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The Ecosystem Management Emulating Natural Disturbance (EMEND) Project: A Description of the Experiment and Data Collection

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Cover image: Aerial view of a treated area as part of the EMEND experiment located NW of Peace River in the Lower Boreal Cordilleran Ecoregion (picture by J. Pinzon).

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Abstract

Retention forestry has been increasingly adopted in North America and globally as an alternative to conventional clearcutting, as it maintains forest legacies within the harvested landscape, therefore being recognized as a more sustainable forest management approach. Areas managed using this approach retain structural features (standing trees, coarse woody debris, etc.) and habitat for forest interior species within the landscape that would enhance forest recovery and maintain biodiversity. The long-term and large-scale Ecosystem Management Emulating Natural Disturbance (EMEND) Project in the boreal forest of northwestern Alberta was initiated in 1998 to test the effects of residual forest structure on ecosystem integrity and forest regeneration. EMEND was designed test how this approach can maintain biotic communities, spatial patterns of forest structure and functional ecosystem integrity in comparison with mixed-wood landscapes that have originated through wildfire and other natural disturbance. This publication aims to provide background information about the project, including a general description of the landscape in which the EMEND project was established, a detailed account of the experimental design, a description of the core data collected over time, and the measures taken to ensure proper data management and storage.

Résumé

La foresterie de rétention est de plus en plus adoptée en Amérique du Nord et dans le monde comme alternative à la coupe à blanc conventionnelle car elle maintient l'héritage forestier dans le paysage exploité, ce qui est reconnu comme une approche de gestion forestière plus durable. Les zones gérées selon cette approche conservent des caractéristiques structurelles (arbres sur pied, débris ligneux grossiers, etc.) et des habitats pour les espèces de l'intérieur des forêts dans le paysage qui amélioreraient le rétablissement de la forêt et maintiendraient la biodiversité. Le projet à long terme et à grande échelle de gestion des écosystèmes émulant les perturbations naturelles (EMEND) dans la forêt boréale du nord-ouest de l'Alberta a été lancé en 1998 pour tester les effets de la structure forestière résiduelle sur l'intégrité de l'écosystème et la régénération forestière. EMEND a été conçu pour tester comment cette approche peut maintenir les communautés biotiques, les modèles spatiaux de la structure forestière et l'intégrité fonctionnelle des écosystèmes par rapport aux paysages de forêts mixtes résultant d'incendies de forêt et d'autres perturbations naturelles. Cette publication vise à fournir des informations générales sur le projet, y compris une description générale du paysage dans lequel le projet EMEND a été établi, un compte rendu détaillé de la conception expérimentale, une description des données de base collectées au fil du temps et les mesures prises pour garantir gestion et stockage appropriés des données.

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1. Introduction

The initial idea of the Ecosystem-based Management Emulating Natural Disturbances (EMEND) project was first brought to light in the early fall of 1995 and was inspired through the formation of the Sustainable Forest Management Network (SFMN; created through the NSERC Network of Centres of Excellence Program). The goal of the EMEND project was to focus on creating a model that would investigate sustainable forest management practices through the implementation of the natural disturbance paradigm. This approach was conceived to manage industrial forests in such a way that forest harvest operations would be planned using natural post-disturbance patterns instead of the then-conventional clear-cutting approach (Franklin 1989a, b). With the main objective of maintaining forest legacies within the harvested landscape, areas managed using this approach would retain structural features (standing trees, coarse woody debris, etc.) and habitat for forest interior species within the landscape that would enhance forest recovery and maintain biodiversity.

The EMEND project has evolved since its conception in the mid-1990s into a widely recognized large-scale and long-term experiment. EMEND is an ongoing project that is currently over 24 years old and was originally conceived to continue and provide information about forest recovery following variable retention harvest prescriptions for one stand rotation of the forest (i.e., 80-100 years). As for any long-term project, a detailed description of EMEND's experimental design and data collection protocols is fundamental and necessary, not only for current and future researchers directly involved in the project, but particularly for practitioners, foresters and other researchers that wish to apply the knowledge derived from the growing project results and implications. As research by graduate students has been one of the major components of the EMEND project, a detailed description of the experiment is also particularly useful for them to understand the underlying design and be aware of the legacy data available to complement and frame the results of their studies. As this experiment is planned to span the careers of multiple generations of stakeholders and outlive the corporate memory, this report is a critical historical document of value to future participants and stakeholders.

The document is divided into seven sections that cover in detail the critical project phases from conception to implementation, including a general description of the landscape in which the EMEND project was established, a detailed account of the experimental design, a description of the core data collected over time, and the measures taken to ensure proper data management and storage.

2. Initial Deliberation and Project Development (1995-1997)

After numerous meetings that started in the fall of 1995 involving many potential stakeholders, an agreement was reached to focus the project on mature and over-mature boreal mixed-wood stands growing on mesic sites. At this time, western boreal mixedwood stands were in the early stages of development and it was generally agreed that the opportunity to implement a new paradigm was most timely in those landscapes. To meet the management needs of the two principal industrial partners, Daishowa-Marubeni International Ltd. [this operation is now owned by Mercer International Inc (Mercer)] and Canadian Forest Products Ltd (Canfor), it was also agreed that the project should incorporate the range of canopy compositions represented in boreal mixedwood forests in northwestern Alberta. Stand selection was based upon provincial assessments following a simplified and generic post-fire forest successional pathway (Rowe 1972), from hardwood to softwood dominant tree species (forest cover-types described in section 5.1). Other key criteria for stand selection were relative homogeneity in dominant tree composition and tree size/age throughout the stands and adequate size to allow each stand to be easily divided into multiple ‘blocks’ to allow multiple treatments to be applied to the same stand to isolate treatment effects from other sources of variation (e.g., spatial). Stands were selected for ground-truthing based on data from the Alberta Vegetation Inventory (Alberta Environmental Protection 1991) and initial flyovers, coupled with spatial considerations and ease of access to the stands.

In the spring of 1997, it was finally agreed that the P2 forest management area (~3,000 ha) of northern Alberta (Townships 89 & 90, Range 03 W6M), now part of P19 (~958,000 ha), met the aforementioned forest requirements and was selected as the general site for the EMEND project (Figure 1). Project size was limited, however, due to the total allowable cut of coniferous timber that the Canfor mill at Hines Creek could use in one year. Due to this limitation, volume estimates from cruise survey data were used to determine the number of replicates for each experimental treatment (treatments described in section 5.2). It was determined that three replicates for each cover type at approximately 10 ha in size (hereafter referred to as compartments) would be ideal to meet the quota at the mill. Individual stand selection was the next step and primary goal of the EMEND management team, with approximately 1,000 ha of total land base needed to be selected within an 8,000-ha landscape.

3. Stand Selection and Pre-Harvest Assessment (1997-1998)

In the late spring of 1997, crews established 450 strip plots (50 x 2 m) across the selected landscape, with plots allocated to each stand in proportion to stand area. Mensuration data collected in each strip plot included: tree species, diameter at breast height (DBH), height to live crown (HLC), and spacing of trees with > 9 cm DBH. The first dominant or co-dominant tree encountered in each plot was cored to ascertain the age for each stand. Mensuration data were used to help researchers select stands to be included in the EMEND experiment. The criteria for stand selection were based on target tree density and stand volume of the deciduous and conifer components of each cover-type. In all, 100 ca. 10-ha compartments, 25 of each of four cover types (sections 5.1 and 5.2), were needed and these were delimited on maps. In the spring of 1998, field crews established and marked the boundaries for the 100 compartments and the permanent sampling plots in each compartment (more details in section 6).

4. The EMEND Landscape

The EMEND landscape is located approximately 90 km northwest of the town of Peace River, Alberta, Canada (56°46′13″ N, 118°22′28″ W; Figure 1) in the Boreal Forest Natural Region of Alberta, specifically within the Lower Boreal Highlands sub-region at the interface of the Lower Foothills and Boreal Ecoregions (Strong & Leggat 1992, Natural Regions Committee 2006). This area is typical of the boreal mixedwood forest plain, having imperfectly drained Luvisolic soils and well drained Orthic Luvic Gleysols (Beckingham & Archibald 1996, for more detailed information see Kishchuk 2004, and Kishchuk et al. 2014) and ranging from 686.8 to 867.7 m.a.s.l. in elevation. Climate in this region is characterized by cold winters and warm summers (January: -14.9±5.5 °C, July: 16.3±1.1 °C) with total annual precipitation of 386.3 mm (rainfall 280.7 mm; snowfall 118.5 cm), a prevailing south-west wind of 12 km/h and an average of 112 days of frost-free period (Environment Canada 2014).

The general landscape in which EMEND is located did not experience any forestry activities prior to the establishment of the experiment. All forest stands in the area originated from a mixed severity wildfire regime, with most trees recruited from wildfires in 1837, 1877 and 1895 (Bergeron 2012, Bergeron et al. 2017). The landscape is, as a consequence, composed of a mosaic of different seral stages that follow a post-disturbance pattern of mixedwood succession (Chen & Popadiouk 2002, Bergeron et al. 2014), with broadleaf tree species, mainly trembling aspen (*Populus tremuloides* Michaux) and balsam poplar (*Populus balsamifera* L.), in early stages of stand development, and conifer species, mainly white spruce (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (Miller)), in later successional stages. Other tree species with a minor contribution on the landscape are tamarack (*Larix laricina* (Du Roi) K. Kock), balsam fir (*Abies balsamea* (L.) Mill.), paper birch (*Betula papyrifera Marsh*) and lodgepole pine (*Pinus contorta* Loudon).

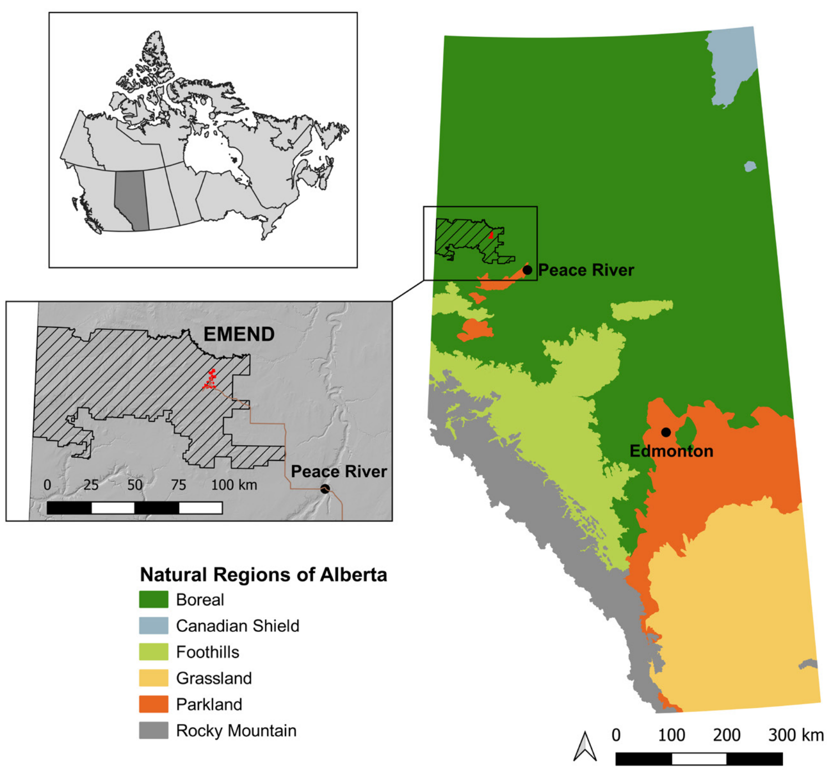

Figure 1. Map of the natural regions in the Province of Alberta showing the location of the EMEND project land base (in red) within the P19 south forest management area (hatched).

5. The EMEND Experiment

The EMEND experimental design has evolved through different phases that involved discussions among members of the project development committee that included researchers from the Canadian Forest Service (Northern Forestry Centre), the University of Alberta, the Forest Engineering Research Institute of Canada and the Alberta Research Council, and professional foresters from the forest industry and the Provincial Government (Spence et al. 1999). These discussions led to different experimental design plans (Volney et al. 1999). Following a field tour in early 1997, logging contractors reported that the preliminary experimental design was too difficult to implement operationally. Thus, these reports lead to some significant alterations in design, and in the winter of 1997-98, two compartments were harvested to prescription to make inferences based on the new design. Inspections of these two harvested compartments and further discussions among researchers, provincial and industrial stakeholders led to the final and present experimental design described below (section 5.2).

The EMEND experiment is a Split-Plot factorial design that includes three main driving factors: time since harvest nested in one of three treatment types: (1) variable retention harvesting, (2) standing timber burns, and (3) prescribed burning after harvest (not in the original plan and implemented later), nested in forest type (i.e., canopy composition). An additional factor (silvicultural ground preparation treatments) nested in a subset of forest types and harvest prescriptions is also included (more details in section 7.4).

5.1. Canopy Composition

The EMEND landscape is covered by a forest mosaic of different seral stages following the most common post-disturbance pattern of succession of the boreal mixedwood forest (Chen & Popadiouk 2002, Bergeron et al. 2014) interspersed with bogs and other wetlands (Figures 2 and 3). The merchantable forest typically includes early successional broad-leaf species and late successional conifer species.

Based on canopy composition, four different stand-types representing different phases of the idealized, classical upland mixedwood succession (Rowe 1972, Bergeron et al. 2014) are incorporated into the EMEND experiment (Spence et al. 1999, Work et al. 2004):

1. ***Deciduous dominated stands*** (DD; Figure 2a) represent an early successional stage with more than 70% of the canopy composed of deciduous tree species, especially trembling aspen (*P. tremuloides*) and balsam poplar (*P. balsamifera*).
2. ***Deciduous stands with conifer understory*** (DU; Figure 2b) represent an early mid-successional stage with more than 70% of the canopy composed of deciduous species and with an understory of white spruce trees (*P. glauca*) reaching at that time no more than 50% of canopy height (≥ 40% stocking of advanced growth and ≥ 30% of the overstory height).
3. ***Mixed stands*** (MX; Figure 2c) represent a late mid-successional stage composed of similar proportions of conifer and deciduous species in the canopy.
4. ***Conifer dominated stands*** (CD; Figure 2d) represent a late successional stage with more than 70% of the canopy composed of conifer tree species, mainly white spruce, and black spruce (*P. mariana*).

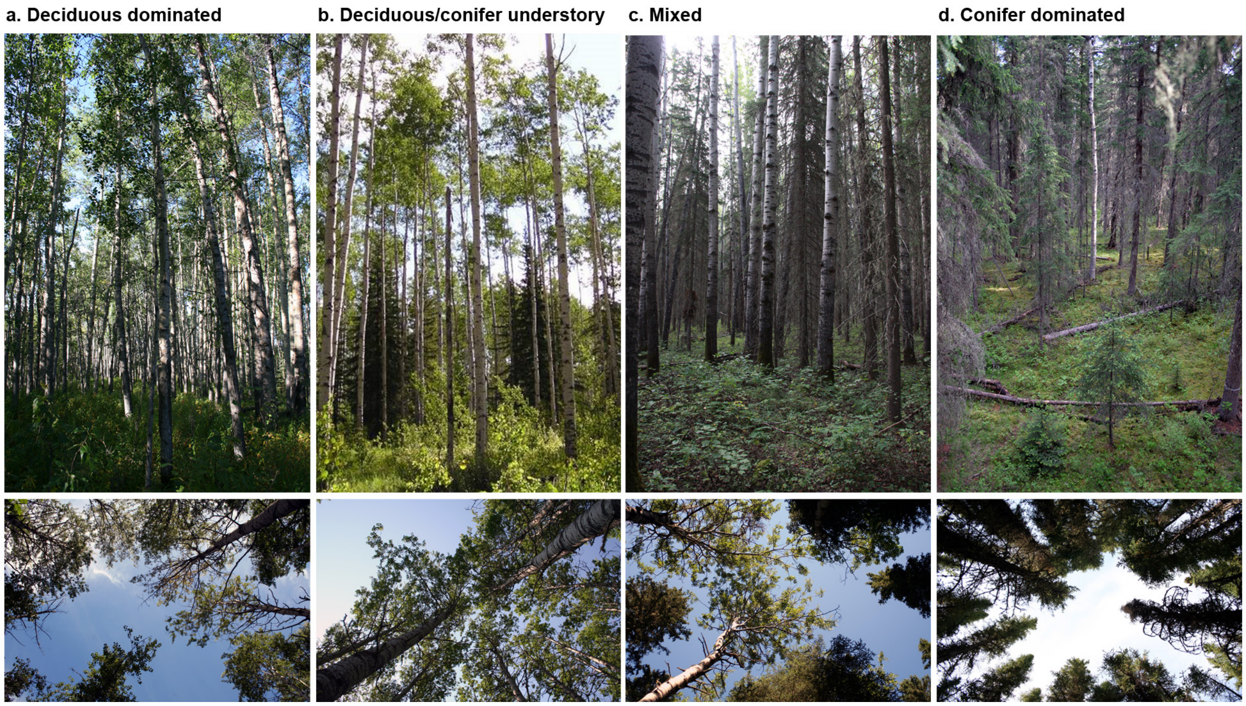

Figure 2. Four main forest cover-types represented in the EMEND experiment, with pictures at the bottom showing the overstory in each type (All pictures by J. Pinzon, except for upper picture in b. by K. Solarik).

5.2. Treatments

The EMEND Experiment was established by applying harvest, silvicultural and prescribed burn treatments in 100 compartments of approximately 10 ha each, in each of the four forest cover-types described above (Figures 2 and 3). Most compartments were harvested during the winter of 1998-1999 (Spence et al. 1999) with subsequent treatments (standing timber burns and slash harvest/burns on 10% residual compartments) applied in later years.

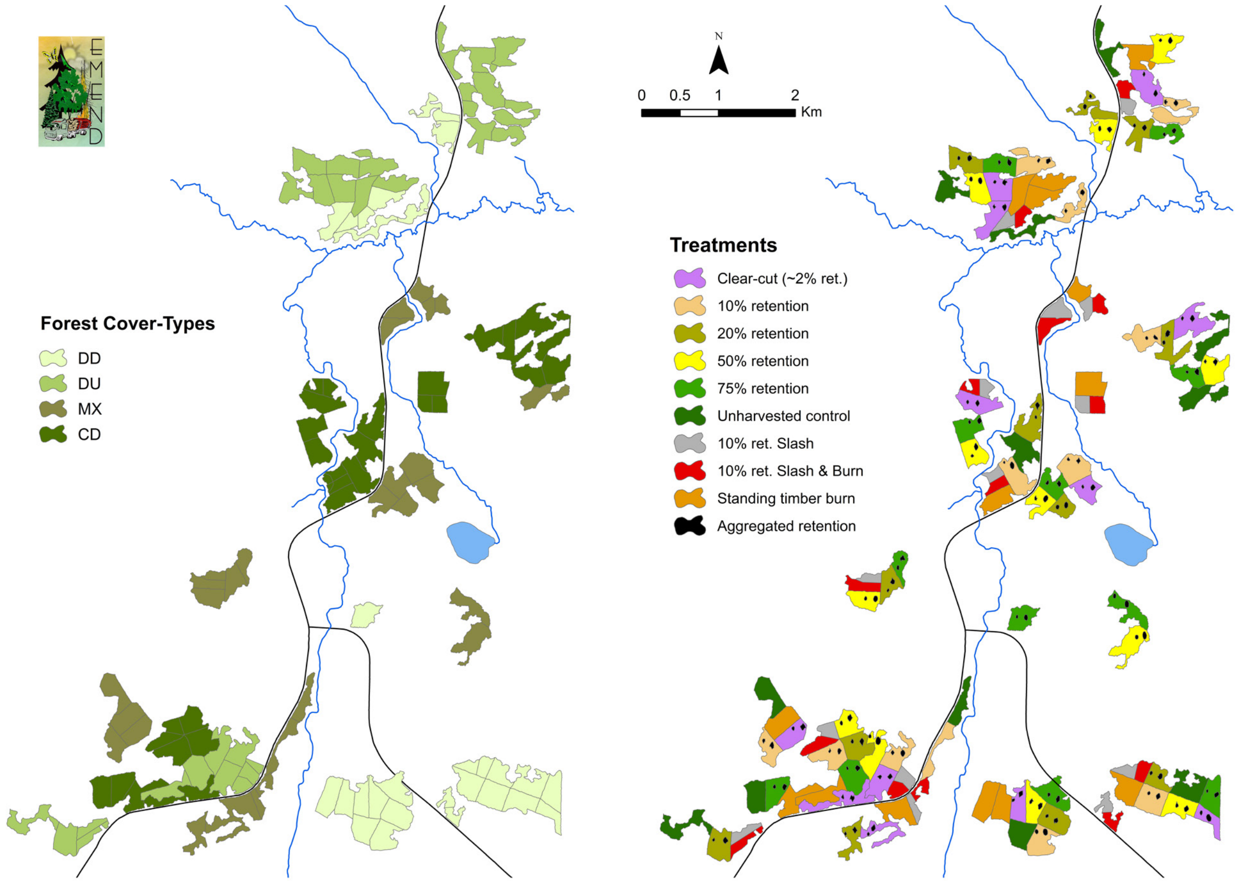

Figure 3. EMEND map showing the various forest cover-types (left) and treatments (right). Each colored polygon represents an approximately 10 ha compartment (except for 10% retention Slash and Slash-Burn, which are paired and together represent the 10 ha compartment).

– <u>Harvest treatments</u>

A range of five harvest intensity treatments in a dispersed retention fashion (Table 1, Figures 4 and 5) was applied to simulate post-fire patterns as a result of different fire intensities. Within each of the harvested compartments, two ellipsoid retention patches (ca. 0.2 and 0.46 ha, 40 m wide by 60 m long and 60 m wide by 90 m long, respectively) were left about 80 m apart at harvest to simulate fire skips (Figure 6). Retention harvest treatments were applied in approximate relation to original (pre-harvest) tree density of each stand. In addition, one compartment in each block was left uncut to serve as a temporal control to assess recovery trajectories of harvested stands to pre-harvest conditions. This design was replicated three times for a total of 72 compartments (6 retention treatments x 4 cover-types x 3 replicates).

Harvesting operations were carried out in a modified two-pass uniform shelterwood pattern using conventional harvesting machinery (i.e., feller-buncher and wheeled skidder). The first pass consisted of 5 m wide machine corridors (Figure 4a) spaced 20 m apart where all trees were felled and removed, leaving a 15 m wide retention strip in between. Machine corridors and retention strips were oriented in a north-south direction, perpendicular to prevailing winds, to help reduce the threat of windthrow. A second pass was applied in which retention strips were thinned by removing a pre-determined tree ratio (cut:uncut) depending on the desired prescription. The targeted retention prescriptions were based on the tree ratio and applied from the machine corridors to avoid soil disturbance to the retention strips. Targeted retention was estimated excluding the two ellipsoid retention patches.

Treatments were applied as follows (Sidders & Luchkow 1988):

1. **75% retention** (R75). This retention level was achieved by applying the first harvest

pass only, with trees cut only from machine corridors and retention strips remaining intact.

2. **50% retention** (R50). Same harvesting pattern as above, but a second pass was applied in which retention strips were thinned by removing one out of every three trees.
3. **20% retention** (R20). Same as above, but three out of every four trees were removed from retention strips in the second pass.
4. **10% retention** (R10). Same as above, but seven out of every eight trees were removed from retention strips in the second pass.
5. **~2% retention or clear-cut** (R0). Compartments were harvested in the normal pattern of operational logging, without any systematic pattern of machine corridors and retention strips.

Harvested trees were skidded along machine corridors (Figure 4b) to landing areas located on one edge of each compartment and then transported to the mill by truck. All harvesting machinery was restricted to move only within the machine corridors to help minimize soil disturbance throughout the block.

a. b.

Figure 4. Harvest operations created the different retention treatments. a. Feller-buncher creating 5 m wide machine corridors, b. Skidder hooking up trees for removal (Pictures courtesy of Eric Phillips).

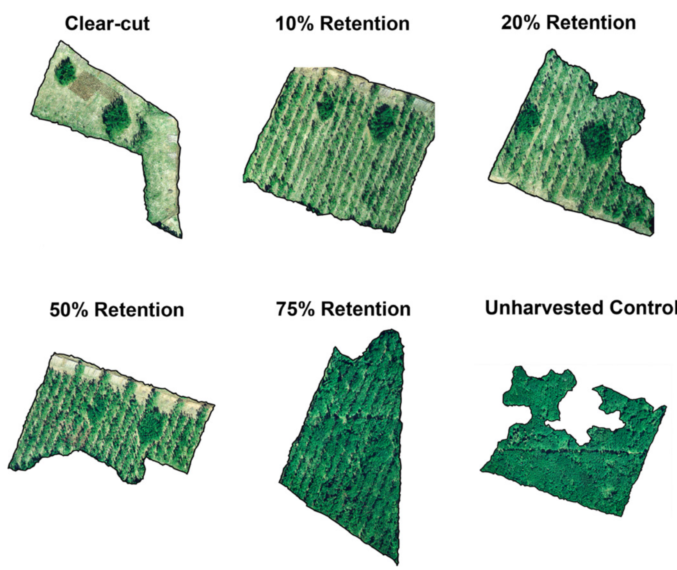

Figure 5. Range of harvest prescriptions applied as part of the EMEND experiment. The images shown were taken in the summer of 1999 and correspond to six compartments in a deciduous dominated stand. Each image, except for the unharvested control, shows the two ellipsoid retention patches left following harvest prescriptions (Pictures obtained from the EMEND database).

Figure 6. Retention patches left after harvest in a deciduous dominated clear-cut-cut (picture taken in 2006). Patch on the left is about 0.2 ha and patch on the right is about 0.46 ha (Picture by J. Pinzon)

Table 1. Variable retention harvest prescriptions applied on the EMEND land base (DD: Deciduous dominated; DU: Deciduous dominated with spruce understory; MX: Mixed; CD: Conifer dominated).

Forest cover-type	Treatment	Year of application	Mean compartment area (ha)	No. of compartments	Mean extracted volume (m^3)
Unharvested Controls					
DD	-	-	9.8	3	-
DU	-	-	8.9	3	-
MX	-	-	9.2	3	-
CD	-	-	10.3	3	-
Harvest Treatments					
DD	Clear-cut	1998	8.3	3	2334.3
	10% retention	1998	10.2	3	1859.4
	20% retention	1998	9.1	3	1961.2
	50% retention	1998	9.5	3	1637.2
	75% retention	1998	10	3	762.6
DU	Clear-cut	1998	11.3	3	3112.5
	10% retention	1998	11	3	2412.1
	20% retention	1998	10.3	3	2245.8
	50% retention	1998	10.7	3	1551.3
	75% retention	1998	9.6	3	884.5
MX	Clear-cut	1998	8.3	3	2374.1
	10% retention	1998	9.1	3	2460.2
	20% retention	1998	7.4	3	1821.7

Forest cover-type	Treatment	Year of application	Mean compartment area (ha)	No. of compartments	Mean extracted volume (m^3)
	50% retention	1998	9.7	3	1784.6
	75% retention	1998	7.9	3	1188.9
CD	Clear-cut	1998	12.3	3	4185.1
	10% retention	1998	10.9	3	3127.7
	20% retention	1998	11.5	3	2885.1
	50% retention	1998	9.4	3	1523.0
	75% retention	1998	8.8	3	1149.0

– Prescribed burns

One of the primary objectives of EMEND is to compare the response of ecosystem processes and biodiversity in variable retention harvested stands to stands that have originated through natural disturbances such as wildfire. Thus, from the start, the experiment was designed to include fire treatments in all four cover types. Fire prescriptions were designed to include three burning intensities: (1) high, which aimed at killing all trees within the compartment, (2) medium, in which a 40-60% of the trees would be killed and (3) low, in which only a few trees would be killed. These prescribed burn treatments were meant to be applied on the remaining 28 compartments that were not used for the retention harvest prescriptions.

The first two treated compartments, burned in 1999 and 2000 (Table 2, Figure 7), showed it was difficult to burn whole compartments with the variation in intensity originally planned. It was concerning that if the fires burned too hot, they could accidentally get out of control and burn surrounding forest and/or other experimental compartments, or if the fires were too weak in intensity it could prevent the entire compartment from being burned. As a result, the burn design needed modification to address these issues. Therefore, prescribed fire was implemented on the EMEND landscape using two methods (Table 2):

Figure 7. Conifer dominated compartment representing the first full standing timber burn at EMEND in August 1999. Images at the bottom are aerial views of the same compartment taken in 1999, 2004 and 2010, respectively (Pictures from the EMEND database).

1. **Full compartment standing timber burns** (Figure 7). Half of the unharvested compartments originally set aside for the burn intensity treatments were selected to be burned (assuring that at least three replicates were used in each cover-type). Compartments were ignited using helicopters equipped with aerial torches (Figure 8), with no desired intensity expected. Preliminary transect surveys were established to assess dead and downed woody debris, and burn pins were placed throughout compartments to measure burn depth and thus fire intensity. In each of the prescribed burn compartments an upper and lower limit Fire Weather Index (FWI) (conducted in 1998, 1999 and 2001) was assigned to estimate fuel consumption, fire intensity and flame length. The FWI was used to distinguish the appropriate time to burn and help crews better predict fire behavior and effects. Five weather stations were set up at various locations across the EMEND landscape, allowing for local weather conditions to be measured between 1998 and 2009 (none was active continuously throughout this period; more details on section 7.2). Data were used to assess more accurately the local burning conditions. A total of 14 compartments (four DD and DU, three MX and CD) were selected for burning; however, given the stringent conditions required to apply the full standing timber burns, the implementation of this treatment across the experiment is currently incomplete and has been conducted across different years from 2000 to 2010. To date, seven compartments have been burned (three DD, one DU, one MX, and two CD). The first compartment was burned in 1999 with subsequent burns in 2000, 2004, 2006 and 2010 (Table 2). These burns have experienced poor to moderate success of burn coverage. The EMEND landscape overall is a relatively wet site, which makes burning an area of 10 ha quite difficult to execute without implementing a high intensity fire and risking damage to neighbouring compartments. Other challenges have also prevented the application of this treatment on the remaining compartments. For example, in 2009, only 10 of 134 days in the burn 'window' met the required relative humidity conditions (<40%) to burn, and when the burn window was open, key personnel were unavailable.

2. **Burns after harvest treatment** (SB). During the fall of 2002, the remaining 14 unharvested compartments (three DD and DU, four MX and CD) that were originally scheduled for standing timber burns were harvested to 10% retention, as described above, with the exception that all logging slash was left on the ground and distributed over the compartment. The following year (2003), compartments were divided into two roughly equal portions, and one portion of each was burned (slash burn or SB) (Figure 9), except for DD stands which were burned in 2005 (additional time was required to achieve the drying needed to ensure spread of ground fires and thus a favorable FWI). Burns were applied using aerial torches and hand-held dip torches (Figure 10). The other portion of each compartment was left unburned (slash harvest or SH; Table 2). Although this fire prescription showed better results than the standing timber burns, with greater area burned, overall, burning was mostly successful within the retention strips while quite poor within machine corridors.

All burn prescriptions were developed by the Canadian Forest Service (CFS) Fire Research Group (http://www.nrcan.gc.ca/forests) and the prescribed fires were conducted by Alberta Environment and Sustainable Resource Development (ESRD) Forest Protection Branch.

Table 2. Prescribed burning treatments applied on the EMEND land base (DD: Deciduous dominated; DU: Deciduous dominated with spruce understory; MX: Mixed; CD: Conifer dominated).

Forest cover-type	Compartment ID	Burn date	Total area (ha)	Burned area (%)	Observations
Standing timber burning					
DD	8570	May 2010	10.8	<10%	Low intensity and poor burning; pending
	8650	May 2010	8.9	50-60%	Low intensity burning
	8660	May 2010	11.1	50-60%	Low intensity burning
	9430	May 2010	9.0	70%	
DU	8830	May 2010	9.3	85%	
	9440	Apr. 2000/ May 2010	8.8	<10%	Burn attempted twice, poor results; pending
	9450	May 2010	9.4	<20%	Poor burning, only edges burned; pending
	9600	-	9.9	-	Too wet for burning; pending
MX	8720	-	10.4	-	Too wet for burning; pending
	9010	May 2006/ Oct. 2010	10.4	<20%	Burn attempted twice, poor results; pending
	9370	Jul. 2004	5.9	50%	
CD	8910	May 2006	9.8	40-50%	Very wet unburned area
	9150	-	8.9	-	Too wet for burning; pending
	9260	Aug. 1999	11.5	70%	Patchy burns in some areas
10% retention slash harvest (SH) and burns after harvest treatment (Slash-Burn; SB)*					
DD	8561, 8562	May 2005	4.2, 3.7	70%	Poor burns in corridors
	8581, 8582	May 2005	3.6, 3.4	70%	Poor burns in corridors
	9421, 9422	May 2005	3.8, 4.0	70%	Poor burns in corridors
DU	8781, 8782	Oct. 2003	4.2, 4.4	60%	N/W sides and in corridors
	8851, 8852	Oct. 2003	4.3, 4.2	70-75%	Poor burns on west side
	9581, 9582	Jun. 2003	4.0,3.5	40-50%	Poor burns in corridors
MX	8701,8702	May 2003	3.1,3.1	70%	Poor burns in corridors
	9041,9042	Jun. 2003	5.9,3.1	75-85%	Poor burns in corridors
	9361,9362	May 2003	3.9,3.5	75-80%	Poor burns in corridors
	9381,9362	May 2003	6.2,6.4	80-90%	Poor burns in corridors
CD	8971,8972	Apr. 2003	5.8,4.2	60-70%	Poor burns in corridors
	9161,9162	Oct. 2003	3.7,3.0	85-90%	
	9231,9232	Apr. 2003	3.2,3.3	90-95%	Poor burns in corridors
	9251,9252	Jun. 2003	4.4,4.0	60-70%	Poor burns in corridors

* Compartments were harvested to 10% retention treatment with all slash remaining on ground and distributed throughout compartments. About half of each compartment was subsequently burned (slash-burn treatment; SB) and the remainder left unburned (slash-harvest treatment; SH), resulting in a reduced treated area for both prescriptions (areas provided for SB and SH, respectively). Original compartment IDs were assigned a 1 (for SB) or a 2 (for SH). Values of area burned correspond to the percentage of only SB.

Figure 8. Standing timber prescribed burning. Helicopter approaching and igniting forest using an aerial torch (Pictures from the EMEND database).

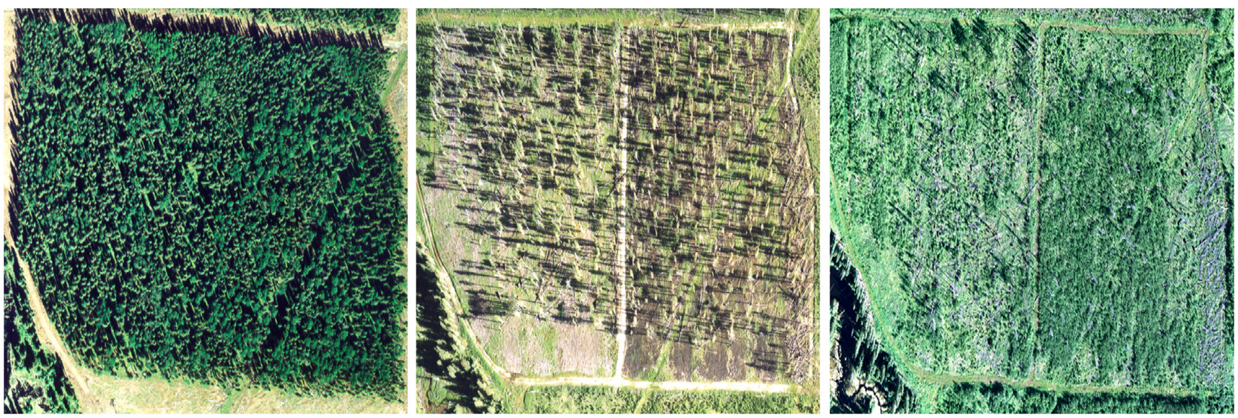

Figure 9. A conifer dominated compartment before and after the application of slash-harvest (SH) and slash-burn (SB) treatments. The left image shows an aerial view taken in 1999 prior to treatment application. The compartment was harvested to 10% retention in 2002, divided into two roughly equal sections, and one section (right-hand side) was burned in 2003. The center and right images show two aerial views of the same compartment taken in 2004 and 2010. (Pictures from the EMEND database).

Figure 10. Burning after 10% harvest retention. Prescriptions were applied using hand-held dip torches to ignite underbrush (Pictures from the EMEND database).

6. EMEND Core Data

The EMEND experiment has been designed not only to assess the impact of different management prescriptions (variable retention harvesting and fire) on both forest structure and biodiversity, but also to evaluate how stands managed in such way recover from disturbance. To provide measurements to meet the experiment objectives, a long-term surveying method was developed prior to treatment applications. The method ensures that data are collected consistently across the experiment over time via the establishment of permanent sampling plots (PSP). Thus, six PSPs were established in each of the 100 compartments (avoiding ellipsoid retention patches), for a total of 600 plots, to record several variables (Table 3, Figure 12). Each PSP consists of a 40 m line randomly placed perpendicular to machine corridors (avoiding plot overlap), in most cases in an east-west orientation with one end located near the center of a retention strip (Figure 11). Depending on the target data to be collected, sub-plots nested within the PSP or extended plots containing each PSP were installed. Various data were collected from the PSPs (including sub-plots and extended plots) before harvest prescription application in 1998, and subsequently after harvest at approximately five-year intervals, except for the last assessment (15 years post-harvest), which was expected to be accomplished in 2014 but took three years for completion (Table 3). This sampling schedule was applied to all uncut controls and variable retention harvest treatments. However, additional sampling was implemented in other years, particularly in compartments with slash harvest/slash burn treatments and compartments with successful standing timber burns (Table 3).

Table 3. Sampling schedule and description in each EMEND permanent sampling plot (PSP), sub-plot (contained within the PSP), and expanded plot (containing the PSP). DD: Deciduous dominated canopy; DU: Deciduous dominated canopy with spruce understory; MX: Mixed canopy of deciduous and conifer; CD: Conifer dominated canopy; SH: Slash harvest (10% retention with slash distributed through the compartment); SB: Slash burn (10% retention with slash distributed through the compartment and subsequently burned).

Collection year	No. compartments	No. of PSPs	Description
Tree plots [Source: Langor et al. (2006)]			
1998	100	600	All plots assessed
1999	73	438	All plots in controls and harvest treatments; 6 in one burned compartment
2002	17	51	Plots in SH/SB; many not assessed (SH: 2 plots in DD and MX, 1 plot in DU and CD; SB: 2 plots in DU, 3 plots in CD)
2003-2004	100	600	All plots assessed
2007	2	12	Compartments burned in 2006
2008-2009	100	600	All plots assessed
2014-2015	100	600	All plots assessed
Snag plots and extended plots [Source: Langor (2007b)]			
1998	86	516	All plots assessed, except for those in SH/SB
2000	86	516	All plots assessed, except for those in SH/SB
2001	86	516	All plots assessed, except for those in SH/SB
2003	100	600	All plots assessed
2004	14	84	All plots in SH/SB
2005	100	600	All plots assessed
2007	3	15	All plots in two burned compartments (DU, CD) and one SB compartment (DU)
2008-2009	100	600	All plots assessed
2016-2017	86	450	All plots assessed, except for those in DU compartments for all treatments

Collection year	No. compartments	No. of PSPs	Description
Downed coarse woody debris sub-plots [Source: Langor (2007a)]			
1998	100	600	All plots assessed
1999	100	600	All plots assessed
2001-2002	100	600	All plots assessed
2003	14	84	All plots in SH/SB
2004	100	600	All plots assessed
2007	2	12	All plots in two burned compartments (DU, CD)
2008-2009	100	600	All plots assessed
2016-2017	86	450	All plots assessed, except for those in DU compartments for all treatments
Shrub sub-plots [Source: Macdonald & Volney (2007)]			
1998	86	516	All plots assessed, except for those in SH/SB
2001-2002	86	516	All plots assessed, except for those in SH/SB
2003	14	84	All plots in SH/SB
2004	14	84	All plots in SH/SB
2005	100	600	All plots assessed
2007	2	12	All plots in two burned compartments (DU, CD)
2010-2013	100	600	All plots assessed
2016-2017	86	450	All plots assessed, except for those in DU compartments for all treatments
Understory vegetation sub-plots [Sources: Macdonald & Johnson (2007), Bartels et al. (2018), Bartels & Macdonald (2023)]			
1998-1999	100	600	All plots assessed
2001	100	600	All plots assessed
2003	14	84	All plots in SH/SB
2004	100	600	All plots assessed
2007	2	12	All plots in two burned compartments (DU,CD)
2009-2010	100	600	All plots assessed
2015-2016	100	600	All plots assessed
Arthropod sampling points [Sources: Work et al. (2004), Spence (2008), Pinzon (2011), Pinzon et al. (2016), Wu (2018), Wu et al. (2020), Lee et al. (2023), Shorthouse (unpub. data)]			
1998	-	-	Traps were deployed in three stands of each forest cover-type before compartments were delineated and plots established
1999	100	300	Three PSP out of six available were selected in each compartment, with two pitfall traps per plot; all plots assessed
2000	100	300	Same as above; all plots assessed
2004	100	300	Same as above; all plots assessed
2009	100	300	Same as above; all plots assessed
2014	100	300	Same as above; all plots assessed

Figure 11. Example of the location of the six 40 m permanent sampling plots in a 10% retention compartment (Picture from the EMEND database).

Permanent sampling plots (Figure 12) include different subplots and extended plots for the collection of the different datasets listed in Table 3 and described below (Figure 13; a detailed data collection protocol at each plot is also provided in the Appendix [A1-A5]):

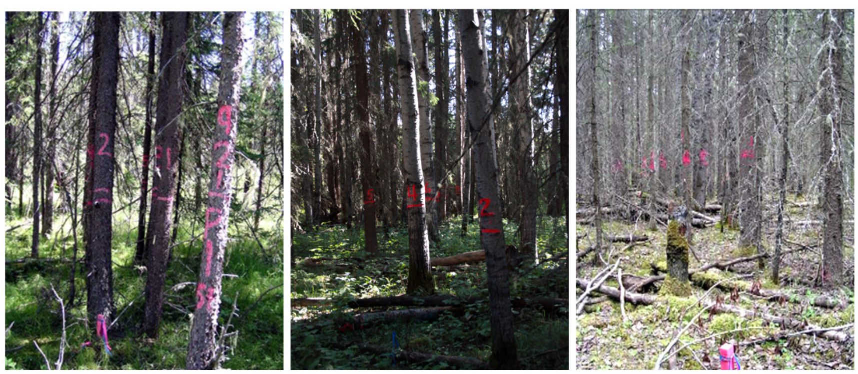

Figure 12. Examples of Permanent Sampling Plots (PSPs) at EMEND (Pictures from the EMEND database).

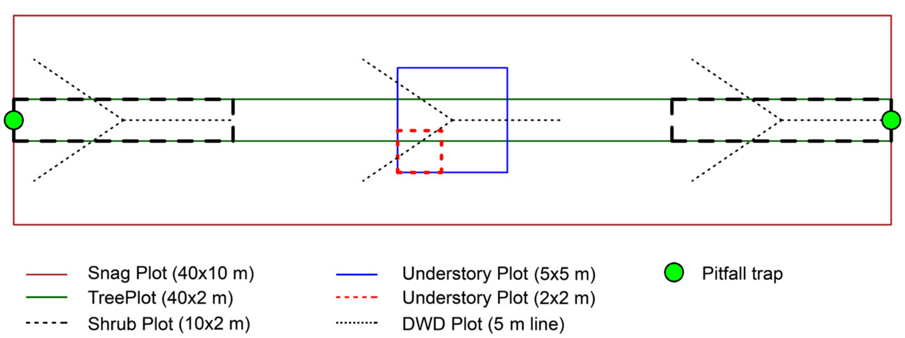

Figure 13. EMEND permanent sampling plot layout displaying the different types of subplots and extended plots used to collect various data. Six of these plots are randomly located within each EMEND compartment (avoiding ellipses) for a total of 600 plots throughout the whole experiment.

1. **Tree plots** (40 x 2 m). All trees with diameter at breast height (DBH) ≥ 5.0 cm and height ≥ 1.3 m were tagged with a unique identifier on a metal tree tag. Tree species, DBH (cm), height (m), height to base of live crown (m), height of live crown (m) and status (dead or alive) were recorded (Appendix A1).

2. **Snag plots** (40 x 2 m; 40 x 10 m extended plots). Pre-harvest (1998) snag assessment was conducted using the tree plots (40 x 2 m), but this was later deemed to be too small to adequately sample snags. Thus, all post-harvest assessments were done in 40 x 10 m extended plots. All snags with DBH ≥ 7.0 cm, height ≥ 1.3 m and lean < 45° from vertical were tagged with a unique identifier on a metal tree tag. Species, DBH, height, percent of bark remaining, and decay class (there were three classes) were recorded (Appendix A2).

3. **Downed coarse woody debris (DWD) sub-plots** (star line intersect sub-plots). DWD was assessed at each survey from three 'star plots', each located randomly at three of eight distances (0, 5, 10, 15, 20, 25, 30, 35 m) from the start of the permanent tree plot center line. Distances were set at 5 m intervals to assure no plot overlap as star plots consist of three 5 m long transects (numbered 1 to 3 in a clockwise fashion) originating from plot center, each transect directionally separated from the others by 120°, and with transect 1 along the center line of the permanent tree plot in the direction away from the start. All logs with a diameter ≥7.0 cm (at the point of intersection with plot transects) intersecting any of the three transects were tallied. Species (when possible), decay class (three), diameter at point of intersect with the transect, and percentage of bark remaining were recorded.

4. **Shrub sub-plots** (10 x 2 m). Located at each end of the PSP (retention strip and machine corridor, respectively). Shrub sub-plots were established as a means of accurately monitoring changes of biomass in the shrub component following the various treatments. All live and dead stems with diameter ≥1.0 cm at a height of 0.3 cm were tallied, with tree recruits with DBH < 5 cm at 1.3 m and all shrubs within each plot surveyed. Species, diameter (cm) at height of 0.3 m and height (m) were recorded, as well as condition of each stem (whole, broken, browsed) (Appendix A4).

5. **Understory vegetation sub-plots**. A 5 x 5 m sub-plot was located at the center of the PSP and included a nested 2 x 2 m subplot on the southwest corner. Species were identified and percent cover estimated for each species for all tall shrubs (DBH < 5 cm and height > 1.5 m) on the 5 x 5m plot. On each 2 X 2 m subplot, species were identified, and percent cover of each species estimated for low shrubs (DBH < 5 cm and height < 1.5 m), forbs, graminoids, bryophytes and lichens (Appendix A5).

6. **Arthropod sampling points**. Three of the six PSPs per compartment were randomly selected and two pitfall traps installed, one at each end of the plot (retention strip and machine corridor, respectively). Traps were serviced at three-week intervals during most of the ice-free season of each sampling year (typically mid-May to end of August). Spiders, ground beetles (Carabidae) and rove beetles (Staphylinidae) were extracted from pitfall trap samples, identified to species (except for aleocharine rove beetles), and included in analyses. Each pitfall trap consists of two plastic containers, one inside the other dug into the ground (Figure 14). The outer container is a 1-L cup (11.2 cm top diameter) placed in the ground with the rim leveled to the litter layer and with perforations at the bottom to allow drainage. This container remains in the ground maintaining the integrity of the hole. The inner container is a removable 0.5-L cup filled to one third with glycol (silicate-free ethylene glycol in early surveys and propylene glycol in later surveys) as killing agent and preservative. Each trap is shielded by a corrugated plastic roof suspended 1-2 cm over the trap with wire to avoid debris and rainfall (Spence & Niemelä 1994, Digweed et al. 1995, Bergeron et al. 2013). Pre-harvest (1998) pitfall trap collections were conducted using three transects of six traps spaced 30 m apart in each of the four cover types given that PSPs were not assigned at the time of trap setup.

Figure 14. Pitfall traps used for the collection of ground-dwelling arthropods. The left picture shows the location of the trap at one end of the PSP (see plot marker at the top left corner and the trap at the bottom right corner), the middle picture shows the trap with some invertebrates already collected, and the right picture shows a cross section of the trap setup (Pictures J. Pinzon).

7. Other EMEND Data

In addition to the EMEND core data, which has been systematically collected at roughly five-year intervals across the experimental area, additional efforts have been invested into collecting experiment-wide or other relevant data. Although several datasets from specific research projects (led mostly by graduate students) area also available, these are not described below

7.1. EMEND Retention Patches

Although much of the core data collected at EMEND come from the PSPs described above, some additional data have been acquired from the ellipsoid retention patches left within harvested compartments. Such information is not part of the core data as retention patches have not been assessed consistently through the different experiment-wide surveys. However, for the purpose of documenting its existence, it is described here. In 1999, spiders were collected using directional pitfall traps at the edges of both retention patches in deciduous dominated compartments harvested to 50, 20, 10 and 2% (clear-cuts) (D. Shorthouse, unpub. data). In 2006, spiders were collected using pitfall traps from both retention patches in deciduous and conifer dominated compartments harvested to 75, 10 and 2% (clear-cuts) retention (in addition to dispersed retention in those same compartments and unharvested controls), with supplementary forest structure data (tree and snag density and basal area, DWD density and volume) (Pinzon et al. 2012). In 2009-2010, saproxylic beetles were collected using window traps and emergence traps from both retention patches in conifer dominated compartments harvested to 50, 20 and 10% retention (in addition to unharvested controls), with supplementary DWD volume and tree density data (Lee et al. 2017). In 2014, understory vegetation (shrubs, forbs and graminoids) and sapling density were assessed from both retention patches in conifer dominated compartments along the full retention prescriptions and unharvested controls (Franklin et al. 2018).

7.2. Songbirds

Songbird counts are available at EMEND, but not assessed from the PSPs but from point count stations at other locations within a subset of compartments across the experiment. Thus, one or two point count stations were included within each of the harvested and control compartments of all four forest cover types, for a total of 107 stations (for more details see Harrison 2002, Harrison et al. 2005). Field crews visited each station 3-5 times in paired years (1998, 2000, 2005, 2006, 2012 and 2013), between sunrise and 10 am during the songbird breeding season (late May to early July). At each sampling point, over a five-minute sampling period, crews recorded visual/auditory observations of species (excluding flying individuals), estimating distance (<50 m, 50-100 m and >100 m) and direction of each observation from the point count station. Species counts were then summarized for each station. Results from these assessments are presented in Harrison (2002), Harrison et al. (2005), (Odsen 2015), Odsen et al. (2018).

7.3. Hydrology

A subset of EMEND compartments representing the full range of tree retention from clear-cut to unharvested control within a coniferous dominated stand were selected to describe the effects of variable retention harvesting on soil temperature, subsurface water, snow accumulation and hydrology. Dataloggers (to record soil temperature and water content), precipitation gauges, groundwater wells and piezometers were installed in 1999 in treed and cut areas of each compartment and were monitored until 2007 to describe hydrological changes over time. Hydrological data are available through the EMEND database.

7.4. Meteorology

Five temporary weather stations were installed and active during various times from 1998 to 2009. These stations were located across the EMEND landscape, in compartments 9180 (EM918) and 9380 (EM938), and at the parking area (Camp, CampFire) and radio tower (EMCTWR) (Figure A1). Two of these stations (EM918, Camp and CampFire) were installed by the CFS, while the other two (EM938, EMCTWR) were installed by Alberta Sustainable Resource Development. The Camp/EM918 stations collected weather data for the year, while the EM938/EMCTWR/CampFire stations collected data only for the fire burn window. These data were collected to record short-term local weather conditions and are compiled into two datasets, available through the EMEND database: EMEND

Weather and Fire Weather. The EMEND Weather dataset was collected to extend short-term weather records for the EMEND site into the past by establishing a relationship to longer-term records. The Fire Weather dataset was created as part of development of a fire effects module to complement the current Fire Weather Index (FWI) and Fire Behavior Prediction (FBP) Systems of the Canadian Forest Fire Danger Rating System (CFFDRS). Overall, the data collected provide basic local climatic information (temperature, relative humidity, wind speed and precipitation) on a daily, hourly or noon basis for the EMEND research site. Meteorological data are available through the EMEND database.

7.5. Soils

In the summer of 1999, just after harvest prescriptions were applied to the different experimental units, 25 soil pits were installed across the experimental area, for the purpose of providing a description and classification of soil profiles at EMEND, including the assessment of various physical/chemical properties and carbon/nutrient pools. Results from this study are summarized in Kishchuk (2004). In addition to this general assessment, additional soil data were collected in 1998, 1999 and 2005 from each of the PSPs within harvested and control compartments to evaluate the effects of retention harvesting on soil physical and chemical properties. Results from this study are described in Kishchuk et al. (2014).

7.6. Spruce Regeneration Following Ground Preparation

In addition to the PSPs, it was agreed that EMEND should incorporate alongside the variable retention harvesting and burn prescriptions a set of silvicultural prescriptions including some form of site preparation (results from this silvicultural trial are described in Gradowski et al. (2008), Lieffers et al. (2019)). In the spring of 1999, after harvest prescriptions were applied, a 50 x 50 m silviculture plot was established in each of the clear-cut, 50% and 75% retention prescriptions in both deciduous and conifer dominated forest types. Silviculture plots were subdivided in four 25 x 25 m sub-plots, each randomly assigned one of the four following site preparation treatments:

1. **High-speed, horizontal bed mixing (meri-crusher).** Sites assigned to this treatment were prepared by using a 1.4 m wide Suokone Oy, Meri Crusher, with a high-speed drum mulcher (500-600 rpm) that was attached to an excavator boom. This equipment mixed the organic layers and mineral soil together to a depth of 12-18 cm within a square area of 1-1.5 m2.
2. **Mounding.** Sites assigned to this treatment were prepared using a curved bucket that allowed 7-15 cm of mineral soil to top a double layer of forest floor material, creating an inverted mound (0.8 x 0.8 m).
3. **Scalping.** Sites assigned to this treatment were prepared using similar machinery to that of mounding, where duff layers (including the H horizon layer) were pulled back to expose an area (1 x 1 m) of upper mineral soil.
4. **No site preparation.** The control treatment was left untouched by any machinery.

A tracked excavator with quick-attach assembly for specific site preparation tools was used to help minimize disturbance, with all trekking limited to the machine corridors, by using the excavator's boom to reach into the retention strips to create the necessary treatments within each compartment. Two to four weeks after treatment application, plots were planted with 100-one year old summer container stock (415-B plug size; 4 cm diameter and 15 cm long) white spruce seedlings (800 seedlings/ha) at 2.5 m spacing.

7.7. Forest Biomass Estimations

The Biomass and Leaf Area Estimators study was established at EMEND to determine the long-term net primary productivity forest response to treatments at the 600 permanent sample plots, in conjunction with other EMEND core studies focused on collecting tree, shrub, snag and downed coarse woody debris measurement data. The objective of this study assess biomass for trees and shrubs. The tree biomass data was collected in 1999 to determine the most efficient allometric equations to estimate leaf area index, root biomass, foliage biomass, branch, and stem biomass, using easily measured tree attributes. Sample trees (34 white spruce, 34 aspen and 8 balsam poplar) were selected from 27 compartments representing the various forest cover types at EMEND (details in section 5.1). Each tree was sectioned to obtain total foliage, current foliage production, twigs, branch and stem biomass. Stumps with their large and small roots were removed and weighed. These variables were examined for their dependence on DBH, height and sapwood area. These estimators, combined with measured data from tree permanent sample plots, can be used to make area wide estimates of productivity and biomass and determine the changes in experiment-wide net primary productivity. Results from the tree biomass estimations and development of local allometric equations are described in Xing et al. (2019).

The shrub biomass was collected in 2001-2002. For this study, shrubs were considered as woody vegetation with DBH < 5.0 cm and include tree species. A total of 122 shrubs were collected to measure the above ground biomass of 12 species (*Abies balsamea, Alnus crispa, Alnus tenuifolia, Amelanchier alnifolia, Picea glauca, Picea mariana, Populus balsamifera, Populus tremuloides, Rosa acicularis, Salix* species*, Shepherdia canadensis and Viburnum edule*). Variables measured were diameter (at 30cm), height, stem weight and volume, branch weight and volume, leave weight and volume, root volume. The biomass for shrubs was summing the oven dried weight of the various components. These data are available through the EMEND database.

8. The EMEND Database: Storing, Maintaining, and Managing Data Derived from the Experiment

The purpose of the EMEND Database is to archive all scientific data collected on the EMEND study site, both core data and other data gathered by students and researchers, providing a single location with uniform data administration to support knowledge transfer and ongoing and future scientific research for the duration of the experiment. The establishment of the EMEND Database promotes data sharing and collaboration within the EMEND research community. The main objectives of maintaining this database are to:

1. Maintain participant profile information so that experts in specific research discipline at EMEND can easily be identified and contacted.
2. Maintain metadata for research studies and their associated datasets contained within the EMEND Database.
3. Maintain a bibliography of EMEND refereed publications and other knowledge exchange sources, such as non-refereed publications, conference/public presentations, etc.
4. Maintain data quality, integrity, and accessibility.
5. Provide a data environment that is convenient and efficient to use.
6. Produce summaries of core datasets to be utilized by participating researchers.
7. Enhance and support the collaborative research community at EMEND.

The ecological systems approach to the EMEND Project has brought together a research community from a multitude of forest ecosystem disciplines. The EMEND research community has included over 34 research scientists, 11 post-doctoral fellows, 21 PhD students, 38 MSc students and >200 research technical support staff (indeterminate and seasonal) who have contributed to the >138 research studies conducted at EMEND to date.

The large amount of scientific data collected at EMEND over >20 years requires considerable effort to proof, enter, organize, and maintain. A database is essential to keep the data organized to facilitate effective and efficient access, management, and updating, all essential to ensuring data integrity and longevity. The development of a database avoids the need to maintain and keep track of multiple electronic spreadsheets and paper files at many locations that can easily become unorganized, misplaced, and absent of any documentation, a largely impossible task for a project the size and complexity of EMEND. The database and its active management ensure regular updates and easy and fast response to the increasing number of requests for data access by EMEND stakeholders, students, and researchers in many parts of the world. Researchers can access the most current version of data and rapidly summarize it for scientific analysis and reports.

The success of the EMEND Project has been largely attributed to the forging of an active and trusting relationship between academic and federal researchers, industry partners from multiple companies, and the Alberta government (landowner and regulator). The involvement of such a large group of participants with multiple affiliations and scattered across a large geographic range, each with unique data needs and an expectation of ready access to the most current versions of data can only be achieved through the database that has been developed to serve participants at EMEND.

There are three principal components to EMEND field research and thus three broadly different types of datasets. Experiment-wide core research forms the foundation of the EMEND database design. These core datasets are collected across all the experimental design, concentrating on the general response of the forest ecosystem to the treatments, and are added to at regular intervals along the anticipated duration of the experiment. Data for these core datasets is updated with the completion of periodic experiment-wide sampling. A second research component is conducted by researchers interested in answering specific questions other than those being addressed by the core studies, but still within the EMEND Project design. Most frequently these datasets are collected across only a portion of the experiment and for only a relatively short period (1-4 years). These datasets are archived within the EMEND database at the completion of the study. The third type of EMEND research consists of either using results from EMEND to design and test hypotheses on the surrounding operational landscape, or using the structure and industrial activity on this landscape to implement research that is complementary to but not possible on the 1,000 ha EMEND experimental design. These datasets are also organized and archived within the EMEND database on their completion.

8.1. Database Platform

The database was first developed in 2002 using MS Access as the platform. This served the initial purpose of quickly organizing the data and being able to disseminate data and summary information to researchers. The initial database was migrated to a MySQL platform in 2006, to address the data growth storage requirements and increase the accessibility of information via the internet. The creation of the MySQL database also allowed for the inclusion of datasets compiled from research on the industrial landscape surrounding EMEND. To this date, the database now utilizes the open-source platform MariaDB 10.3 for Linux (compatible with MySQL) and is reviewed and upgraded as required. This database platform can address the data growth storage and query requirements in addition to increase accessibility options.

8.2. Datasets

Currently, 52 datasets are being managed within the EMEND Database. The number of datasets archived in the database continues to increase as graduate students complete their projects at EMEND and take the step of data archiving. EMEND researchers can submit an electronic copy of their data with a description of each field and the study methods to the database administrator (currently at the Northern Forestry Center (Canadian Forest Service, Edmonton)).

A series of data quality and assurance checks are conducted to ensure data is consistent, accurate and conforms to the established parameters for data validation. These data validation procedures reduce errors and improve data accuracy and confidence in the information being reported. Studies that have repeated assessments over several years benefit from the data continuity the database structure provides. Historic data from permanent sample plots is used in the field for the following measurement. This information is useful for capturing new data as it reduces errors and confusion in the field.

In addition to the digital data stored in the EMEND database, a wealth of information is stored as biological specimen vouchers, particularly of arthropods, in curated and maintained reference collections (e.g., Northern Forestry Center Arthropod Collection, E. H. Strickland Entomological Museum) and their corresponding specimen databases. These collections are essential to support biodiversity research, for example, to support species identifications and as specimen-based data archives.

8.3. Access and Security

The database is hosted on a server at Natural Resources Canada. Security protocols for the database are continually reviewed and maintained to meet the standards established by the Treasury Board of Canada and Natural Resources Canada.

Access to the EMEND Database is restricted to researchers and partners participating in the EMEND Project. An EMEND Data Use Agreement was developed to formalize the request and use of data between data owning agents and requesting researchers for the core datasets. Access to other datasets that are not part of the core research component require requesting researchers to contact the scientific authority responsible for the specific dataset they are interested in for potential collaborative research opportunities.

The database allows researchers to familiarize themselves with previous and current research projects so that they may identify research areas that need to be addressed to further understand how forest ecosystems recover from disturbances. As the EMEND Project is planned to follow the forest response for a complete harvest rotation the data that is collected will increase in usefulness and value over time and can be developed into further value-added products.

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Appendices

Permanent Sampling Plot Establishment

Six permanent sampling plots (PSP; Figures 11-13) were randomly located within each compartment (Figure A1), for a total of 600 plots in the EMEND project. All tree plots were established in an east-west orientation so that they are perpendicular to the north-south orientated machine corridors. A measuring tape was stretched out in a west or east direction from the plot start point for 40 meters to establish the mid-line of the plot. The mid-line UTM coordinates for the start and end of each plot was determined using a GPS unit with differentially corrected data, using a hand-held Geo Explorer II (data from the GPS unit was downloaded at Mercer International Peace River facilities and their GPS technician corrected the data). The start and end of the mid-line in each plot was marked with a pigtail. To allow greater visibility of the plot boundaries, wooden stakes painted pink were put in at the start and end of all the plots. Solid aluminum redi-rods with a length of approximately 3 feet were also pounded into the ground. The intent of the metal rods is to make a more permanent marking of the plots so that they can be re-located in the future. In 1998, PSPs were assigned a unique code corresponding to the compartment identifier (Table A1) and numbered 1 to 6. After harvest treatments were applied in the winter of 1998-1999, some plots were destroyed beyond the limits of the prescribed treatment and were therefore replaced. Thus, in the summer of 1999, plot numbering starting at 7 was established where required to replace identifiers of plots that were destroyed to maintain the six plots per compartment design. The first tree plot is usually located from a baseline. Double pink ribbon on a tree on the baseline indicates the start of the trail to the first plot. A trail in pink X's (marked on trees using tree and log marking paint) lead the way between each plot. Details on the establishment of each individual sampling plot type are provided below.

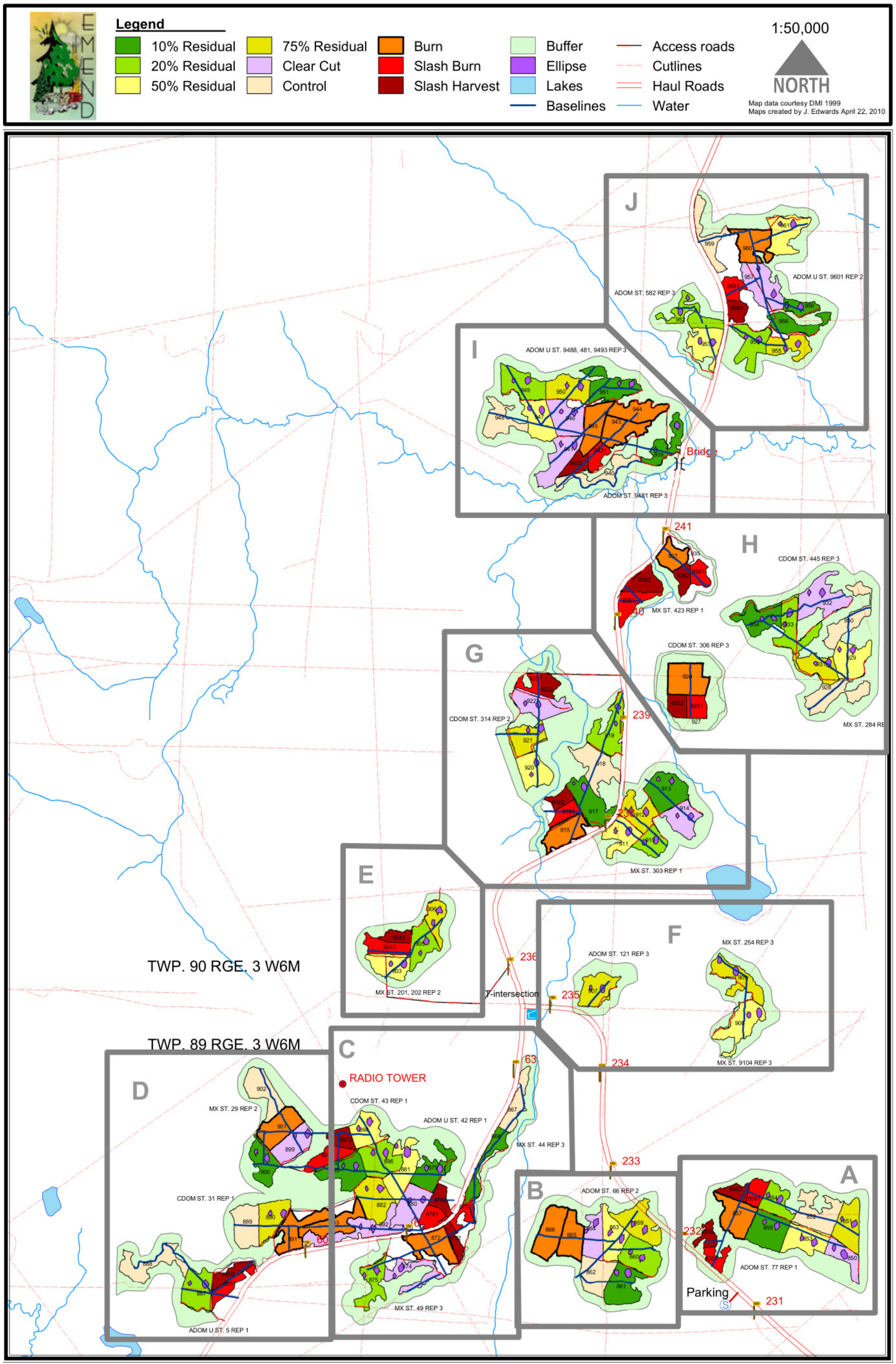


Figure A1. Map of EMEND compartments with their unique identifiers. Different replicated stands shown as grey squares (Blocks A-J). Map taken from the EMEND database.

The difficulty in conducting the prescribed standing burn treatments resulted in 14 compartments having their prescribed treatment revised in 2002. Each of the designated compartments was split in half, thereby creating two new compartments (Figure A1). From the original compartment, one half was treated with a 10% Residual Slash Harvest (SH) and the other half was treated with a 10% Residual Slash Harvest + Burn (SB). Three permanent sampling plots were retained or re-established in each of these new compartments.

Table A1. List of compartment unique identifiers with their corresponding forest cover-type and harvest treatment (DD: Deciduous dominated; DU: Deciduous dominated with spruce understory; MX: Mixed; CD: Conifer dominated; SH: Slash-harvest; SB: Slash-burn). Blocks correspond to the grey squares in Figure A1.

Compartment ID	Block	Cover-type	Treatment	Observations
8500	A	DD	Clear-cut	
8510	A	DD	75% retention	
8520	A	DD	Untreated	Designated as unharvested control
8530	A	DD	50% retention	
8540	A	DD	20% retention	
8550	A	DD	10% retention	
8570	A	DD	Untreated	To be burned
8590	B	DD	75% retention	
8600	B	DD	20% retention	
8610	B	DD	10% retention	
8620	B	DD	Untreated	Designated as unharvested control
8630	B	DD	50% retention	
8640	B	DD	Clear-cut	
8650	B	DD	Standing timber burn	Burned in 2010
8660	B	DD	Standing timber burn	Burned in 2010
8670	C	MX	Untreated	Designated as unharvested control
8680	C	MX	10% retention	
8720	C	MX	Untreated	To be burned
8740	C	MX	Clear-cut	
8750	C	MX	20% retention	
8790	C	DU	10% retention	
8800	C	DU	Clear-cut	
8810	C	DU	50% retention	
8820	C	DU	75% retention	
8830	C	DU	Standing timber burn	Burned in 2010
8870	D	DU	20% retention	
8880	D	DU	Untreated	Designated as unharvested control
8890	D	CD	Untreated	Designated as unharvested control
8900	D	CD	75% retention	
8910	D	CD	Standing timber burn	Burned in 2006
8920	C	CD	Clear-cut	
8950	C	CD	10% retention	
8960	C	CD	20% retention	

Compartment ID	Block	Cover-type	Treatment	Observations
8980	C	CD	50% retention	
8990	D	MX	Clear-cut	
9000	D	MX	10% retention	
9010	D	MX	Untreated	To be burned
9020	D	MX	Untreated	Designated as unharvested control
9030	E	MX	50% retention	
9050	E	MX	20% retention	
9060	E	MX	75% retention	
9070	F	DD	75% retention	
9080	F	MX	50% retention	
9090	F	MX	75% retention	
9100	G	MX	20% retention	
9110	G	MX	50% retention	
9120	G	MX	75% retention	
9130	G	MX	10% retention	
9140	G	MX	Clear-cut	
9150	G	CD	Untreated	To be burned
9170	G	CD	10% retention	
9180	G	CD	Untreated	Designated as unharvested control
9190	G	CD	20% retention	
9200	G	CD	50% retention	
9210	G	CD	75% retention	
9220	G	CD	Clear-cut	
9260	H	CD	Standing timber burn	Burned in 1999
9280	H	MX	Untreated	Designated as unharvested control
9290	H	CD	50% retention	
9300	H	CD	Untreated	Designated as unharvested control
9310	H	CD	75% retention	
9320	H	CD	Clear-cut	
9330	H	CD	20% retention	
9340	H	CD	10% retention	
9370	H	MX	Standing timber burn	Burned in 2004
9390	I	DD	10% retention	
9400	I	DD	Untreated	Designated as unharvested control
9410	I	DD	Clear-cut	
9430	I	DD	Standing timber burn	Burned in 2010
9440	I	DU	Untreated	To be burned
9450	I	DU	Untreated	To be burned
9460	I	DU	Clear-cut	
9470	I	DU	50% retention	
9480	I	DU	Untreated	Designated as unharvested control

Compartment ID	Block	Cover-type	Treatment	Observations
9490	I	DU	20% retention	
9500	I	DU	75% retention	
9510	I	DU	10% retention	
9520	J	DD	20% retention	
9530	J	DD	50% retention	
9540	J	DU	20% retention	
9550	J	DU	75% retention	
9560	J	DU	10% retention	
9570	J	DU	Clear-cut	
9590	J	DU	Untreated	Designated as unharvested control
9600	J	DU	Untreated	To be burned
9610	J	DU	50% Retention	
8561, 8562	A	DD	SH, SB	Untreated before 2002
8581, 8582	A	DD	SH, SB	Untreated before 2002
8701, 8702	C	MX	SH, SB	Untreated before 2002
8781, 8782	C	DU	SH, SB	Untreated before 2002
8851, 8852	D	DU	SH, SB	Untreated before 2002
8971, 8972	C	CD	SH, SB	Untreated before 2002
9041, 9042	E	MX	SH, SB	Untreated before 2002
9161, 9162	G	CD	SH, SB	Untreated before 2002
9231, 9232	G	CD	SH, SB	Untreated before 2002
9251, 9252	H	CD	SH, SB	Untreated before 2002
9361, 9362	H	MX	SH, SB	Untreated before 2002
9381, 9382	H	MX	SH, SB	Untreated before 2002
9421, 9422	I	DD	SH, SB	Untreated before 2002
9581, 9582	J	DU	SH, SB	Untreated before 2002

Data Quality and Assurance

A field program should be established to cross-check the quality assurance and control of the data being collected in the field for the tree plots. A training program of all field crews is required to ensure all personnel are collecting data in a consistent manner. Field crews must have a full understanding of how to apply class codes and how measurements are taken. A random selection of plots should be re-examined throughout the field season by another field crew or supervisor to confirm assessments are being conducted in a consistent manner.

In 2003 and 2008, field crews used a relational field database built with SprintDB Pro, on Dell Axim Pocket PCs. The use of Pocket PC in conjunction with a field database has contributed significantly to cleaner and more precise data being collected. Field PC tablets along with programs such as MS Access or Excel should be utilized for data collection. All field data is subjected to a series of validation programs before being incorporated into the EMEND Database.

Data Submission

All data is to be validated and crosschecked prior to submission to the EMEND Database for archiving. Any error or discrepancies found must be noted and validated in the field prior to submission. The best practice is to conduct any field validations in the year the data was collected or in the following year if required. Once current survey data has been validated, format the data in the same structure as the previous survey data was downloaded from the EMEND Database and save as an Excel spreadsheet. Data should be submitted within one year of collection.

Appendix A1. Tree Plot Survey Methods

The goal of the research is to monitor the structure and the rate of change in the tree component of a forest stand when subjected to various harvesting treatments to determine which treatment best emulates a natural fire disturbance. Monitoring surveys to identify the species, DBH (cm), height (m), height to base of live crown (m), height to top of live crown (m), dead top length (m), total stem volume (m3), merchantable stem volume (m3), crown class, tree condition, and health damaging agents of trees have been conducted at EMEND in each compartment. Data have been collected from the tree plots (40x2 m) as in Figure 13.

Plot Establishment

Tree plot sides are 1 meter on either side of the PSP mid-line for a plot width of 2 meters. Figure 13 illustrates the layout of the tree plot in relation to other the other plots contained within each PSP.

Tree Numbering

Only tree species (not shrub species) are to be inventoried in the Tree Plot. Table A2 lists the coding used to identify tree species. The mid-line of each plot was walked with a 1-meter stick and each tree with a DBH >=5.0cm, height >=1.3m and its germination point within 1 meter perpendicular to the mid-line was sequentially numbered (starting with 1) and the DBH reference line painted using pink spray paint. The tree numbers painted on the trees should be whole numbers and the use of decimals (e.g., x.1 or x.2) should be avoided. The compartment number, plot number, tree number and species were recorded. Once the experimental treatment was conducted in the compartment a unique metal tree tag was attached to each tree still standing with electrical phone wire at DBH. This metal tree tag number is now used to identify the tree. Subsequent in-growth of trees will be added to the data during the next re-measurement period. The in-growth trees will be tagged with a unique metal tree tag and assigned the next tree number in the sequence for the plot. The tag numbers used at EMEND are unique and shared between the Tree, Snag and Growth & Yield Plots. If a tree is missing the original assigned tag, then a 'write-on' tag is to be used as a replacement with the original tag number clearly inscribed on it. Do not assign a previously tagged tree a new tag number as a replacement for the missing tag.

Table A2. Tree species code list.

Species	Common Name	Scientific Name	Vegetation Type
.	no trees		T
Abibal	balsam fir	*Abies balsamea*	T
Betpap	white birch	*Betula papyrifera var. papyrifera*	T
Conifer	unknown conifer species	*Conifer species*	T
Larlar	tamarack	*Larix laricina*	T
Picgla	white spruce	*Picea glauca*	T
Picmar	black spruce	*Picea mariana*	T
Picspp	spruce species	*Picea species*	T
Pinban	jack pine	*Pinus banksiana*	T
Pincon	lodgepole pine	*Pinus contorta var. latifolia*	T
Pinspp	pine species	*Pinus species*	T
Popbal	balsam poplar	*Populus balsamifera*	T
Popspp	poplar species	*Populus species*	T
Poptre	trembling aspen	*Populus tremuloides*	T

Tree Aging

To estimate the age of each compartment, trees outside each PSP were cored in 1998. For every tree species found within each tree plot, two trees were selected near the start and end of the PSP. Trees were cored perpendicular to the tree at DBH and at 30 cm from the base.

Tree Data Collection

Data collection on the Tree Plot consists of a tree mensuration and health survey. The mensuration portion of the survey has each tree assessed for status (living, dead, fallen or cut), DBH (cm), height (m), height to base of the live crown (m), and height to the top of the live crown (m). DBH is to be measured at 1.3 m from the point of germination. The heights are to be measured perpendicular to any lean that may exist. Figure A2 and show field an information sheet to assist surveyors during the forest mensuration survey.

The forest health portion of the survey includes the assessment of crown class, tree condition, number of damaging agents, damaging agent, part affected, sign & symptom, and the extent & severity, for each tree. Figures A3 to A6 and Table A3 are field information sheets to assist the surveyors in conducting the forest health portion of the survey.

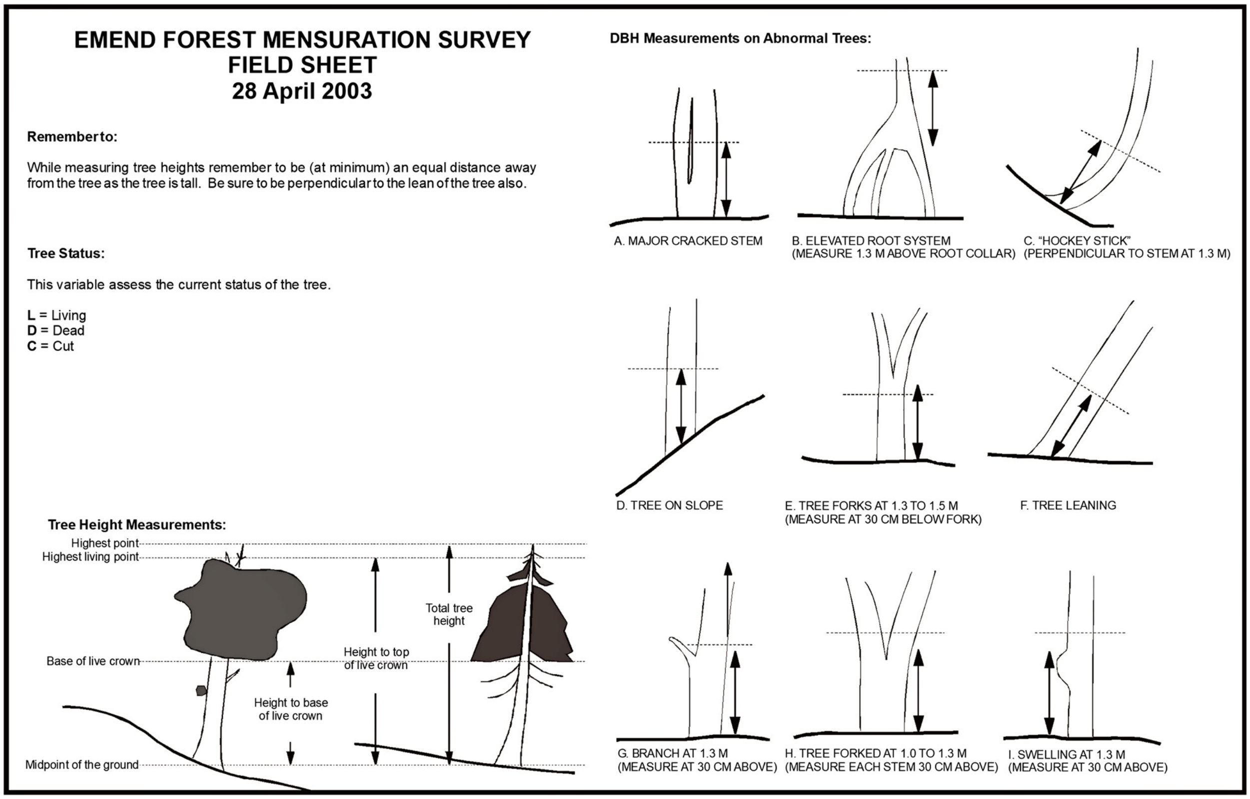


Figure A2. Field information sheet to assist surveyors during the forest mensuration survey.

The tree plots established in 1999 to replace those that were no longer representative of the prescribed treatment had the diameter of the stumps recorded for trees that were harvested. The stump diameter for these cut trees was used to calculate the DBH and height of the tree. The coefficients and formula for calculation of DBH based on stump diameter, merchantable volume, and total stem volume for Natural Region 11 were taken from "Ecologically Based Individual Tree Volume Estimation for Major Alberta Tree Species, Report #1, Individual Tree Volume Estimation Procedures for Alberta: Methods of Formulation and Statistical Foundations", by Shongming Haung, 1994, Alberta Environmental Protection, Land and Forest Service, Forest Management Division. Crown length, dead top length, and basal area are calculated using SAS based on the field data collected.

The tree plots were scheduled to be surveyed on a 5-year cycle with the baseline year as 1998. Study wide surveys were conducted in 1998, 1999, 2003, 2008 and 2014. In 1998, separate forest mensuration and health surveys were conducted in all compartments. The forest mensuration survey was conducted by EMEND Core Crew members and the forest health survey was conducted by CFS, Forest Health Technicians. In 1999, a forest mensuration survey was conducted on the new tree plots that were established to replace those plots that no longer met the experimental treatment parameters. A forest health survey was not conducted on the new plots in 1999. A pre-harvest mensuration survey was conducted in 2002 for the newly created 10% Residual Slash/Slash Burn compartments. In 2003 and 2008, the forest mensuration and health surveys were combined and completed at the same time. A post treatment survey was conducted in 2007 for compartments 8830 and 8910 following burn treatments in 2006. The 2014 survey did not assess each tree for damaging health agents.

Tree Plot Re-Assessment

For subsequent remeasurement of tree plots the following steps are recommended to be followed to ensure the integrity of the dataset.

1. Download the data from the previous survey from the EMEND Database. The previous survey data provides field crews with a list of trees present and the measurement data during the last assessment to assist with data collection consistency between surveys.

2. Upload the data to a field database application installed on an electronic field data collection device. Data field parameters should be set to ensure only valid codes are used and deviations from a normal progression are flagged so field crews can re-check the data being entered.

3. Each tree is to be assessed using the established protocols and codes described above:

- Establish the 40 m mid-line for the tree plot.

- All trees with a germination point within 1 m perpendicular to the mid-line, with a complete DBH >= 5.0 cm and height >= 1.3 m are to be assessed. Previous surveyed trees no longer meeting the criteria are to be recorded as fallen. Once a tree is recorded as fallen it no longer needs to be assessed in subsequent surveys. Large diameter trees that were not included in previous surveys were considered to not be within the plot boundary and should not be added as ingrowth.

- Previously assessed trees have retained their assigned unique tag number for the duration of the study. Tree and Snag plots overlap, Growth & Yield plots are adjacent to some Tree plots and share the same unique tag number sequence. Do not reuse tags once they have been assigned. If this is done it will have a significant impact on the analysis and future assessments of the tree and snag plots. Previously assessed trees with missing tags should be searched at their base. If the original tag is unable to be located, use a 'write-on' tag with the assigned tag number clearly inscribed on it and attach it to the tree.

- DBH: Using a measuring stick, measure the DBH at 1.3 m and record the diameter in centimeters to one decimal place. Mark the DBH line for subsequent remeasurements and note any variations of the DBH if any from the previous assessment (Figure A2).

- Height: Measure the tree height to the highest point and record the height in meters to one decimal place. Care must be taken to measure the height perpendicular to any lean. Heights must be taken from a location at minimum distance from the tree as it is tall. Note any deviations, if any, and leans in the comments and health portion of the survey (Figure A2).

- Height to Top of Live Crown: Measure the height of the crown to the highest point of the live crown and record the height in meters to one decimal place. The height to the top of the live crown should not be greater than the total height of the tree. Note the presence of dead tops in the comments and health portion of the survey (Figure A2).

- Height to Base of Live Crown: Measure the height of the crown to the lowest point of the main live crown and record the height in meters to one decimal place. A general rule to observe is that if there is more than a 2 m gap between the main part of the crown and a lower superfluous foliage branch then the lower branch is not to be considered part of the lower crown (Figure A2).

- Crown Class: Follow the crown class codes provided in Figures A3 and A4. These codes are specific to assessing the crown class and should not be confused with the height class codes used in the Snag Plot survey.

- Tree Condition: Follow the tree condition class codes provided in Figure A4.

- Number of Agents: Record the total number of agents affecting the health of the tree.

- Agent: Record each agent along with the specific part affected, sign and symptom and the extent and severity (Figure A4, Table A3).

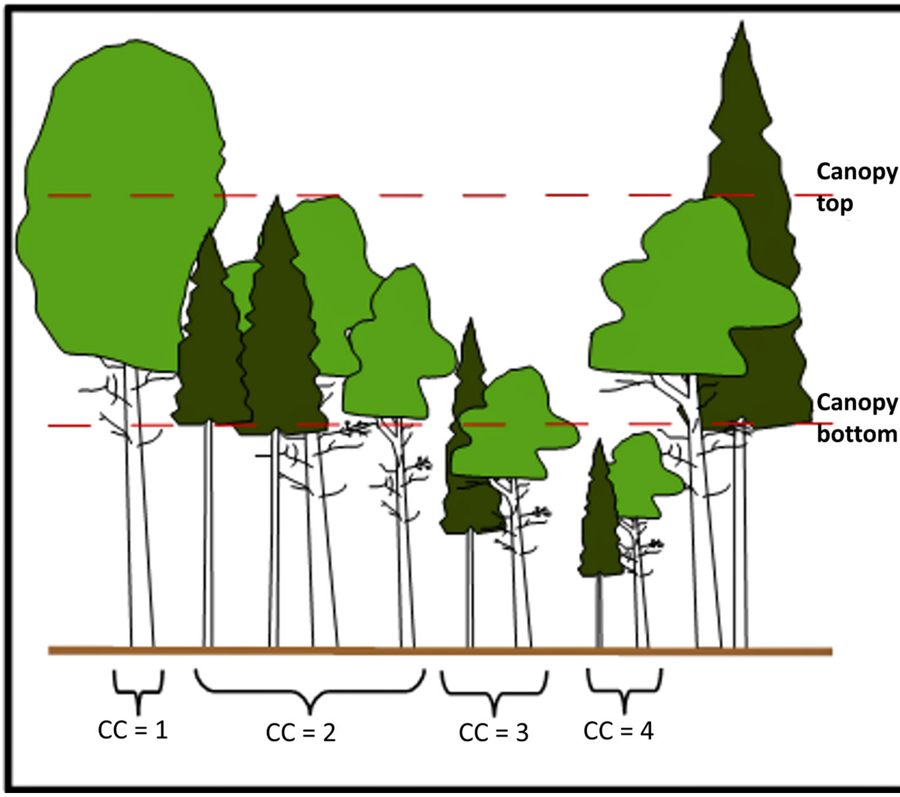
- Part Affected: The part of the tree being affected by the agent being recorded (Figure A3).

- Sign & Symptom: The signs or symptoms visible on the tree being caused by the agent being recorded (Figure A5).

- Extent & Severity: Based on the part affected and the sign & symptom, use the appropriate codes for assessing the extent and severity of damage caused by the agent (Figure A5).

- Comments: All deviations from a normal progression of a tree (i.e., DBH, height and health) are to be noted in the comments. This is necessary to assist with data validation and analysis. Any additional information not addressed in the data fields should be made in the comments field.

- Equipment required: 40m tape, DBH tape, 1.3 m Measuring stick, Clinometer, Data sheets or data-logger.



Tree Crown Class Codes	
0	Not applicable
1	**Dominant** – Crown extends above the top of the general canopy level and receives full sunlight from above and partial sunlight from the sides.
2	**Co-dominant** – Crown extends just up to the top of the general canopy level and receives full sunlight from above, but little sunlight from the sides. May be somewhat crowded at sides.
3	**Intermediate** – Crown extends into the general canopy level, but shorter than Co-Dominant trees. They receive little sunlight from above or sides.
4	**Suppressed** – Crown is entirely below the general canopy level

Figure A3. Tree crown class codes used for tree mensuration assessments.

EMEND FOREST HEALTH SURVEY FIELD SHEET
28 April 2003
Sheet 1 of 2

Remember to:

1. No destructive sampling of healthy on-plot trees.
2. Assess by viewing at least 3 sides of the tree (binoculars are not required).
3. Be thorough when assessing damaging agents (use binoculars).

Crown Class:

Foliage quantity and quality is assess based on the normal compliment of foliage for the species.

1 = Dominant (Crown extends above the top of the general canopy level and receives full sunlight from above and partial sunlight from the sides.)
2 = Co-dominant (Crown extends just up to the top of the general canopy level and receives full sunlight from above, but little sunlight from the sides. May be somewhat crowded at sides.)
3 = Intermediate (Crown extends into the general canopy level but shorter than Co-dominant trees. They receive little sunlight from above or sides.)
4 = Suppressed (Crown is entirely below the general canopy level.)
0 = Not applicable

Tree Condition:

This variable is based the assessors impression of the tree's overall health taking into consideration dieback, foliage quality/quantity, defoliation, and damaging agents.

1 = Healthy
2 = Declining or Dying (death in 2-3 years)
3 = Dead <=1 year (fine twigs or needles retained)
4 = Dead >1 year (no fine twigs or needles)
5 = Logged
6 = Missing
0 = Other (specify in comments)

Tree Part Affected Codes:

The part of the tree being affected by the damaging agent.

1 = Roots and Root Collar
2 = Stem (not including terminal)
3 = Crown
4 = Crown Apex or Terminal

Figure A4. Forest health survey field sheet, part one.

EMEND FOREST HEALTH SURVEY FIELD SHEET
28 April 2003
Sheet 2 of 2

Sign & Symptom Codes:	Extent & Severity Codes:	
1 = Bark damage (animal/mechanical)	l	Light (1-30%)
	m	Moderate (31-80%)
	s	Severe (81-100%)
2 = Resinosis (or mycelium)	l	Light (1-25%)
	m	Moderate (26-50%)
	s	Severe (51-100%)
3 = Insect girdling and pitch (on stem)	l (on stem)	Light (1-30%)
	m (on stem)	Moderate (31-80%)
	s (on stem)	Severe (81-100%)
	(on branches)	Record numbers to 10+
4 = Deformity J-root	.	Leave blank
5 = Cankers	l	Light (1-25%)
	m	Moderate (26-50%)
	s	Severe (51-100%)
6 = Stem Galls		Record numbers to 10+
7 = Conks, fruiting bodies		
8 = Insect entry holes		
9 = Sapsuckers	l	Light (1-30%)
	m	Moderate (31-80%)
	s	Severe (81-100%)
10 = Deformity (lean)	.	Leave blank
11 = Deformity (crook)		
12 = Deformity (crack)		Record length of crack in meters
13 = Deformity (fork)		Record height of form in meters
14 = Deformity (broken)		Record height to break in meters
15 = Fire scar (girdling)	l	Light (1-30%)
	m	Moderate (31-80%)
	s	Severe (81-100%)

Sign & Symptom Codes:	Extent & Severity Codes:	
16 = Brooms (Hawksworth's Coding)	1	1/6 of tree
	2	1/3 of tree
	3	1/2 of tree
	4	2/3 of tree
	5	5/6 of tree
	6	Whole tree
17 = Chlorotic foliage	t	Trace (<5%)
18 = Defoliation/Skeletonizing	l	Light (6-35%)
19 = Flagging (branches)	m	Moderate (36-70%)
20 = Organisms on foliage	s	Severe (71-100%)
21 = Stunted/deformed foliage or shoots		
22 = Branch galls		Record number to 10+
23 = Bud proliferation/leaf clumping		
24 = Browse	t	Trace (<5%)
	l	Light (6-35%)
	m	Moderate (36-70%)
	s	Severe (71-100%)
25 = Dead terminal	.	Leave blank
26 = Multiple terminals		
27 = Die-back (upper crown)	t	Trace (<5%)
	l	Light (6-35%)
	m	Moderate (36-70%)
	s	Severe (71-100%)
28 = Dead top		Record length in meters
29 = Broken branches (mechanical)	t	Trace (<5%)
	l	Light (6-35%)
	m	Moderate (36-70%)
	s	Severe (71-100%)
0 = Other		Leave blank and use comments

Figure A5. Forest health survey field sheet, part two.

Table A3. List of agents and corresponding codes used in the field for tree health assessments.

Agent	Common Name	Scientific Name
A/M	Animal/mechanical bark damage	
ABIOTIC	Abiotic Agent	
ACEPAR	Poplar Bud Gall Mite	*Aceria parapopuli*
ACIDFOG	Acid Fog	
ACLVAR	Eastern Blackheaded Budworm	*Acleris variana*
ACOspp	Leaf Gall Mite	*Acotyledon spp.*
ADECOO	Cooley Spruce Gall Adelgid	*Adelges cooleyi*
ADELAR	Spruce Gall Adelgid	*Adelges lariciatus*
ADEspp	Spruce Gall Adelgid species	*Adelges spp.*
ADESTR	Pale Spruce Gall Adelgid	*Adelges strobilobius*
ALCALC	Moose	*Alces alces*
ANT	Unknown Ant species	
APHIDS	Unknown Aphid	
ARCAME	Lodgepole Pine Dwarf Mistletoe	*Arceuthobium americanum*
ARCPUS	Eastern Dwarf Mistletoe	*Arceuthobium pusillum*
ARGTAB	Jack Pine Tube Moth	*Argyrotaenia tabulana*

Agent	Common Name	Scientific Name
ARMspp	Armillaria species	*Armillaria spp.*
ATRPIN	Atropellis Canker	*Atropellis piniphila*
BATPRA	Petiole Crotch Borer	*Batrachedra praeangusta*
BLINDCNK	Blink Conk	
BLKDUST	Unknown Black Dust	
BLKGALL	Black gall (unknown cause)	
BLOTCH	Unknown Blotch	
BONUMB	Ruffed Grouse	*Bonasa umbellus*
BROK/T	Broken terminal	
BROKEBR	Broken Branch	
BROKEST	Broken Stem	
BROKETP	Broken Top	
BUCCAN	Birch Skeletonizer	*Bucculatrix canadensisella*
CAMHER	Carpenter Ant	*Camponotus herculeanus*
CAMspp	Carpenter Ant	*Camponotus spp.*
CANK/S	Unidentified cankers on stem	
CASCAN	Beaver	*Castor canadensis*
CAST	Unknown Needle Cast	
CERFIM	Ceratocystis Canker	*Ceratocystis fimbriata*
CHAPOP	Smokeywinged Poplar Aphid	*Chaitophorus populicola*
CHIPIN	Pine Needle Scale	*Chionaspis pinifoliae*
CHLO/F	Chlorotic foliage	
CHOCON	Large Aspen Tortix	*Choristoneura conflictana*
CHOFUM	Spruce Budworm	*Choristoneura fumiferana*
CHOPIN	Jack Pine Budworm	*Choristoneura pinus*
CHRARC	Yellow Witches' Broom	*Chrysomyxa arctostaphyli*
CHRCRO	Aspen Leaf Beetle	*Chrysomela crotchi*
CHRFAL	Leaf Beetle	*Chrysomela falsa*
CHRLED	Needle Rust of Spruce	*Chrysomyxa ledi*
CHRLEDI	Needle Rust of Spruce	*Chrysomela ledi*
CHRMAI	Alder Leaf Beetle	*Chrysomela mainensis*
CHRspp	Needle Rust	*Chrysomyxa spp.*
CHRWEI	Needle Rust	*Chrysomyxa weirii*
CIBWHE	Ink Spot	*Ciborinia whetzellii*
COLPIC	Orange Spruce Needleminer	*Coleotechnites piceaella*
COLSTA	Northern Lodgepole Needleminer	*Coleotechnites starki*
CONK/S	Unidentified conks on stem	
CRACK	Unidentified crack in stem (frost?)	
CROOK	Crooked stem	
CRYLIG	Cryptosphaeria Canker	*Cryptosphaeria lignyota*
CYDTOR	Eastern Pine Seedworm	*Cydia toreuta*
CYTCHR	Cytospora Canker	*Cytospora chrysosperma*
DASBAL	False Balsam Gall Midge	*Dasineura balsamicola*

Agent	Common Name	Scientific Name
DASVAG	Tussock Moth	*Dasychira vagans*
DAVAMP	Needle Cast	*Davisomycella ampla*
DEAD/T	Dead terminal	
DEADTOP	Dead top	
DEFO/?	Unidentified defoliation	
DEFO/D	Unidentified defoliation (disease)	
DEFO/I	Unidentified defoliation (insect)	
DEFR/F	Stunted/deformed foliage or shoots	
DENCAN	Spruce Grouse	*Dendragapus canadensis*
DENOBS	Blue Grouse	*Dendragapus obscurus*
DENPON	Mountain Pine Beetle	*Dendroctonus ponderosae*
DENRUF	Spruce Beetle	*Dendroctonus rufipennis*
DIEBACK	Die-back (upper crown)	
DIOREN	Spruce Coneworm	*Dioryctria reniculelloides*
DIPTUM	Diplodia Galls	*Diplodia tumefaciens*
DROUGHT	Drought	
DRYPIL	Pileated Woodpecker	*Dryocopus pileatus*
ELYDEF	Elytroderma Needle Cast/Pine	*Elytroderma deformans*
ENADEC	Aspen Twoleaf Tier	*Enargia decolor*
ENCPRU	Sooty-bark Canker	*Encoelia pruinosa*
ENDHAR	Western Gall Rust	*Endocronartium harkensii*
ENTMAM	Hypoxylon Canker	*Entoleuca mammata*
EREDOR	Porcupine	*Erethizon dorsatum*
ERIspp	Gall Mites	*Eriophyes* spp.
FENPUS	Birch Leafminer	*Fenusa pusolla*
FIRE	Fire	
FLAG/C	Flagging branches	
FLECKING	Needle Flecking	
FORK	Forked stem	
FROSTCK	Frost Crack	
GALL	Unknown Gall	
GALL/B	Unidentified branch galls	
GALL/S	Unidentified stem galls (prob. Disease)	
GONAME	American Aspen Beetle	*Gonioctena americana*
GROUSE	Grouse species	
HAILCR	Hail Crown Damage	
HAILST	Hail Stem Damage	
HERBIC	Herbicide Damage	
HYACEC	Cecropia Moth	*Hyalophora cecropia*
HYDCARB	Hydrocarbons	
HYLWAR	Root Collar Weevils	*Hylobius warreni*
HYPMAM	Hypoxylon Canker	*Hypoxylon mammatum*
INSH/R	Unidentified insect holes in the roots	

Agent	Common Name	Scientific Name
INSH/S	Unidentified insect holes in the stem	
LEAN	Leaning stem	
LFBEET	Unknown Leaf Beetle	
LFRUST	Unknown Leaf Rust	
LIRMAC	Needle Cast	*Lirula macrospora*
LOBNIV	Twolinded Aspen Looper	*Lobophora nivigerata*
LOGGED	Logged	
LOPCON	Needle Cast	*Lophodermella concolor*
MALDIS	Forest Tent Caterpillar	*Malacosoma disstria*
MAYPIC	Spruce Gall Midge	*Mayetiola piceae*
MECHSCAR	Mechanical Scars	
MELMED	Leaf Rust	*Melampsora medusae*
MINER	Unknown Leafminer	
MITE	Unknown Mite	
MITEGALL	Unknown Gall Forming Mite	
MONSCU	Whitespotted Sawyer Beetle	*Monochamus scutellatus*
MOTTLE	Mottled Foliage	
NECCIN	Nectria Canker	*Nectria cinnabarina*
NECROSIS	Necrosis	
NEOspp	Sawfly species	*Neodiprion* spp.
NONE	No damage recorded	
NOx	Nitrogen Oxides	
ODOVIR	White-tailed Deer	*Odocoileus virginianus*
OLIUNU	Spruce Spider Mites	*Oligocentria ununguis*
OPEBRU	Bruce Spanworm	*Operophtera bruceata*
OTH/R	Other damage to the roots	
OTH/S	Other damage to the stem	
OZONE	Ozone Flecking	
PARTUM	Balsam Gall Midge	*Paradiplosis tumifex*
PEMPOP	Poplar Petiole Gall Aphid	*Pemphigus populitransversus*
PEMspp	Aphid species	*Pemphigus* spp.
PENPOL	White Rot	*Peniphora polygonia*
PENspp	Peniophora species	*Peniphora* spp.
PETALB	Northern Pitch Twig Moth	*Petrova albicapitana*
PETspp	Pitch Moth	*Petrova* spp.
PHEPIN	Red Ring Rot Fungus/Conifers	*Phellinus pini*
PHEspp	Phellinus species	*Phellinus* spp.
PHETRE	False Tinder Conk	*Phellinus tremulae*
PHRspp	Leaf Beetles	*Phratora* spp.
PHYNIP	Leaf Miner	*Phyllonorycter nipigon*
PHYPOP	Aspen Serpentine Leafminer	*Phyllocnistis populiella*
PHYSAL	Leaf Miner	*Phyllocnistis* spp.
PICspp	Woodpecker species	*Picoides* spp.

Agent	Common Name	Scientific Name
PINSIM	Ragged Spruce Gall Adelgid	*Pineus similis*
PISSTR	White Pine Weevil	*Pissodes strobi*
PISTER	Lodgepole Terminal Weevil	*Pissodes terminalis*
PROTHO	Ambermarked Brich Leaf Miner	*Proteoteras thomsoni*
PSEORE	Aspen Leafroller	*Pseudexentera oregonona*
PUCEPI	Needle Rust	*Pucciniastrum epilobii*
REDBELT	Redbelt	
RESN/S	Unidentified resinosis/mycelium on the stem	
RHYBAR	Rough Bark	*Rhytidiella baranyayi*
RHYspp	Jack Pine Shoot Borer	*Rhyacionia* spp.
ROLLER	Unknown Leafroller	
RUST	Unknown Rust	
SAPCAL	Poplar Borer	*Saperda calcarata*
SAPFLOW	Unknown Sapflow	
SAWFLY	Unknown Sawfly	
SKEL	Unknown Skeletonizer	
SNOWLEAN	Snow Damage Leaning	
SO2	Sulfur Dioxide	
SPHVAR	Yellow-bellied Sapsucker	*Sphyrapicus varius*
STRESSCK	Stress Crack	
SUNSCALD	Sun Scalding	
TAMHUD	Red Squirrel	*Tamiascurus hudsonicus*
TARGET	Unknown Target Canker	
TRYRET	Bark Beetle	*Trypodendron retusum*
UNCADU	Powdery Mildew	*Uncinula adunca*
UNK	Unknown Agent	
URSAME	Black Bear	*Ursus americanus*
URSARC	Grizzly Bear	*Ursus arctos*
VENMAC	Leaf and Twig Blight	*Venturia macularis*
WEATHE	Weather Damage	
WHIPPING	Whipping	
WINFLECK	Winter Needle Flecking	

Appendix A2. Snag Plot Survey Methods

Appendix A2. Snag Plot survey methods

The goal of the research is to monitor the structure and the decay of the standing dead tree (snag) component of a forest stand when subjected to various harvesting treatments, to determine which treatment best emulates a natural fire disturbance. Monitoring surveys to identify the species, DBH, height, height class, percent bark retention, and decay class have been conducted at EMEND in each compartment.

Plot Establishment

The 1998 snag survey initially utilized the six permanent tree plots (measuring 40x2 m) that were randomly located within each compartment. In 2000, however, it was decided that the permanent tree plots did not provide a sufficient sample area to survey snags. An expanded snag plot design (40x10 m) was overlaid on the existing permanent tree plot. Figure 13 illustrates the layout of the tree plot in relation to other the other plots contained within each PSP.

Snag Numbering

All standing dead rooted or not rooted trees (snags) meeting the following criteria of the point of germination within 5 m perpendicular to the plot mid-line, a complete DBH >=5.0 cm, height >=1.3 m, and lean <45o from vertical are assessed. The compartment number, plot number, snag number (if within the tree plot), tag number and species were recorded. Table A4 lists the coding used to identify tall shrub species in addition to those tree species listed in Table A2. Once the experimental treatment was conducted in the compartment a unique metal tree tag was attached to each snag still standing with electrical phone wire at DBH. This metal tag number is now used to identify the snag. New snags since the last assessment will be added to the data and tagged with a unique metal tree tag. The tag numbers used at EMEND are unique and shared between the Tree, Snag and Growth & Yield Plots. If a snag is missing the original assigned tag, then a 'write-on' tag is to be used as a replacement with the original tag number clearly inscribed on it. Do not assign a previously tagged snag a new tag number as a replacement for the missing tag.

Table A4. Shrub species code list.

Species	Common Name	Scientific Name	Vegetation Type
Alncri	green alder	*Alnus crispa*	S
Alnrug	mountain alder	*Alnus rugosa*	S
Salspp	willow species	*Salix species*	S
Unk	unknown		

Snag Data Collection

Each snag is assessed for status (dead, fallen, cut), DBH (cm) (Figure A2), height (m), height class (Figure A6), decay class (Figure A7), and percent bark retention (to the nearest 20%) (Table A5). In 1998, the height of each snag was measured. Surveys conducted in 2000, and 2001 did not measure the height of each snag, but instead assigned each snag a height class. The full height in meters was assessed again in 2004 for all snags surveyed and all subsequent surveys. Snag plot surveys commenced with 1998 serving as the baseline year and subsequent study wide surveys occurring in 2000, 2001, 2003, 2005, 2008 and 2016. In 2004, a post treatment snag survey was conducted in the slash harvest (SH) and slash burn (SB) compartments. In 2007, a post treatment survey was conducted in compartments 8830 and 8910 following burn treatments in 2006.

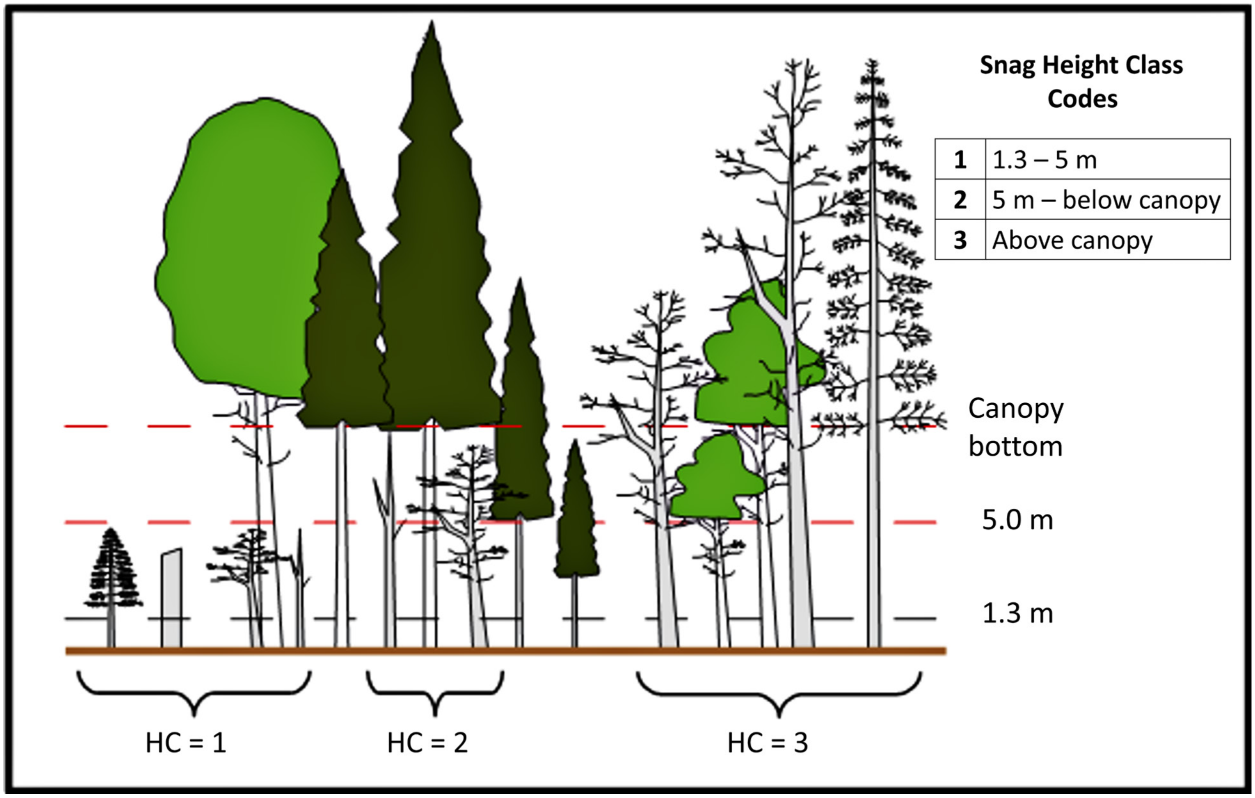


Figure A6. Snag height class codes used as part of the snag assessment.

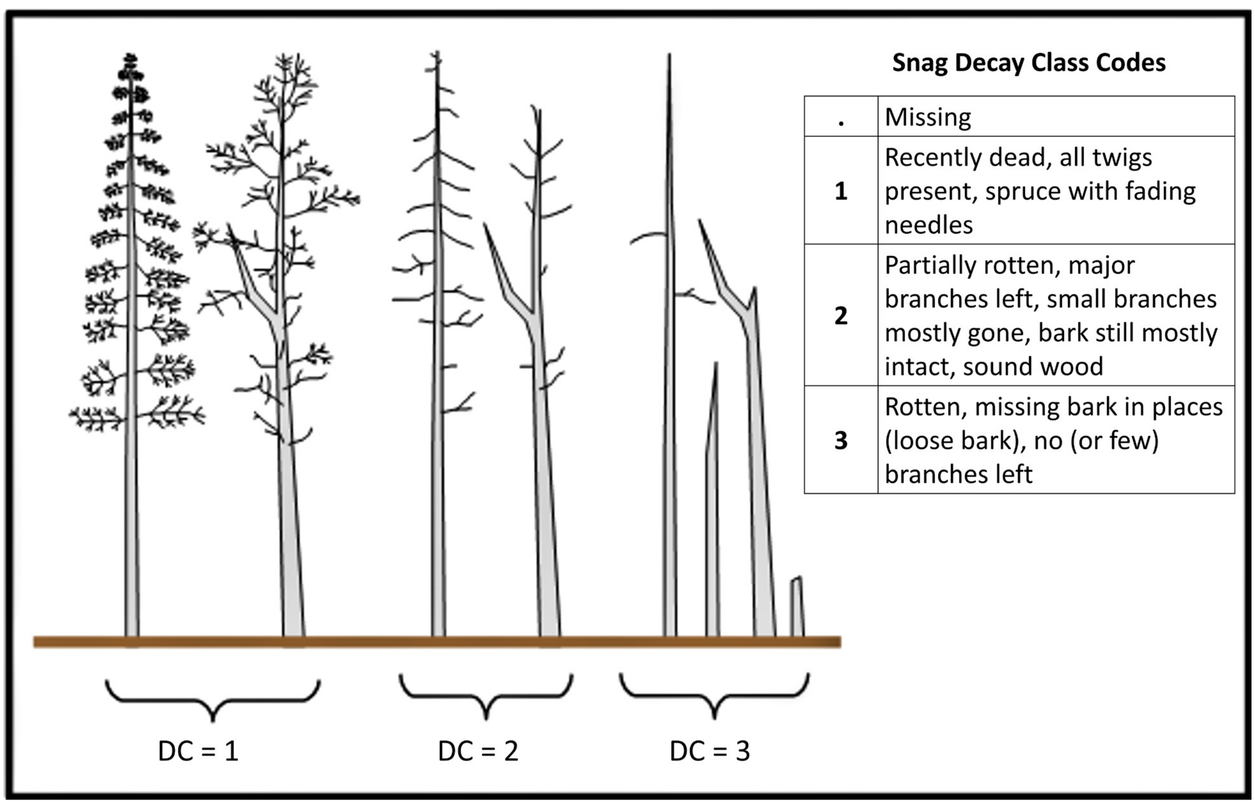


Figure A7. Snag decay class codes used as part of the snag assessment.

Table A5. Coding to denote percent bark retention classes on snags.

% Bark Retention	Percent Bark Retention Definition
0	No bark present
20	20% of the bark retained
40	40% of the bark retained
60	60% of the bark retained
80	80% of the bark retained
100	100% of the bark retained

Snag Plot Re-Assessment

For subsequent remeasurement of Snag Plots the following steps are recommended to be followed to ensure the integrity of the dataset.

1. Download the data from the previous survey from the EMEND Database. The previous survey data provides field crews with a list of snags present during the last assessment to assist with data collection consistency between surveys.

2. Upload the data to a field database application installed on an electronic field data collection device. Data field parameters should be set to ensure only valid codes are used and deviations from a normal snag progression are flagged so field crews can re-check the data being entered.

3. Each snag is to be assessed using the established protocols and codes described above in the methods.

– Establish the 40 m mid-line for the snag plot.

– All snags with a germination point within 5 m perpendicular to the mid-line, with a complete DBH >= 5.0 cm, height >= 1.3 m and lean <45o from vertical are to be assessed. Previous surveyed snags no longer meeting these criteria are to be recorded as fallen. Once a snag is recorded as fallen it no longer needs to be assessed in subsequent surveys.

– Previously assessed snags have retained their assigned unique tag number for the duration of the study. Snag and Tree plots overlap and share the same unique tag number sequence. Do not reuse tags once they have been assigned. If this is done it will have a significant impact on the analysis and future assessments of snag and tree plot. Previously assessed snags with missing tags should be searched at their base. If the original tag is unable to be located, use a 'write-on' tag with the assigned tag number clearly inscribed on it and attach it to the snag.

– DBH: Using a measuring stick, measure the DBH at 1.3 m and record the diameter in centimeters to one decimal place. Mark the DBH line for subsequent remeasurements and note any variations of the DBH if any from the previous assessment. The DBH should not change significantly between assessments (Figure A2).

– Height: Measure the height of the snag to the highest point of the snag and record the height in meters to one decimal place. Care must be taken to measure the height perpendicular to any lean. Heights must be taken from a location at minimum distance from the snag as it is tall. Note any deviations, if any, and leans in the comments. Snags should not increase in height from the previous assessment unless the previous measurement was incorrect.

– Height Class: Follow the height class codes provided in Figure A6. All snags less than or equal to 5 m are coded as '1'. Codes '2' and '3' are based on the general compartment level height of the bottom of the crown.

– Decay Class: Follow the decay class codes in Figure A7. The logical progression of a snag is to decay over time moving from class 1 to 3.

– Percent Bark Retention: Record the percentage of bark retain to the nearest 20% category (Table A5).

– Comments: All deviations from a normal progression of a snag (i.e., DBH growth, height growth, improvement in the height class, decay class or percent bark retention) are to be noted in the comments. This is necessary to assist with data validation and analysis.

– Equipment required: 40m tape, DBH tape, 1.3 m Measuring stick, Clinometer, Data sheets or data-logger.

Appendix A3. Downed Coarse Woody Debris (DWD) Plot Survey Methods

The goal of the research is to monitor the structure and the decay of the Downed Coarse Woody Debris (DWD) component of a forest stand when subjected to various harvesting treatments to determine which treatment best emulates a natural fire disturbance. DWD is an important aspect of the structure and dynamics of forests. It provides critical wildlife habitat, contributes to nutrient cycling and energy flow, and provides structure for regulating sediment displacement. Insight into the dynamics of DWD will help to understand the impact of proposed experimental treatments on the DWD cycle. Therefore, DWD quantity, quality, and dynamics represent core variables to be measured across the entire EMEND experiment. Monitoring surveys to identify the species, diameter (cm) at intersect, and decay class have been conducted at EMEND in each compartment.

Plot Establishment

The DWD survey co-locates plots within the six Tree plots located within each compartment. All Tree plots were established in an east-west orientation so that they are perpendicular to the north-south orientated machine corridors. Refer to the EMEND Tree Plot Survey Methods for a detailed description on how these plots were established.

In 1998, a CWD survey was conducted on each of the Tree plots. A transect line (40 m) was established down the center of the Tree plot. Logs (downed material) that were >= 7.0 cm in diameter found inside the plot, as well as snags and stumps (standing material) were all measured in the same pass.

In 1999, a method change was introduced to the CWD survey, and a star plot design was adopted in place of the single transect line which to address issue of including CWD pieces that fell parallel to the transect line. The Tree plot 40 m mid-line was divided into 5 m intervals to avoid overlapping of plot lines. Three star-plots are randomly placed at an interval of 0, 5, 10, 15, 20, 25, 30, and 35 meters as measured from the start point of each Tree plot, so that line 1 of each CWD plot would fall within the Tree plot. The new permanent CWD plots were established starting with the first plot 'x.1' nearest the beginning of the transect line, followed by 'x.2' and finally 'x.3', where 'x' is in reference to the Tree plot number (Figure 13). Subsequent surveys conducted in 2001, 2004 and 2008 were conducted at these established locations. In 2016, the location of the CWD plots were randomly selected again along the Tree plot mid-line. Future surveys should use the original established plot distances prior to 2016. There are 18 CWD plots in each compartment, except for the slash harvest (SH) and slash burn (SB) compartments, in which there are 9 CWD plots, each.

The CWD plot consists of three lines (numbered 1 to 3 in a clockwise fashion), 5 m long, separated by 120o with line 1 placed along the Tree plot mid-line in the direction away from the permanent tree plot start (Figure A8). At the time of plot establishment, the location of each line within a plot is determined for its relation to the harvesting treatments and recorded (Table A6). This is completed the first time the plot is established and is not required to be completed in subsequent surveys unless the plot is moved from the original position.

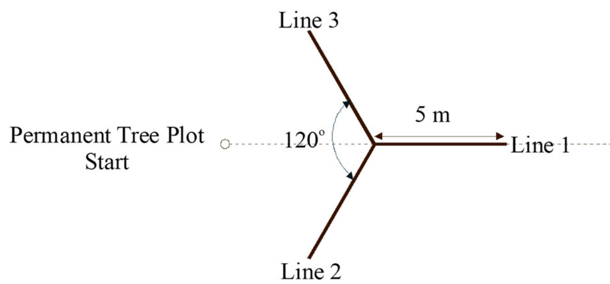


Figure A8. Diagram of star plot setup in relation to the PSP.

Table A6. Codes used to denote star plot location within each PSP.

Location	Location Definition
0	Missing or not applicable
1	Treatment retention strip / Control
2	Harvesting machine corridor / Clear cut
3	Edge (where line includes both locations, 1 & 2, in any arrangement)

Downed Coarse Woody Debris Data Collection

DWD plot surveys commenced with 1998 serving as the baseline year. Each piece of DWD on the Tree plot with a diameter >= 7.0 cm that intersected the transect line 'A' (the left side plot edge) was assessed for species (Table A7), diameter A, and decay class (Table A8). In addition, a diameter at the mid-point of the length, diameter B, elevation and percent bark retention was also measured. All pieces of DWD found inside the Tree plot were also assessed. The additional variables and assessment of all DWD pieces found inside the Tree plot were subsequently dropped from other surveys and therefore, not included data set.

Subsequent surveys were conducted with the new star-plot design, occurring 1999, 2001, 2004, 2008 and 2016. In 2003, a post-harvest survey was conducted in the slash harvest (SH) and slash burn (SB) compartments. In 2007, a post treatment survey was conducted in compartments 8830 and 8910 following burn treatments in 2006.

Table A7. Species codes used for DWD pieces.

Species code
. (No DWD)
Abies balsamea
Alnus crispa
Alnus rugosa
Alnus tenuifolia
Alnus species
Betula papyrifera
Betula species
Coniferous
Deciduous
Larix laricina
Picea glauca
Picea mariana
Picea species
Pinus contorta
Pinus species
Populus balsamifera
Populus species
Populus tremuloides
Salix species
Unk (unknown)

Table A8. Downed woody debris decay classification.

Decay Class	Leaves/ Needles	# Limbs > 1m long	% of stem covered by moss or lichen (applies more to *Populus*)	% of cross-sectional area showing decay (applies more to *Populus*)	% Bark cover	Wood condition
1	Few or absent	>20	0-10	<10	90-100	Still hard and/or dry
2	Absent	5-19	11-30	10-50	60-90	Beginning to soften, often can be cracked with effort
3	Absent	<5	>30	>60	<60	Soft and punky/damp

Measurements:

Data collected for each plot should include the date, crew, compartment, DWD plot identifier, distance from the Tree plot start and line location (if moved from previous established distance). For the EMEND experiment, a piece of DWD is defined as fallen coarse woody material with a diameter >= 7.0 cm and a lean > 45o. Field crews should make every effort to disturb the DWD as little as possible as measurements will continue to be taken in future surveys. As much as possible, use the same person to take the measurements. The following variables are assessed for each DWD piece.

– Piece number: Each piece of DWD that is intersected by the sample line moving from the center pole to the end of the line is to be assessed. The numbering of pieces starts with 1 for each of the three lines in the plot. Those lines with no DWD present have a piece number of -9 with the comment 'No DWD present.' entered in the data.

- Species: The species of each piece being assessed is to be recorded. Table A7 provides a list of species that have been recorded in previous surveys. Pieces of DWD that are difficult to identify to species may still yield information and some attempt is to be made to categorize them. Unknown pieces of DWD are of little or no use in answering any advanced biological questions about changes in DWD composition among compartments. As a rule of thumb, most problematic DWD pieces can be placed into one of three broad categories that still yield some biological information:
- Deciduous Understory: Primarily alder and willow, but also any other deciduous species whose normal growth form is significantly below normal co-dominant canopy height (e.g., mountain ash, Saskatoon, etc., but only providing the pieces meet the minimum diameter criteria).
- Deciduous Overstory: Primarily aspen and balsam poplar pieces where exact species identification is problematic, but also any other deciduous species whose normal growth form is often within normal co-dominant canopy height (e.g., birch).
- Conifer: Any coniferous species.

A nested approach to species identification is the most useful. Begin by assigning the piece of DWD to one of the above categories and continue to narrow the identification down to the species level if possible. For example, a piece of wood could be identified as follows:

1. Is it coniferous or deciduous? Answer: Coniferous.
2. Is it a spruce, fir, larch, or pine? Answer: Picea spp.
3. Is it a white spruce or a black spruce? Answer: Picea glauca.

If at any time in the identification chain an answer cannot be answered, then the lowest taxonomic category obtained should be entered in the data. For the above example, if question 1 is the only level that can be achieved with confidence, then the species is 'Coniferous', if question 2, then 'Picea spp.', if question 3 then 'Picea glauca'.

- Diameter: Diameters are to be recorded to the nearest 0.1 cm at the point where the line first intersects the material, perpendicular to the long axis of the piece, not the length crossed by the plot line (Figure A9).
- Decay class: Each piece is assessed using the codes provided in Table A8. The decay classes are highly variable and somewhat subjective, and not every piece of DWD will be consistent for all criteria. These criteria are surrogates for wood condition. The best approach is to consider all pieces of DWD to be decay class = 2, unless proven otherwise with reasonable certainty. Final decay class assignment will be the result of a balance of all criteria.
- Comments: Comments concerning the piece being assessed should be recorded to assist in providing researchers and explanation of any variations being observed.
- Equipment Required: 60m tape, Compass, Clinometer, Star-plot center pole with 5m cord, DBH tape, data sheets or data-logger

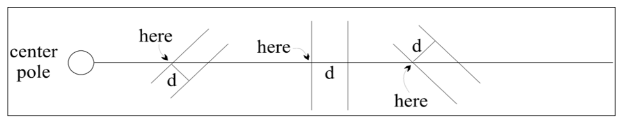


Figure A9. Visual description on how the diameter of DWD pieces should be taken depending on their orientation along the plot line.

Downed Woody Debris Plot Re-Assessment

1. As individual DWD pieces are not tracked from survey to survey there is no need to download the previous survey data. A complete list of the DWD plots with their distance locations should be provided to ensure all plots are assessed and are relocated at the previously established locations.
2. A field database application installed on an electronic field data collection device is recommended. Data field parameters should be set to ensure only valid codes are used and deviations in data entry are flagged so field crews can re-check the data being entered.
3. A crew of two is likely the ideal size for data collection. A measuring tape or chain should be run down the mid-line of the Tree plot from the start peg to the end peg. Keep the line as straight as possible and let it rest on the ground. Relocate the DWD plot centers at the previously determined distances. This distance was originally randomly selected and

will vary so care must be exercised to ensure the DWD plot is re-established in the correct spot.

4. Establish the three lines in each DWD plot. Each of the three lines in the DWD plot are separated by 120o with the first line established on the Tree plot mid-line.
5. A list of vegetation species previously observed during the DWD survey can be found in Table A7 and printed off for the field crews to use as a reference.
6. Each piece is to be assessed using the established protocols and codes described above in the methods. A list of the decay class codes can be found in Table A8 and printed off for the field crews to use as a reference.

Appendix A4. Shrub Plot Survey Methods

The goal of the research is to monitor the structure and the rate of change of biomass in the shrub component of a forest stand when subjected to various harvesting treatments to determine which treatment best emulates a natural fire disturbance. Monitoring surveys to identify the species, height (stem length) and diameter at 0.3 m above the point of germination for shrubs (tree species <5.0 cm at DBH) have been conducted at EMEND in each compartment.

Plot Location and Size

A permanent shrub plot (measuring 2 x 10 m) was located and overlaid at the start and end of each permanent tree plot in a compartment, therefore, twelve permanent shrub plots were established in each compartment for a total of 1200 plots across the EMEND landscape. To set up the shrub plots, a measuring tape measure was run from the start to the end of the 2 x 40 m tree plot. Extra care was taken to set the tape as close to the mid-line as possible. A 2 x 10 m plot was created at the start (and, later, the end) of the tree plots by using a second measuring tape; one meter of the plot was placed on either side of the tree plot mid-line (Figure 13). A pigtail marked with blue flagging tape was placed along the mid-line at the end of each shrub subplot (10 m in from the start/end of the tree plot). All shrub plots located at the start of the tree plot were numbered with the suffix "-1" (e.g., 1-1 is the shrub plot located at the start of the tree plot 1). Shrub plots located at the end of the tree plot were numbered with the suffix "-2" (e.g., 1-2 is the shrub plot located at the end of the tree plot 1). The mid-line UTM coordinates for the start and end of each plot were determined in SAS using the coordinates provided for the associated tree plot. After the treatments were conducted in the winter of 1998 some plots were destroyed beyond the limits of the prescribed treatment and were therefore replaced. In 1999, new shrub plots were established to replace those that were destroyed, to maintain the twelve plots per compartment design.

Each plot was assessed for the percentage of the plot being in a machine corridor, vegetation strip, or clear-cut in 2001/2002.

Shrub Data Collection

Each shrub is assessed for location (machine corridor, vegetation, clear cut), species, status (living, dead), diameter (cm) at 0.3 m, height (m), browsed (yes, no) and broken (yes, no). For a shrub stem to be considered "on-plot" it had to be rooted inside the permanent shrub plot. A shrub stem could be rooted inside the plot and be leaning out. All shrub and tree species were considered in this survey. Shrub stems with a diameter ≥ 1.00 cm at a height of 0.3m and tree species stems with a diameter ≥ 1.00 cm at a height of 0.3 m and a diameter < 5.0 cm at 1.3 m (DBH) were assessed. All stems were assessed even if they shared the same base with another stem.

Some areas around the EMEND site were observed to be heavily browsed by ungulates (moose and deer). As such, a survey, done in conjunction with the shrub biomass project, was conducted in 2001 to estimate the amount of ungulate browsing at the EMEND site. Each stem measured in the shrub biomass study was assessed for any indication of browsing. Browsing was defined as any twig or branch that appeared to be cleanly snipped off. In addition, a count of all shrubs under 1.00 cm diameter (at 0.3 m above ground) and > 0.3 m tall was conducted and all counted shrubs were assessed for browsing. Defoliated leaves and leaves removed at petiole are not considered evidence of browsing. Initial analysis of the 2001 Shrub "Browsing" data of stems <1.00 cm in diameter indicated non-significant results and as such, no 2002 shrub browsing data for stems <1.00 cm in diameter were collected. In the years post 2002, shrub stems were continued to be noted when browsed to help explain data inconsistencies (for example, a browsed stem may have a lower height:diameter ratio than expected).

Shrub plot surveys commenced in 1998 serving as the baseline year with subsequent study wide surveys occurring in 2001 (2001/2002), 2005, 2010 (2010/2011/2013) and 2016 (2016/2017 all compartments except DU compartments). In 2003, all slash burn compartments were assessed as a post-harvest – pre-burn assessment and a post-burn assessment was conducted in 2004. A partial shrub survey was conducted in 2007 in the newly burnt compartments 8830 and 8910.

In some compartments it was difficult to differentiate between the retention strips and the machine corridors (especially in 10% and 20% treatments). Total values in the retention strips (VEG TOTAL) and machine corridors (COR TOTAL) may thus seem off for some shrub plots in these compartments. In addition, some plots in higher retention treatments (i.e., 50%, 75% and Burns) had COR TOTAL values that were high (or, in the case of burns, present when they should not have been). Smaller variations in corridor width for plots in 50% and 75% retention treatments were normally due to minute inconsistencies during harvesting. Larger variations were most often due to factors such as adjacency to compartment boundaries or ellipses.

Shrub plot descriptions (i.e., number of meters of "Vegetation," "Corridor" or "Clear-Cut" in each 10m shrub plot) were re-checked for each of the shrub plots in the slash burn (SB) compartments in 2005 to rectify inconsistencies between 2003 and 2004 shrub plot descriptions. A complete shrub plot description list for all EMEND shrub plots is now available for future measurements. Note: Some 2005 slash-burn shrub records have a measurement in the comments section – this measurement is the distance of the shrub stem from the start of the shrub plot. These measurements were taken to try and rectify data problems arising from varying shrub plot descriptions between years.

Some shrubs in the data set seem unusually short when compared with their corresponding diameters. These shrubs were most likely broken or heavily browsed. The absence of the shrub being indicated as broken or browsed is likely a result of recording error.

In all the years post-harvest when shrub data was collected (2001 - present), shrub "height" is equivalent to stem length. Since no shrub assessment methods could be found from 1998, it is unknown whether shrub heights taken during this year's assessment were also equivalent to stem length or if the height was measured straight up from the ground to the highest point on the stem.

Shrub Plot Re-Assessment

For subsequent remeasurement of shrub plots the following steps are recommended to be followed to ensure the integrity of the dataset.

1. As individual shrubs are not tracked from survey to survey there is no need to download the previous survey's data. A complete list of the shrub plots should be provided to ensure all plots are assessed.
2. A field database application installed on an electronic field data collection device is recommended. Data field parameters should be set to ensure only valid codes are used and deviations in data entry are flagged so field crews can re-check the data being entered.
3. Each shrub is to be assessed using the established protocols and codes described above in the methods.

- Establish the 40 m mid-line for the tree plot from the start of the plot. The first 10 m are shrub plot *-1 and the last 10 m are shrub plot *-2 (* refers to the compartment and pot unique identifier). Shrub plots are 2 x 10 m in dimension.
- Assess all shrubs (> 1 cm at 0.3 m above ground) and all tree species (> 1 cm at 0.3 m above the ground, but < 5.0 cm DBH) that have germinated within 1 m perpendicular to each side of the mid-line.
- Species: record the species of the shrub.
- Status: Living or Dead.
- Diameter: measure the diameter of the stem 0.3 m above the ground. Diameters are recorded in centimeters to two decimal places.
- Height: record the length of the shrub in meters to one decimal place.
- Browsed: indicate if the stem has been browsed (Yes/No).
- Broken: indicate if the stem has been broken (Yes/No).
- Comments: Record any additional comments concerning the shrub.
- Equipment required: 40m and 30m tape, Metric carpenter's tape, 6 pigtail pegs, Small calipers, Marker, DBH tape, Blue flagging, Data sheets or data-logger.

Appendix A5. Understory Vegetation Plot Survey Methods

The goal of the research is to monitor the type, direction, and rate of change in the ground vegetation following the various treatments to evaluate if the pattern of change is the same, or if not, what level of tree retention comes closest to emulating the effects of fire. Monitoring surveys to identify the presence and percent cover of vegetation species have been conducted at EMEND in each compartment.

Plot Location and Size

An Understory Vegetation plot was located at the midpoint of each permanent tree plot in a compartment (Figure 13). Therefore, six Understory Vegetation plots measuring 5x5 m were established in each compartment for a total of 600 plots. The Understory Vegetation plot is used to assess the percent cover of trees and tall shrubs. A 2x2 m subplot was nested in the southeast corner of each Understory Vegetation plot and the percent cover for species belonging to the low shrubs, forbs, graminoids, bryophytes, and lichens vegetation strata is assessed.

Understory Vegetation Data Collection

The percent cover of foliage for each species identified is estimated as follows in the following categories: 0.1%, 0.5%, 1-20% (to nearest %), and 20%+ (to nearest 5%). Species are classified into 7 different vegetation strata (Table A9).

Table A9. Vegetation strata classification codes used for the understory vegetation data collection.

Classification code	Stratum
1	Trees (DBH > 5 cm)
2	Tall shrubs (Height > 1.5 m)
3	Low shrubs (Height < 1.5 m)
4	Graminoids
5	Forbs
6	Bryophytes
7	Lichens

The percent cover for trees and tall shrubs is determined on the 5x5 m Understory Vegetation plot. The percent cover for low shrubs, forbs, graminoids, bryophytes, and lichens is determined on the 2x2 m nested subplot. Species from the low shrubs, forbs, graminoids, bryophytes, and lichens strata not assessed on the 2x2 m subplot but found within the 5x5 m Understory Vegetation plot are recorded in the data with the percent cover as −1% to indicate the presence of the species. The field data collection sheets used for each plot to collect the Understory Vegetation data are displayed on Figure A10.

ECOSYSTEM MANAGEMENT EMULATING NATURAL DISTURBANCE (EMEND)

Compartment:________ **Plot**:______ **Date:**____________ ,2004 **Observers:**____________________________
Tagged Tree Numbers: ________________ Standing Dead Trees: Sp. ________ No. ____ Sp. ________ No. ____
Comments:____
____

Strata	ht(cm)	cov	**Strata Cover**		**Tree Understory** (<5 cm DBH)			
tree (>5cm DBH)		___	grass cover	_____	Based on 5 x 5 m plot			
tall shrub (>150 cm)	____	___	forb & dwarf shrub cover	_____		spp	ht (cm)	no.
low shrub (<150 cm)	____	___	moss cover	_____	>150 cm	___	____	___
Note: Trees smaller than 5 cm DBH			lichen cover	_____		___	____	___
are put into the appropriate shrub					<150 cm	___	____	___
strata.						___	____	___

Cover: + (0.1), 0.5, 1-20 (to nearest %), 20+ to nearest 5 %. This is based on foliage cover. Tree and tall shrub cover based on 5x5 m plot, the rest based on 2x2 m plot. Record low shrub, forb, moss & lichen species found in 5x5 m plot but not found in 2x2m plot as P (present).

Trees	**LS**	**TS**	**T**(%,# Live)
Abi bal	___	___	_____,_____
Bet pap	___	___	_____,_____
Pic gla	___	___	_____,_____
Pic mar	___	___	_____,_____
Pin con	___	___	_____,_____
Pop bal	___	___	_____,_____
Pop tre	___	___	_____,_____
___ ___	___	___	_____,_____

Shrubs	**Low**	**Tall**
Aln cri	_____	_____
Aln ten	_____	_____
Ame aln	_____	_____
Bet pum	_____	_____
Cor sto	_____	_____
Led gro	_____	_____
Lon dio	_____	_____
Rib gla	_____	_____
Rib hud	_____	_____
Rib lac	_____	_____
Rib oxy	_____	_____
Rib tri	_____	_____
Ros aci	_____	_____
Rub ida	_____	_____
Sal ____	_____	_____
She can	_____	_____
Sym alb	_____	_____
Vac cae	_____	_____
Vib edu	_____	_____
___ ___	_____	_____
___ ___	_____	_____

Graminoids

Agr tra	_____
Cal can	_____
Cin lat	_____
Car ____	_____
Ely inn	_____
Poa ____	_____
Sch pur	_____
___ ___	_____
___ ___	_____
___ ___	_____

Forbs

Ach mil	_____
Act rub	_____
Ara nud	_____
Arn cor	_____
Ast ame	_____
Ast cil	_____
Ast con	_____
Cal bul	_____
Cir alp	_____
Cor can	_____
Cor tri	_____
Del gla	_____
Dry car	_____
Epi ang	_____
Equ arv	_____
Equ pra	_____
Equ sci	_____
Equ syl	_____
Fra vir	_____
Gal bor	_____
Gal tri	_____
Geo liv	_____
Goo rep	_____
Gym dry	_____
Hab orb	_____
Her lan	_____
Lat och	_____
Lin bor	_____
Lyc ann	_____
Lyc com	_____
Mai can	_____
Mer pan	_____
Mit nud	_____
Moe lat	_____
Mon uni	_____
Osm dep	_____
Ort sec	_____
Pet pal	_____
Pyr asa	_____
Pyr chl	_____
Rub pub	_____
Tha ven	_____
Vac vit	_____
Vic ame	_____
Vio ren	_____
___ ___	_____
___ ___	_____
___ ___	_____
___ ___	_____

Mosses

Amb ser	_____
Aul pal	_____
Bra spp	_____
Cer pur	_____
Cli den	_____
Dic fra	_____
Dic fus	_____
Dic pol	_____
Dic und	_____
Dre unc	_____
Eur pul	_____
Hyl spl	_____
Mni spi	_____
Onc wah	_____
Pla cus	_____
Pla dru	_____
Pla ell	_____
Ple sch	_____
Poh nut	_____
Pol com	_____
Pol jun	_____
Pti pul	_____
Pti cri	_____
Pyl pol	_____
Rhi pse	_____
Sph ___	_____
Thu rec	_____
Tom nit	_____
___ ___	_____
___ ___	_____
___ ___	_____
___ ___	_____

Lichens

Cla mit	_____
Cla spp	_____
Cla ___	_____
Nep res	_____
Pel aph	_____
Pel can	_____
Pel eli	_____
Pel mal	_____
Pel nec	_____
Pel neo	_____
___ ___	_____
___ ___	_____
___ ___	_____

Figure A10. Understory vegetation field data collection form using in 2009.

Understory Vegetation Plot Re-assessment

For subsequent remeasurement of understory vegetation plots the following steps are recommended to be followed to ensure the integrity of the dataset.

1. As individual plants are not tracked from survey to survey there is no need to download the previous survey's data. A complete list of the understory vegetation plots should be provided to ensure all plots are assessed.
2. A list of vegetation species previously found at EMEND can also be downloaded and printed off from the EMEND Database (Species_Vegetation_Codes table) for the field crews to use as a reference.
3. A field database application installed on an electronic field data collection device is recommended. Data field parameters should be set to ensure only valid codes are used and deviations in data entry are flagged so field crews can re-check the data being entered.
4. Each vegetation species is to be assessed using the established protocols and codes described above.

- Establish the 40 m mid-line for the tree plot from the start of the plot and locate the 5 x 5 m understory vegetation plot in the center. The 2 x 2 m subplot should be in the SE corner of the 5 x 5 m plot.
- Estimate the percent cover for each species in the appropriate vegetation strata as outlined above.
- Collect and appropriately label unknown species for identification in the laboratory.
- Estimate the total percent cover for each vegetation strata.
- Record any additional comments as required.
- All new species or changes to accepted names is to be recorded on a separate worksheet in the data file being submitted. Data should be submitted within one year of collection.
- Equipment required: 50m tape, Metric carpenter's tape, 1% square, Vegetation plot tags, 8 pigtails, Cheeto flagging tape, Data sheets, Marker, DBH tape, Calipers, Sample bags and labels, Plant identification books (Suggested references include Moss, E. H. 1983. Flora of Alberta. Second edition. University of Toronto Press, and Johnson, D., Kershaw, L., Mackinnon, A., Pojar, J. 1995. Plants of the Western Boreal Forest & Aspen Parkland. Lone Pine.)