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ASSESSING COMPONENTS OF ECOSYSTEM INTEGRITY IN THE EMEND EXPERIMENT

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ABSTRACT

One overall objective of the Ecosystem Management Emulating Natural Disturbance (EMEND) experiment is to compare the response of harvested forests to those that arise through wild fire and other natural disturbances. An optimal impact experiment was designed to use wild fire and untreated checks as the basis for inferring the effects of harvesting on ecosystem function. The size and cost of the experiment required stratification of forested landscapes to obtain homogeneous stand groupings in order to account for the effects of variation in cover types and initial stand structure on responses monitored. To the extent possible, forest stand descriptions (including understory vegetation, aspen (*Populus tremuloides*) regeneration, coarse woody debris, fuel loading, soil moisture and temperature, nutrient pools and arthropod diversity) are being monitored on a system of nested plots randomly located within the treatment compartments. Primary productivity, biodiversity of selected taxa, and nutrient fluxes will be derived from these estimates to provide the basis for powerful experiment-wide comparisons of ecosystem integrity among cover types and harvesting intensities.

INTRODUCTION

The origin and evolution of the Ecosystem Management Emulating Natural Disturbance (EMEND) project are described in a companion paper by Spence *et al.* (1999). The general objectives of the project focus on developing an understanding of the impacts of forest management activities on northern mixed-wood forests. This will allow us to select appropriate forestry practices to mitigate any adverse effects of those practices. These objectives are i) to determine which harvesting and forest regeneration practices best maintain ecosystem structure and function in comparison with mixed-wood landscapes that have arisen from the current natural disturbance regime, and ii) to assess the economic viability and sustainability, and social acceptability of these forestry practices.

This paper focuses on the design and implementation of an experiment to address questions that relate to the first objective. Thus questions that relate to the current composition of biotic communities, spatial patterns of forest structure, and the productive capacity of existing forest stands have to be answered. Also, the characteristics and temporal distribution of natural disturbances that influence forest stand development must be described. Most importantly, however, a system of observations is required to support comparisons and strong inferences regarding treatment effects on several ecosystem attributes. As is inevitable in long-term experiments, objectives not perceived at the inception of a project will probably develop before its termination (Franklin *et al.* 1990). It is therefore essential that experimental protocols be developed that do not unnecessarily restrict future options and permit maximum flexibility in addressing questions related to the ecological functioning of the system. The links and opportunities for investigations that address the economic and social concerns related to sustainable forest management are examples of the latter.

EXPERIMENTAL DESIGN CONSIDERATIONS

The experiment is a partially replicated 4 X 9 factorial experiment. Four levels of cover type make up the first factor. These cover types probably represent a successional chronosequence starting with deciduous-dominated stands (> 70% aspen, *Populus tremuloides* Michx.), deciduous stands with a conifer (white spruce, *Picea glauca* (Moench) Voss) understory up to 50 % canopy height, mixed-wood stands where conifers share the canopy, and terminating with conifer-dominated stands (with > 70% conifer cover). The treatments make up the second factor. Six harvest (0% retention = clearcut, 10%, 20%, 50%, 75% and 100% = untreated check) and three fire treatments (low, medium, and high intensity burns) make up levels of the second factor. With one exception, all factor combinations were replicated three times.

The single departure from a fully replicated balanced design was required because it would be risky to attempt 12 high-intensity experimental burns in the study area. The cost, and availability of suitably trained personnel to conduct these prescribed burns was not only prohibitive, but the chance of fire escaping control and damaging other experimental units becomes unacceptably high when the full suite of burns is contemplated. In addition, the possibility of having to burn several areas simultaneously adds unnecessarily to this risk. Thus, the need for full replication in this instance was compromised by the recognition that a single high-intensity burn in each of the cover types would probably suffice in providing estimates of system responses to the extremes of the burn treatments. An indicator of burn intensity will be used in the final analysis and synthesis of results. This is not only a result of the unbalanced design but results from our inability to control burns to exactly prescribed tolerances. Thus burn intensity will probably be modeled as a covariate in the final analysis.

The harvesting treatments can be controlled to a greater degree than prescribed burns. The various levels of harvest will include the extremes of full retention (essentially an undisturbed control) and a clearcut (a control that represents current practice). For the variable retention cuts, 5-m wide machine corridors, centred 20 m apart, will be cut in each compartment. All corridors will be oriented in a north/south direction. These are oriented perpendicular to prevailing winds so as to minimize wind-throw. The 75% retention treatment will comprise of machine corridors only. In the other harvest compartments, individual trees will be removed on either side of the corridor to achieve the desired retention level. The 75% retention harvest also permits us to study the effects of machine corridors alone.

The complexity of the experiment arises because of the various controls built into the experiment. What constitutes a control treatment in this experiment depends on the objective being pursued. Several comparisons are possible. i) There are temporal controls: a database has been compiled prior to treatment. A series of repeated observations on the same experimental units thus gives the researcher the option of conducting longitudinal studies. ii) There are successional controls: the burned areas may function as the natural disturbance that regenerates stands to which anthropogenic disturbances might be compared. iii) There are the untreated controls: several questions arise that can only be answered by comparing the response of the various treatments to undisturbed stands. iv) There are intra-stand controls: two elliptical patches (c 0.25 and 0.50 ha) located in each of the harvested blocks provide for comparisons on a sub-compartment scale (10 to 100 m). v) Finally, there are individual trees: they provide opportunities for comparisons among units under varying treatments at local at very scales (c. 1 to 10 m). Accommodation of these various controls within the experiment provides the basis for multifaceted analyses.

The experiment is large. In all, 100 candidate compartments, each 6 to 10 ha in area, were required for the full experimental layout. In total, close to 1 000 ha are monitored in the study area. Concerns about efficiency and costs combine with the need to integrate several observations on identical experimental units required that special monitoring protocols be implemented. Sub-sampling of the compartments was necessary to adequately represent conditions over the experimental unit (the compartment). The harvesting treatments will also introduce variability within the compartment. By orienting the machine corridors in a uniform direction throughout the experiment, the pattern of this disturbance is largely controlled. This uniform pattern also suggests the sub-sampling strategy that protects against selection bias of sub-unit location to study vegetation responses. A sub-unit or plot that is 40 m long and oriented perpendicular to the machine corridors will traverse the equivalent of two corridors and the associated residual strips. A completely unbiased selection of plots and the vegetation within them required that the start of these plots be located at random throughout the compartment. By making these plots 2 m wide, an adequate number of trees (about 10 in a mature stand) within the plot would be sampled. Six such plots were located and sampled within each compartment giving a total of 600 plots for the entire experiment.

A major concern in large ecological experiments that are cast over heterogeneous landscapes is the inevitable variability of experimental units. As the overall objective of the experiment is to compare responses in the various cover types to the various treatments, it is essential that the vegetation within replicates be fairly homogenous. By making each replicate homogenous (*i.e.* by stratifying stands based on volume), the design amplifies the signal that can be detected among the contrasts contemplated by the experiment. To do this, several candidate stands were sampled in 1997. The density and standing volume of trees within these stands were estimated. Groupings of stands (strata) were made based on the results of this preliminary survey. Those that did not come within 10% of the stratum target volume were eliminated. Compartments were delineated within these stands. Fire treatments were assigned to compartments within each replicate so as to maximize the opportunity to safely conduct the prescribed burn. The remaining compartments were randomly assigned the harvest treatments.

The power of the experiment is derived from its size and peculiar design characteristics. By re-measuring identical experimental plots before and after treatments, variability among plots is eliminated as a source of variance among temporal contrasts. Blocking experimental units within homogeneous stands minimizes the unexplained variation among blocks (or replicates) as a source of noise in the experiment (Mendenhall 1968). Contrasts that compare responses among cover types rely on measurements made on 25 experimental compartments (or 150 plots) per cover type and comparisons among harvest treatments depend on 12 experimental compartments (or 72 plots) per treatment. By treating fire intensity as a continuous variable, responses in the burn treatments will be based on results from 20 compartments (or 120 plots). Detailed power calculations (Morrison 1967) can be made following the first re-measurements to estimate variation of the specific responses being investigated. Extreme treatments advocated by Franklin *et al.* (1990) amplifies the power of the experiment to detect differences among contrasts in the responses investigated (Spence *et al.* 1999) in addition to exploring the natural variability of conditions extant on forested landscapes.

GENERALITY OF FINDINGS

The scale over which these observations apply directly varies from a few millimetres to hundreds of metres. The units depend on the level to which responses are investigated. Thus for arthropod diversity, the trapping radius may be a few metres but the ecosystem response to cutting may extend to several hundred metres. Similarly, the temporal scales may extend from a few weeks to several decades (the period over which re-measurements will be made). By contrast, the ecosystems of concern extends over hundreds of kilometres and may persist for centuries. Nevertheless, the EMEND project offers the opportunity to probe the consequences of treatments over these scales because of the unique combination of studies investigating processes by which ecosystems respond to harvests using an experimental approach. Furthermore, the entire study area will be repeatedly photographed from the air to provide a permanent record of responses to treatment by the major vegetation types. This photography provides a census of an area that extends over tens of kilometres in which the compartments and plots of the EMEND study represent an embedded ground truthing network.

It is quite legitimate to ask how general the findings of this study can be. The narrowest geographical area to which results apply is management unit P2 in northwestern Alberta because the area from which candidate stands were selected was limited to that area. Several other considerations built into the studies underway make the findings far more general in their application. By investing in process studies, the results of research undertaken in the EMEND project can reasonably be expected to apply wherever similar assumptions and conditions occur. Furthermore, this is not an isolated study but one in which similar undertakings have been deployed on the landscape. These studies include comparisons of the responses of biota i) to clear cutting in lodgepole pine stands in chronosequence studies (Niemelä *et al.* 1993), ii) to fires in a chronosequence study of aspen stands (Spence *et al.* 1997), iii) to defoliation in controlled experience (*sensu* Tukey) longitudinal studies of jack pine stands in Saskatchewan (Volney 1998), and iv) to experimental manipulation of spruce stands in northern Alberta (Volney *et al.* In prep.). The range and conditions investigated by this array of studies provide data sets for reciprocal illumination and a basis for independent verification of findings of the EMEND project. This range includes all the major forest types of the western boreal forest and spans most of the western boreal forest. Thus the unique combination of process studies, in which several observations are conducted on the same experimental units, in combination with the array of other investigations conducted throughout the western boreal forest permit projection of EMEND project results far beyond the P2 management unit.

OPPORTUNITIES

Many of these studies in the core program (Spence *et al.* 1999) investigate the biological indicators of sustainability. Apart from the extensions described above, many of the investigations lend themselves to collaboration with other research networks. The array of responses being investigated in the EMEND project is indicative of the range of opportunities for such linkages.

One 50 X 100 m silviculture trial area is associated with each compartment to assess regeneration treatments. Economic evaluation of these trials is an opportunity to comment on an essential component of sustainable forest management.

Studies of arthropod indicators of biodiversity provide one such opportunity. Unlike the case for most vertebrate species, arthropods can not be managed as the term is applied to wildlife species. Arthropods provide an independent indicator of ecosystem integrity. They thus become indicators of sustainability and useful in the assessment of the social acceptability of forestry practices. The same arguments can be used for investigations of plant species other than those valued for their timber.

Similarly, studies of productivity permit timber volumes and the physical attributes of the forest to be used in economic analyses of sustainability. These same attributes may be used in assessing the non-timber values of forests such as their scenic beauty and recreation potential.

Nutrient budgets and assessment of carbon fluxes within the ecosystem are indicators of how management activities address societal goals of maintaining the integrity of biogeochemical cycles. Carbon pools and the manner in which forestry practices change their content are concerns of regional and national governments and international agencies. Ultimately the content and changes of nutrient pools can be objective indicators of sustainability that may be used in assessing the industry's progress in implementing sustainable forest management.

The EMEND project relies on an optimal impact design (Green 1979). This design permits a comparison of control and treated experimental units before and after treatment application. The several types of controls incorporated in the EMEND project make this an experiment with the best statistical approach feasible. The issues raised by Franklin *et al.* (1990) relating to long-term research sites have all been addressed. Some, such as replication and use of extreme treatments, have been embedded in the experiment. The overall appeal of the EMEND project in the context of sustainable forest management should guarantee future and sustained interest in the project. Observations should continue periodically for at least one rotation. As this project will outlast the life-spans of the current investigators, there is need to address issues related to continuation of individual studies, succession of leadership and preparation of the synthesis of final results. However, if northern forestry remains an economically viable industry in the next century, interest in such long-term projects should be easily sustained. The experiment will become more valuable and more informative if and when advantage is taken of the many opportunities to evaluate the social and economic acceptability of forestry practices.

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