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LANDSCAPE ISSUES IN SUSTAINABLE FOREST MANAGEMENT: WILDLIFE MODELING, LANDSCAPE SIMULATION AND MODEL-BASED SAMPLING

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Background and Objectives:

Adaptive resource management requires information on the potential outcomes of policy decisions and management actions, from which hypotheses are generated. Implemented management strategies are treated as experiments, and observed consequences are used to test hypotheses and refine management. The work described here is one component of a group project within the Boreal Ecology and Economics Synthesis Team (BEEST). The primary goal of BEEST is to contribute to the development of an integrated suite of models for use in management scenario evaluations and policy analysis, and in the formulation and exploration of new hypotheses. The objectives of the research described here were to:

1) improve landscape simulation tools for use in scenario analysis,

2) enhance understanding of the relationships between forest management activities and system response through habitat-based and demographic wildlife modeling, and

3) develop methods for model-based field sampling programs.

Improving Landscape Simulation Tools

FEENIX is a grid-based landscape simulation framework that integrates models of wildfire, stand dynamics, harvesting and habitat availability, in order to evaluate various management scenarios. A detailed description of an earlier version of FEENIX can be found in Cumming et al. (1998). A number of improvements made to the FEENIX software during this research period are described below, including automation of simulations, increased speed and efficiency, and integration with commercially available GIS products.

In addition to enhancements and improvements in these areas, a "stripped-down" version of FEENIX has been produced to serve as a basis for developing simple spatial models that use the FEENIX data structure, its output and results. The goal was to decrease reliance on an individual programmer to build, test, and use models. The "stripped-down" version contains only basic spatial data management and graphics. It is intended to simplify model production to make it more accessible to non-programmers. Functionality is basic but provides the foundation for creating spatial ecological models. The tool is ideal for bottom-up ecological model development, so that researchers can build models without the overhead of complex detail and management options currently in FEENIX. Because all internals are compatible with FEENIX, the functionality can then be transferred to FEENIX and integrated by an experienced programmer. The shell version has all the same input, output and scenario evaluation capabilities as the full version.

A wide variety of enhancements were made to the FEENIX code. Legacy code was removed, several bugs were repaired, and algorithms were improved, resulting in speed improvements of up to 80%, and up to 10-fold in some individual modules. Several improvements were made to the way FEENIX opens and closes files. In addition, a rigorously tested random number generator was implemented into the FEENIX software. Given the importance of random number generation in simulation analysis, it was deemed important to ensure that results were not biased due to inadequate randomness in simulations.

Substantial improvements were made with regards to GIS import/export capabilities. FEENIX can import any number of layers using ESRI ascii grid formats. It can also, through user intervention or automatically, export maps of key spatial layers at any time. This provides an extension that is useful to look at spatial and temporal distributions of animal abundances and landscape features during and at the end of simulations.

Additional functionality was added to allow FEENIX to run without requiring users to constantly interact with the graphic user interface. A "batch processing" mode allows users to predefine the basis for simulations in a project definition file and run simulations unattended. An added benefit to this is that simulations run much faster when graphics are turned off. The natural extension to this is to run the same simulations multiple times to look at the statistical distributions of simulation results. This capability, known as "Monte Carlo Simulation", is now completely automated. A user can define a simulation run with a range of parameter choices, automatically run all combinations of options, and examine the results in FEENIX's structured simulation output. Users can define as many projects, with as many parameter combinations as desired, and repeat simulations with any frequency. This provides extremely flexible scenario evaluation.

As an extension to batch processing and Monte Carlo simulation, vast improvements have been made in the way simulation output is created, documented and stored. A sophisticated file naming convention produces documented, structured simulation output that can be post-processed for scenario evaluation.

Code enhancements made to FEENIX vastly improved the software's usefulness for analysis of forest management policies. With a modest amount of forethought and preparation, users can design very extensive scenario evaluations and answer questions pertaining to effects of annual allowable cut (AAC), size and spatial arrangement of cutblocks, species composition, fire control policies, wildlife viability analyses and spatial scale of analyses. In its current format, the software can run a multitude of simulations of any variety of combinations of policies. The following table provides an example of the types of analysis that are possible:

Projects	Policy variable 1	Policy variable 2	Policy variable 3	Policy variable 4
	AAC	ApplyFire (Y,N)	OldFirst (Y,N)	LN Block (Y,N)
1: 9ha scale	v1,v2,v3	Y	Y	Y
2: 3ha scale	v1,v2,v3	Y	Y	Y
3: Single	v1	N	Y	Y
4: MC 100	v1,v2,v3	Y	Y, N	Y,N

Projects can be designed to address a single question or, alternately, to simulate the result of combining several management options simultaneously. In the example above, projects 1 and 2 both contrast combinations of variables 1, 2, 3 and 4. Any file output produced by FEENIX will document that it comes from project 1 or 2, and from a specific combination of policy variables. Project 4 extends this idea to Monte Carlo simulation. Output will still be created for the project but simulation will be repeated 100 times and additional documentation will reflect simulation results for each run.

Creating project definition files allows users to consider the management variables that have the potential to affect ecological or economic outcomes. Predefining a range of policies, using a range of values for policy variables, forces FEENIX to repeat the simulation for each value, and to combine each value with all other combinations of policy variables. The result is a sensitivity analysis across all ranges of policies. If stochastic variation has the potential to affect outcomes, the addition of the Monte Carlo option provides a means of examining the range of variability resulting from policy choices within a stochastic environment. A good example arises when the stochastic nature of both random fires and random block size selection are combined. Generating 100 simulations, all from the same policy variables, will produce a range of outcomes. Post-simulation analysis can reveal the emergent statistical properties of the outcomes, which is useful for performing a viability analysis on policy options, particularly in the context of wildlife populations. This extension to FEENIX's capabilities makes it a powerful wildlife population viability analysis tool. It has been used extensively to track habitat for songbirds under a range of forest management strategies, but has been extended to perform population viability analyses on woodland caribou populations.

Enhanced Understanding of Wildlife Response to Forest Management

Forest Birds

Over much of boreal Canada, the natural disturbance model (NDM) has become the banner for large-scale industrial forestry. This coarse-filter approach is considered conservative in minimising risk to non-timber values, such as biodiversity, given presumed resiliency of the biota to large-scale disturbances. In boreal systems, fire is considered the dominant disturbance agent and driver of landscape-level patterns and processes. Successful application of the NDM in these systems hinges on three major assumptions: 1) that the natural fire regime can be adequately characterised, 2) that harvesting is largely compensatory to fire; a corollary of which is that burn rates must be reduced in harvested landscapes, and 3) that in the absence of fire, harvesting acts as a surrogate in maintaining biotic processes and patterns. We have assembled databases, and developed empirical models, to test these assumptions for a large region in northeast Alberta. We used landscape simulations to explore the consequences of fire and harvesting, at a variety of spatial scales. To address the first two assumptions of the NDM, fire is modeled as a three-stage stochastic process (ignition, escape and spread) with forest-type specific parameters (Cumming 2001) and an estimated fire suppression effect (Cumming *in prep*). Forest harvesting is multi-industry (deciduous and coniferous tenures), and uses yield tables and silviculture rules provided by industrial agents active in the area, modified by an aspen/spruce stand dynamics model. We use the bird community as a focal group to represent biotic response.

We have developed statistical models of bird species distribution and abundance at several spatial scales, using bird survey and forest inventory data. Fine-scale models are based on 10 years of bird data from a long-term study site at Calling Lake, Alberta (Schmiegelow et al. 1997), and use Poisson regression to predict expected abundance at a site, given standardised sampling and knowledge of local (3 ha) and neighbourhood (81 ha) habitat covariates (Vernier et al. 2002). The habitat variables characterise forest structure and composition. These models have been generated to act as ecological indicators in our FEENIX landscape simulation framework. We report here on the results of simulations considering three scenarios: 1) a natural fire regime (the baseline); 2) forest harvesting with no fire (a best case for industry); and 3) forest harvesting with suppressed fire (realistic). The following maps illustrate the predicted distribution of "good habitat" for an older forest specialist, the Black-throated Green Warbler (Figure 1) under these scenarios. Good habitat is defined as that of sufficient quality (age, composition and minimum patch size) to support consistently high numbers of birds, relative to our empirical data.

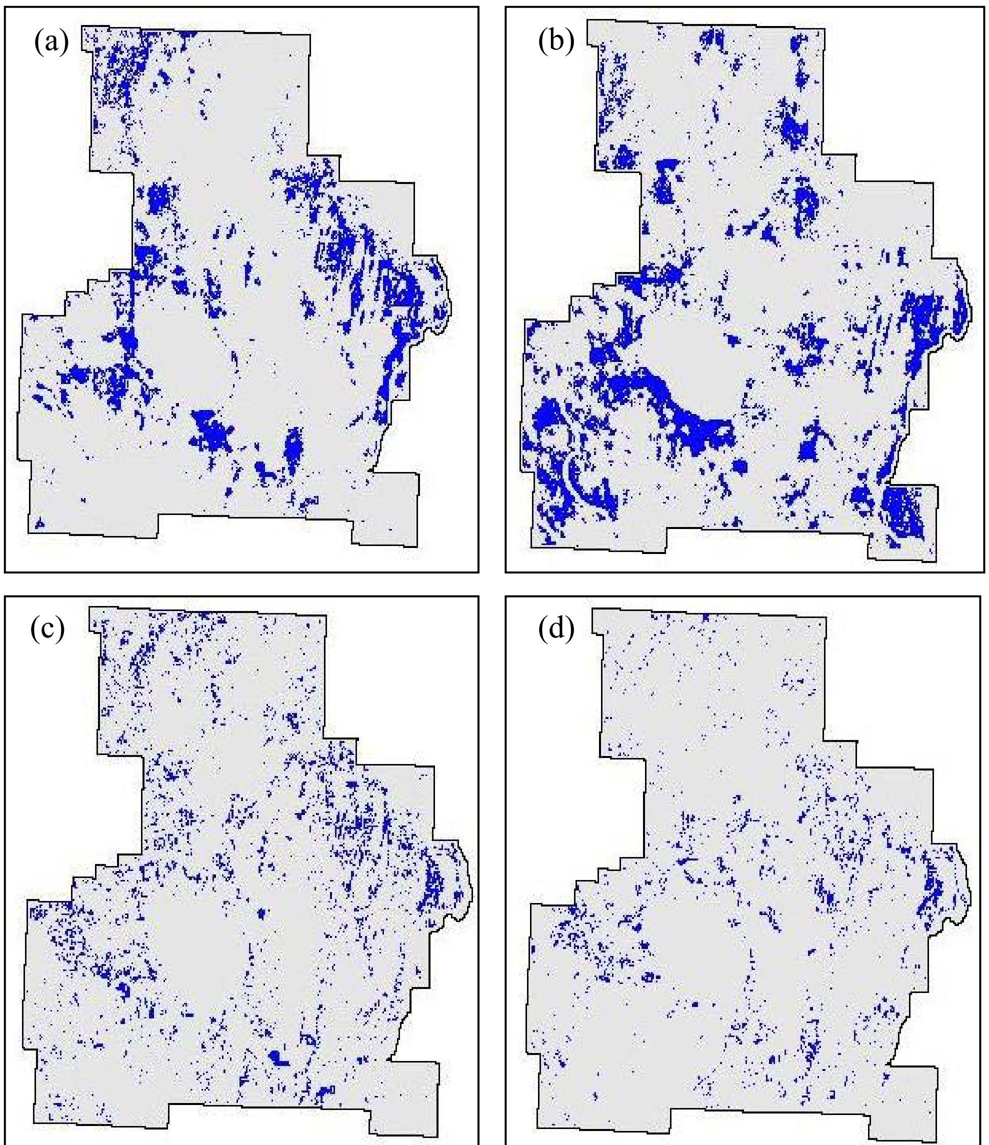


Figure 1. Predicted distribution of good habitat for the Black-throated Green Warbler at present (a), and in 200 years under three scenarios: natural fire regime (b), forest harvesting with no fire (c), and forest harvesting with suppressed fire (d).

Our work to date suggests that while abundances of forest specialist species are maintained in simulations where fire is the dominant disturbance agent, they decline significantly in harvest-dominated landscapes, due to both habitat loss and fragmentation (Figure 2).

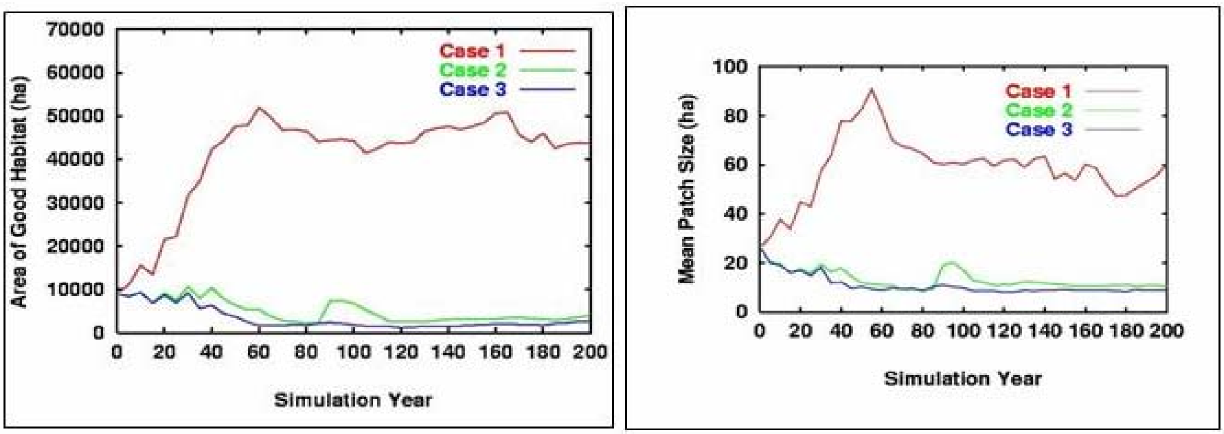


Figure 2. Predicted amount and mean patch size of good habitat for the Black-throated Green Warbler, over 200 years, under three scenarios: 1) natural fire regime; 2) forest harvesting with no fire, and 3) forest harvesting with suppressed fir.

These results suggest that present forest management will create future landscapes with no past analogues. Given that a number of bird species are sensitive to the amount and spatial distribution of habitat at multiple spatial scales, this change in pattern may also alter important ecological processes. We are now embarking on a series of field-based and simulation studies to explore conditions for the persistence of regional populations of sensitive species.

Woodland Caribou

There is a growing conflict between development and caribou conservation in Alberta, and a strong need for a solid foundation to derive decisions on harvesting and landscape management approaches that integrate caribou conservation and sustainable forest management.

Caribou population viability analyses are being implemented in several ways. One approach uses a simplified version of FEENIX, a single species model which includes only survival and fecundity, but incorporates forest age structure as a driving variable for survival rates. Another approach uses a multi-species predator-prey model to examine the effects of forest management and active control of species abundances on the dynamics of a caribou/moose/wolf system. Forest management effects are exhibited as changes to search rate and carrying capacity parameters. The model examines the relative benefits of establishing protected areas vs. actively controlling predator and alternate prey densities. Additional plans, which are currently under way, include: 1) predicting distribution of species abundances based on evolutionary fitness optimization principles, and 2) performing sensitivity analysis of alternate harvest scenarios generated by exogeneous harvest schedulers.

The caribou models are aimed at comparing the usefulness of single-species, multi-species, and spatially explicit models for predicting population dynamics. Carrying out all three options in a spatially explicit context vs. a mixed pool model is intended to demonstrate the utility of incorporating spatial information into key population parameters. A full model comparison is being conducted as part of Bob Lessard's PhD thesis work. The results will compare predictions to empirically observed trends in a local system and extend predictions to incorporate broader scale patterns observed across a variety of other study areas, and across different spatial and temporal scales. The final product, as a result of comparing spatial and non-spatial models, will be a more thorough understanding of the implications of evaluating systems constrained to certain spatial and temporal scales, and also an understanding of the implications of forest management within those same scales.

Development of Methods for Model-based Field Sampling Programs

Undertaking field research at scales appropriate to many forest management questions is logistically challenging and expensive. It is therefore desirable to ensure that investments in field programs yield the best data possible relative to the question(s) being posed. We previously investigated cost-effective sample designs for large-scale monitoring of forest bird population trends (Carlson and Schmiegelow 2002). Here, we report on the development of new methods to achieve optimal sample design for testing hypotheses of bird response to landscape change. We first describe the problem and selection of design variables, then present two methods employed to maximise the expected gain in information through field sampling.

These methods were applied to a large-scale field program in 2001 and 2002, the details and results of which are presented in Schmiegelow and Cumming (2004).

Design Variables

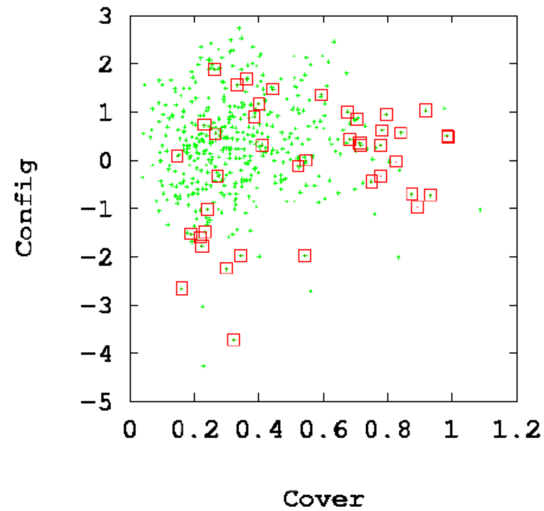
The goal of this study was to better understand the effect of industrial development in the boreal forest on forest songbirds. In Alberta, the main concerns relate to the forest and energy sectors. We required a small set of relevant landscape-level variables that would be sensitive to their activities, or the "industrial footprint". Forest harvesting in northeast Alberta is concentrated on upland mesic stands composed mostly of trembling aspen or white spruce in some combination. Stands older than the rotation age will become rare in the future. The rotation age for white spruce is about 120yr. The rotation age for deciduous stands is shorter (70-80yr) but these stands are more abundant. We adopted upland mesic forest older than 90yr as our focal habitat type. Forest harvesting will reduce the overall abundance of this habitat, but will also change its configuration, or the spatial arrangement of habitat patches within landscape units. Habitat patches in managed forests are projected to become smaller and more isolated from each other than they are in the natural forest. Therefore, we needed variables measuring the abundance and configuration of focal habitat. It is easy to generate an enormous variety of patch configuration metrics using computer programs such as Fragstats, but we could use only one, and had no *a-priori* grounds for choosing it. The industrial footprint includes both temporary or semi-permanent clearings, such as cut-blocks and well sites, and a network of linear features. The most important types of linear features are, in decreasing order of abundance, seismic lines, industrial roads, pipeline rights-of-way, and provincial roads. We needed additional variables to measure these factors.

Landscape sampling in 2001 was based on only 4 design variables: `Cover`, `Config`, `Loss`, and `Wells`. `Cover` is the abundance of focal habitat, expressed as a proportion of total landscape area. `Config` is an omnibus measure of landscape patch configuration. It is derived mathematically from the total number of habitat patches on the landscape, and the mean and standard deviation of the log-transformed patch sizes (Cumming and Schmiegelow, 2001; Cumming and Vernier, 2002). `Config` is strongly correlated with specific landscape pattern metrics of patch shape and edge density (e.g. total or mean core area, mean shape indices). It is also significantly related to purely spatial configuration metrics, such as the mean distance between a habitat patch and its nearest neighbour, and the structure of the forest matrix between habitat patches. `Loss` is the proportional area of recently harvested forest, defined as mapped cut-blocks younger than 30yrs. Several retrospective studies of young regenerating stands have found that ecological indicators measured in fire-origin and harvested stands tend to converge within about 30yrs. `Wells` is the landscape density of drilled wells, in units of wells per 10,000ha. Within landscapes, we found moderately strong correlations between the densities of drilled wells and all four types of linear features (R^2 ranged from 32 to 44%). These correlations were obtained from non-linear regression models of linear feature densities with `Wells` as the independent variable. Thus, `Wells` is a surrogate for linear features in general.

Statistical analysis of the 2001 field data showed that some species of old forest songbirds were sensitive to our measure of the energy sector footprint: their abundances were inversely related to `Wells`. However, we could not tell whether the birds were sensitive to wells as such, or to one or more of the linear features instead. Therefore, in 2002, we added a fifth design variable. `P1` is a combination of the residuals from the regression models mentioned above, that measures the overall density of linear features relative to `Wells`.

2001: Balanced design

The 2001 study region included more than 700 landscapes. Naturally, we could only do field surveys in a small proportion of these (43, as it turned out). The design problem was to choose a few landscapes (the sample) out of the full set of landscapes in the region (the population) that were likely to do a good job of meeting the study objectives. In 2001, there were two related objectives. We wanted to determine if the design variables really had any effect on the abundances of forest songbirds. More importantly, we wanted to model the functional relationships, that is, to describe how the abundances of particular species change with landscape structure, as measured by the four variables. An ANOVA design is not the best way to achieve this. Instead, we considered that the design should cover the entire range of each variable as evenly as possible. We developed custom software to automate multivariate balanced sample design. Units are added to a sample one at a time. At each step, a goodness-of-fit statistic identifies the most unbalanced design variable. The cell that most improves the balance for that variable is then added to the sample. Technically, this procedure only balances the marginal distributions. It does not guarantee multivariate balance or independence, but we have found these criteria are generally met in practice, as the accompanying figure illustrates. The distribution of `Cover` and `Config` in the 2001 sample (red squares) covered the range of the population (green dots) very well. The program accounts for landscapes in the population that cannot be sampled (e.g. because of poor access). It is also easy to update a design during a field season, if logistic considerations or unforeseen events require that some landscape be dropped from the original design. For example, forest fires in 2002 rendered some of the landscapes we had initially selected unsuitable, forcing a re-design mid-way through the field season. Because we had full information on all potential sample landscapes in hand, this was accomplished efficiently, with minimal loss of valuable field time. The software has since been applied to several other sample design problems in SFMN research projects.



2002: Model-based design

Models of species abundance or presence/absence data collected in the 2001 field season showed that many species were sensitive to one or more of the design variables. Notably, both landscape fragmentation and the industrial footprint negatively affected many old-forest species. Abundances of some "matrix" species (species more common in the triangles than the grids) were also negatively related to the new design variable for linear feature density. The purpose of the 2002 field season was to test and refine these models. For this purpose, we needed an entirely different sample design. Model-based sampling uses existing models to predict species abundances or presence/absence probabilities at new locations. The prediction error at each location depends on the precision of the model parameter estimates, the values of the design variables at the location, and the measurement error. It measures the expected information to be gained by sampling at the new location. A model-based design selects landscapes where the prediction error is high. The 2002 design was based on three different models, chosen to represent various combinations of the design variables and a range of species responses: 1) an abundance model of a guild of triangle species (Gray Jay and Warbling Vireo); 2) an abundance model of a guild of old-forest species (Black-throated Green Warbler, Magnolia Warbler and Golden-crowned Kinglet); and 3) a presence/absence model for the Canada Warbler in deciduous-dominated old forest patches. Again, we developed custom software to automate the design process.

Benefits of This Research

The focus of this research was the development of tools, and assembly of data bases, for use in landscape simulations to explore a variety of forest management scenarios. This is a critical step in adaptive resource management, an approach to which most Sustainable Forest Management Network partners are committed. The tools developed have applications far beyond those detailed here, and will be used in subsequent work by researchers in BEEST, and by other researchers. The scenario analyses we report on here have direct implications for forest management in Alberta.

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