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Bulkley Valley Centre for Natural Resources Research & Management

Extension Note 5

Local Level Vegetation Indicators for Boreal Mixedwood Forests

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Vegetation Indicators of Sustainable Forest Management

Adoption of a results-based approach to managing British Columbia's forest lands has stimulated great interest in the use of indicators for monitoring the sustainability of forest practices. These sustainable forest management (SFM) indicators are used by forest licensees, government agencies and others to determine whether higher level environmental, social and economic objectives set out in international agreements, legislation, planning and certification processes are being met.

Environmental indicators generally address the maintenance of biodiversity and ecological integrity across a wide range of spatial and temporal scales. There are many different schemes and biophysical indicators in use to monitor biodiversity and ecological integrity. One example is the Forest and Range Evaluation Program (FREP), introduced by the BC Ministry of Forests and Range to ensure that the eleven resource values identified in British Columbia's Forest and Range Practices Act (FRPA) are maintained (BC Ministry of Forests and Range 2007).

Plants and plant communities are among the best-understood and most easily measured indicators for monitoring the health and integrity of forest ecosystems. Moreover, "biodiversity" and "forage and associated plant communities" are listed as two of the eleven resource values to be maintained under FRPA. During the first round of FREP development, a provincial-scale sampling protocol was adopted that monitors the same set of environmental indicators province-wide. Because vegetation is so variable across the province, vegetation monitoring was restricted to generic indicators such as coarse woody debris and retention trees for monitoring biodiversity and invasive alien plants for monitoring the condition of forage and associated plant communities.

With the huge variability in environmental conditions and threats to resource values that exists across British Columbia, it is unlikely that these generic indicators will provide an accurate picture of what is happening to resource values at regional and local scales. A combination of the following options will be needed to adapt FREP to local scales of forest management:

- Add locally-relevant indicators to the FREP monitoring protocol.
- Develop separate local level monitoring protocols to be undertaken by licensees, local organizations and agencies.
- Conduct effectiveness or validation monitoring at local scales to ensure that retention of coarse woody debris and wildlife trees actually maintains forest-dependent biodiversity, and that the abundance of invasive alien plants is an effective surrogate for the overall condition of forage and associated plant communities.

This Extension Note addresses the development of local level vegetation indicators for monitoring biodiversity, forage and associated plant communities values in boreal white spruce-trembling aspen mixedwood forests of the Peace River region of northeastern British Columbia, an area known as the Peace variant of the moist, warm subzone of the Boreal White and Black Spruce biogeoclimatic zone (BWBSmw1, Figure 1).

Characteristics of a Good SFM Indicator

Methodological Relevance

- Easy to use in the field and easy to interpret
- Can be used to test management questions
- Can be used for hypothesis testing
- Adaptable to a range of spatial and temporal scales of monitoring

Biological Relevance

- Exhibits changes in response to stress
- Intensity of changes relate to intensity of stressors
- Changes are biologically important and can be detected early enough to prevent catastrophic effects

Societal Relevance

- Of interest to the public
- Easily understood by the public
- Relates to human health or to ecological services valued by the public
- Cost-effective

modified from: Burger, J. and M. Gochfeld. 2001. On developing bioindicators for human and ecological health. Envir. Monitor. Assess. 66: 23-46.

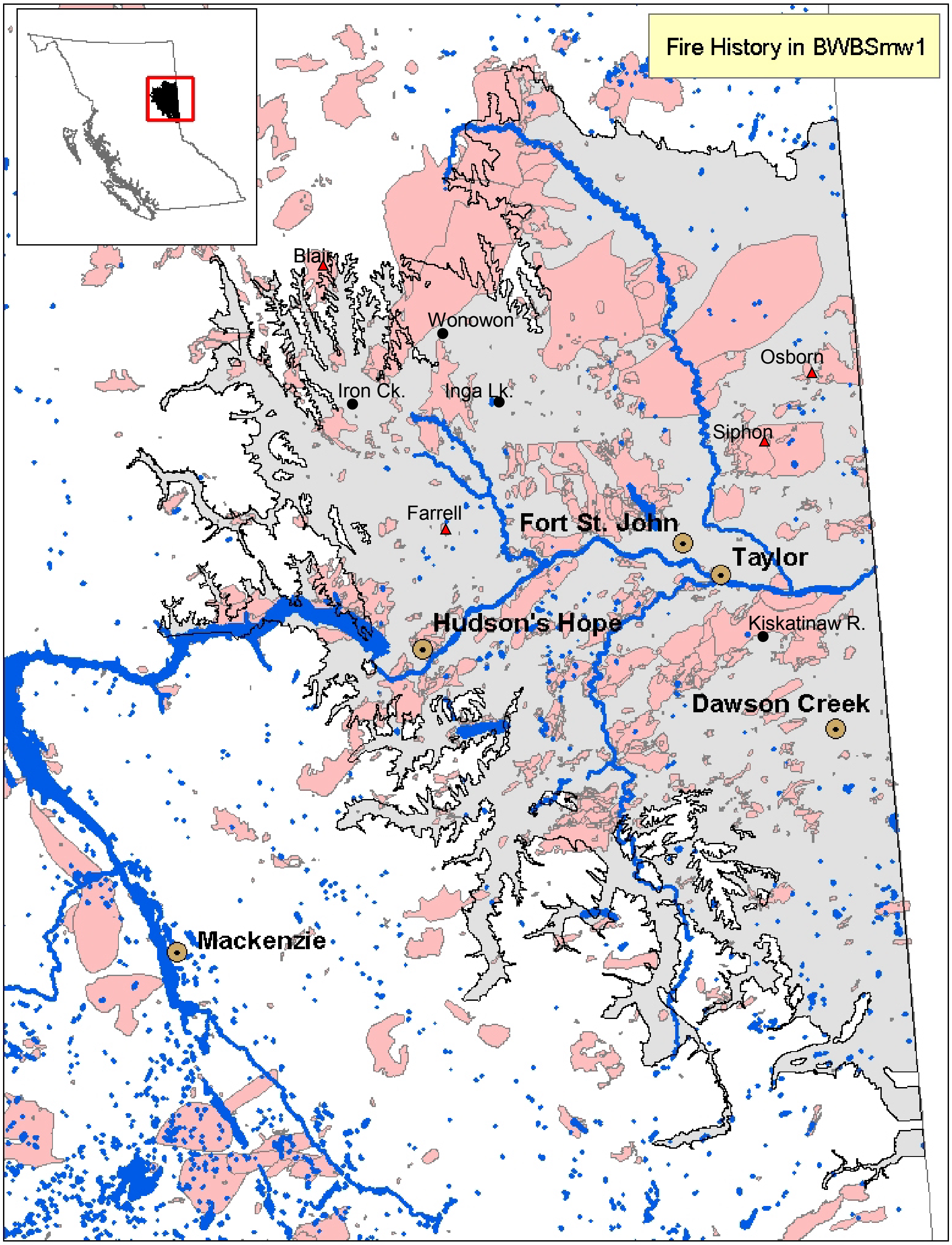


Figure 1. *Map of the BWBSmw1 biogeoclimatic variant (gray-shaded area outlined in black) in the Peace River region of northeastern British Columbia, showing the location of all wildfires recorded from 1920 to 2000 (pink polygons) and the eight study sites (▲ = sampled wildfires, ● = silvicultural trials). Map courtesy Steve Taylor, Canadian Forest Service (unpublished data).*

Why study the BWBSmw1?

We considered the BWBSmw1 to be ideally suited for pilot-testing local level vegetation indicators for the following reasons:

- It is the largest, most uniform biogeoclimatic unit in British Columbia (see *inset map*, Figure 1).
- It supports major forest products, agricultural and oil and gas industries that have expanded in recent decades.
- Rapid growth has raised concern over cumulative human impacts on biodiversity, wildlife and other resource values.
- Most development is recent, thus there are many forest areas still relatively untouched by human activity.
- Wildfire activity is greater here than in any other region of British Columbia after the Okanagan region.
- Unmanaged wildfire areas can serve as reference areas for monitoring the effects of human disturbances on boreal forests *.*
- A network of well-replicated forestry experiments established by the Canadian Forest Service and BC Forest Service has monitored vegetation development after clear-cutting and site preparation for up to 20 years.
- Results from these forestry experiments are published in peer-reviewed journals, providing a solid scientific basis for monitoring.
- Peer-reviewed scientific data from similar southern boreal mixedwood forests in Alberta and across Canada may also be applicable to the Peace Region.

Study Objectives

1. To contrast vegetation succession on BWBSmw1 experimental sites exposed to gradients of silvicultural disturbance to succession on closely-matched BWBSmw1 wildfires.
2. To identify candidate vegetation indicators for monitoring sustainable forest management in the BWBSmw1.
3. To compare the range of variability of these vegetation indicators after silviculture and wildfires.
4. To make recommendations for operational monitoring of forest vegetation after clear-cutting and site preparation in the BWBSmw1.

Study Areas

We had an existing database describing 4- to 16-yr vegetation response to a range of low to very high impact logging and silvicultural treatments from four well-replicated experiments in the Peace River region (Inga Lake, Iron Creek, Wonowon, Kiskatinaw River). All of the trials are located on mesic White spruce–Trembling aspen-Stepmoss (BWBSmw1/01) and subhygric White spruce–Currant-Bluebells (BWBSmw1/06) site series (DeLong et al. 1990) with gently rolling glacial till soils and mixedwood forest composition ranging from dominantly aspen to dominantly white spruce. The results of these studies are documented in peer-reviewed scientific papers (see References).

In 2006, we remeasured plant communities at the Inga Lake and Iron Creek silvicultural trials to obtain 19-yr and 20-yr data, respectively, using the methods described in the previous studies.

In 2006, we also located four wildfires in the BWBSmw1 (Osborn, Siphon Ck., Farrell Ck., Blair) that closely matched the ecosystems in the silvicultural trials in terms of their landforms, soil texture, moisture and nutrient regimes, pre-disturbance forest composition, years since disturbance, degree of landscape fragmentation and proximity to agricultural and industrial activity. The eight study sites (4 wildfires, 4 silvicultural trials) are mapped in Figure 1 and described in Table 1.

Field Sampling

All four silvicultural trials had rectangular treatment plots (0.1 – 0.3 ha) planted to white spruce seedlings. At Inga Lake, Iron Creek and Wonowon, we randomly located three sets of nested rectangular quadrats within each treatment plot to assess the percent cover of trees and shrubs > 2 m height (25 m^2), trees and shrubs < 2 m height (9 m^2), herbs and substrates (3 m^2), bryophytes and lichens < 1.3 m above the ground (1 m^2). At Kiskatinaw River percent cover of all vascular species and a few dominant mosses were recorded on 50m^2 circular quadrats located near the four corners of each plot.

In the four wildfires we located uniform polygons of BWBSmw1/01 and /06 site series within unsalvaged, untreated and unplanted portions of the wildfire with dominantly white spruce or aspen snags present. We located transects oriented so as to bisect the full range of burn severity (based on live residual trees and snag condition) within the polygon and established plots at 50 m spacing. At each plot, we assessed site, soil and stand characteristics and randomly located three sets of nested quadrats within each plot (dimensions as above).

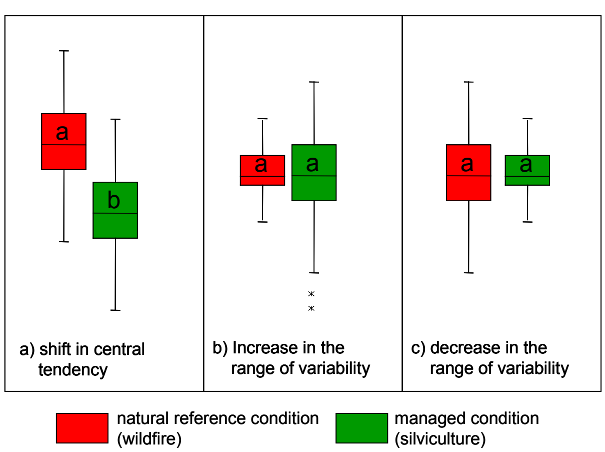
Comparing Indicators to the Range of Natural Variability

SFM Indicators are used to:

- Track changes in the condition of a resource value over time.
- Compare the condition of a resource value to a desired or reference condition.

In some cases, (e.g., monitoring invasive alien species) the desired condition is well understood (no invaders). Often it is not. In such cases, the desired or reference condition can be a naturally disturbed, unmanaged forest ecosystem of the same age.

The natural disturbance model of forest management is based on the premise that practices that closely emulate the range of variability found in unmanaged, naturally-disturbed forest ecosystems are most likely to maintain biodiversity and ecological integrity. According to this model, a potential risk to a resource value exists when the SFM indicator shows one or more of the following: a) a shift in the central tendency (mean or median), b) an increase in the range of variability (i.e., management creates novel conditions lying outside the range of natural variability), or c) a decrease in the range of variability (i.e., management artificially constrains the natural range of variability).



Reading box-and-whisker diagrams:
The centre line of the box represents the median; the lower and upper edges of the box are 25th and 75th percentiles, respectively. Lower and upper whiskers represent the minimum and maximum, except when extreme or far outside values, indicated by asterisks, are present. The mean is not shown, but the lower case letter (a or b) inside the box indicates whether means are significantly different with 95% confidence.

Data Analysis

We first compared the range of variability in the composition of plant communities on the wildfire plots to that on the silviculture plots using non-metric multi-dimensional scaling (NMS). Site descriptors were overlain onto the NMS ordination to determine which variables had the greatest influence on plant community composition. The first round of analysis showed that, regardless of the type and severity of disturbance, the 4-yr old Kiskatinaw River plots were different from all of the other wildfire and silviculture plots. This result was due to a combination of different sampling technique, high densities of 4-yr old aspen suckers, and a warmer environment with many native and alien plants not found at higher elevations and latitudes. When these plots were removed, a second NMS ordination was carried out that provided better insight into differences between wildfire and silviculture. The resulting ordination was rotated so that differences due to disturbance were oriented parallel to Axis 1.

Next, we compiled a list of candidate vegetation indicators from our prior studies and compared the range of variability of each indicator after wildfire and after silvicultural treatments at the quadrat scale. We used a cube-root transformation, as needed, to normalize the indicators. Indicators that could not be normalized because they had too many zero observations were analysed in a two-step approach (logistical regression to compare the frequency of occurrence, followed by linear regression of all non-zero observations). We used stepwise linear regression to identify factors that significantly influenced each indicator, then partialled out covariables (e.g., soil moisture regime) that were unrelated to the type of disturbance.

Because the wildfire sample size (42 quadrats) was so much smaller than the silviculture sample size (594 quadrats), we used stratified random sampling to obtain subsets of 42 silviculture quadrats that matched the wildfire quadrats in terms of stand age and significant covariables and to subdivide the silviculture dataset into disturbance categories identified as important during the regression analysis (e.g., low vs. high soil disturbance; glyphosate-treated). We used t-tests with unequal variances and a Bonferroni adjustment for multiple pairwise comparisons to contrast wildfire and silviculture means, and box-and-whisker diagrams to compare the range of variability of the 42-sample subsets.

Table 1. Study area description.

Study Area	Elev (m)	Disturbance Date	No. of trts	Disturbance Type or Treatments (trts)	Date – Age sampled	No. of plots (quadrats)	Pre-disturbance forest condition*
Wildfire							
Osborn	786	burned 2000	1	▪ wildfire	2006 - 6yr	2 (6)	140yr Sw-Pl-At-Sb forest
Siphon Ck.	771	burned 1990	1	▪ wildfire	2006 - 16yr	3 (9)	115yr At-Sw-Pl forest
Farrell Ck.	831	burned 1990	1	▪ wildfire	2006 - 16yr	5 (15)	120yr At-Sw forest
Blair	1020	burned 1983	1	▪ wildfire	2006 - 23yr	4 (12)	120yr Sw-Pl-Sb-At forest
Silviculture							
Inga Lake site preparation trial	890	site prep 1987 planted 1987 sprayed 1990 manual cut 1991, 1993, 1995, 1996, 1998, 2000	6-7	▪ winter sheared (ws) ▪ ws + disk trench ▪ ws + breaking or bedding plow ▪ ws + rotoclear ▪ ws + windrowed + burned ▪ ws + glyphosate + manual cut	1997 - 10yr 2002 - 15yr 2006 - 19yr	85(255)	immature alder-willow-At-Sw-Sb scrub
Iron Creek site preparation trial	820	high grade 1966 clear-cut 1977 site prep 1986 planted 1987 manual cut 2000	2-4	▪ clear-cut (cc) + ws ▪ cc + ws + mound ▪ cc + ws + plow ▪ cc + ws + glyph. + manual cut	1996 - 10yr 2002 - 16yr 2006 - 20yr	43(129)	120yr Sw-Pl-At-Ac forest
Wonowon site preparation trial	900	logged 1977 planted 1984 sprayed 1984	2	▪ cc (no site preparation) ▪ cc + spot application of glyph.	1996 - 12yr	10 (30)	mature Sw-Pl-At-Ep-Sb forest
Kiskatinaw River boreal long term soil productivity study	720	logged, soil disturbed & planted 1995, 1997, 1998	18	▪ cc (stem removed) ▪ cc (stem + crown removed) ▪ cc (stem + crown + forest floor removed) ▪ all of above + light soil compaction ▪ all of above + heavy soil compaction ▪ all of above + manual cut	1998 - 4yr 2001 - 4yr 2002 - 4yr	27 (108)	100yr At forest

* tree species abbreviations: At = trembling aspen, Sw = white spruce, Pl = lodgepole pine, Ac = balsam poplar, Ep = paper birch

Results and Discussion

It was difficult to find unsalvaged wildfires that closely matched the silvicultural trials. Most recent, unsalvaged wildfires were small and dominated by non-commercial cover (e.g., black spruce bogs, dry aspen woodland). As a result, the wildfire sample size (14 plots, 42 quadrats) was smaller than desired, and the match between wildfires and clearcuts was less than perfect. Moreover, the tiny patches of unsalvaged spruce and aspen forest that we were able to locate were somewhat compromised as natural reference areas because their successional development was influenced by proximity to heavily salvaged and silviculturally treated areas or to non-commercial forest types.

Objective 1: Trends in Overall Plant Community Composition after Wildfire and Silviculture (Figure 2).

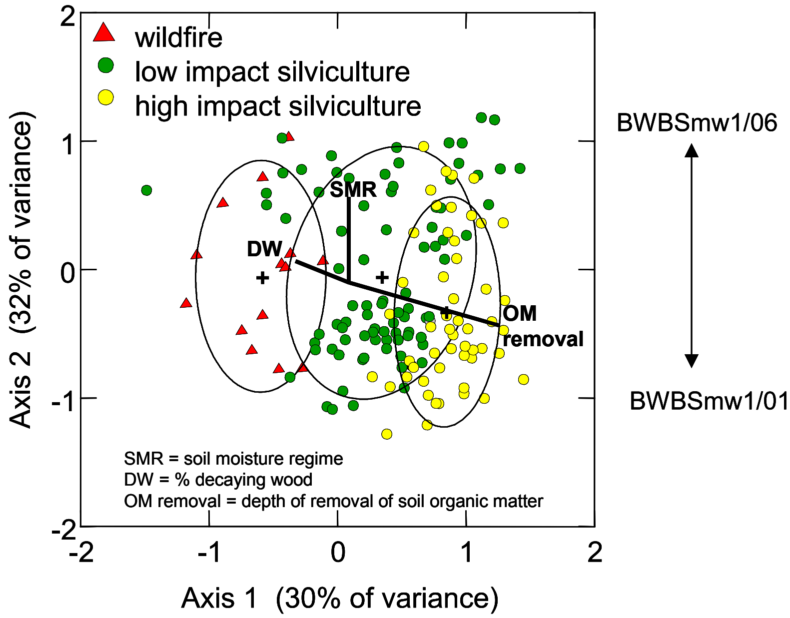


Figure 2. *The range of variability in plant community composition after wildfire, low and high impact silviculture. Each symbol represents a plot (Kiskatinaw River omitted). The ellipse encloses ±68.3% of total variability around the centroid (+) for each group. Vectors show that Axis 1 is strongly correlated with the amount of decaying wood and organic matter removal, and Axis 2 with the soil moisture regime.*

The largest source of variability in plant community composition (32% of total variance) was differences in soil moisture regime (SMR). This variability, well studied by the BEC program (Delong et al. 1990) and not of particular interest to the current study, is displayed on Axis 2. Mesic BWBSmw1/01 plots are situated in the bottom half of the ordination and moister BWBSmw/06 plots are located in the upper half of the ordination.

The second largest source of variability in plant community composition (30 % of total variance) was differences in the type and severity of disturbance. These differences were of primary interest in our study and are therefore displayed on Axis 1. The ellipses surrounding wildfire, low impact silviculture and high impact silviculture indicate that plant community composition on the silvicultural trials was mostly outside the range of "natural" variability. This was particularly true after high impact treatments such as windrowing or rotoclearing that eliminated slash, decaying wood and forest floor layers, and glyphosate followed by repeated manual brushing.

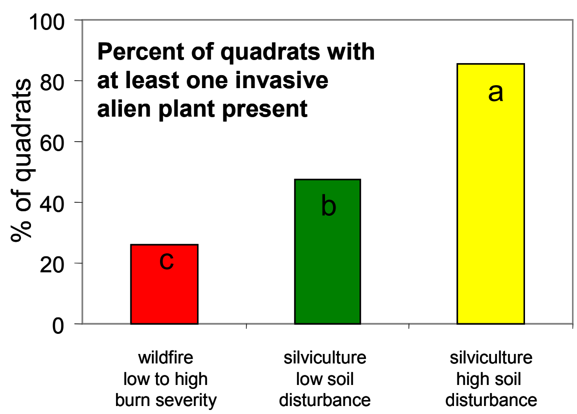
In general, wildfires had more residual live trees, more lodgepole pine and black spruce regeneration, more false sarsaparilla and northern bedstraw, and more epiphytic lichens and bryophytes than the silvicultural trial sites. Most of the wildfire-associated plant species either germinated from dormant seed or grew on live or dead wood.

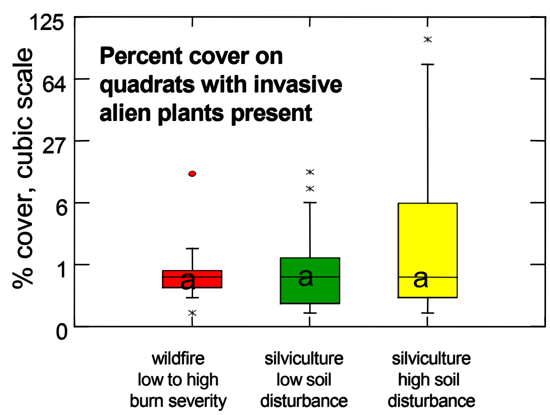
By contrast, the silvicultural trial sites had more white spruce seedlings and saplings, which is not surprising, since they were all spruce plantations. They also had more balsam poplar, more grasses, wild strawberry, dandelion, clover, and fringed aster than the wildfires. Most of the silviculture-associated plants were native and alien plants that invade sites by germinating from seed in disturbed mineral soil. Not surprisingly, such species were most abundant after higher impact silvicultural treatments that removed woody debris, forest floor layers including buried seeds, roots and rhizomes, and created a mineral soil seedbed.

Stand age was not a significant variable in the ordinations. This finding indicates that differences caused by disturbance type and severity were relatively persistent and were more important in explaining community composition than the age of the stand.

Objectives 2 and 3: Testing Candidate Indicators

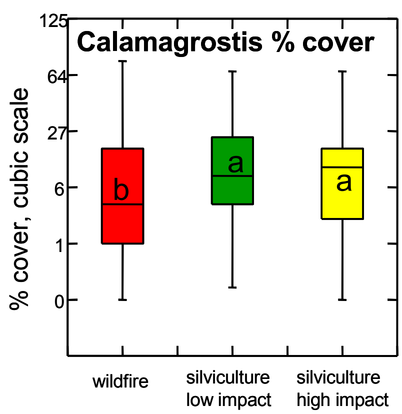
1. Invasive Alien Plants





Invasive alien plants are most abundant in fragmented landscapes near roads, industrial, agricultural or urban activity. Within similar landscapes, invasive alien plants occurred more frequently in silvicultural trials than on wildfires, especially after high impact treatments where abundant mineral soil was exposed. Silvicultural treatments also increased the range of variability in invasive plant cover and were more likely to have a high cover (> 5%) of invasive alien plants. In the BWBSmw1 invasive alien plants currently include clovers, tame grasses, dandelion, and a variety of agricultural weeds.

2. Calamagrostis canadensis (bluejoint reed grass)

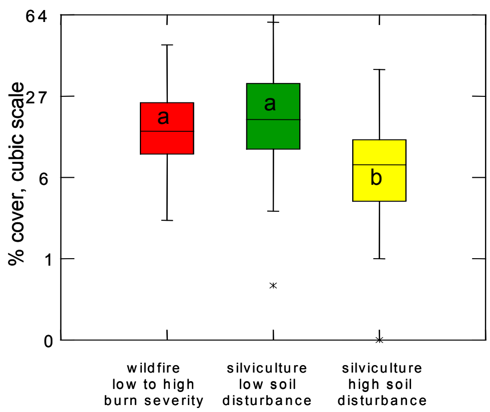


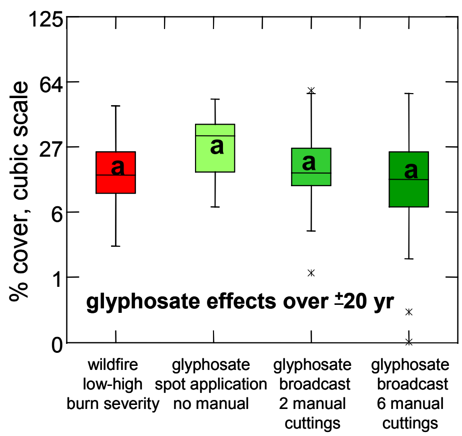
Calamagrostis is a highly competitive, sod-forming native grass that impedes tree growth and reduces the diversity of other plants with higher forage and wildlife value, when abundant. Silviculture increased the mean and median abundance of Calamagrostis compared to wildfire and greatly reduced the percentage of sites with low (< 5%) Calamagrostis cover.

3. All grasses (includes native and alien species)

Because grasses can be difficult to tell apart, and are increasing worldwide in boreal forests in response to nitrogen deposition and other factors, we considered using "all grasses" as an alternative to Calamagrostis alone. However, we found that grasses other than Calamagrostis were strongly negatively correlated with Calamagrostis abundance. Calamagrostis excludes other grasses when abundant, and other grasses increase when Calamagrostis is controlled by glyphosate or scalping. We therefore concluded that "all grasses" should not be used as a substitute for monitoring Calamagrostis alone, although they could be monitored in addition to Calamagrostis. Trends were similar whether we included or excluded grass-like plants such as sedges and rushes (*Carex* spp., *Luzula* spp., *Juncus* spp.).

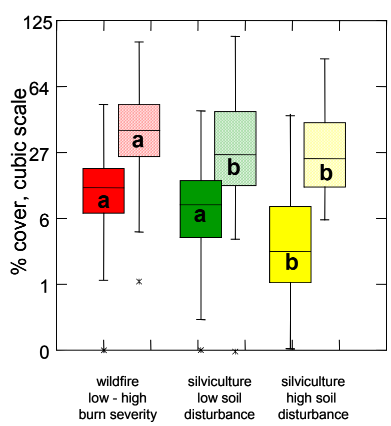
4. Berry-producers

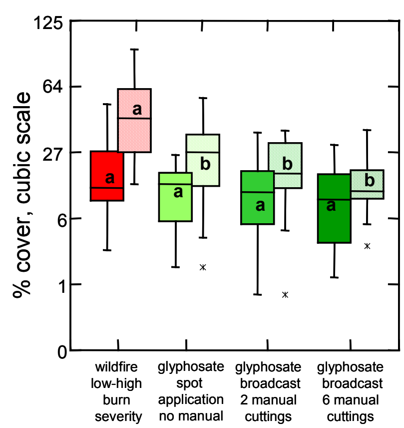




Plants that produce edible berries have important cultural and wildlife values. It is difficult to monitor berry production because of seasonal and interannual variability. We used percent cover of all berry-producers as a surrogate. Silvicultural disturbances that removed forest floors had significantly lower abundance of berry producers than wildfires or silvicultural treatments that left forest floors mostly intact. We expected glyphosate to reduce the abundance of berry-producers compared to wildfire, but this did not occur over the 20-yr timeframe of our studies. Glyphosate mostly reduced aspen and Calamagrostis, allowing berry-producers to flourish.

5. Moose browse species[1]





[1] Lower boxes with dark colours indicate cover of moose browse species < 2 m height, upper boxes with pale colours indicate the total cover at all heights. Means (a or b) should be compared only within the same height class.

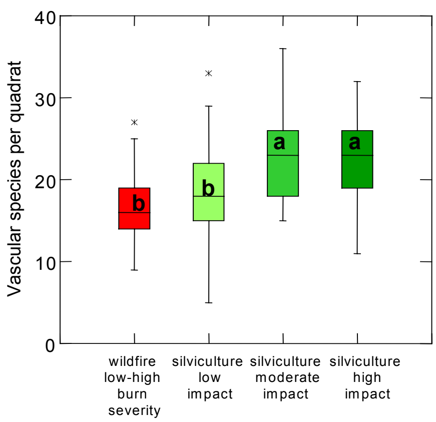
BWBSmw1/01 and /06 ecosystems are prime moose habitat. Moose browse in young stands is often so heavy that it drives forest succession. Major moose browse species are: Willows, paper birch, aspen, balsam poplar and high-bush cranberry. Red-osier dogwood and saskatoon are also browsed when present. The browse line is approximately 2 m high. When shrubs exceed 2 m, they usually have little available browse, because lower branches are shaded or nibbled off. We used percent cover < 2 m height of all moose browse species (dark boxes) as a surrogate for the amount of available browse, and compared this to the total browse species cover at all heights (pale boxes).

Moose browse species were more abundant after wildfires than after silviculture, especially where there was heavy soil disturbance. Ten to 20 years after disturbance, however, the temporal availability of browse complicates the picture. Sites sprayed with glyphosate (& manually cut) had just as much available moose browse (< 2 m) as wildfires, because most of the browse on wildfires had already grown beyond reach. Thus, although brushing does reduce the total amount of browse produced, it can be used selectively to manage browse availability over time to avoid a feast-or-famine situation after major disturbances such as clear-cutting or wildfire.

6. Species richness or diversity

There is widespread concern that forestry practices create monocultures and reduce plant species diversity. For this reason, there has long been an interest in using measures of species diversity such as richness (the number of species within a plot of a given size) as indicators of ecological integrity. Our experience in boreal mixedwood forests is that such indicators are difficult to measure, easy to misinterpret, and not particularly consistent or sensitive in their response to silvicultural practices. We don't recommend that they be used for operational monitoring.

6a. Vascular plants (trees, shrubs, herbs)

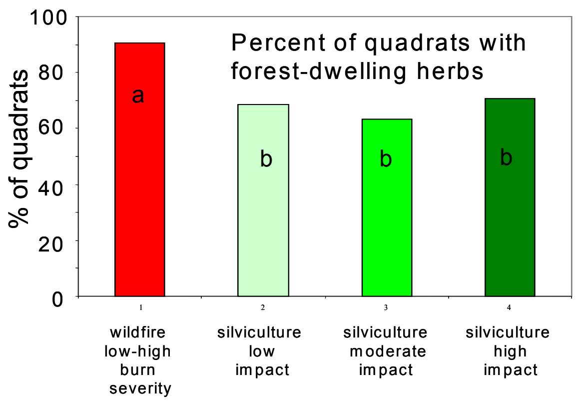


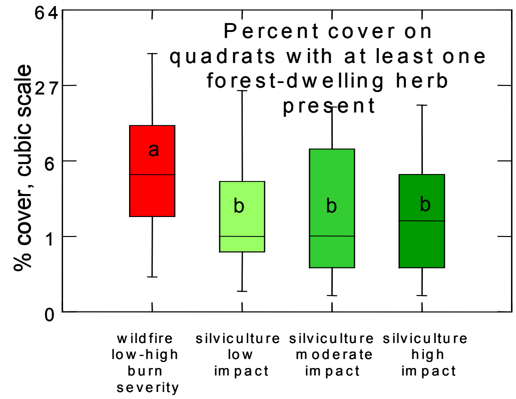
We have found no evidence that silvicultural practices in southern boreal mixedwoods reduce the richness of vascular plants (trees, shrubs, forbs, grasses) over the first 20 years of forest succession. Most often, silvicultural treatments increase mean or median richness and increase the range of variability compared to wildfire. Higher impact treatments often increase species richness because they create openings for shade-intolerant plants that regenerate from seed. Low impact treatments (e.g., clear-cutting with no site preparation) sometimes create patches with lower richness than is found on wildfires because of the dominance of Calamagrostis or an abundance of slash.

6b. Non-vascular plants (mosses, liverworts, lichens)

Non-vascular species richness is much more sensitive to silvicultural practices than vascular species richness and highly dependent on retention trees, coarse woody debris and landscape continuity. Richness increases quickly with time after disturbance and is higher in conifer-dominated than deciduous-dominated stands. We found no difference in non-vascular richness between wildfires and silviculture after controlling for these factors. We do not recommend using non-vascular species richness as an operational indicator because there are few trained botanists available and the work is very labour-intensive. However, non-vascular plants should be monitored to determine whether strategies for green tree and coarse woody debris retention are effectively conserving biodiversity.

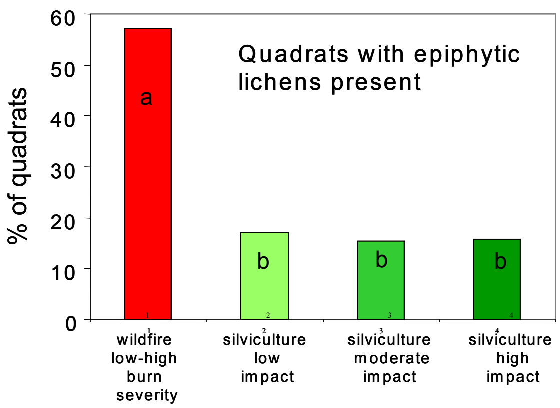
7. Shade-loving, forest-dwelling herbs

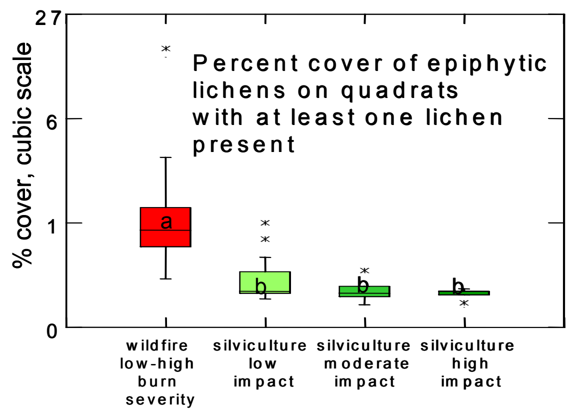




Boreal mixedwood forests contain few herbs that cannot survive in full sunlight, but there are a variety of species that prefer shade and typically become more abundant as the forest matures. These species, including many ferns, orchids, wintergreens, lilies and several other groups, are usually associated with coniferous trees and were significantly more abundant following wildfire than on the silvicultural trials, perhaps because they compete poorly with Calamagrostis and other herbs that proliferated on the silvicultural trials.

8. Epiphytic lichens





Epiphytic lichens were much more frequent and more abundant on wildfires than on the silvicultural trials. None of the silvicultural trials had retention trees or snags, which increase rates of lichen survival and colonization of regenerating trees. This indicator includes all epiphytic lichens, regardless of their sensitivity to forest disturbance and is measured as the percent cover of lichens fallen on the forest floor or growing on trees, shrubs and snags below 1.3 m height.

Conclusions and Recommendations

- High impact silviculture that removes woody debris and exposes mineral soil causes substantial changes to early succession of boreal mixedwood plant communities when compared with wildfire. Ten to 20-yr successional patterns after lower impact treatments such as disk trenching, a single application of glyphosate, or raw planting more closely resemble the range of variability after wildfire but also cause noticeable change.

- The following vegetation indicators are recommended for operational monitoring of biodiversity and ecological integrity of plant communities on BWBSmw1/01 and /06 ecosystems in the Peace River region:

    - Invasive alien plants.
    - Calamagrostis (bluejoint reed grass) – currently poses a greater threat to plant diversity than invasive alien plants.
    - Berry-producers.
    - Moose browse species.
    - Epiphytic lichens.
    - Shade-loving, forest-dwelling herbs (contact the author for an appropriate list of species).

  Any one or more of these indicator groups can be incorporated into a local monitoring protocol. We recommend using the line intercept method to record their percent cover on line transects established for monitoring coarse woody debris, because this method is less subjective than an ocular estimate. Other indicators examined in this report are not recommended for operational use at this time.

- The recommended indicators should receive further testing and validation before being implemented on a wide scale because:

    - A larger wildfire dataset is needed.
    - The silvicultural trials were on "backlog" sites that do not reflect current operational practices. For example, there was no retention of snags or green trees, coarse woody debris was completely removed from many plots, and there was no mixed pine-spruce planting. Treatments plots were also very small allowing for more rapid recolonization than would occur in a large operational cutblock.

- Monitoring a larger sample of unsalvaged wildfires in the BWBS would improve our ability to identify and interpret indicators. Unsalvaged reserve areas should be much larger than those left in the 1980s and 90s and should include commercially valuable forest types. These benchmarks, together with long-term silvicultural trials, can be used to monitor not only stand-level effects of silvicultural practices but also the cumulative effects of climate change, land use practices & invasive species.

- It is worth investigating whether a single multi-metric vegetation index of ecological integrity similar to the indices of biotic integrity (IBI) used in aquatic and wetland systems (Mack 2004) or the stream crossing quality index (Beaudry 2007) can be developed for BWBSmw1/01 and /06 ecosystems. IBIs combine a variety of metrics known to respond consistently across a disturbance gradient into a single indicator. They are difficult to develop for forest vegetation because the long-term nature of forest succession means that even in pristine ecosystems the relative proportions of different plant groups changes progressively after a disturbance.

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