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# A practical approach for comparing management strategies in complex forest ecosystems using meta-modelling toolkits

## Highlights

- Sustainable forest management requires a multi-scale perspective that considers both stand and landscape scale processes as well as short- and long-term effects.
- Most models are designed to work within specific ranges of spatial and temporal scales and include only a few dynamic processes.
- Meta-modelling can link a set of more specialized models, where output from one model can be used as input to another.
- Meta-modelling supports a multi-faceted view of complex systems and problems (e.g. regarding spatial and temporal scales of ecological processes and operational and strategic planning), and facilitates an integrated whole-systems approach.
- Existing and new models can be linked together in a meta-modelling framework to meet a host of challenges facing forest managers.

**The complexity and multi-scaled nature** of forests poses significant challenges to understanding and management. Models can provide useful insights into processes and their interactions, and implications of alternative management options. Most models, particularly scientific models, focus on a relatively small set of processes and are designed to operate within a relatively narrow spatial and temporal range. This limits their efficacy in managing multiple objectives across large spatial and temporal scales. A key challenge to using models in sustainable forest management is overcoming the pressures of improving the reliability and scientific credibility of models, while simultaneously expanding the whole-system view required for integrated management.

This research note summarizes work presented in Sturtevant et al. (2007) and describes a practical approach to the analysis of complex systems in which diverse models are viewed as a set of tools that support diverse and novel interconnections in a two-level modelling structure. At the tool level, scientifically-based models can be refined to provide as accurate and reliable results as possible within a specific domain of expertise. At a higher level, models can be joined into a framework, creating a meta-model that is capable of addressing questions at various scales. This is particularly relevant to forest managers because it allows utilization of appropriate tools for questions and enables efficient use of skills and time. This in turn leads to timely provision of the best available information. This is one of several research notes synthesizing results of the Labrador forest management model integration project.

## Challenges of sustainable forest management and complex systems

Assessing sustainability of forest management alternatives requires the ability to project forest values over relevant time frames (e.g. several forest rotations or centuries) in order to identify trends and causal

links between present decisions and long-term consequences. A wide variety of models have been built and applied to explore expected forest outcomes, including models designed for timber supply, landscape fire, growth and yield, carbon flux, habitat supply, and population dynamics. In addition, models have been built to quantify indicators of forest values, which may include simple outputs such as area of old forest or volume harvested, or more complex outputs such as number of potential home ranges for a given species, or kilometres of road required to build or maintain. Visualization tools communicate outputs using visual displays (e.g. realistic rendering of potential forest conditions to assess visual quality, or graphic methods to explore complex patterns of correlation among indicators).

Sustainable forest management (SFM) often requires taking a systems view of a landscape. For example, one may be interested in how forest disturbances such as fire, logging, and road building influence the amount and connectivity of Woodland caribou (*Caribou tarandus*) habitat, and, in turn, potential effects on caribou population viability. Or one might be interested in how logging might affect understory regeneration, consequent shifts in species and growth & yield, and long-term risks of insect outbreaks. Such questions link processes both within a similar scale (e.g. landscape, stand) and across scales and emphasize the need for a meta-modelling approach.

## Meta-modelling using a toolkit approach

It is neither feasible nor desirable to build a single enormous model that includes all processes and scales of interest within forest management. Rather, models should be only as complex as they need to be. Reliable scientific models require large investments of time and energy to develop, and their applicability tends to become very specialized over time. In contrast, meta-modelling treats individual models as components that can be linked together to create higher-level system models as needed for decision-support in complex environments.

Model decomposition, another principle for modelling complex systems, aims to divide a problem into smaller components where possible. Model abstraction aims to reduce complexity while retaining general reliability. Problems can be divided between scales across which interactions are often more limited, or within a scale (e.g. focus on a specific process or set of highly interactive processes), provided feedbacks are adequately accounted for. For example, a detailed fire model could be used to examine a fire regime and questions regarding natural variability. On the other hand, a harvest optimization model might be used to examine timber supply or economic questions. A more general, integrated model might be derived from these two specific models to examine interactions between fire and logging. Hence, decomposition facilitates in-depth examination of system components, and by abstracting some details and parameters from more specific models, one can construct more workable meta-models.

A key requirement for meta-modelling is the ability to connect models that are applicable to a study area, but were developed for different goals and scales. We don't advocate a tightly-coupled approach, where one model may directly invoke another, as this introduces unnecessary model dependencies and technical complications. Rather, we propose a loosely-coupled approach, where output from one model becomes input to another. This output may be in the form of individual parameter values, tables, non-spatial time-series, spatial data or spatial time-series. Outputs may need some processing (e.g. to compute a parameter during a calibration process), but in general the more automated the connection the better. Hence, models and tools with open/flexible input/output interfaces are best suited to meta-modelling.

## An example from Labrador

We applied our meta-modelling approach in District 19A, south-central Labrador (Figure 1). The study landscape of approximately 2 million hectares covers a diverse range of boreal land types. The forest is dominated by black spruce (*Picea mariana*), although other coniferous and deciduous species are present.

Our group was approached by the provincial Department of Forest Resources and Agrifoods to help examine SFM planning in this area, in particular issues and questions regarding forestry, Woodland caribou, access management, natural disturbance and economic/social well-being.

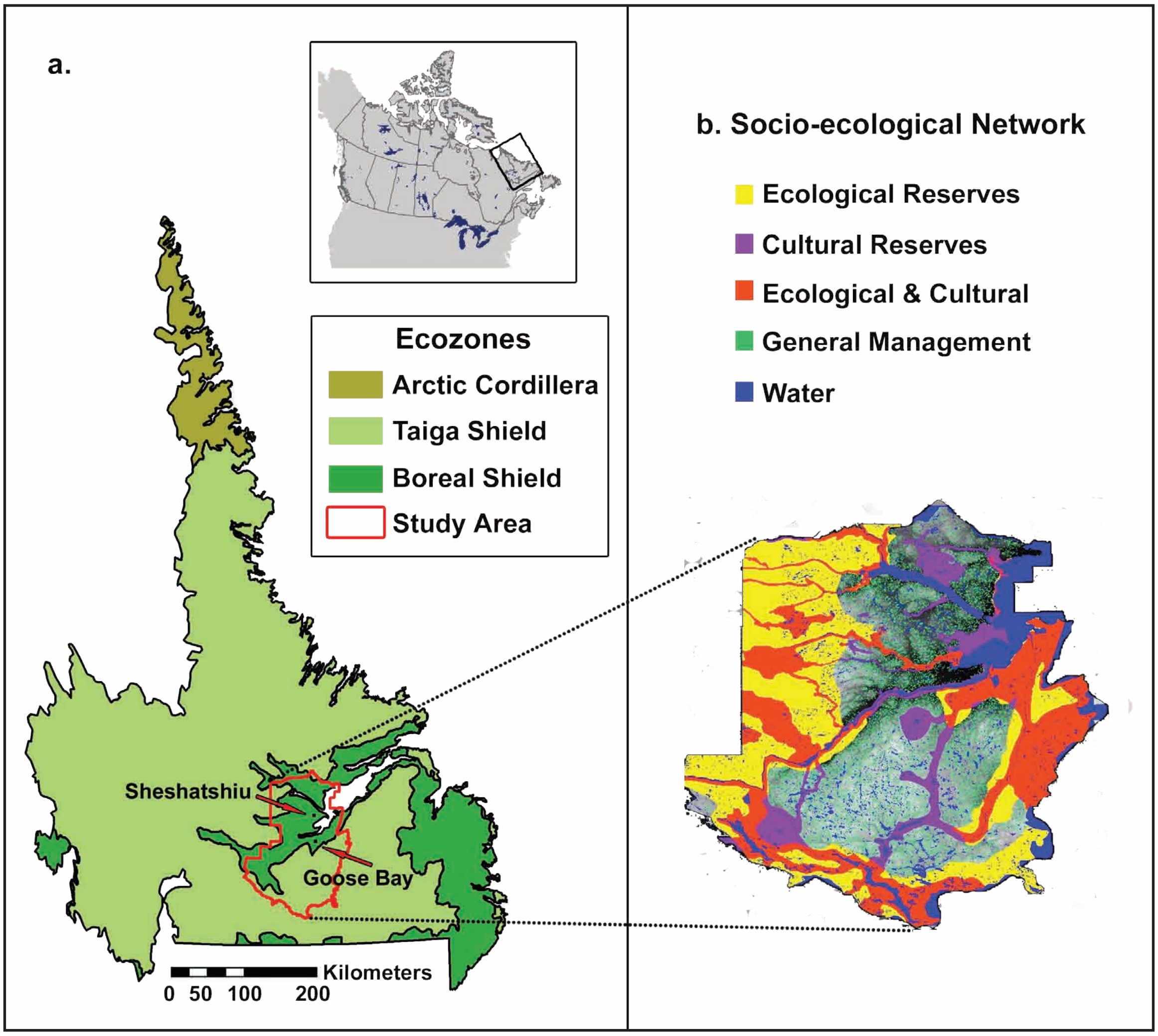


**Figure 1.** Forest Management District 19A (Labrador, Canada) straddles a major ecotone between boreal (closed canopy) and taiga (open canopy) ecosystems, and serves as a test case for our toolkit approach. The socio-ecological conservation network outlined in the 20-year forest plan accounts for both ecological and cultural reserves, as well as connecting corridors. Fine-scale forest retention (i.e. retention of individual trees or groups of trees within harvest units; not shown in figure) was based on targets in the 20-year plan.

Our research group developed a toolkit for the study landscape based on our collective experience and familiarity with modelling tools and platforms (Figure 2). At the landscape scale, we used “Patchworks” for economic timber supply optimization, while the focus of “LANDIS II” was fire and succession. “SELES” was used to construct the “D19aLM” landscape model, which included natural disturbance, forestry, road building and succession processes. SELES was also used to produce some indicator outputs. At the stand scale, we used growth and yield data from a provincial stand-scale model as inputs for estimating timber volumes. We used the Canadian Forest Service Fire Behaviour Prediction system to estimate finer-scale fire spread rates. At yet finer, individual tree scales, we used “SORTIE” to explore uneven-aged management and detailed succession, while “Linkages” was used to estimate tree species establishment coefficients. “Real Options” is an approach to economic assessment that we used to explore social-ecological tradeoffs, while the “Biodiversity Assessment Project” (BAP) was used to produce ecological indicators of wildlife and forest conditions.

By including researchers with expertise in these different tools and domains, we were able to analyse the study landscape from a variety of perspectives. The D19aLM landscape model was transferred to provincial staff, along with some training on its use, and applied in the 5-year plan review (mainly for timber supply analysis). Indicator outputs were communicated with local stakeholders to explore support for the current management plan, and to assess tradeoffs between forestry and caribou habitat.

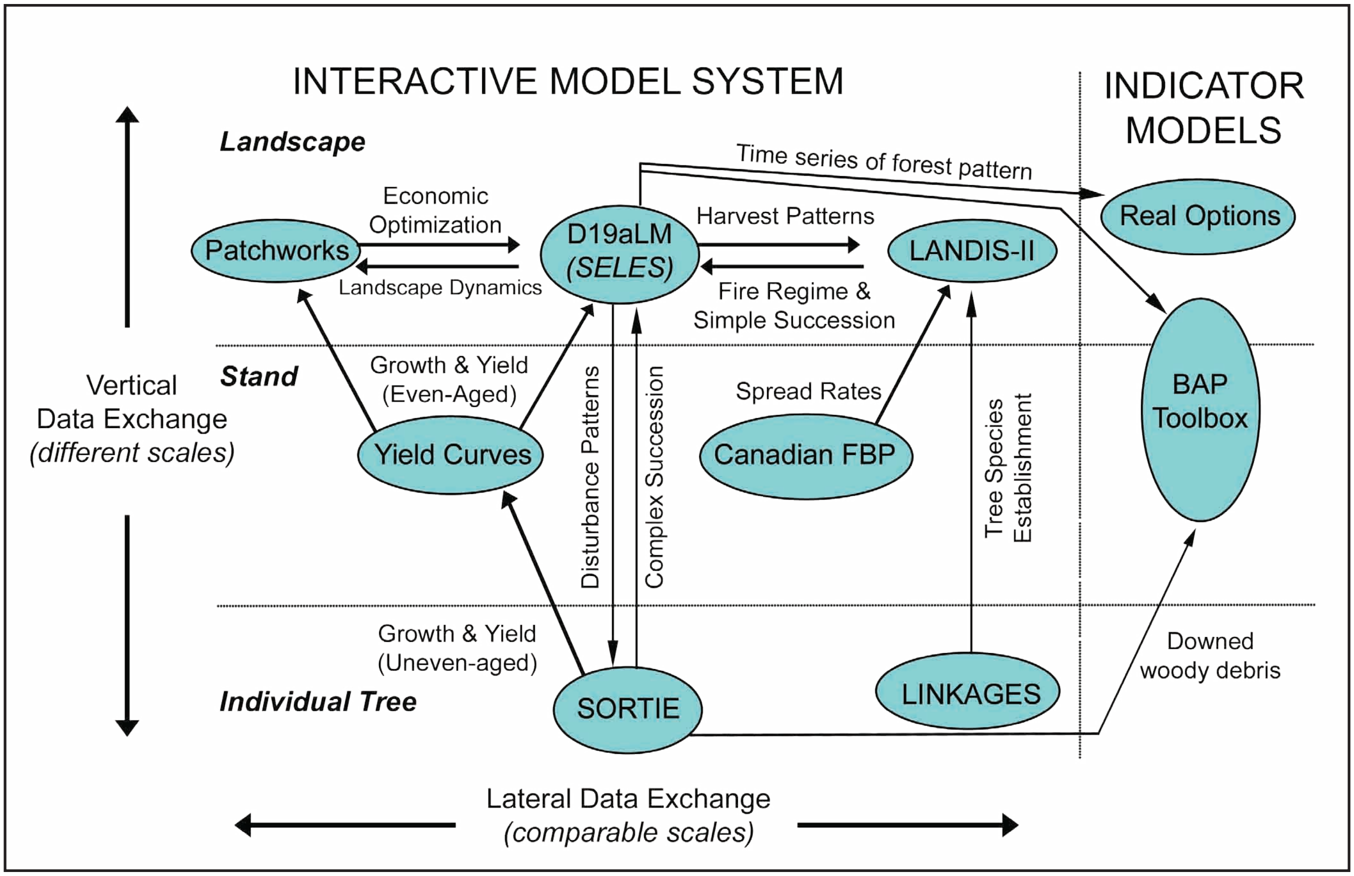


**Figure 2.** Information flow between different models (shaded in blue) in the toolkit for the Labrador District 19A system. Information exchange between models is organized in vertical (cross-scale) and horizontal (same scale) dimensions. See Sturtevant et al. (2007) for detailed descriptions of the forested system and model elements.

## Pros and cons of the meta-modelling approach

The meta-modelling approach has a number of key benefits. It can take advantage of the wide range of existing specialized and powerful models, while retaining the necessary flexibility to adapt to local conditions, data and specific needs. It can make efficient use of time for both researchers and managers, since multiple people can work on various aspects of a problem simultaneously (even across geographic distance as was the case for our research group), resulting in timelier and higher quality results. It allows each component to be individually scrutinized. It supports comparisons of model components, which can help to improve models as well as understanding of complex interactions needed for effective management. Likewise, the loosely-coupled approach supports output from one model to be used by multiple other components, which can improve consistency by reducing duplication as well as create intermediate data sets that can be archived for future analysis and verification (e.g. as part of monitoring and adaptive management). Finally, the meta-modelling approach supports structured scenario and model sensitivity analyses to account for and estimate the key uncertainties of future outcomes.

There are also some key challenges of the meta-modelling approach. Model components may need modification to support inter-operability (or at least reduce the effort to transform outputs from one tool into inputs to another). Fully automated connections may not be feasible in some cases (e.g. where intermediate analysis and interpretation or abstraction is necessary). It is imperative that ecological and empirical relationships integral to model components be verified and adapted to the new region of application. Verification (ensuring a model matches its design), validation (comparison with independent data) and full model testing pose challenges for any complex system. Meta-modelling facilitates testing of each model component, but diligence is needed for whole-model testing (e.g. via sensitivity analysis to assess how changes propagate through the system).

From a manager's perspective, key challenges include assembling a team with diverse modelling and analysis capabilities, and ensuring a broad spectrum of tools are considered (i.e. seeking cooperative inter-operability not competitive exclusion). Overarching leadership is needed to ensure cohesive progression of tasks, to foster communication of results between components and to the decision process (e.g. via an ftp site and reporting), and to maintain a clear vision of the overall objectives. As with any toolkit, assembling a varied set of high quality tools is not the ultimate goal; rather, focus must be kept on the problem to which the tools are applied.

The complexity and multi-scale nature of sustainable forest management requires flexible, modular, transparent and efficient approaches to provide information in a timely manner to support decisions. A toolkit approach that can link existing and new models into meta-models provides a practical approach to meet this challenge.

## Further reading


Berninger, K. 2008. *Collaborative modelling and social learning: engaging local people in the development and use of decision-making tools.* Research Note No. 45. Sustainable Forest Management Network. Edmonton, Alberta. Online: www.sfmnetwork.ca/docs/e/RN_E45_SocialLearning.pdf

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### Management Implications

- Complex systems are best addressed by decomposing, where possible, into sub-components.
- Models and tools should be designed with inter-operability as a goal.
- Modelling expertise is a limiting factor – let modelers use familiar tools if possible, but ensure linkages with inputs/outputs are feasible.
- It is important to understand the effects of the key processes at different scales.
- To provide effective decision-support, tools must be adaptable to local conditions and needs.

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