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PROJECT REPORTS 2003/2004

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January 2004

Published: 6 February 2004

Related SFM Network Project:
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Project name: Impacts of post-burn salvage logging on plant biodiversity and tree regeneration of the mixedwood boreal forest

IMPACTS OF POST-FIRE SALVAGE LOGGING ON TREE REGENERATION AND PLANT COMMUNITIES IN THE MIXEDWOOD BOREAL FOREST OF ALBERTA

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Keywords: boreal mixedwood forest, salvage logging, fire, plant biodiversity, tree regeneration, forest structure, coarse woody material

January 2004

Abstract

We examined the impacts of post-fire salvage logging on the forest structure, tree regeneration and understory plant communities of burned, aspen-dominated mixedwood forest stands of North-eastern Alberta, Canada. Representative unsalvaged and salvage logged burned forest stands were compared for early (2 years post-disturbance) and mid (34 years post-disturbance) successional forest development stages. Deciduous regeneration in the immediate post-disturbance time period was significantly better in unsalvaged stands with greater sapling heights and nearly double the stem densities of salvage logged stands. In the older stands, there was no evidence of effects of salvage logging on regeneration of aspen. However, conifer regeneration in salvaged stands was substantial, likely due to post-salvage site preparation and aerial seeding. The understory plant communities of early successional salvaged stands were characterized by the presence of introduced weedy species, greater patchiness within stands, and marked differences in species composition. Notably, salvaged stands had higher abundances of shrubs and grasses, and lower abundances of post-fire specialist plant species as compared to unsalvaged stands. For the older stands, differences in understory composition between the salvaged and unsalvaged treatments were relatively weak and were complicated by the influence of important drivers of understory composition; e.g., the presence, or lack therefore, of white spruce. Salvaged stands were also characterized by relatively high densities of tall shrubs. We conclude that salvage logging may negatively affect aspen regeneration, and will influence the forest microenvironment, amounts of dead wood, and the understory plant community. Thus the ecological structure, habitat value, and biodiversity of salvage logged stands are likely to be different than of unsalvaged wildfire stands.

Background and Objectives

The nature of large-scale, stand-replacing disturbance in the boreal mixedwood forest of Alberta has been altered in recent decades. Increased efficiency in fire detection and suppression has resulted in a decrease in the number of wildfires (Cumming 1997, Murphy 1985), while forest harvesting is becoming an increasingly prevalent disturbance on the boreal landscape. To compound this effect, salvage logging of fire-damaged, merchantable-sized trees has become a common activity immediately following many wildfires in the western boreal forest of Canada. As a result, unmanaged post-burn forest ecosystems are becoming increasingly rare on the commercial forest landbase and may be in danger of being eliminated from the boreal landscape.

Plant communities of early post-fire forest stands support unique understory plant assemblages, dominated by species that are uncommon or rare at other stages in forest succession (Lee 1999, Crites 1999). Shade intolerant, early successional species, and post-fire specialists dominate early post-fire communities (Rowe 1983, Turner et al. 1997, Whittle et al. 1997, Crites 1999). In the boreal forest several species [corydalis (*Corydalis sempervirens, C. aurea*), Bicknell's geranium (*Geranium bicknellii*), American dragonhead (*Dracocephalum parviflorum*)] are known to be dependent upon wildfire to break seed dormancy and remove surface layers of soil organic matter (Johnson 1981, Fyles 1989, Crites 1999). Early post-fire plant communities may be even more distinctive than those communities associated with old growth aspen mixedwood forests (Stelfox 1995).

Salvage logging is likely associated with important changes in forest microenvironment, including effects on light, air temperature, and relative humidity. In addition, removal and disturbance of downed wood and the organic layer likely affect the nature and availability of regeneration microsites (Noël 2002). These changes are expected to influence plant regeneration and growth (Ne'eman et al. 1995, Martinez-Sanchez et al. 1999). In addition, newly regenerating trees may be damaged during salvage logging operations (Martinez-Sanchez et al. 1999, Fraser et al. in press). Finally, salvage logging operations may also result in the introduction of invasive or exotic species to forest stands (Crites & Hanus 2001).

Effects of salvage logging on early post-disturbance regeneration and community establishment may persist for decades or even result in forest stands following an alternative pattern of successional development, as compared to unsalvaged post-fire stands. A major long-term effect is expected to arise from the loss of the snags, which would have eventually become downed logs serving a number of important ecological roles (Carleton & MacLellan 1994, Brais et al. 2000). In summary, harvesting of forests post-fire acts as an additive disturbance to wildfire, and has potentially important ecological implications for stand dynamics, nutrient availability and the subsequent regeneration and diversity of these forests.

In this study we investigated the impacts of post-fire salvage logging on the microclimate, tree regeneration, availability and characteristics of regeneration microsites, and patterns of understory plant diversity and composition in aspen-dominated (*Populus tremuloides*) mixedwood forest stands of northeastern Alberta.

Our key questions were as follows:

1) Does salvage logging significantly alter tree regeneration and subsequent stand development?

2) Does salvage logging significantly alter understory plant biodiversity, and thus might extensive salvage logging place early post-burn plant species and communities 'at risk'?

3) How might we alter the practice of salvage logging to minimize these impacts?

Methods

We found unsalvaged burned forest stands and comparable salvage logged stands for each of two ages since disturbance: 2 years post-fire ("young stands" below) and 34 years post-fire ("older stands" below). Stands were successfully identified using provincial forest inventory and fire data, historic air photos and interviews with government and industry personnel. Three representative stands of both young unsalvaged and salvaged treatments were selected from 1999 wildfires and two representative stands of both older unsalvaged and salvaged treatments were selected from 1968 wildfires (Table 1).

Table 1. Attributes of wildfires in which sampled stands were located. Fire ID represents provincial fire identifier (Alberta fire incidence database). Stand location is identified using legal land locations (meridian, township, range and section).

				Fire Start Location		Disturbance Type		Stand Location
Fire ID	Year	Fire Start Date	Size (ha)	Latitude	Longitude	Unsalvaged	Salvaged	Mer-Twn-Rng-Sec(s)
E02-038-99	1999	May-25	7,207	55.8 N	110.7 W	X		04-78-05-27, 26, 35
							X	04-78-05-22, 27, 34, 35
E02-043-99	1999	May-25	3,801	55.9 N	111.0 W	X		04-79-07-13, 18
E02-091-99	1999	July-12	4,333	55.3 N	111.9 W	X		04-73-12-10, 16, 17
							X	04-73-12-09, 17
E04-026-99	1999	May-24	1,952	55.4 N	114.2 W		X	05-74-01-09, 04
DL3-005-68	1968	May-19	15,030	55.1 N	113.3 W	X		04-71-22-21, 28
DS2-020-68	1968	June-19	401,327	54.4 N	114.3 W	X		05-71-06-25, 26, 35, 36
							X	05-71-05-31 & 05-71-06-36
DS3-021-68	1968	July-19	77,839	55.1 N	115.3 W		X	05-72-11-34, 35

Stands were sampled during the summers of 2001 and 2002. Sampling was conducted in 15 to 20 sites (each 100m^2) within each stand. Field sampling included:

a) forest structure (residual live and dead trees)

b) dead wood (amount and characteristics of downed logs)
c) regeneration microsites (availability and characteristics of: downed wood, bryophyte covered non-woody substrates, and patches of organic and exposed mineral soil)
d) forest environment (light, soil moisture, nutrients and compaction, air temperature and relative humidity)
e) tree regeneration (density and height)
f) understory plant community (composition and diversity of vascular plants)

Results

Forest structure and environment - Unsurprisingly, salvage logging of burned forest stands resulted in a drastic decline in the density of snags and residual live trees in the immediate post-disturbance period along with an increase in the total volume of downed recently-dead wood, likely owing to the volume of slash created by salvaging operations (Table 2). Older unsalvaged stands had nearly double the snag density of salvaged stands. Also, the older unsalvaged stands had greater amounts of downed dead wood than the comparable salvaged stands.

The younger salvage logged stands had significantly higher light and air temperature, and lower relative humidity than in the comparable unsalvaged wildfire stands. While canopy closure was lower in the older unsalvaged stands than in salvaged stands, this did not translate into differences in light, air temperature, relative humidity or soil moisture. Older salvaged stands did, however, have double the density of tall shrubs compared to unsalvaged stands. This tall shrub community was composed predominately of willow (*Salix* spp), alder (*Alnus* spp.) and cherry (*Prunus* spp.).

The younger salvaged stands showed no evidence of soil compaction as a result of machine traffic but in the older salvaged sites soil compaction was higher than in the comparable unsalvaged stands.

Availability of the two predominant regeneration microsite types (mineral soil, litter/organic soil) did not differ between treatments for the younger stands. However, availability of bryophyte covered non-woody microsites and other substrates was higher in unsalvaged stands compared with that of salvaged stands (Table 2).

Tree Regeneration – In the younger stands, the majority (95 %) of tree regeneration in both treatments was composed of deciduous saplings (primarily trembling aspen). Salvage logging had a significant impact on regeneration, with substantially better regeneration in unsalvaged stands. Regeneration density in unsalvaged stands was nearly double that of salvaged stands [157,239 $\pm$ 6573 ($\pm$ one standard error) stems per hectare (sph) *versus* 85,111 ($\pm$ 6411) sph]. Saplings were also taller in unsalvaged stands [1.01 ($\pm$ 0.03) m *versus* 0.59 ($\pm$ 0.03) m in salvaged stands].

In the older stands there was substantial conifer regeneration in salvaged stands, likely owing to site preparation (straight blade scarification) and aerial seeding that was conducted post-salvage. White spruce (*Picea glauca*) densities averaged 3034 ($\pm$ 429) sph as compared to natural regeneration densities of 968 ($\pm$ 410) sph in unsalvaged stands. In the older stands deciduous regeneration density and height did not differ between salvaged and unsalvaged stands.

Table 2. Descriptive statistics for stand, environmental, and regeneration variables in young (2 years) and older (34 years) post-fire stands subjected to salvage logging or not. Values provided are means (± one standard error). Young stands: Unsalvaged n=3 stands (43 sites total); salvage n=3 stands (45 sites total). Older stands: both unsalvaged and salvaged n=2 stands (40 sites total).

	2-years post-fire		34-years post-fire	
	Unsalvaged	Salvaged	Unsalvaged	Salvaged
Residual (live + dead) tree density (stems/ha)	1966.7 ± 181.4	146.9 ± 30.7	36.2 ± 11.4	27.0 ± 13.7
Residual DBH (cm)	14.3 ± 0.4	14.2 ± 0.9	34.0 ± 2.4	31.0 ± 2.5
% of total residuals that were dead (snags)	100.0	87.2	87.8	59 %
volume of downed wood (m^3/ha)	63.7 ± 7.6	110.0 ± 12.9	222.9 ± 24.6	172.1 ± 20.2
Light (% full light)	15.2 ± 1.98	60.9 ± 4.05	9.7 ± 0.57	10.9 ± 1.01
% Canopy cover	17.7 ± 1.1	3.1 ± 0.7	75.8 ± 2.9	86.9 ± 0.5
Air Temperature (^oC mean difference from open)	-1.2 ± 0.1	-0.56 ± 0.14	-1.2 ± 0.15	-1.4 ± 0.08
Relative Humidity (% mean difference from open)	10.1 ± 0.9	7.1 ± 0.7	11.2 ± 1.3	12.3 ± 1.0
Soil compaction (kg/cm^2)	1.6 ± 0.06	1.8 ± 0.05	1.14 ± 0.06	1.40 ± 0.09
% Cover of mineral soil	6.1 ± 2.5	11.0 ± 3.5		
% Cover of litter/organic material	80.7 ± 3.4	86.7 ± 3.5		
% Cover of bryophytes	10.7 ± 2.0	1.8 ± 0.9		
% Cover of other substrates	2.6 ± 0.8	0.6 ± 0.2		
Tall shrub density (stems/ha)			1987.8 ± 460.3	4981.5 ± 655.9
Conifer seedling density (stems/ha)			967.7 ± 409.7	3033.8 ± 428.7

The understory plant community - Plant communities of the younger unsalvaged and salvaged stands were significantly different from one another with the main distinctions being a result of the increased abundances of grasses [e.g. marsh reed grass (*Calamagrostis canadensis*), hairy wild rye (*Elymus innovatus*)] and introduced weedy species [e.g. common dandelion (*Taraxacum officinale*), sow thistle (*Sonchus arvensis*), Canada thistle (*Cirsium arvense*)] in the salvaged stands and higher abundances of post-fire specialists (e.g. Bicknell's geranium, pink corydalis) in the unsalvaged stands (Appendix 1). Salvaged stands had a higher richness of vascular plant species (as measured by the average number of species per 100 m^2 sample site and by the total number of species per stand) than unsalvaged wildfire stands (Table 3). This was attributable to both the presence of introduced species and the retention of low levels of post-fire specialist species.

Within stand variability in species composition (in terms of differences in species assemblage from one sample site to another within a stand, as quantified by Whittaker's beta diversity), was greater in salvaged stands. However, considering within treatment variability, the unsalvaged stands were more variable in terms of differences in species composition from one stand to another, as compared to salvaged stands (Table 3).

Table 3. Understory plant richness (number of species) for sample sites and for stands and variability in understory composition among sample sites within stands (quantified by Whittaker's beta diversity) or among stands for each treatment for young (2-years) post-fire stands which were salvage logged or not.

Treatment	Stand Name	# sites sampled	Mean # species per 100 m^2 site	total # species per stand	# herb species per stand	# shrub species per stand	Variability in species composition among sites within stands
Unsalvaged	Benson	15	27.9	72	51	21	2.58
	Chard	13	28.3	60	42	18	2.12
	Mena	15	27.3	69	49	20	2.53
Salvaged	Cowper	15	29.3	82	59	23	2.80
	Fawcett	15	37.2	93	68	25	2.50
	Philomena	15	33.7	88	61	27	2.61
							among stands within treatment
Unsalvaged	All fires	43	67.0	93	67	24	1.37
Salvaged	All fires	45	87.7	111	80	31	1.27

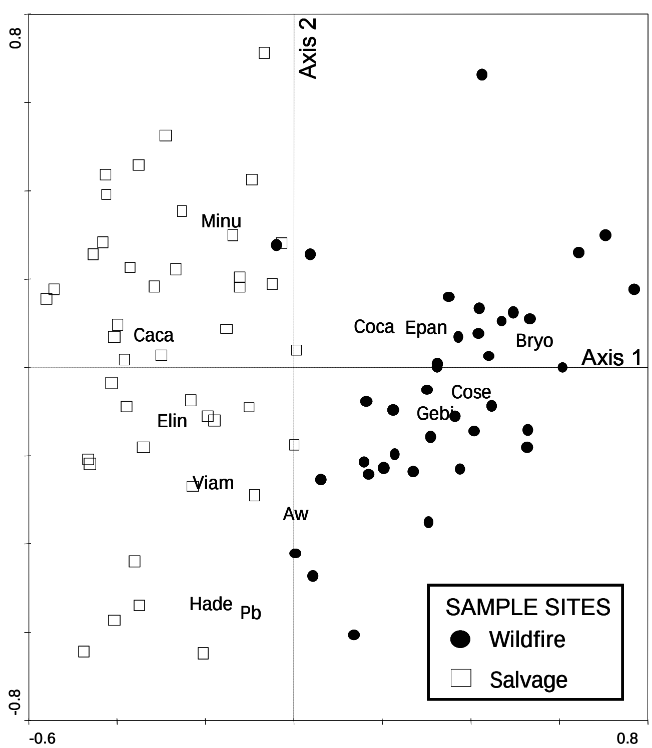

Figure 1. Young (2-years) post-fire stands: Ordination diagram illustrating understory species assemblage for sample sites from salvaged and unsalvaged stands. Sample sites which are close together in the diagram were similar in terms of the understory species assemblage. Four letter codes show the species which were relatively more common in salvaged or unsalvaged sample sites (see Appendix 1) [plot out of distance-based Redundancy Analysis (Legendre & Anderson 1999)].

The salvaged *versus* unsalvaged early post-fire stands were significantly different from one another in terms of their species assemblages [tested by Multi-response permutation procedures (MRPP)]. This is further illustrated by the separation of salvaged *versus* unsalvaged sample sites in an ordination of the species composition data (Figure 1). Note that salvaged sample sites separate strongly from unsalvaged sample sites along the first axis.

In the older post-fire stands, there were only minor differences in species richness, both per sample site and per stand, and in the variability in species assemblage among sample sites within stands or treatments (Table 4). There were no significant differences in species assemblages between salvaged and unsalvage older post-fire stands (tested by MRPP).

Table 4. Understory plant richness (number of species) for sample sites and for stands and variability in understory composition among sample sites within stands (quantified by Whittaker's beta diversity) or among stands for each treatment for older (34-years) post-fire stands which were salvage logged or not.

Treatment	Stand Name	# sites sampled	Mean # species per 100 m^2 site	total # species per stand	# herb species per stand	# shrub species per stand	Variability in species composition among sites within stands
Unsalvaged	Calling L	20	35.38	79	53	26	2.21
	Flattop	20	45.3	97	67	30	2.14
Salvaged	Kinuso	20	45.1	92	63	29	2.04
	Slave	20	46.4	94	66	28	2.03
							among stands within treatment
Unsalvaged	All fires	40	88.0	111	78	33	1.26
Salvaged	All fires	40	93.0	115	83	32	1.24

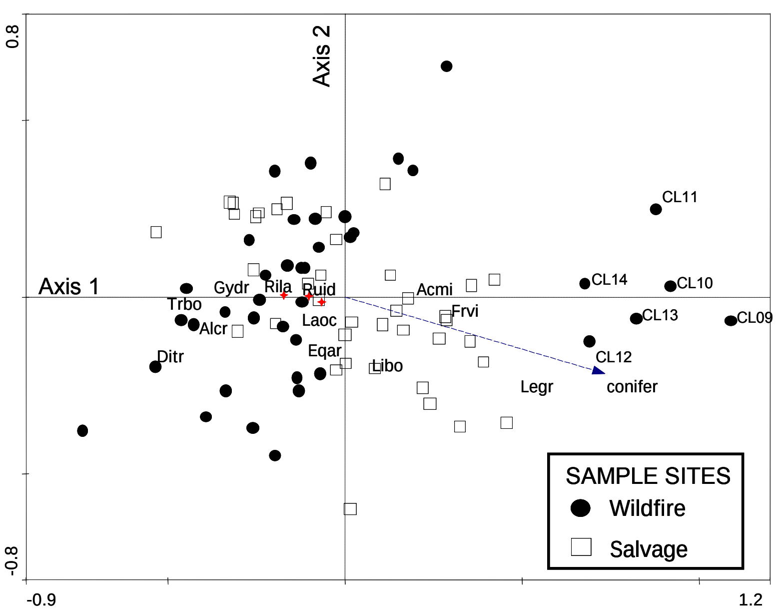

Figure 2. Older (34-years) post-fire stands: Ordination diagram illustrating understory species assemblage for sample sites from salvaged and unsalvaged stands. See Figure 1 for details. Arrow pointing to "conifer" indicates a gradient of increasing conifer abundance. Sample sites labelled "CL" were in the Calling Lake unsalvaged stand. See Appendix 2 for species codes.

Differences in older stands seemed to be among stands, as opposed to being related to treatment (salvaged *versus* unsalvaged). Note the relatively larger differences in species richness between the two unsalvaged stands in particular (Table 4). The overriding influence of differences among stands is further illustrated by the ordination of the species composition data (Figure 2). At first the diagram suggests very little separation of unsalvaged *versus* salvaged sample sites. However, the cluster of unsalvaged sample sites to the right of the diagram represent sample sites from the Calling Lake unsalvaged stands in which there was substantial natural regeneration of white spruce. Interestingly, these sites have an understory species assemblage similar to many of the salvaged sites, in which white spruce was present due to artificial regeneration. With removal of these Calling lake sample sites the diagram would suggest a much higher degree of separation between salvaged *versus* unsalvaged sample sites along the first axis. It is also noteworthy that the understory of older salvaged stands was generally dominated by shrub species [e.g. saskatoon (*Amelanchier alnifolia*), bracted honeysuckle (*Lonicera involucrata*), wild rose (*Rosa woodsii*)] to a much greater extent than the unsalvaged stands.

The results from these older stands can not be considered representative of the future outcome for the young post-fire salvaged stands because of differences in salvage harvest techniques and the confounding effect of site preparation and aerial seeding. The salvage operation in the older post-fire stands consisted largely of the removal of burnt conifers while deciduous trees were left on-site. This is highlighted by the fact there were relatively small differences in the volume of downed wood between salvaged and unsalvaged older stands.

Summary of Results and Interpretation

Our results illustrate that in early wildfire stands, salvage logging creates a more extreme environment with higher light and air temperature, and lower relative humidity than in unsalvaged stands. This can be attributed to the increased exposure resulting from the removal of sheltering residual trees and snags and likely has a significant influence on tree regeneration and understory plant cover.

Aspen regeneration density and height were negatively affected by salvage logging, although densities in salvaged stands were still quite high. In stands 34 years after salvage logging, there was no evidence of a difference in aspen regeneration, as compared to unsalvaged stands. However, the salvaging practices employed in these older stands were not the same as those used today; the higher retention of dead wood in these older salvaged stands likely influenced regeneration processes at the time of disturbance.

In general, plant communities associated with early unsalvaged and salvaged stands are similar with distinctions occurring as a result of the presence of introduced species and higher abundances of grasses, and some shrub species in salvaged stands, and higher abundances of bryophytes and herbaceous post-fire specialists in unsalvaged wildfire stands. Recently salvaged stands have higher richness of vascular plant species than unsalvaged stands and this is attributable to the presence of weedy species. Shortly after salvaging, stands had greater patchiness in understory plant communities than that found within unsalvaged stands. This may be due to salvaging operations creating heterogeneity in the microenvironment and regeneration microsites. At a coarser scale, however, stands which had been salvaged logged were more similar to one another in terms of understory species composition, than were unsalvaged stands, suggesting that salvaging could result in a more homogeneous landscape.

In older post-fire stands, differences in understory plant communities seemed to be related more strongly to differences among stands, rather than the effects of salvaging. In particular, the presence of conifer regeneration seemed to be related to differences in understory plant communities. This suggests that events (natural or human-influenced) occurring in the early post-disturbance period, which influence canopy composition and structure of the forest over successional time, are likely to influence understory composition as well.

Key Findings and Deliverables

Overall, our results showed that salvage logging significantly alters forest structure, tree regeneration, and understory plant community composition and diversity as compared to unsalvaged post-wildfire stands. Some of these effects were still evident 34 years after salvage logging.

Evidence suggests that salvage logging may result in poorer natural regeneration of aspen on mixedwood sites. This, along with differences in the forest environment and amounts of dead wood, could influence the future successional development of stands including individual tree and total volume growth, mortality processes, and effects on the understory environment and plant community. Thus, the ecological structure, habitat value, and biodiversity of salvage logged stands are likely to be different than in unsalvaged wildfire stands.

Salvaged stands also do not host the same understory communities that are found in unsalvaged wildfire stands in the early post-disturbance period. This creates some concern that in the long term, extensive post-fire salvage logging could lead to substantial declines in abundance of plant species which are specialists for early post-fire conditions of mesic stands. Additionally, over time, salvage logging could result in increased populations of introduced and weedy species. The longer-term impacts of salvage logging on understory composition of a stand will depend upon how the salvaging has affected the important drivers of understory community development (light, microenvironment, and regeneration microsites).

Given these findings it would seem prudent to develop a plan for protection of some proportion of merchantable forest stands from salvage logging. In addition, developing salvage logging practices which minimize damage to regenerating trees, and disturbance of the forest floor and organic layer, would likely reduce the impacts on regeneration and understory community diversity and composition.

Areas for future research include the potential for partial salvage logging to minimize negative impacts. In addition, it would be interesting to examine the population dynamics of post-fire specialist plant species in terms of: 1) the potential for burned, non-commercial stands to serve as population sources for these species; and 2) the likely impacts of salvage logging on long-term population viability.

Acknowledgements

Funding for this research was provided by the Sustainable Forest Management Network, Biodiversity Challenge Grants (supported by Alberta Conservation Association), and the Canadian Circumpolar Institute. S. Kurulok gratefully acknowledges financial support from the Natural Sciences and Engineering Research Council (NSERC), Alberta-Pacific Forest Industries Inc., and the Department of Renewable Resources and the Faculty of Graduate Studies and Research, University of Alberta. We would like to thank L. Strilchuk and N. Lipton for assistance with the field work and M. Molina-Ayala for assistance with the laboratory anayses.

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Kurulok, S.E. and S.E. Macdonald. 2002. Impacts of post-fire salvage logging on regeneration and plant communities in the mixedwood boreal forest. 4th International Workshop on Disturbance Dynamics of the Boreal Forest. Prince George, BC. August 2002. (Oral).

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Appendix 1. Understory vascular plant occurrence in young (2-years) post-fire stands which were salvage logged or not. Proportion of sample sites in which each species occurred. ✓ species only found in one treatment type. * shrub species. Nomenclature follows Moss (1983).

Frequency of Occurence				Species	Species Code
Wildfire		Salvage			
0.24		0.40		*Achillea millefolium*	Acmi
0.03	√	0.00		*Achillea sibirica*	Acsi
0.16		0.40		*Actaea rubra*	Acru
0.00		0.07	√	*Agropyron repens*	Agre
0.11		0.07		*Agropyron spp.*	Agrospp
0.03		0.04		*Agropyron trachycaulum*	Agtr
0.00		0.04	√	*Agrostis scabra*	Agsc
0.58		0.51		*Alnus crispa**	Alcr
0.29		0.40		*Amelanchier alnifolia**	Amal
0.00		0.02	√	*Androsace septentrionalis*	Anse
0.79		0.69		*Aralia nudicaulis*	Arnu
0.21		0.40		*Arctostaphylos uva-ursi**	Aruv
0.03		0.13		*Arnica cordifolia*	Arco
0.03		0.09		*Aster ciliolatus*	Asci
0.11		0.36		*Aster conspicuus*	Asco
0.50		0.62		*Aster puniceus*	Aspu
0.03		0.09		*Astragalus americanus*	Asam
0.00		0.04	√	*Betula glandulosa**	Begl
0.39		0.51		*Betula papyrifera*	Bepa
0.03	√	0.00		*Botrychium lunaria*	Bolu
0.00		0.09	√	*Bromus ciliatus*	Brci
0.11		0.20		*Bromus inermis*	Brin
0.97		1.00		*Calamagrostis canadensis*	Caca
0.03		0.07		*Campanula rotundifolia*	Caro
0.24		0.29		*Carex aurea*	Caau
0.26		0.27		*Carex siccata*	Casi
0.63		0.64		*Carex spp.*	Carexsp
0.00		0.04	√	*Chenopodium capitatum*	Chca
0.05		0.20		*Cirsium arvense*	Ciar
0.03		0.04		*Coptis trifolia*	Cotr
1.00		0.93		*Cornus canadensis*	Coca
0.00		0.02	√	*Cornus stolonifera**	Cost
0.16		0.07		*Corydalis aurea*	Coau
0.42		0.24		*Corydalis sempervirens*	Cose

0.00		0.07	√	*Corylus cornuta*	Coco
0.00		0.02	√	*Delphinium glaucum*	Degl
0.00		0.07	√	*Disporum trachycarpum*	Ditr
0.13		0.16		*Dracocephalum parviflorum*	Drpa
0.76		0.82		*Elymus innovatus*	Elin
1.00		1.00		*Epilobium angustifolium*	Epan
0.16		0.09		*Epilobium ciliatum*	Epci
0.39		0.22		*Equisetum arvense*	Eqar
0.18		0.16		*Equisetum pratense*	Eqpr
0.68		0.60		*Equisetum sylvaticum*	Eqsy
0.03		0.04		*Erigeron philadelphicus*	Erph
0.55		0.60		*Fragaria virginiana*	Frvi
0.71		0.76		*Galium boreale*	Gabo
0.05		0.07		*Galium triflorum*	Gatr
0.03	√	0.00		*Gentianella amerella*	Geam
0.95		0.62		*Geranium bicknelli*	Gebi
0.16		0.56		*Halenia deflexa*	Hade
0.03		0.09		*Hieracium umbellatum*	Hium
0.11		0.18		*Hordeum jubatum*	Hoju
0.63		0.71		*Lathyrus ochroleucus*	Laoc
0.16		0.09		*Lathyrus venosus*	Lave
0.37		0.20		*Ledum groenlandicum**	Legr
0.03		0.44		*Lilium philadelphicum*	Liph
0.82		0.58		*Linnaea borealis**	Libo
0.13		0.53		*Lonicera involucrata**	Loin
0.39		0.29		*Lycopodium annotinum*	Lyan
0.03		0.04		*Lycopodium complanatum*	Lyco
0.95		0.96		*Maianthemum canadense*	Maca
0.05		0.02		*Melampyrum lineare*	Meli
0.74		0.69		*Mertensia paniculata*	Mepa
0.29		0.47		*Mitella nuda*	Minu
0.00		0.07	√	*Moehringia lateriflora*	Mola
0.24		0.24		*Orthilia secunda*	Orse
0.00		0.02	√	*Parnassia palustris*	Papa
0.03		0.11		*Pedicularis labradorica*	Pela
0.84		0.73		*Petasites palmatus*	Pepa
0.03		0.04		*Petasites sagittatus*	Pesa
0.08		0.18		*Picea glauca*	Pigl
0.42		0.29		*Pinus banksiana*	Piba
0.03		0.13		*Plantago major*	Plma
0.08		0.13		*Poa pratensis*	Popr
0.13		0.29		*Populus balsamifera*	Poba

1.00	1.00		*Populus tremuloides*	Potr
0.08	0.09		*Potentilla gracilis*	Pogr
0.03	0.11		*Potentilla tridentata*	Potri
0.13	0.20		*Prunus pensylvanica**	Prpe
0.11	0.13		*Pyrola asarifolia*	Pyas
0.00	0.09	√	*Ranunculus acris*	Raac
0.00	0.02	√	*Rhinanthus minor*	Rhmi
0.00	0.02	√	*Ribes americanum**	Riam
0.03	0.09		*Ribes hudsonianum**	Rihu
0.00	0.09	√	*Ribes lacustre**	Rila
0.00	0.09	√	*Ribes oxycanthoides**	Riox
0.45	0.51		*Ribes triste**	Ritr
0.92	0.91		*Rosa acicularis**	Roac
0.26	0.38		*Rubus idaeus**	Ruid
0.68	0.87		*Rubus pubescens**	Rupu
0.47	0.47		*Salix spp*	Salix
0.08	0.11		*Schizachne purpurascens*	Scpu
0.00	0.11	√	*Senecio vulgaris*	Sevu
0.03	0.13		*Shepherdia canadensis**	Shca
0.03	0.58		*Sonchus arvensis*	Soar
0.00	0.04	√	*Stellaria longipes*	Stlong
0.13	0.27		*Symphoricarpos albus**	Syal
0.00	0.27	√	*Symphoricarpos occidentalis**	Syoc
0.00	0.04	√	*Tanacetum vulgare*	Tavu
0.11	0.29		*Taraxicum officinale*	Taof
0.03	0.18		*Thalictrum venulosum*	Thve
0.66	0.51		*Trientalis borealis*	Trbo
0.03	0.29		*Trifolium spp.*	Trispp
0.08	0.11		*Vaccinium caespitosum**	Vaca
0.79	0.71		*Vaccinium myrtilloides**	Vamy
0.03	0.04		*Vaccinium vitis-idaea**	Vavi
0.74	0.78		*Viburnum edule**	Vied
0.53	0.56		*Vicia americana*	Viam
0.03	0.09		*Viola adunca*	Viad
0.24	0.33		*Viola canadensis*	Vica
0.11	0.02		*Viola nephrophylla*	Vine
0.24	0.42		*Viola renifolia*	Vire

Appendix 2. Understory vascular plant occurrence in older (34-years) post-fire stands which were salvage logged or not. Proportion of sample sites in which each species occurred. ✓ species only found in one treatment type. * shrub species. Nomenclature follows Moss (1983).

Frequency of Occurence				Species	Species Code
Wildfire		Salvage			
0.30		0.15		*Abies balsamea*	Abba
0.33		0.65		*Achillea millefolium*	Acmi
0.08		0.30		*Achillea sibirica*	Acsi
0.93		0.98		*Actaea rubra*	Acru
0.13		0.15		*Agropyron spp.*	Agrospp
0.08		0.10		*Agrostis scabra*	Agsc
0.30		0.50		*Alnus crispa**	Alcr
0.58		0.83		*Amelanchier alnifolia**	Amal
0.05		0.08		*Anemone canadensis*	Arnu
0.93		1.00		*Aralia nudicaulis*	Anca
0.05		0.20		*Arnica chamissonis*	Arch
0.03	√	0.00		*Arnica cordifolia*	Arco
0.43		0.65		*Aster conspicuus*	Asco
0.85		0.98		*Aster puniceus*	Aspu
0.08	√	0.00		*Betula glandulosa**	Begl
0.73		0.88		*Betula papyrifera*	Bepa
0.00		0.03	√	*Botrychium lunaria*	Bolu
0.00		0.23	√	*Botrychium virginianum*	Bovi
0.20		0.05		*Bromus ciliatus*	Brci
0.78		0.80		*Calamagrostis canadensis*	Caca
0.03		0.15		*Calamagrostis inexpansa*	Cain
0.03	√	0.00		*Caltha palustris*	Capa
0.08		0.00		*Campanula rotundifolia*	Caro
0.08		0.13		*Carex aurea*	Caau
0.15		0.38		*Carex spp.*	Carex
0.03	√	0.00		*Chrysosplenium tetrandrum*	Chte
0.13		0.03		*Circaea alpina*	Cial
0.08		0.03		*Clematis occidentalis*	Cloc
0.05		0.05		*Corallarhiza maculata*	Coma
0.00		0.15	√	*Corallarhiza trifida*	Cotr
1.00		0.85		*Cornus canadensis**	Coca
0.78		0.90		*Cornus stolonifera**	Cost
0.03		0.05		*Corylus cornuta**	Coco
0.28		0.20		*Delphinium glaucum*	Degl
0.30		0.15		*Disporum trachycarpum*	Ditr

0.35		0.10		*Dryopteris carthusiana*	Drca
0.13		0.03		*Elymus innovatus*	Elin
0.95		0.93		*Epilobium angustifolium*	Epan
0.05	√	0.00		*Epilobium ciliatum*	Epci
0.73		0.70		*Equisetum arvense*	Eqar
0.13		0.23		*Equisetum pratense*	Eqpr
0.88		0.90		*Equisetum sylvaticum*	Eqsy
0.03		0.25		*Fragaria vesca*	Frve
0.30		0.60		*Fragaria virginiana*	Frvi
0.00		0.05	√	*Galeopsis tetrahit*	Gate
0.95		1.00		*Galium boreale*	Gabo
1.00		0.98		*Galium triflorum*	Gatr
0.05		0.03		*Geum aleppicum*	Geal
0.05		0.23		*Geum macrophyllum*	Gema
0.60		0.65		*Gymnocarpium dryopteris*	Gydr
0.00		0.03	√	*Habenaria orbiculata*	Haor
0.03		0.03		*Halenia deflexa*	Hade
0.48		0.40		*Heracleum lanatum*	Hela
0.85		1.00		*Lathyrus ochroleucus*	Laoc
0.10		0.05		*Lathyrus venosus*	Lave
0.10		0.30		*Ledum groenlandicum**	Legr
0.70		0.65		*Linnaea borealis**	Libo
0.00		0.03	√	*Listera borealis*	Lisbor
0.70		0.88		*Lonicera dioica**	Lodi
0.95		1.00		*Lonicera involucrata**	Loin
0.18		0.15		*Lycopodium annotinum*	Lyan
0.03		0.03		*Lycopodium complanatum*	Lyco
0.03	√	0.00		*Lycopodium obscurum*	Lyob
0.70		0.98		*Maianthemum canadense*	Maca
0.05		0.45		*Matteuccia struthiopteris*	Mast
0.00		0.08	√	*Mentha arvensis*	Mear
0.98		1.00		*Mertensia paniculata*	Mepa
0.95		0.98		*Mitella nuda*	Minu
0.15		0.08		*Moehringia lateriflora*	Mola
0.03		0.03		*Moneses uniflora*	Moun
0.03	√	0.00		*Oplopanax horridum*	Opho
0.05		0.08		*Orthilia secunda*	Orse
0.28		0.20		*Osmorhiza depauperata*	Osde
0.88		0.98		*Petasites palmatus*	Pepa
0.73		0.98		*Picea glauca*	Pigl
0.00		0.03	√	*Poa palustris*	Popa
0.18		0.10		*Poa pratensis*	Popr

0.00		0.03	√	*Poa spp.*	Poa
0.75		0.83		*Populus balsamifera*	Poba
1.00		0.98		*Populus tremuloides*	Potr
0.00		0.05	√	*Potentilla norvegica*	Pono
0.18		0.10		*Prunus pensylvanica**	Prpe
0.05		0.05		*Prunus virginiana**	Prvi
0.80		0.93		*Pyrola asarifolia*	Pyas
0.05	√	0.00		*Pyrola chlorantha*	Pych
0.03	√	0.00		*Ribes americanum**	Riam
0.20		0.20		*Ribes glandulosum**	Rigl
0.20		0.40		*Ribes hudsonianum**	Rihu
0.73		0.73		*Ribes lacustre**	Rila
0.95		0.95		*Ribes oxycanthoides**	Riox
0.98		0.98		*Ribes triste**	Ritr
1.00		0.83		*Rosa acicularis**	Roas
0.60		0.73		*Rosa woodsii**	Rowo
0.83		0.90		*Rubus idaeus**	Ruid
1.00		1.00		*Rubus pubescens**	Rupu
0.08		0.18		*Salix discolor*	Sadi
0.65		0.95		*Salix spp.*	Salix
0.10		0.05		*Sanicula marilandica*	Sama
0.03		0.05		*Schizachne purpurascens*	Scpu
0.03		0.05		*Scutellaria galericulata*	Scga
0.03	√	0.00		*Senecio vulgaris*	Sevu
0.03		0.25		*Shepherdia canadensis**	Shca
0.13		0.10		*Smilacina racemosa*	Smra
0.20		0.20		*Smilacina stellata*	Smst
0.10		0.53		*Solidago canadensis*	Soca
0.00		0.03	√	*Sonchus arvensis*	Soar
0.28		0.08		*Sorbus scopulina**	Sosc
0.00		0.03	√	*Spiranthes romanzoffiana*	Spro
0.08		0.10		*Stellaria longifolia*	Stlo
0.00		0.05	√	*Stellaria longipes*	Stlong
0.00		0.03	√	*Stellaria media*	Stme
0.25		0.23		*Streptopus amplexifolius*	Stam
0.30		0.53		*Symphoricarpos albus**	Syal
0.05		0.00		*Tanacetum vulgare*	Tavu
0.13		0.33		*Taraxicum officinale*	Taof
0.00		0.05	√	*Thalictrum dasycarpum*	Thda
0.05		0.03		*Thalictrum venulosum*	Thve
0.03	√	0.00		*Tiarella trifoliata*	Titr
0.48		0.48		*Trientalis borealis*	Trbo

0.03	0.05		*Trifolium spp.*	Trispp
0.13	0.13		*Urtica dioica*	Urdi
0.00	0.08	√	*Vaccinium myrtilloides**	Vamy
1.00	0.98		*Viburnum edule**	Vied
0.65	0.58		*Vicia americana*	Viam
0.28	0.25		*Viola canadensis*	Vica
0.13	0.15		*Viola nephrophylla*	Vine
0.98	0.93		*Viola renifolia*	Vire