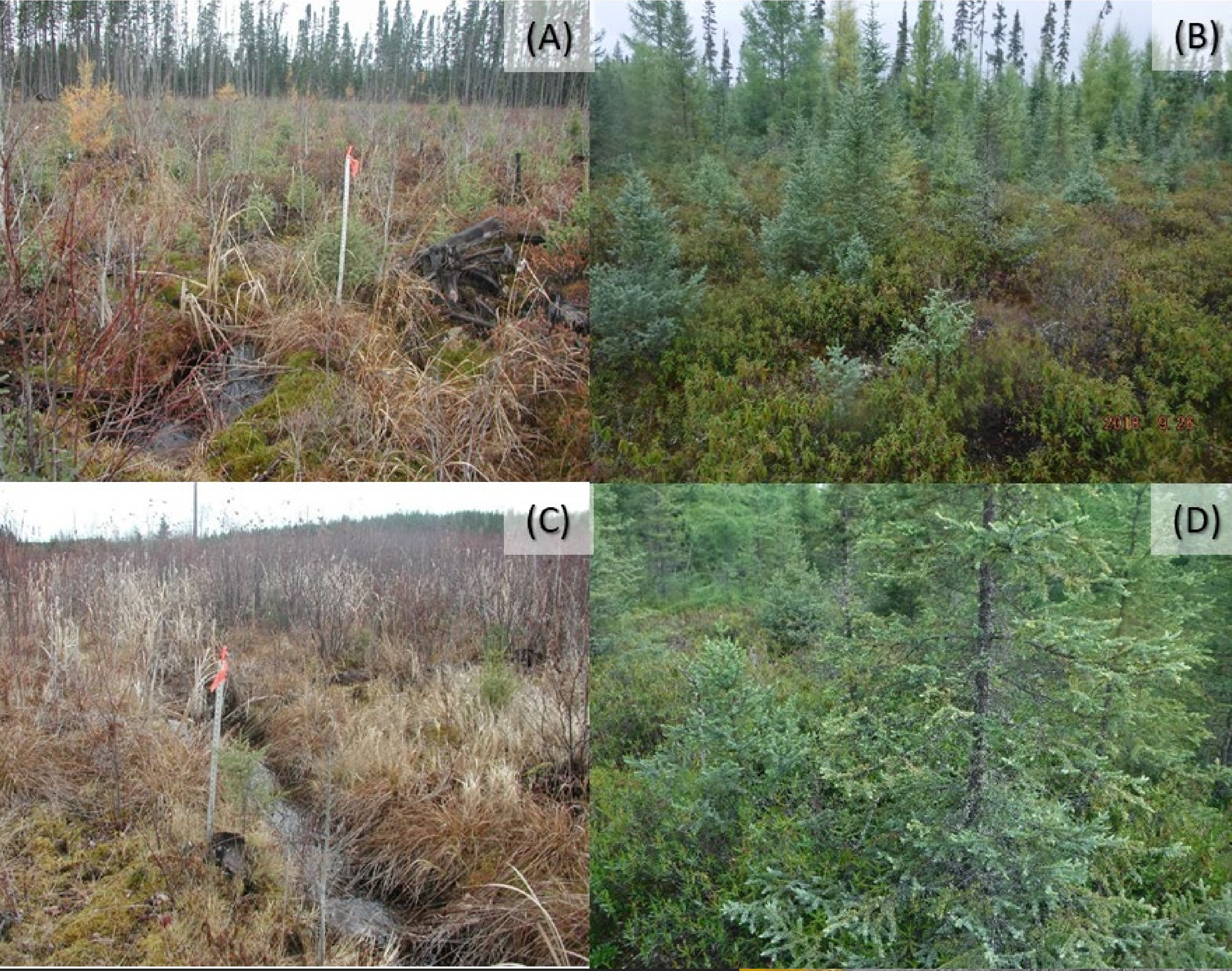

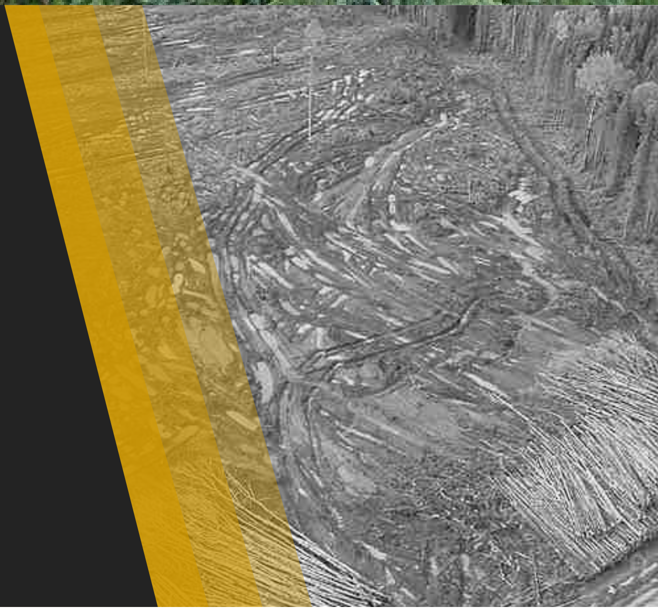

Rutting severity effects on black spruce performance after two decades

Technical Report TR-67

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Rutting severity effects on black spruce performance after two decades

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Summary

In a review of Ontario's Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales (SSG), questions and concerns were raised about the site disturbance guidelines related to rutting. Previous studies by Kimberly-Clark and the Centre for Northern Forest Ecosystem Research (CNFER) were revisited and resampled to provide quantitative information to support decisions about guide updates. Data from 50 plots ranging from non-rutted to severely rutted were analyzed to answer the questions: (1) How do ruts fill in over time?, (2) What is the effect of rutting intensity on black spruce planted seedlings occurring on lowland organic full-tree harvested sites?, and (3) Is there a rutting threshold for effects on crop tree growth or site productivity?

Twenty-three years after harvesting, ruts on moderately rutted sites filled in faster than those on severely rutted sites based on area disturbed (decreased 57–49%), mean rut width (decreased 40–26%), and mean rut depth (decreased 24–10%). The area disturbed on moderately and severely rutted sites decreased from 26 to 11% and 43 to 22%, respectively. On the CNFER study site, filled in ruts resembled the pit and mound microtopography typically found in undisturbed black spruce peatlands.

Rutting severity did not affect individual tree growth; however, on severely rutted sites, site productivity, in terms of stand density and basal area, declined. Planted seedlings (height increment) and stands (total density and basal area) benefited from moderate site disturbance, which acts as a form of site preparation on these lowland sites, breaking up the ericaceous shrub layer and reducing competition. Some individual seedling growth declines were observed on plots that exceeded a rutted area of 40%, which is currently below the SSG threshold of 50% of any 0.1 ha circle within a harvest block. While this finding would support a lower maximum rutting threshold, the main goal of the SSG standard remains to minimize rutting on areas susceptible to site damage to support successful regeneration and subsequent tree growth.

Résumé

Effets de la sévérité de l'orniérage sur le rendement de l'épinette noire après deux décennies

Dans le cadre d'un examen du *Guide de gestion forestière pour la conservation de la biodiversité à l'échelle du peuplement et du site*, des questions et des préoccupations ont été soulevées au sujet des lignes directrices relatives à la perturbation du site en ce qui concerne l'orniérage. Des études antérieures menées par Kimberly-Clark et le Centre de recherche sur l'écosystème des forêts du Nord ont été réexaminées et rééchantillonnées afin de fournir des renseignements quantitatifs permettant d'étayer les décisions relatives à la mise à jour du Guide. Les données provenant de 50 parcelles allant de non-orniérées à gravement orniérées ont été analysées pour répondre aux questions ci-après. 1) Comment les ornières se remplissent-elles avec le temps? 2) Quel est l'effet de l'intensité de l'orniérage sur les semis d'épinette noire plantés sur des sites biologiques de basses terres exploités par arbres entiers? et 3) Existe-t-il un seuil d'orniérage relativement aux effets sur la croissance des arbres cultivés ou sur la productivité du site?

Vingt-trois ans après la récolte, les ornières des sites modérément orniérés se sont comblées plus rapidement que celles des sites gravement orniérés selon la surface perturbée (diminution de 57 à 49 %), de la largeur moyenne des ornières (diminution de 40 à 26 %) et de la profondeur moyenne des ornières (diminution de 24 à 10 %). La surface perturbée des sites à ornières modérées et graves a diminué de 26 à 11 % et de 43 à 22 %, respectivement. Sur le site d'étude du Centre de recherche sur l'écosystème des forêts du Nord, les ornières comblées ressemblent à la microtopographie des fosses et des monticules que l'on trouve généralement dans les tourbières d'épinette noire non perturbées.

La gravité de l'orniérage n'a pas affecté la croissance des arbres individuels. Cependant, dans les sites gravement orniérés, la productivité du site, en matière de densité du peuplement et de surface terrière, a diminué. Les semis plantés (augmentation de la hauteur) et les peuplements (densité totale et surface terrière) ont bénéficié d'une perturbation modérée du site, qui agit comme une forme de préparation du site dans ce type de basses terres, en brisant la couche d'arbustes éricacés et en réduisant la concurrence. Certaines baisses de croissance de semis individuels ont été observées sur des parcelles dont plus de 40 % de la surface était orniérée, ce qui est actuellement inférieur au seuil du *Guide de gestion forestière pour la conservation de la biodiversité à l'échelle du peuplement et du site* de 50 % de tout cercle de 0,1 ha à l'intérieur d'une parcelle de récolte. Bien que cette constatation plaide en faveur d'un seuil maximal d'orniérage inférieur, l'objectif principal de la norme établie dans le *Guide de gestion forestière pour la conservation de la biodiversité à l'échelle du peuplement et du site* reste de réduire au minimum l'orniérage dans les zones susceptibles d'être endommagées, afin de favoriser une régénération réussie et la croissance ultérieure des arbres.

Acknowledgements

We thank Jim Rice (retired) and Ken Lennon (retired), both formerly with MNR for re-measuring the Kimberly Clark trials established in 2013 and providing the data for this analysis. We also acknowledge Centre for Northern Forest Ecosystem Research (CNFER) staff for overcoming access obstacles and inclement weather to collect data in fall 2018. Special thanks to Jodi Hall and Gordon Kayahara for their constructive comments/suggestions on earlier versions of this manuscript, and a thorough editorial review by Lisa Buse and Gillian Muir. Finally, thanks to the support/collaboration with forest industry that included Kimberly-Clark (KC trial on the Kenogami Forest) and Abitibi-Price (CNFER trial on the Spruce River Forest). We also acknowledge financial support from the ministry's Forest Policy Division for the remeasurement of the CNFER trial in 2018.

Contents

Introduction

Soil is an essential component of forest ecosystems, determining forest productivity by providing nutrients and moisture for tree growth, and serving as a medium for root growth. Disrupting the soil profile during forestry operations can affect site hydrology by altering drainage patterns, which increases the potential for channeling, sedimentation, and mercury contamination.

One of the main causes of soil disturbance in forests occurs through rutting, which happens when downward pressure exceeds soil shear strength causing support failure. This process can occur, for example, when forest harvesting equipment traverses wet sites. Rutting is more common on sites with saturated soils or where a strong root mat is lacking. Except in very wet to saturated deep organic soils, rutting is often accompanied by mineral soil compaction.

Generally, fine textured soils, such as silts and clays, are more susceptible to rutting and compaction than coarse textured soils (Arnup 1999). Organic soils — those with more than 40 cm of wet organic material — are susceptible to rutting as their load-bearing strength is low. The spring snowmelt and ground thawing season has the highest rutting hazard potential.

The objectives of this study were to remeasure rutting trials established in the late 1990s/early 2000s to increase our understanding of the long-term effects of site disturbance on boreal forest site productivity.

Background

Historically, the Ministry of Natural Resources has used the Forest Operations Information Program (FOIP) to ensure compliance with the Crown Forest Sustainability Act, its regulated manuals, and forest management plans. The FOIP reports were used to document undesirable site damage from forest operations and, in conjunction with Independent Forest Audits (IFAs), identify long-term site damage trends. This information is used to report on compliance with soil protection guidelines (criterion 3.1) included in the state of Ontario's forests reports (OMNR 2012). Drawing conclusions about possible changes in site productivity from visual inspections, combined with the lack of direct indicators of potential soil productivity loss, make it difficult to determine causal effects (i.e., direct link between site disturbance and effects on long-term site productivity) (Duckert et al. 2009).

The development and implementation of Forest Management Guidelines for the Protection of the Physical Environment (Archibald et al. 1997) provided forest resource managers with best management practices by summarizing the main types of site damage that can occur during forest operations. Site damage fact sheets were also developed to help identify sensitive sites using a series of hazard rating tables that could be used during planning and operations. However, the lack of quantitative standards or measures in this guide resulted in continuing concerns about soil compaction and rutting during compliance inspections and IFAs.

An evaluation of the 2004–2008 compliance reports, provided in the 2011 State of Ontario's Forest report, revealed that 4 to 7% of forest harvest operations resulted in soil site damage (OMNR 2012). However, the key issue with respect to the protection of the forest soil resource indicator, adopted from the Canadian Council of Forest Ministers (CCFM 2003), was that Ontario had not developed quantitative measures or a clear definition (standard) to document the occurrence of site damage. The qualitative assessments made for inconsistent reporting and low value summary data (Duckert et al. 2009). In response, a site disturbance task team was formed, with members from various ministry business areas, including science, policy, and forest operations, to identify critical knowledge gaps and ultimately a consensus on developing a quantitative site disturbance standard. The 2016 State of the Forest report indicated an increase in compliance to over 99%, with 2011 to 2013 showing full compliance after the standard was fully adopted in forest management plans in 2011 (OMNR 2016).

Development of site disturbance standards

Any development, review, or revision to a provincial forest management guide is accomplished with advice from the legally mandated Provincial Forest Technical Committee. While compiled by ministry staff, guide development is based on knowledge and expertise from a range of science experts, forest practitioners, and other stakeholders interested in managing public forests.

Extensive literature reviews revealed considerable information about soil disturbance, but most was focused on soil compaction with few studies on rutting. A threshold for when disturbance becomes damage was difficult to establish using the existing literature, so client surveys and regional workshops were conducted to better define and address the challenges, and develop a preliminary quantitative standard to address rutting in forest operations.

Surveys and workshops

Based on survey responses (60% government employees, 40% private sector), consensus was that existing forest management guidance (Archibald et al. 1997) was outdated and vague, leading to varied interpretations. In the Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales (SSG; OMNR 2010) that was then in development, respondents wanted (a) measurable and enforceable upper limits and standards for rutting, (b) examples that supported the recommendations, (c) regional and site-specific guidance, and (d) recommendations and guidance on mitigation techniques. The effects on future stand productivity were thought to differ between alteration of soil physical properties (Northern Ontario; boreal forest) and damage to residual stems (central and southern Ontario; Great Lakes-St. Lawrence (GLSL) forest). These effects were also linked to forest region and silvicultural system (i.e., clearcut in boreal and shelterwood or selection harvest in GLSL). All respondents indicated a need for additional operator training to recognize differences in site sensitivity and strongly supported the inclusion of a site disturbance standard in the forthcoming guide. Respondents emphasized the need for these standards and assessments to be easily understood and implemented consistently across jurisdictions (Duckert et al. 2009).

Seven workshops with 87 participants (54 government, 33 industry) were held across Ontario to incorporate knowledge of and experience with rutting and associated monitoring for all silvicultural systems. Forest industry representatives felt the standard needed to be science-based and highlighted that they would need time to adjust to new operating procedures with a phase-in period with respect to compliance. Government staff were unanimous that a standard was needed.

Recommendations

The task team suggested a first iteration soil disturbance standard. Key recommendations included a statement of site protection goals, a definition of disturbance, a classification of site types, a provision for consistent surveys across jurisdictions, and an adaptive management process to redefine goals and limits as new information becomes available.

The team suggested considering three interconnected site protection goals for the general harvest area:

- maintaining site productivity
- protecting hydrologic function
- enhancing wood quality

Site productivity would be the primary indicator for the collective maintenance of all three goals, as it is relatively easy to measure and embedded in the silvicultural prescription.

Ontario's first iteration of a site disturbance standard was meant to be achievable by defining a threshold length of 4 m, depth of 30 cm, and an area of 5 to 10% of the harvest block for partial to clearcut harvest systems. To limit areas of continuous rutting, no more than 50% of a 30 x 30 m area was permitted in ruts, making it easy to visually inspect for compliance. Minimizing these continuous rutting zones would help protect small, highly sensitive areas within larger harvest blocks. In alignment with the provincial adaptive management approach, additional standards based on soil sensitivity could be introduced when site-specific data was obtained and analyzed from an effectiveness monitoring program.

Ontario's stand and site guide

In the SSG (OMNR 2010), rutting was defined as a trench or furrow created by machine wheel or tracks that is >30 cm deep and has a continuous length of >4 m. The rationale states that 30 cm depths exceed the rooting depth of feeder roots for most tree species (Burns and Honkola 1990, Finér et al. 1997) and the depth needed for effective site preparation (~20 cm; Sutherland and Foreman 1995), and may result in altered surface and subsurface water flows. The 4 m continuous length criterion is consistent with national and international standards (Duckert et al. 2009, OMNR 2010).

The SSG standard for a clearcut silvicultural system has three parts:

1. No more than 50% of any 0.1 ha circle is permitted in ruts to avoid a concentration of rutting in any portion of the harvest block. Rutting of >50% of the surface area could lead to hydrological disruption and result in unproductive areas in a harvest block.
2. Ruts that channel water into or within 15 m of water features (e.g., lakes, ponds, rivers, streams, etc.) are not permitted to minimize the risk of sediment transport into adjoining water features, as this sediment can alter aquatic habitat and adversely affect water quality and aquatic organisms.
3. No more than 10% (5% on shallow soils, i.e., <30 cm to bedrock) of any 20 ha area (or the operating block if <20 ha) is permitted in ruts. Future growth is less of a concern in clearcut than partial harvest systems, other than for tree species dependent on suckering (i.e., regeneration could be affected by root shearing). Productivity may be affected by compaction, hydrological alteration, and increased competition; except in organic soils where evidence is insufficient to support any effect on productivity. The 20 ha rule allows machine operators to test soil conditions without immediate concerns of exceeding the standard. On sites with shallow soils, the per cent cover is reduced as

rutting may expose bedrock, thereby increasing the potential for localized erosion, resulting in expanded non-productive areas.

As per declaration order MNR-71 condition 38c, forest management guides should be reviewed, and possibly revised, every 5 years (now every 10 years). Workshops were set up across the province in 2014–2015 to seek feedback from ministry and forest industry representatives who have implemented the SSG. Key comments and concerns about the soil disturbance standards raised at those workshops were:

- Forest management units that set their own measurable standards set lower acceptable levels than the SSG direction. These differences might encourage operators to interpret that rutting to the threshold is acceptable. The perception was that rutting had increased but because extent/severity did not exceed the SSG standards, it was deemed acceptable.
- Whether the increased rutting was directly linked to implementing the SSG standards or simply that operational practices were focused on getting wood to the landings as quickly as possible.
- The 50% threshold in a 0.1 ha circular plot would rarely be exceeded and many felt that a lower threshold would result in reduced effects. Options suggested included lowering the threshold to 40% or reducing the plot size.
- Circular plots may not adequately capture the extent of rutting, as ruts are a linear feature that can extend beyond the plot perimeter.
- Few forest management units had agreed upon a standardized site disturbance assessment methodology.

Ontario rutting studies

Throughout the development of a site disturbance standard, the task team recognized the value of science-based threshold levels and limits and their link to maintaining site productivity (Duckert et al. 2009). Field trials (Kimberly-Clark, CNFER, and Hearst trials) were established to fill knowledge/data gaps (OMNR 2012) and improve our collective understanding of the effects of site disturbance on long-term site productivity. The remeasurement of the established trials were designed to address the following questions:

1. How persistent were the originally identified ruts or have they “filled in” over time?
2. What was the long-term (to 25 years) effect of rutting intensity on the survival and growth of planted and natural-origin black spruce seedlings in lowlands (peaty phase soils)?
3. What is the rutting threshold (e.g., % area in ruts) that, when exceeded, significantly reduced individual tree- or stand-level growth metrics?
4. How does this threshold compare to the current SSG 50% rule or the suggested reduction to 40%?

Kimberly-Clark trial

Established in 2004, the objectives of the Kimberly-Clark (KC) trial (Wiebe et al. 2004) were to determine (a) the effects of rutting in lowland organic full-tree harvested sites on site productivity and growth of planted black spruce and (b) the ideal microsites for planting black spruce on lowland organic sites. Ten- to seventeen-year-old plantations were selected to capture differences in site productivity resulting from the original planting microsite selection. Using aerial photographs taken the year after harvesting, major rutting areas were identified along with adjacent areas where no (or minimal) rutting was evident. Site disturbance was verified in the field with 10 pairs of sites (10 rutted and 10 non-rutted) selected.

At each site, five 5.64 m radius plots (100 m^2) spaced 30 m apart were established. Vegetation, ecosite, and soil types were recorded for each plot based on the northwestern Ontario ecosystem classification system (Sims et al. 1989). Rut depth and width were measured every 2 m along the rut, and total length was used to calculate the total rutted area in each assessment plot. Commercial trees (i.e., black spruce – *Picea mariana*, white spruce – *Picea glauca*, jack pine – *Pinus banksiana*, red pine – *Pinus resinosa*, white pine – *Pinus strobus*, balsam fir – *Abies balsamea*, tamarack – *Larix laricina*, white birch – *Betula papyrifera*, and aspen – *Populus tremuloides*) were tagged; their microsite locations recorded in relation to the rut (i.e., top, side, bottom, or not on the rut), and measured for height and root collar diameter. Individual tree stem volumes were calculated using the volume equation of a cone and density per hectare was extrapolated from the tree counts for each plot to provide a total stand volume estimate.

Results:

- Trees on rutted and non-rutted sites had similar growth characteristics, with no significant relationships with rut depth and width.
- Species composition was similar between rutted and non-rutted sites.
- Rutting did not seem to affect black spruce regeneration on lowland sites.
- Planted trees were much larger than ingress (naturally regenerated trees) on both rutted and non-rutted sites, reaching free to grow (FTG) status sooner.
- On rutted sites, the ideal microsite for tree growth was on top of ruts (disturbed edge).

Hearst rutting trial

Established in spring 2003 (McPherson et al. 2007), the Hearst rutting study was implemented to (a) address issues raised from compliance inspections and IFAs, (b) determine the threshold at which ruts reduce regeneration success and seedling growth, and (c) determine acceptable site disturbance levels. More specific questions included, (a) does severe rutting of peat soils impede regeneration, and if so, is it temporary?, (b) how is competing vegetation affected by rutting?, and (c) does planting or artificial seeding benefit regenerating rutted sites?

Six transects (10 continuous 2 x 2 m quadrants) per treatment were in four replicate blocks. Three silvicultural treatments were applied to transects in each block – natural group seed tree, hand seeding, and planting of black spruce container stock – presumably at the standard 2 m spacing, resulting in 72 transects.

In each 4 m^2 quadrant, per cent cover was assessed in 2003 and 2006 for severe ruts (churning), light ruts (depression), pooled water, competing vegetation, receptive seedbed, and slash. Root mat condition, presence/absence of plantable spots, and vegetative composition were also recorded. The number, tree origin, species, and condition of each tree was recorded in every quadrant and heights were recorded in 2006. In the initial rut assessments, per cent rut coverage for each quadrant was converted to a category: low (0–30%), medium (31–60%), or high (61–100%).

Results:

- On heavily rutted sites (>60% coverage), spruce stocking was below 40% in naturally regenerated plots, suggesting that in fill planting would be needed to meet regeneration standards.
- Relying on natural regeneration alone across rutted sites would not meet renewal objectives in a timely manner.
- Hand seeding slightly improved stocking, but only if the substrate provided a suitable/receptive seed bed (i.e., sphagnum instead of feathermoss).
- The need for release treatments (competing vegetation control) was identified, with the caveat that the relationship between the level of vegetative competition and rutting severity needed further examination.

Centre for Northern Forest Ecosystem Research trial

To understand when soil rutting can disrupt ecosystem function and compromise regeneration and tree growth, the objectives of this study, hereafter referred to as CNFER study (Morris et al. 2009), were to (a) quantify and compare rutting severity on lowland black spruce harvest blocks, (b) document changes in microsite conditions over a 10-year period, (c) determine effects of rut severity and microsite position on planted black spruce seedling performance, and (d) determine if delayed planting on rutted sites would improve black spruce seedling survival and growth. Two harvested sites, each about 50 ha in size, in moderately productive lowland black spruce stands were harvested in the winter of 1994–1995. After visual inspection in spring 1995, areas in the sites were characterized as severely or moderately rutted. Each site also had area with no visual evidence of rutting (treated as controls). Four plots (480 m^2) were established in areas of both rutting severity levels, and eight plots (4 per site) in the non-rutted controls.

Each plot was marked with planting pins on a 2 x 2 m grid allowing for 120 microsite assessment points per plot. All 1920 microsites were evaluated before planting in early June for planting suitability, moisture, position, competition, and planting medium. These microsites were re-assessed 5 and 10 years after establishment to evaluate changes over time. After the initial assessment, rows were randomly assigned a planting date (immediate, 1-, 2-, or 3-year delay), with 30 trees per plot assigned to each date. If natural regeneration occurred within 1 m of an assessment pin, the spot was not planted and was identified as a natural origin seedling. Detailed assessments occurred in 2001 and 2006 to evaluate survival, health condition, total height and current annual increment, and root collar diameter. In 2006, the competing vegetation surrounding each planted seedling was assessed and categorized as none, light, moderate, or heavy. At this time, four fixed area regeneration subplots (3.99 m radius; 50 m^2) were randomly established in each main plot.

Results:

- Black spruce seedling survival was significantly lower in the severely rutted area, with moisture class having the largest influence on the probability of seedling survival.
- A canonical discriminant analysis showed competition factors (ericaceous shrub cover) as the most influential microsite factors affecting seedling growth.
- The moderately rutted areas created conditions that resulted in high conifer recruitment and high seedling survival and growth, suggesting black spruce peatland sites may benefit from a moderate level of site disturbance during harvesting operations.

Methods

Kimberly-Clark and CNFER trial re-assessments

In 2013, the KC trial (10 sites, each with rutted versus non-rutted blocks) was re-assessed using a series of 100 m^2 circular plots (5 subplots per treatment block), measuring tree growth (i.e., height and ground level diameter) of all commercial tree species, including planted and natural ingress trees. Ruts were measured within the plot boundary by measuring width and depth every 2 m along the rut and recording total rut length.

In 2018, the CNFER study was re-assessed using a series of 50 m^2 circular plots (4 subplots per treatment plot), measuring planted tagged trees for height and diameter at breast height. Ingress of all commercial tree species were also measured for diameter at breast height. Ruts were measured within the original 480 m^2 treatment main plots using a line transect method. Two 20 m transects were established across each main plot, with rut depth and width recorded at the intersection point of each rut along the established transects. The length of each intersecting rut was also recorded.

Data summary and analysis

Mean annual increment data was used to standardize individual seedling growth between the two studies as stands of various ages were used in the analysis. One- and two-way ANOVAs, and curvilinear regressions were used to analyze relationships between individual seedling growth parameters (height, diameter), area-based seedling performance (density and basal area of planted and total seedlings), rut characteristics (rut depth, rut width, % area covered), and microsite assessments (moisture, position, and vegetative competition).

Results and discussion

Rutted sites from forestry operations may recover in part or completely, however, the recovery rate across a range of forested ecosites is not well understood. Natural processes such as freeze-thaw cycles, soil fauna, and root activity have been identified as agents that facilitate recovery in as little as 5 to 20 years (Wasterlund 1992, Arnup 1999). More conservative estimates (Hatchell and Ralston 1971, Wert and Thomas 1981, Froehlich and McNabb 1984) have indicated that recovery may take as long as a full rotation. However, if detrimental soil disturbance occurs during harvest operations, the potential effects on forest growth may extend the time needed for ecosystem recovery (OMNR 2010). In the 2018 re-assessment of the CNFER study, the per cent area covered in ruts decreased by 52% from the original post-harvest assessment in 1995 (Table 1). Rut width and depth also decreased by 32% and 18%, respectively. The moderately rutted area (Area 2, figures 1a,1b) recovered better based on rut area, width, and depth, which were 57%, 40%, and 24% lower than the original assessments, compared to 49%, 26%, and 10% reductions in the severely rutted treatment plots (Area 1, figures 1c,1d; Table 1).

Table 1. Change in rutted area (% coverage) and rut characteristics (length and depth) from 1995 (initial assessment) to 2018 (23 years post-initial assessment) at the CNFER Study.

Rutting damage	Rep	Area rutted (%)		Rut length (cm)		Rut depth (cm)	
		2018	**1995**	**2018**	**1995**	**2018**	**1995**
Severe	1	21.2	45.5	69.4	82.8	16.5	20.9
	2	23.9	53.3	103.6	133.2	17.8	15.0
	3	11.8	22.0	59.8	109.8	18.9	29.8
	4	30.0	50.0	64.1	75.7	24.1	19.9
	Mean	**21.7**	**42.7**	**74.2**	**100.4**	**19.3**	**21.4**
Moderate	1	10.9	27.4	40.0	91.3	21.6	34.3
	2	14.3	31.7	60.0	81.8	21.4	27.0
	3	9.8	21.0	46.4	83.8	26.6	30.4
	4	9.9	24.2	56.7	80.7	22.7	29.7
	Mean	**11.2**	**26.1**	**50.8**	**84.4**	**23.1**	**30.4**

Seedling productivity based on microsite condition

When seedlings were planted in the CNFER trial from 1995 to 1998, each planted microsite was assessed for moisture (fresh, moist, wet), competition (heavy, moderate, light, none), and planting position (no rut, between ruts, side of rut, bottom of rut). Due to the staggered planting schedule, productivity measures of seedling height and diameter (Dbh) were analyzed as mean annual increments to standardize data. Seedlings growing on fresh microsites had the largest height and Dbh growth increments at 18.8 cm yr^{-1} and 0.23 cm yr^{-1}, respectively (figures 2a, b). Overall, seedlings on the fresh and moist microsites were more productive on rutted sites than non-rutted sites, but exhibited poorer growth on wet microsites (Figure 2).

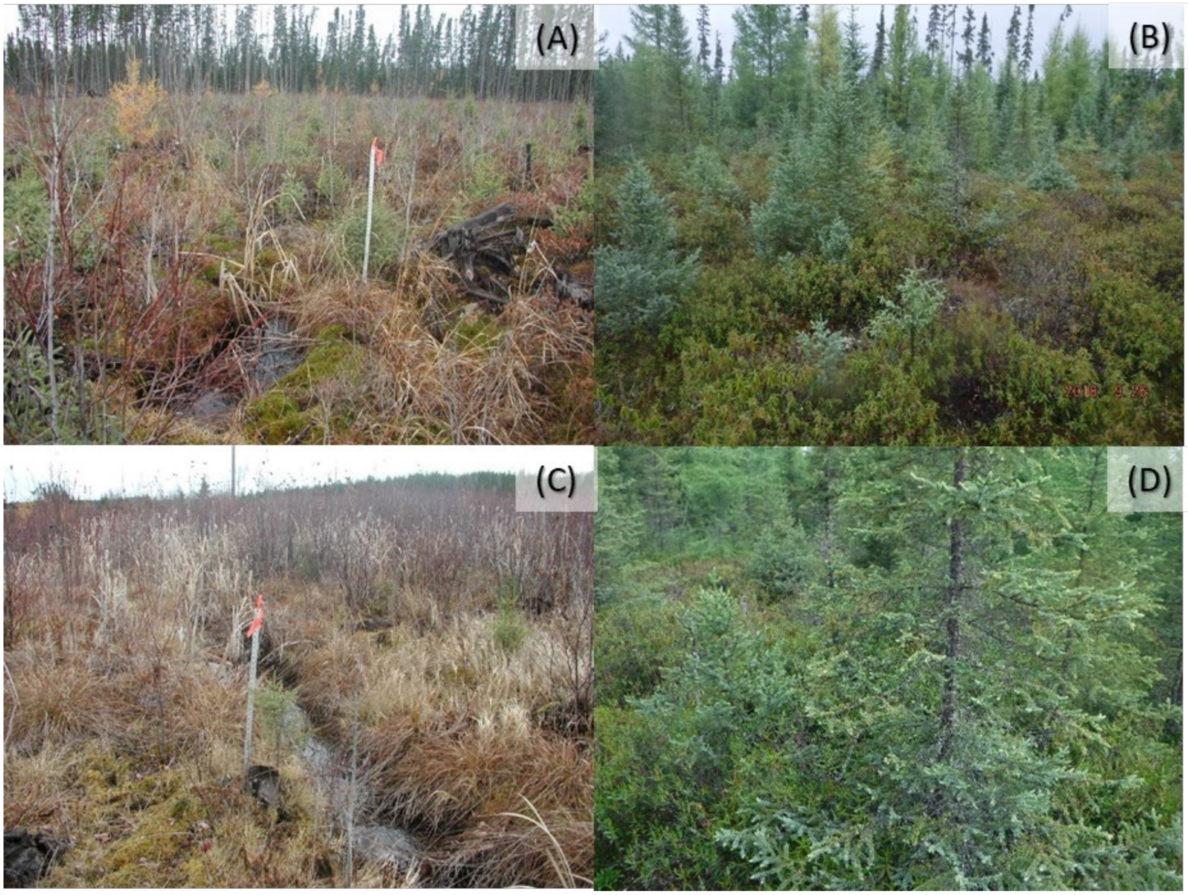


Figure 1. Photos of the moderately rutted site (A) and the same site 23 years post-harvest (B); the severely rutted site (C) and the same site 23 years post-harvest (D). Both sites are situated in northwestern Ontario.

Trees in rutted wet sites had the smallest height and Dbh annual growth increments at 12.9 cm yr^{-1} and 0.14 cm yr^{-1}, respectively. However, the differences in individual seedling growth between rutted and non-rutted sites across all microsite moisture regimes were not significantly different from each other.

As competition at each plantable spot increased, seedling height increment decreased in both rutted and non-rutted plots (Figure 3a). Seedling height increment on non-rutted plots declined from 15.7 cm yr^{-1} (no competition) to 10.2 cm yr^{-1} (heavy competition) (p = 0.0274). Height increment on the rutted plots was generally larger, particularly at the heavy to moderate competition levels, ranging from 17.4 cm yr^{-1} to 13.5 cm yr^{-1}, but were not significantly different (p = 0.6220) across competition levels. The largest difference was between rutted and non-rutted plots at the moderate competition level, as seedlings in rutted plots had height increments 5.7 cm yr^{-1} greater than those on non-rutted plots (Figure 3a). Diameter increment followed a similar pattern, except a significant rutting treatment and competition interaction existed (p = 0.0118; Figure 3b). In this case, seedlings on rutted plots with no competition (0.21 cm yr^{-1}) had significantly greater increments than those on non-rutted plots with moderate competition (0.11 cm yr^{-1}). Like the height increment results, the largest difference in seedling diameter increment was between rutted and non-rutted plots at the moderate competition level, with increments on rutted plots 0.08 cm yr^{-1} greater than those on non-rutted plots (Figure 3b).

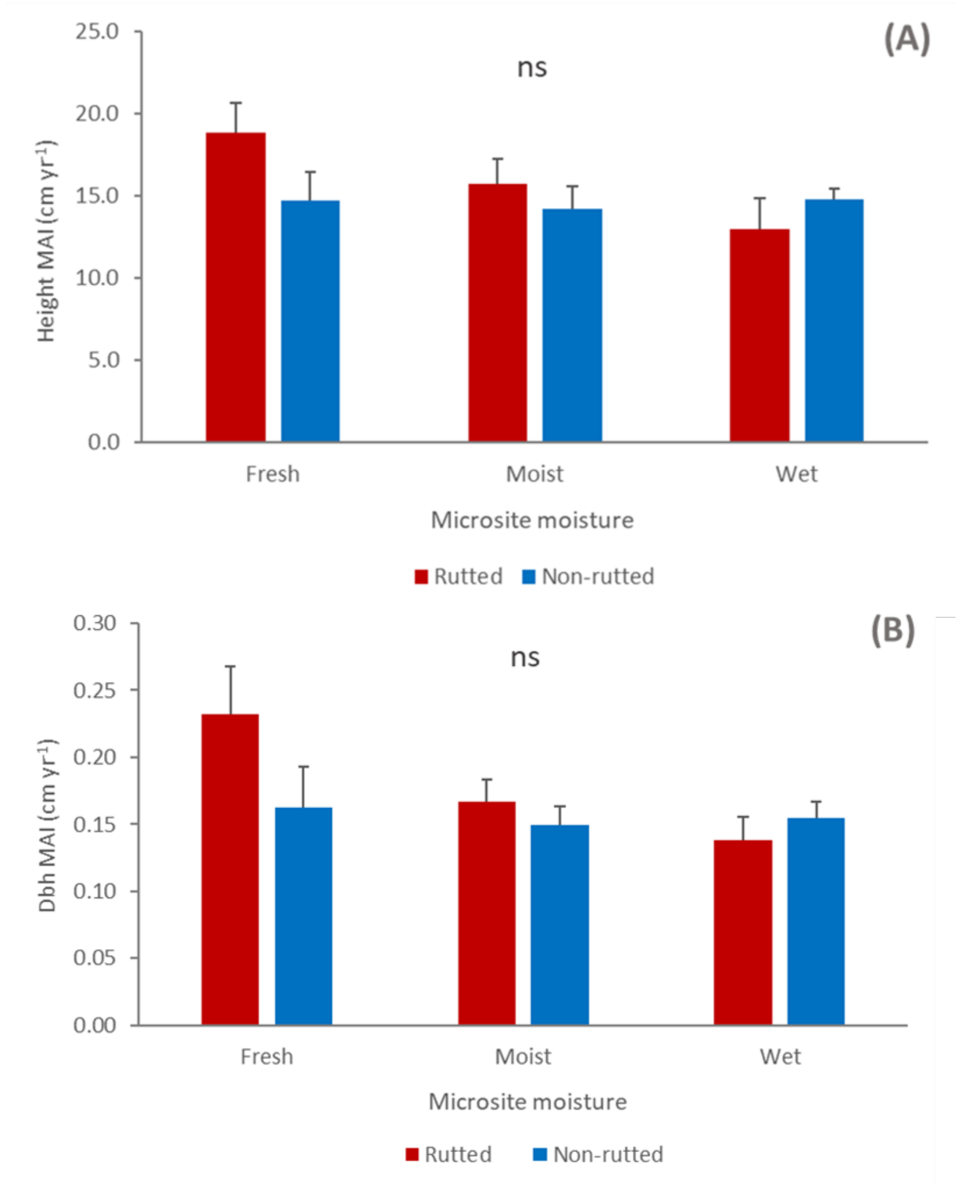


Figure 2. Mean annual black spruce seedling height (A) and Dbh increments (B) across microsite moisture regimes for rutted and non-rutted plots. (ns=not significant).

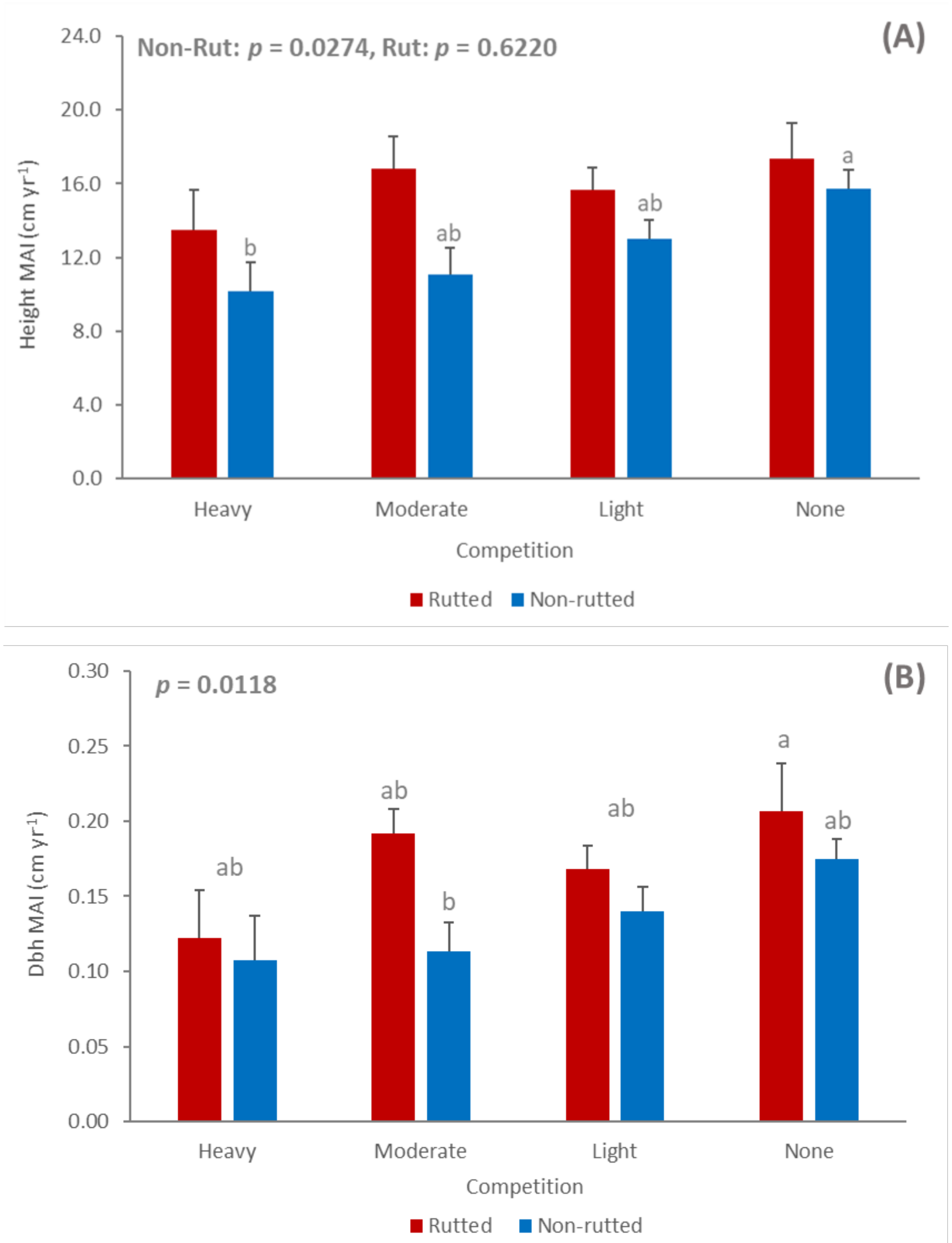
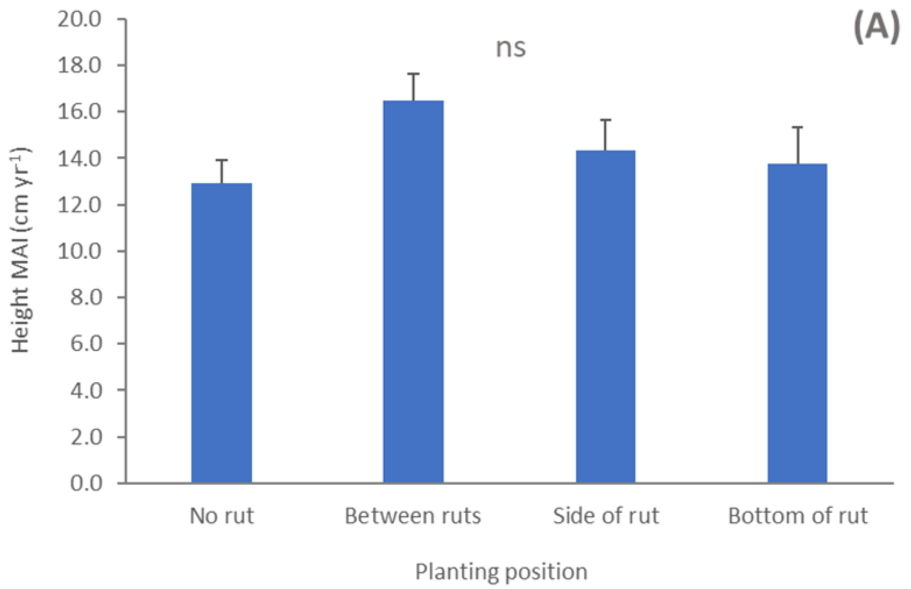


Figure 3. Mean annual black spruce seedling height (A) and Dbh (B) increments across microsite competition levels for rutted and non-rutted plots in a northwestern Ontario study. Lowercase letters above the bars indicate significant differences ($p<0.05$).

When the forwarding equipment unintentionally broke up the continuous ericaceous shrub layer, the rutting provided site preparation by reducing competition. For example, 62% of the microsites within the non-rutted plots had no or only light competition, compared to 78% in the rutted plots. Only 2% of the planted seedlings experienced heavy competition on the rutted plots.

Planting position did not significantly affect seedling annual height increment, however, long-term, seedlings planted at the bottom of ruts performed better than seedlings planted on non-rutted plots (height increment of 13.8 to 12.9 cm yr^{-1}, respectively; Figure 4a). Seedlings planted on the undisturbed flat area between ruts had the largest annual height increment at 16.5 cm yr^{-1}. In contrast, annual diameter increment was significantly (p = 0.0485) affected by planting position as seedlings that grew between ruts (0.18 cm yr^{-1}) had greater increment than those planted at the bottom of ruts (0.12 cm yr^{-1}; Figure 4b). Annual diameter increment for seedlings planted on non-rutted treatment plots fell between these values at 0.14 cm yr^{-1}.

With average rut depths reaching 34.3 cm (Table 1), seedlings planted at the bottom of ruts started at a disadvantage. The greater annual height increments in seedlings planted at the bottom of ruts compared to those on non-rutted plots may reflect a shift in allocation to height growth on these more competitive microsites (i.e., trying to access available light).



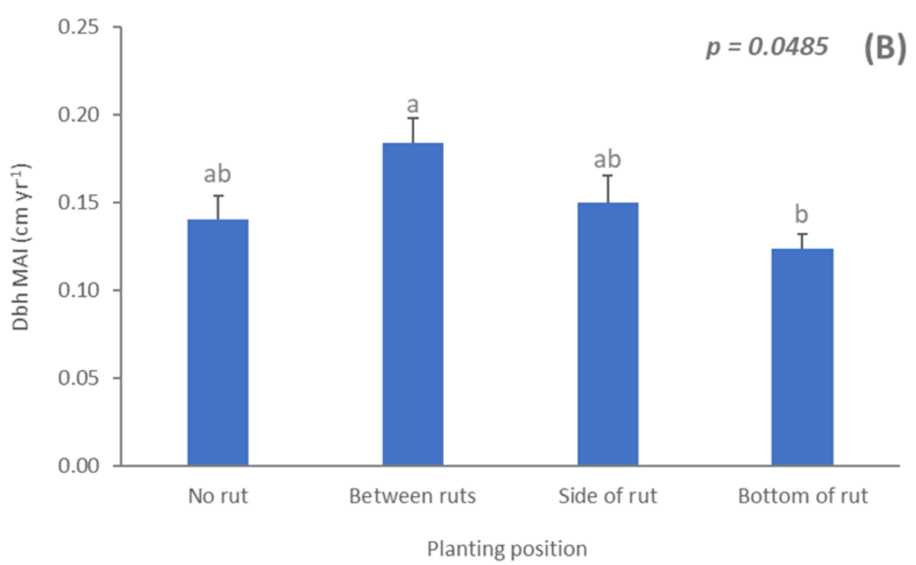


Figure 4. Mean annual conifer seedling height (A) and Dbh (B) increments across planting position for rutted and non-rutted plots in a northwestern Ontario study. Lowercase letters above bars indicate significant differences (p<0.05) (ns = non-significant).

Influence of delayed planting on seedling growth

As part of the CNFER study, trees were planted immediately after harvest, and 1, 2, and, 3 years post-harvest to determine if some of the negative effects of rutting, such as disrupting the soil profile, could be mitigated through delayed tree planting. However, delayed planting on both rutted and non-rutted sites had an extended (i.e., out to 25 years following harvest) negative effect on seedling annual height increment. Seedling annual height increment on rutted sites decreased from 18.8 cm yr^{-1} for immediately planted seedlings to 14.2 cm yr^{-1} when planted three years after harvest (Figure 5a). On non-rutted sites, seedling annual height increment ranged from 15.8 cm yr^{-1} for seedlings planted immediately post-harvest to 9.0 cm yr^{-1} when planted two years post-harvest, with the three-year planting delay resulting in a 12.8 cm yr^{-1} annual height increment. The rutted sites, where planting occurred immediately, had a mean annual height increment significantly higher than non-rutted treatment plots where seedlings were planted 1 and 2-years post-harvest (p = 0.0171; Figure 5a).

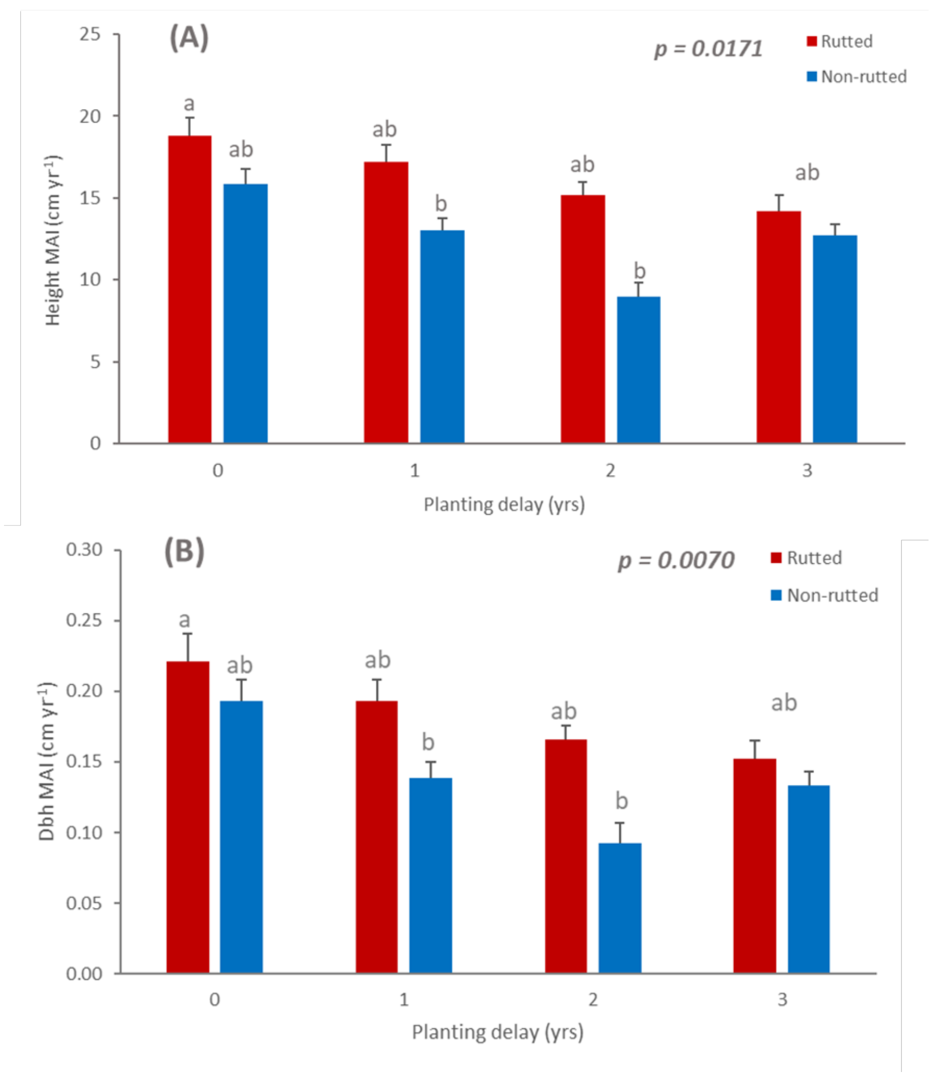


Figure 5. The effects of delayed planting on conifer seedling mean annual height (A) and Dbh (B) increment for rutted and non-rutted plots in a northwestern Ontario study. Lowercase letters above the bars represent significant differences (p<0.05).

Similar trends were found when comparing annual Dbh increment following delayed planting after harvest treatments. Annual Dbh increment on rutted sites planted immediately after harvest was 0.22 cm yr^{-1}, and decreased across the planting delay sequence, with the lowest growth rate recorded in seedlings planted three years after harvesting (0.15 cm yr^{-1}). In the non-rutted plots, we observed a similar trend; average annual Dbh increment of seedlings planted immediately post-harvest was 0.19 cm yr^{-1} and decreased significantly ($p = 0.0286$) to 0.09 cm yr^{-1} with a two-year planting delay (Figure 5b). The planting delay and rutting treatment interaction was significant, where the rutted plots planted immediately post-harvest had a larger mean annual diameter increment than the non-rutted plots where seedlings were planted one- and two-years post-harvest ($p = 0.0070$). The negative effect of delayed planting on seedling height and diameter increment was likely the result of increased competition, as the delay would have allowed other vegetation to establish before the harvested site was re-planted. Overall, the negative effect of increased vegetative competition appeared to override any positive effects that may have occurred from any improved microsite conditions (i.e., fewer planting spots with saturated conditions) on these moderately productive peatland sites.

Site disturbance effects on seedling growth

In these pre-SSG rutting trials (CNFER and KC trials), seedling growth was compared against the amount of soil disturbance, regardless of whether the disturbance met the current SSG definition of a rut. Timing of the original soil disturbance assessments between the trials differed, with the CNFER trial assessed immediately after harvest, and the KC trial plots assessed about 10 years after harvest.

Despite the high variability, seedling annual height increment increased slightly ($r^2 = 0.2065$) with increased soil disturbance (% area disturbed) (Figure 6a). However, for plots more than 50% disturbed, annual height increment decreased, largely corresponding to the height increments measured on non-rutted plots.

When the original soil disturbance data was calibrated to the SSG rutting definition (at least 30 cm deep and 4 m long), little to no relationship was found between annual height increment and per cent area of “SSG-defined” ruts ($r^2 = 0.0332$; Figure 6b). This result suggests that the area (data covers 0 – 53%) with SSG-defined ruts had no lasting (up to 25 years after planting) effect on planted seedling annual height increment.

Similar to height, annual Dbh increment increased ($r^2 = 0.2807$) as soil disturbance increased (% area disturbed), but did not continue to decline beyond a disturbed area of 25% (Figure 7a). For this analysis, only the CNFER study plots had seedling Dbh measurements, resulting in fewer data points in the regression analysis. When the soil disturbance criterion was adjusted to match the SSG rutting definition, the relationship did not change, however, no sites had an area greater than 20% disturbed (Figure 7b).

When combining both studies to compare seedling annual height increment between rutting treatment, planted trees on the rutted sites had higher annual height increment (15.9 and 18.7 cm yr^{-1} for the CNFER and KC plots, respectively, averaging 18.1 cm yr^{-1}; $p<0.001$) than the seedlings established on the non-rutted plots (12.9 and 15.9 cm yr^{-1} for the CNFER and KC plots, respectively, averaging 14.4 cm yr^{-1}; Figure 8a). A smaller difference in annual height increment was found between treatment plots (rutted vs. non-rutted) in the KC study (2.1 cm yr^{-1}) than in the CNFER study (3.0 cm yr^{-1}). However, no significant study and treatment interaction occurred with respect to black spruce seedling annual height increment. Rutting (both sites combined) did not significantly affect Dbh increment of planted seedlings (*p = 0.052*; Fig 8b), with seedling Dbh increment only slightly higher on the rutted sites compared to those growing on the non-rutted sites (0.02 cm yr^{-1}).

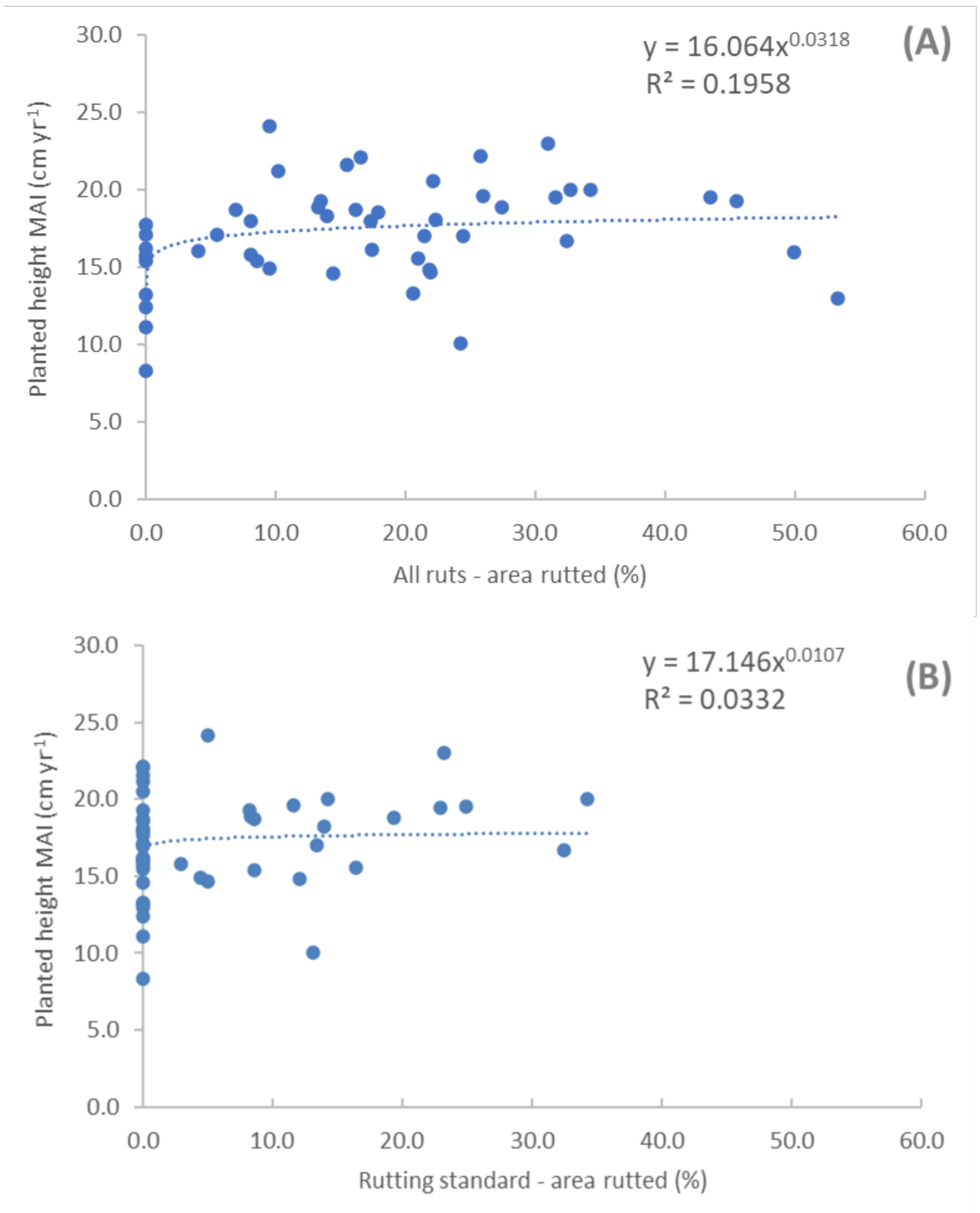


Figure 6. Relationship between mean annual height increment of planted seedlings and the per cent area that was disturbed by either all identified ruts (A) or only those based on the definition of a rut in the provincial stand and site guide (B). These data were collected from two northwestern Ontario studies (CNFER and KC studies).

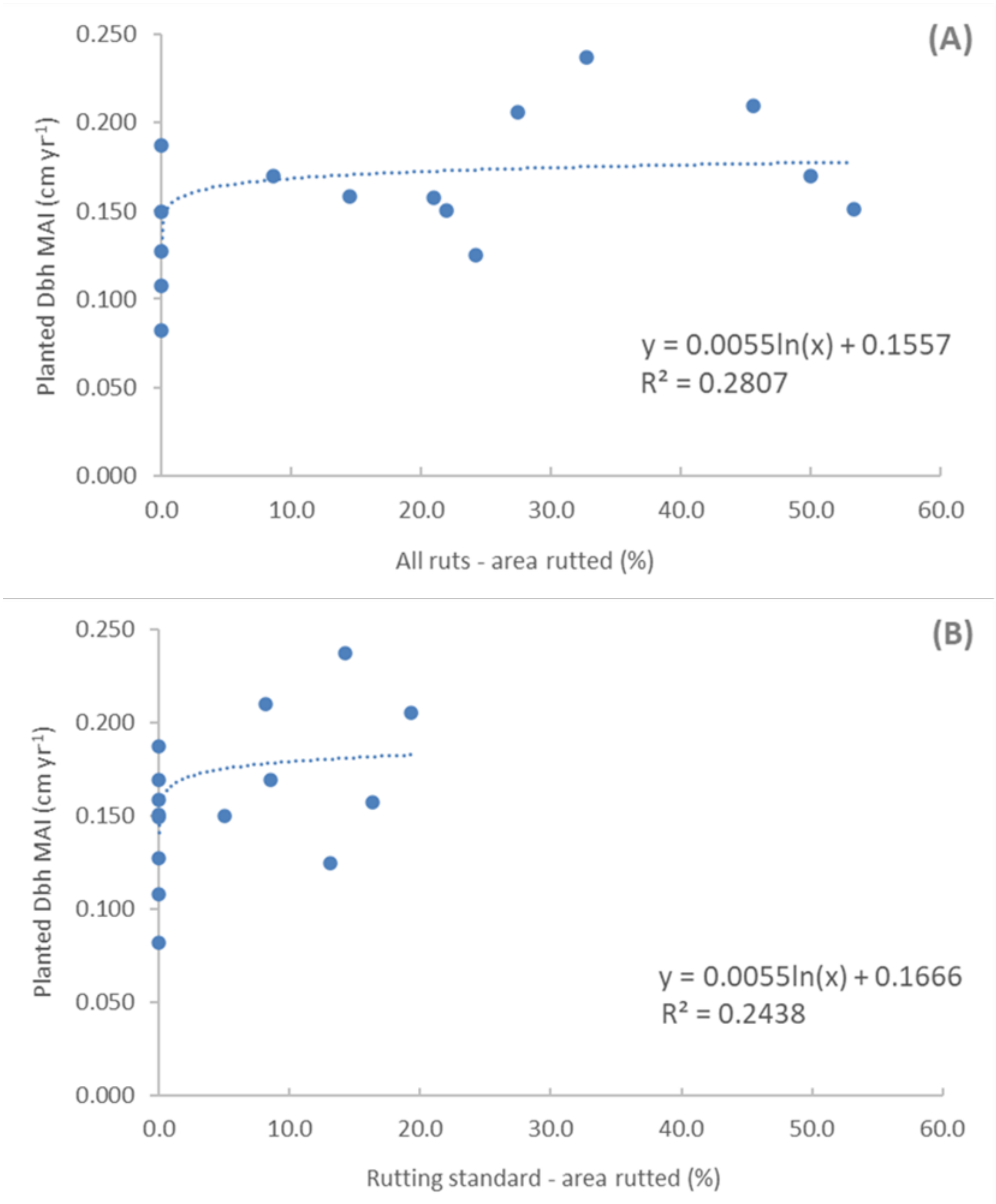


Figure 7. Relationship between mean annual Dbh increment and the per cent of area that was disturbed by either all ruts (A) or only those that met the SSG definition of a rut (B) (CNFER study only).

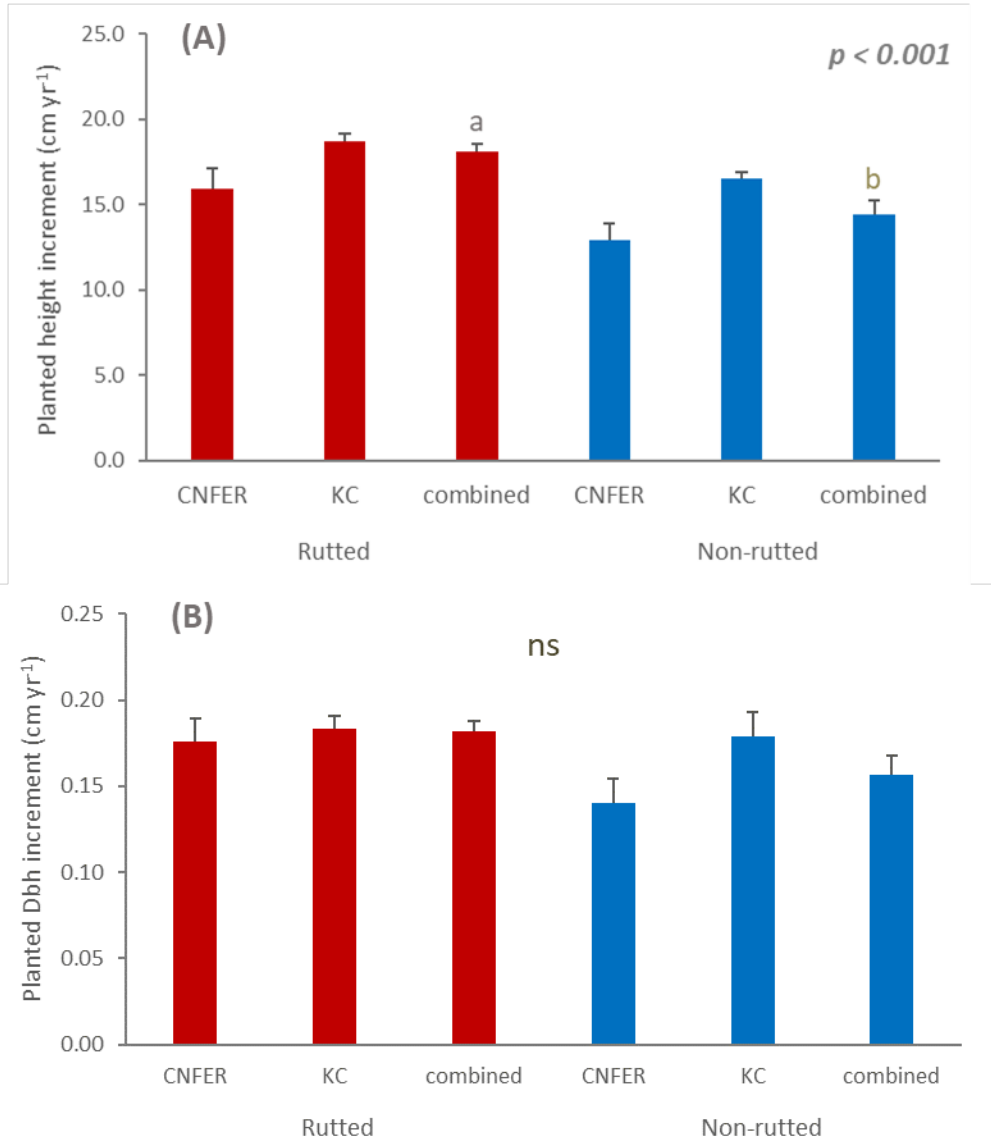


Figure 8. Mean annual height (A) and Dbh (B) increment of planted seedlings on rutted and non-rutted plots in the KC and CNFER studies in northwestern Ontario. Lowercase letters above the bars represent significant differences ($p<0.05$) (ns=non-significant).

Site disturbance effects on basal area and stem density

Overall (both trials combined), rutting did not significantly affect (2.26 m^2 ha^{-1} vs. 2.15 m^2 ha^{-1}; $p = 0.766$) planted seedling basal area, although the KC study non-rutted plots did have the largest planted basal area (3.32 m^2 ha^{-1}) followed by its rutted plots (2.40 m^2 ha^{-1}) (Figure 9a). In contrast, the CNFER rutted plots had a slightly larger basal area than its non-rutted plots (1.72 and 1.31 m^2 ha^{-1}, respectively). When combining data from both trials, no significant difference was observed between rutted and non-rutted total basal area ($p = 0.352$; Figure 9b). However, in the CNFER study when natural ingress was included to provide an estimate of total tree basal area, rutted plot total basal area was significantly higher than non-rutted plots (8.38 m^2 ha^{-1} compared to 3.88 m^2 ha^{-1}; $p = 0.010$).

In both studies, rutting seemed to produce a more receptive seedbed for seeding and provided opportunities for black spruce regeneration through layering. For example, the CNFER rutted plots had almost double the natural ingress, with nearly 6000 stems ha^{-1}, compared to CNFER's non-rutted plots (Figure 9c). This ingress shifted species composition in the KC study from $Sb_8La_1Pj_1$ on non-rutted sites to Sb_7La_3 on rutted sites. In the CNFER study, a similar shift occurred with an increase in eastern larch on the rutted sites, where the species composition shifted from Sb_7La_3 on non-rutted sites to $Sb_5La_4At_1$ on rutted sites.

Rut characteristics and tree density

Planted seedling survival, resulting in higher planted tree densities after at least 20 years, increased on rutted plots as a function of rutting depth up to 35 cm (Figure 10a). Planted tree densities were highest when rutting depth was about 30 cm, with, about 1200 stems ha^{-1} occupying sites with 25–30 cm deep ruts and 1160 stems ha^{-1} on sites with 30–35 cm deep ruts. No consistent trends were evident between planted tree density and rut width, however, total tree density decreased as a function of rutting width ($R^2 = 0.2963$). In this case, total density declined when rutting width was >100 cm (Figure 10b).

Rutting severity

Severe, moderate, and non-rutted blocks were identified in the original CNFER study. Despite the severely rutted block having 64% more area covered in ruts (Table 1), no long-term effect on planted seedling annual height ($p = 0.889$; Figure 11a) or Dbh increment ($p = 0.707$; Figure 11b) was evident in that block. The only significant effect between moderately and severely rutted plots was stand density. In this case, total stem density in moderately rutted blocks was 7750 stems ha^{-1} compared to 2550 stems ha^{-1} in severely rutted areas (Figure 12a; $p = 0.018$). Although not statistically significant, planted tree density and basal area were also higher in moderately rutted areas than severely rutted (1125 stems ha^{-1} versus 962 stems ha^{-1} and 2.09 versus 1.35 m^2 $ha^{-1,}$, respectively; Figure 12b)

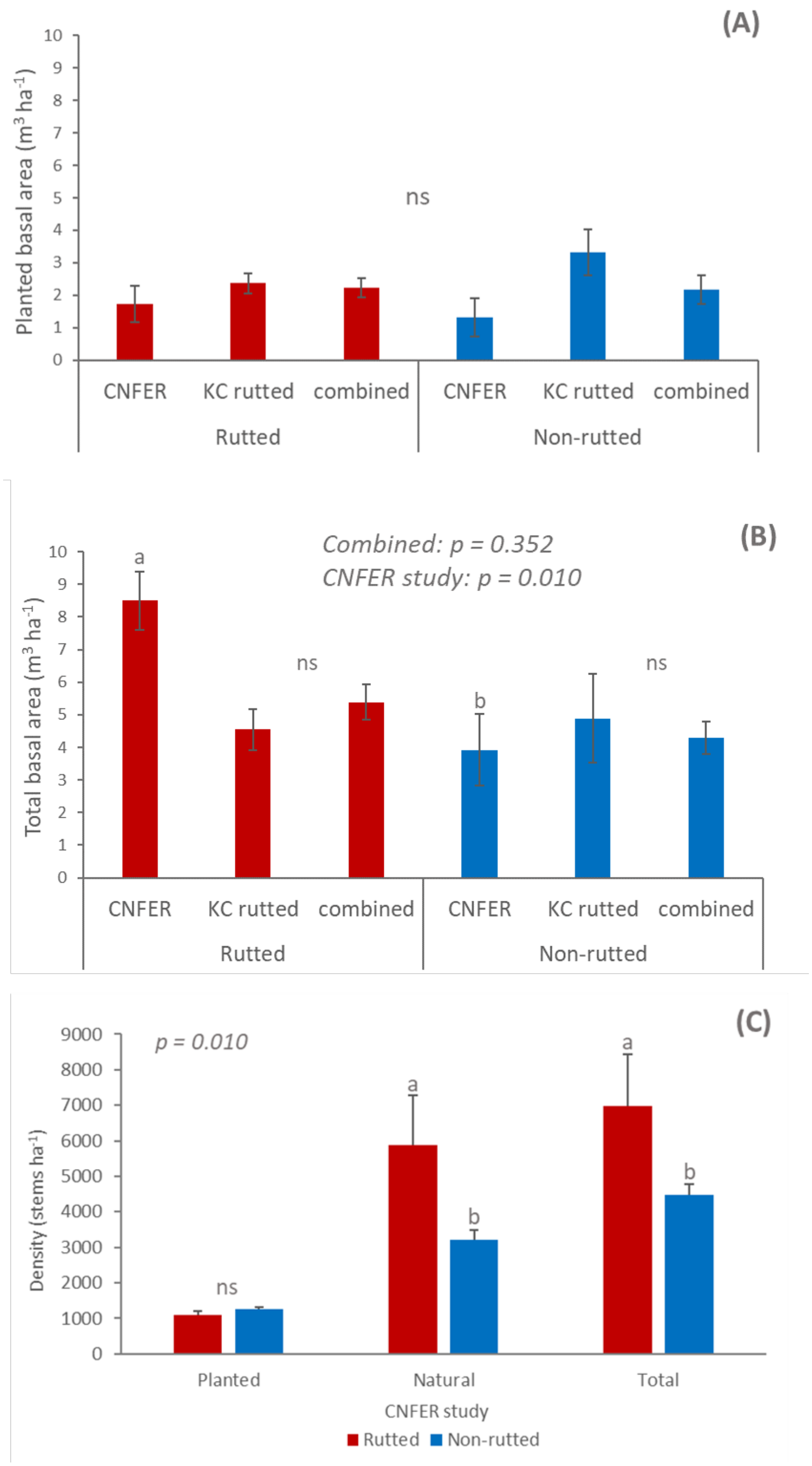


Figure 9. Basal area of planted black spruce (A), total conifer basal area (B), and conifer densities (C) for rutted and non-rutted plots for the KC and CNFER studies in northwestern Ontario.

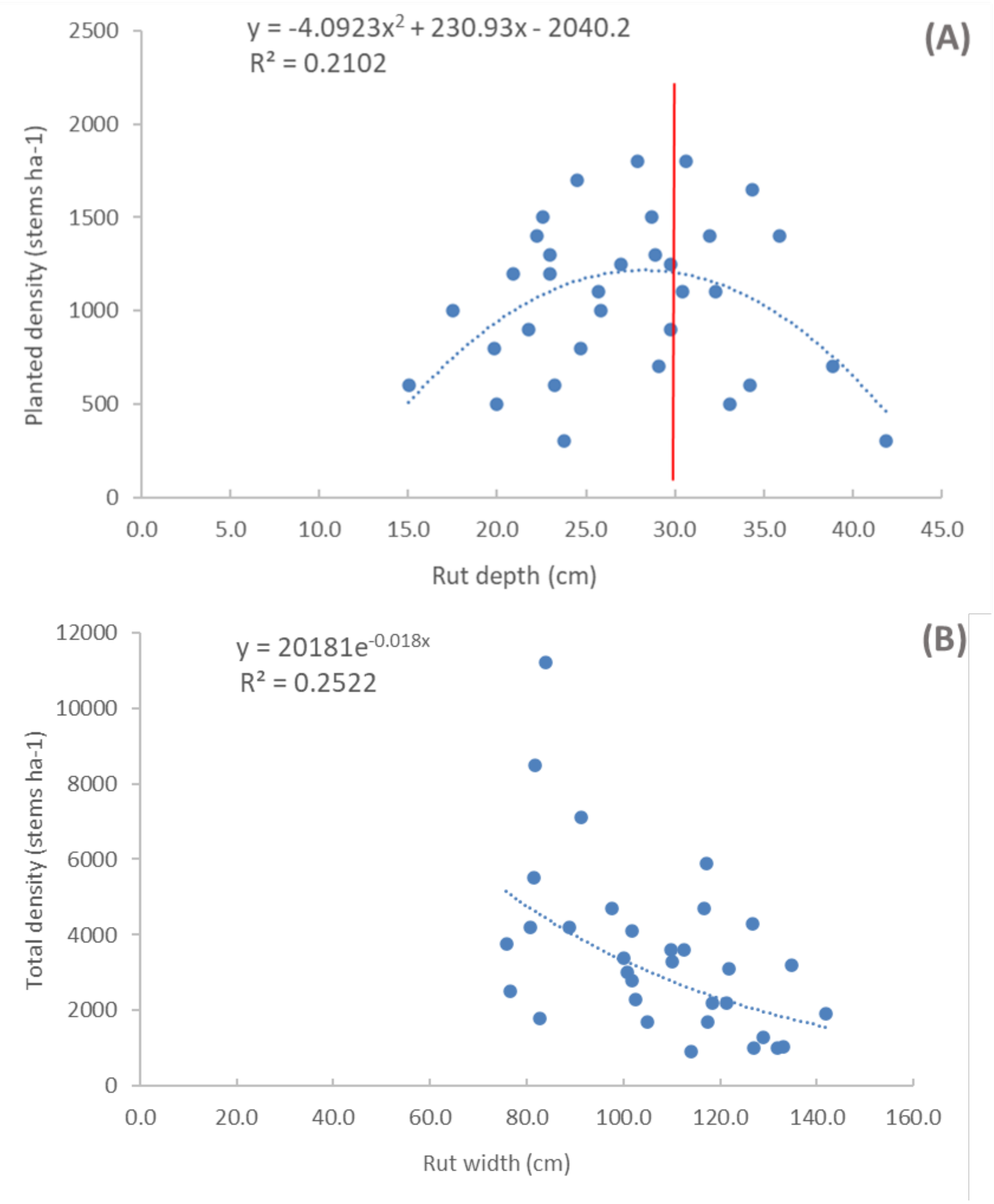


Figure 10. Effects of mean rut depth (A) and width (B) on planted tree density (stems ha^{-1}) on rutted plots in the CNFER and KC studies in northwestern Ontario. Red line marks the provincial stand and site guide rut depth definition of 30 cm.

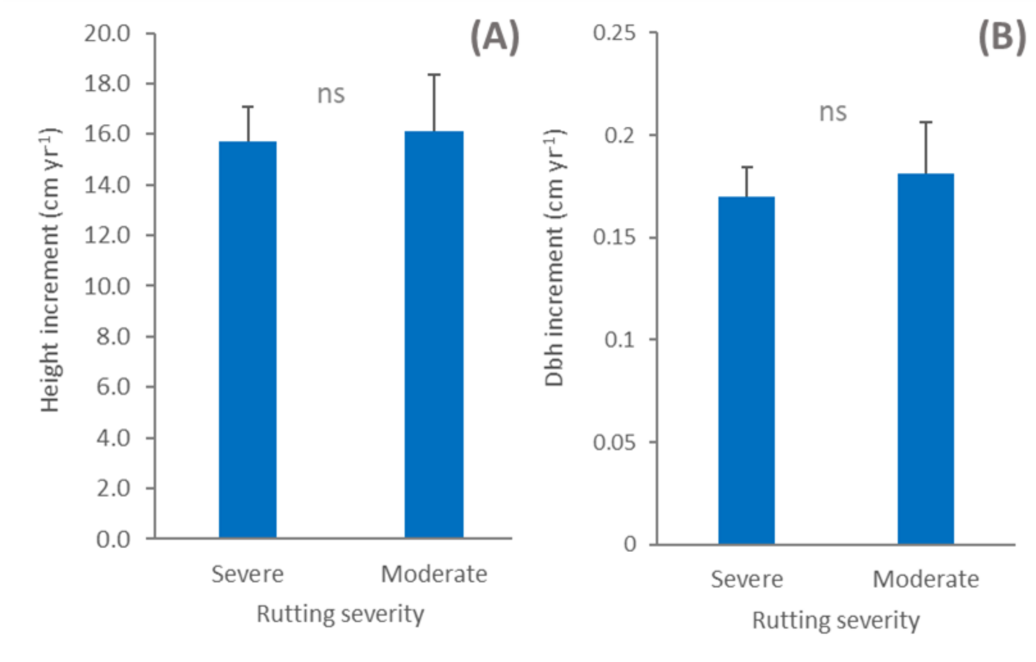


Figure 11. Comparison of annual height (A) and Dbh (B) increments between severely and moderately rutted sites, 23 years after forest harvesting in a northwestern Ontario study. (ns=non-significant).

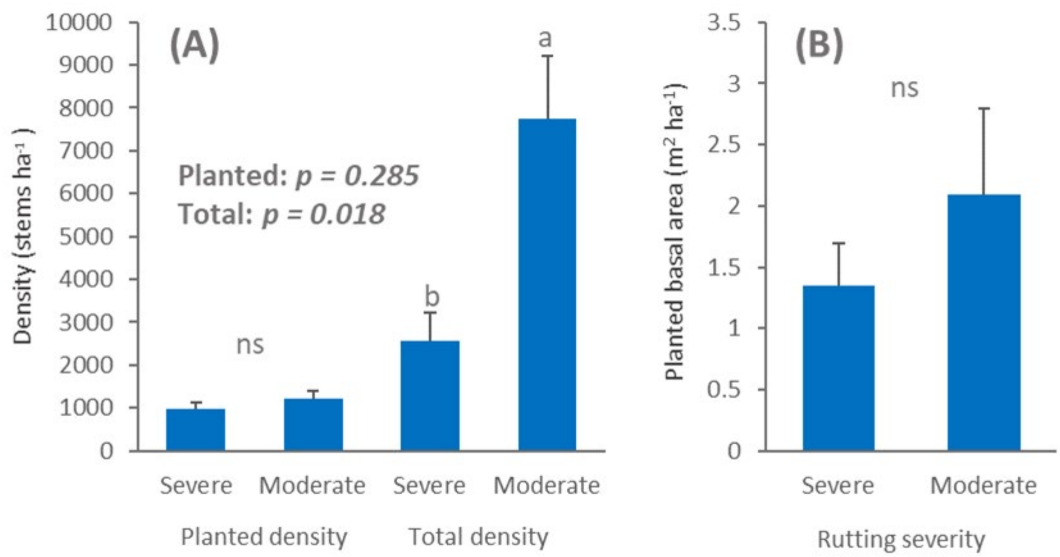


Figure 12. Comparison of planted tree density, total tree density (A), and planted basal area (B) between severely and moderately rutted sites 23 years after harvest in a northwestern Ontario study. Lowercase letters indicate significant differences at p<0.05). (ns=non-significant).

Take home messages

Consistent with findings from the KC (2004) and CNFER (2006) studies, the 2013 and 2018 (respectively) assessments confirmed that rutting, within the assessed severity range, did not reduce planted black spruce seedling survival or growth or survival after as many as 25 years post-harvest. These studies were established before the development of the SSG standards. However, positive effects for planted seedling survival and growth, and conifer seedling recruitment (ingress) occurred when site disturbance was moderate. While remeasuring the CNFER study, field crews observed that filled in ruts at least 20 years post-disturbance now resemble pit and mound microtopography commonly observed in natural black spruce peatlands.

Although the SSG outlines maximum rutting thresholds, the main goal for forest practitioners and operators remains to minimize rutting on areas susceptible to site damage. During the 2014–2015 SSG review (Churcher et al. 2016), concerns were raised that the occurrence of rutting was increasing, and the current standard of no more than 50% coverage in ruts for any 0.1 ha circular plot in a harvest block was questioned. In both studies, assessment plots were smaller than 0.1 ha (0.01–0.05 ha) and per cent area of disturbance that met the rutting standard never exceeded 50%. However, we did observe tree growth declines where rutted area exceeded 40% of the disturbed area, supporting a transition to a 40% rutting threshold in a 0.1 ha circular plot.

References

Archibald, D.J., W.B. Wiltshire, D.M. Morris and B.D Batchelor. 1997. Forest management guidelines for the protection of the physical environment. Ontario Ministry of Natural Resources, Toronto, ON. 39 p. + appendices.

Arnup, R.W. 1999. The extent, effects and management of forestry-related soil disturbance, with reference to implications for the Clay Belt: A literature review. Ontario Ministry of Natural Resources, Northeast Science and Technology Unit, South Porcupine, ON. NEST Technical Report TR-037. 25 p.

Burns, R.M. and B.H. Honkala. 1990. Silvics of North America: 1. Conifers; 2. Hardwoods. USDA Forest Service, Washington, DC. Agricultural Handbook 654. 877 p.

[CCFM] Canadian Council of Forest Ministers. 2003. Defining sustainable forest management in Canada. Criteria and Indicators 2003. Canadian Forest Service, Ottawa, ON. 22 p.

Churcher J., B. Naylor and J. Rice. 2016. Review of the forest management guide for conserving biodiversity at the stand and site scales: Summary of comments heard at the practitioner engagement sessions held during the fall of 2014 and the spring of 2015. Ontario Ministry of Natural Resources and Forestry, Sault Ste. Marie, ON. Unpublished report.

Duckert, D.R., D.M. Morris, D. Deugo, S. Duckett and S. McPherson. 2009. Developing site disturbance standards in Ontario: Linking science to forest policy within an adaptive management framework. Canadian Journal of Soil Science 89: 13–23.

Finér, L., C. Messier and L. De Grandpré. 1997. Fine-root dynamics in mixed boreal conifer broad-leafed forest stands at different successional stages after fire. Canadian Journal of Forest Research 27: 304–314.

Froehlich, H.A. and D.H. McNabb. 1984. Minimizing soil compaction in Pacific Northwest forests. Pp. 159–192 *in* E.L. Stone (ed.). Forest Soils and Treatment Impacts Proceedings of the 6th North America Forest Soil Conference, University of Tennessee, Knoxville, TN. 454 p.

Hatchell, G.E. and C.W. Ralston. 1971. Natural recovery of surface soils disturbed in logging. Tree Planters' Notes 22(2): 5–9.

McPherson, S., L. Quist, N. Woolnough, P. Terris and E. Thompson. 2007. Hearst rutting study. Preliminary draft summary. Unpublished report.

Morris, D.M., R.W. Mackereth, D.R. Duckert and M.K. Hoepting. 2009. The influence of soil rutting severity on regeneration potential and seedling performance for black spruce-dominated peatlands. Canadian Journal of Soil Science 89: 57–66.

[OMNR] Ontario Ministry of Natural Resources. 2010. Forest Management guide for conserving biodiversity at the stand and site scales – background and rationale for direction. Ontario Ministry of Natural Resources, Toronto, ON. 575 p.

[OMNR] Ontario Ministry of Natural Resources. 2012. State of Ontario's Forests. Ontario Ministry of Natural Resources, Sault Ste. Marie, ON. 73 p.

[OMNRF] Ontario Ministry of Natural Resources and Forestry. 2016. State of Ontario's natural resources — Forests 2016. Ontario Ministry of Natural Resources and Forestry, Sault Ste. Marie, ON. 39 p.

Sutherland, B.J. and F.F. Foreman. 1995. Guide to the use of mechanical site preparation equipment in Northwestern Ontario. Ontario Ministry of Natural Resources, Northwest Science and Technology, Thunder Bay, ON. NWST Technical Report TR-87. 186 p.

Wasterlund, I. 1992. Extent and causes of site damage due to forest traffic. Scandinavian Journal of Forest Research 7(1–4): 135–142.

Wiebe, S., L. Challen and W.F. Murphy. 2004. Comparison of black spruce plantations on lowland organic, rutted and non-rutted sites. Forest Renewal Co-Operative Inc., Thunder Bay, ON. Unpublished report.

Wert, S. and B.R. Thomas. 1981. Effects of skid roads on diameter, height, and volume growth in Douglas-fir. Soil Science Society of America Journal 45: 629–632.

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