FREP

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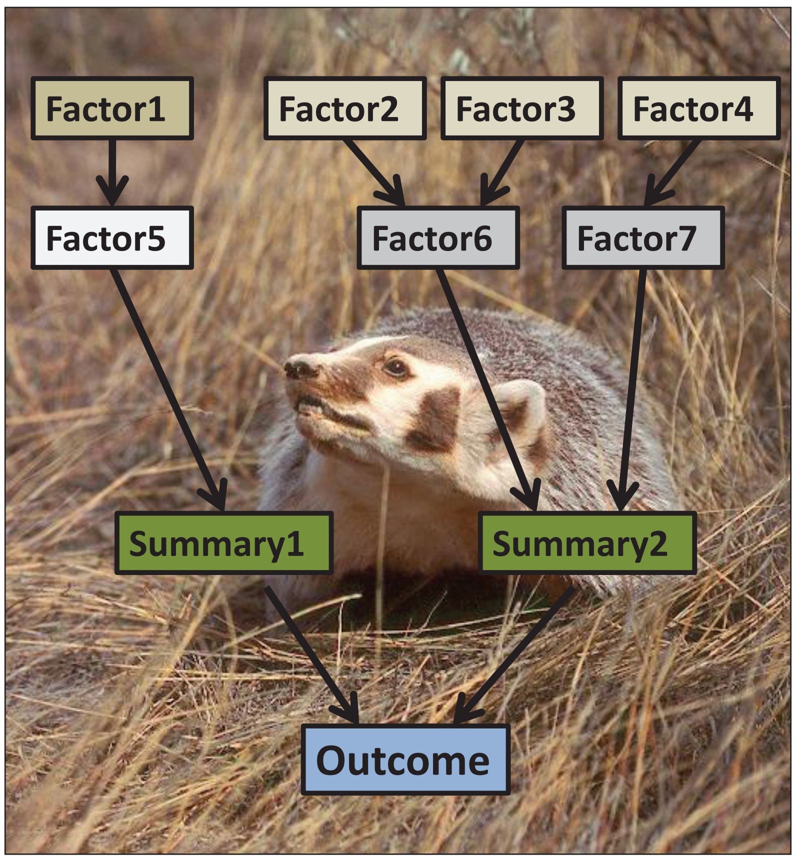
FOREST AND RANGE EVALUATION PROGRAM

May 2010

Conceptual Models for Wildlife Effectiveness Evaluations: A Recommended Approach

Report prepared by Brian Nyberg



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MINISTRY OF FORESTS AND RANGE
FOREST AND RANGE EVALUATION PROGRAM

Conceptual Models for Wildlife Effectiveness Evaluations: A Recommended Approach

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Management of forest and range resources is a complex process that often involves the balancing of ecological, social, and economic considerations. This evaluation report represents one facet of this process. Based on monitoring data and analysis, the authors offer the following recommendations to those who develop and implement forest and range management policy, plans, and practices.

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Prepared by: Brian Nyberg

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EXECUTIVE SUMMARY

Conceptual models are valuable tools for designing monitoring and evaluation plans, and are widely used in monitoring programs for natural resources. This document explores the utility of conceptual models for developing effectiveness evaluation protocols for wildlife species under the Forest and Range Evaluation Program (FREP) in British Columbia.

Conceptual models are defined as formalized representations of reality—such as text descriptions, diagrams, or computer models—that are intended to assist in understanding the characteristics (attributes and processes) of the real world. These models may include quantitative information, but they are less complex mathematically than simulation models and other advanced computer models.

For wildlife evaluations under FREP, conceptual modelling is valuable primarily because it provides a structured way for evaluators to select meaningful monitoring indicators. Other benefits include clear depiction of important factors and linkages in the managed ecosystem, enhanced communication among evaluation team members, documentation of current understanding of the system, and identification of important data gaps and uncertainties.

In this document, the types of conceptual models are reviewed and classified by their conceptual framework and their presentation format. Based on monitoring and evaluation literature, four main types of frameworks are recognized: the Pressure-State-Response framework; the Ecological Causal Web, the Impact Hypothesis Diagram, and the Program Logic framework. Four main types of presentation formats are also described: diagrams; text and tables; mathematical equations and graphs; and mixed diagrammatic and quantitative formats. Examples are provided for each of the types, and their relative advantages and disadvantages for wildlife evaluations are discussed.

The Bayesian Belief Network (BBN) based on an Ecological Causal Web is the recommended conceptual modelling approach for organizing ecological and biological relationships to identify monitoring indicators for FREP wildlife effectiveness evaluation protocols. A BBN is a mixed diagrammatic and quantitative format that is becoming increasingly popular in many natural resource applications; the Ecological Causal Web and similar frameworks are used extensively in forest monitoring programs in the United States. References to more detailed guidance on BBN development and use in the literature are also provided. Where it is not practical (e.g., information is insufficient or there is no access to appropriate software) to develop a true BBN, FREP evaluation protocols can approximate the BBN approach to organizing known information by using box-and-arrow diagrams that can be drawn on flip charts or a computer and then annotated with quantitative data and relations.Acknowledgements

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INTRODUCTION

Under the auspices of British Columbia's Forest and Range Evaluation Program (FREP),[1] the Ministry of Environment and the Ministry of Forests and Range are developing standards and protocols to evaluate the management of wildlife on Crown forest and range lands.[2] One important component of developing standards and protocols is the need to conceptually organize existing knowledge of ecological and biological relationships in a transparent platform to allow for the identification and rationalization of indicators for monitoring and evaluation.

This document reviews various approaches to conceptual modelling with the intent of providing recommendations for an approach best suited to wildlife resource effectiveness evaluations.

In this report, a conceptual model is defined as a formalized representation of reality designed to assist in understanding the characteristics (attributes and processes) of the real world. "Formalized" means recorded as text, a diagram, or as computer code. Conceptual models may or may not include quantitative features; however, if they do, they are not as complex mathematically as simulation models and certain other types of advanced quantitative models. Typically, conceptual models used in environmental monitoring and evaluation applications document the functional relations between stressors such as human activities (e.g., logging and grazing), ecosystem attributes, and eventual environmental or social outcomes.

Conceptual models are used widely in monitoring and evaluation programs, primarily as aids to understand the monitored system and to guide the selection of indicators (Margoluis and Salafsky 1998; Mulder et al. 1999; Bunnell et al. 2003; Conservation Measures Partnership 2004; Niemeijer and de Groot 2007). Some experts advocate that every monitoring and evaluation project should include a conceptual model as part of the project's design. For example, in discussing conservation and development projects, Margoluis and Salafsky (1998:27) assert that: "The foundation of all project design, management, and monitoring activities is a Conceptual Model of the project." Several authors have already developed conceptual models as the basis for identifying questions and indicators as part of the development of effectiveness evaluation protocols for selected wildlife species and groups under FREP (e.g., Ovaska and Sopuck 2004; Hoodicoff 2006; Sutherland 2008). It is expected that conceptual models will continue to be produced to support indicator identification for most, if not all, new monitoring and evaluation protocols (K. Paige, Ministry of Environment, pers. comm., Sept. 2008).

For FREP evaluations, conceptual modelling is valuable mainly because it provides a structured way for evaluators to select meaningful indicators for monitoring. As the conceptual model is developed, the evaluator must consider the ways in which human activities, natural disturbances, and other threats will influence a wide variety of ecosystem attributes, including wildlife habitat characteristics. The evaluator attempts to display in the model all the important relations (e.g., interactions among various components) that collectively determine the ultimate outcome of interest (e.g., the quality of the habitat for a species at risk, or the population size of the species). The thorough analysis that is required in constructing the model helps the evaluator to form clear ideas about the most important influences on the habitat and species, and how those influences are propagated through the components of the ecosystem. With the evaluator's knowledge and concepts organized and documented in a model, monitoring indicators are then selected to track the status and trend of the stressors (e.g., threats), key ecosystem attributes (e.g., habitats), and the wildlife outcomes (e.g., species populations) (Margoluis and Salafsky 1998; Mulder et al. 1999; Nyberg et al. 2006; and Pourret 2008).

Conceptual models may not be, and do not have to be, overly complex; model complexity will reflect the level of knowledge available for a particular species. In many cases there will be limited data to support modelled relationships. The models will be expert-system constructs depicting the best understanding of attributes, stressors, outcomes, and the relationships between these. At the outset of many evaluation efforts, monitoring may be more of a basic study of habitat requirements and identification of potential stressors. This, however, does not eliminate the *a priori* need to formally organize existing knowledge within a transparent framework to facilitate the identification, and subsequent testing and validation, of monitoring indicators.

1 See http://www.for.gov.bc.ca/hfp/frep

2 See http://www.for.gov.bc.ca/hfp/frep/values/wildlife.htm

Although indicator selection is the primary goal of conceptual modelling in FREP wildlife evaluations, there are other important benefits as well. Conceptual models can:

- enable project leaders and participants to see explicitly how different factors (e.g., stressors, ecosystem attributes and outcomes) are linked together, which can suggest the best way to plan and manage a project;
- facilitate stakeholders (i.e., resource managers, users, and others with a particular interest in one or several aspects of the ecosystem or wildlife species) to explicitly state their needs;
- bring team members together through the process of model building, and generate support for a project;
- clarify what is known and unknown and help define relationships that can be tested through monitoring, evaluation, and research;
- make underlying assumptions obvious and evident to everyone involved;
- document a project team's understanding of the system being managed and evaluated;
- communicate the current understanding of a modelled system to interested observers and, in the case of multi-year projects, to those who may later join a project or inherit responsibility for it; and
- identify potential obstacles or difficulties that may be encountered in attempting to achieve a resource objective, and illustrate how planned interventions may affect the target objective.

The following sections provide a review of conceptual models and advice on choosing an approach for wildlife evaluation projects. The various types of available models and their relative merits are described. Recommendations are then offered on how to choose a modelling approach to suit the needs of each project and the resources available. Finally, a more detailed review is provided on the model format recommended for most wildlife evaluation projects.

TYPES OF CONCEPTUAL MODELS

In this section, a wide range of approaches is briefly reviewed. This will provide an overview of methods used in a number of fields and set the context for recommendations on preferred approaches for wildlife evaluations under FREP.

To simplify the distinctions among the types of conceptual models used in monitoring and evaluation projects for natural resources, the various approaches here are classified by the type of conceptual framework they employ and the format in which they are implemented or portrayed. For example, a model based on the Pressure-State-Response approach (its conceptual framework) could be implemented as a written table, as a diagram of boxes and arrows, or as a quantitative model such as a Bayesian Belief Network. For each conceptual framework and presentation format, a brief point-form summary lists the applications in which it is most commonly used, its advantages and shortcomings, and its relative value in conceptual modelling for wildlife evaluations. To illustrate these approaches, examples are provided in this section and in Appendices 1–5.

For most of the examples cited here, the source-documents did not highlight the model factors or attributes that were to be monitored and for which indicator variables would be needed. In the captions for the examples, therefore, comments are provided on the variables for which indicators would probably be identified. In ideal circumstances, indicators would be selected to represent the resource or social outcome at the "end" of each example model. In at least some cases, however, intermediate or surrogate indicators might be measured instead because the ultimate outcome is impractical to monitor. A typical case is one in which habitat variables are chosen for monitoring because it is not feasible to monitor the population status of a rare or sensitive species at risk. The comments in the captions are based on these assumptions.

Conceptual Frameworks

Many different frameworks for organizing the logic of conceptual models can be found in the resource management literature. Most of these frameworks share some common elements. This guide recognizes four dominant types and their variations.

1. *Pressure-State-Response and Related Models*

The most common conceptual framework for monitoring and evaluation is probably the pressure-state-response (PSR) approach and its variations, including driving force-pressure-state-impact-response (DPSIR) and driving force-state-response (DSR). As summarized by Niemeijer and de Groot (2008): " . . . social and economic developments are considered **driving forces** that exert **pressure** on the environment, leading to changes in the **state** of the environment. In turn, these changes lead to **impacts** on human health, ecological systems and materials that may elicit a societal **response** that feeds back on the driving forces, pressures, or on the state or impacts directly" (emphasis added). Figure 1 is an example of a "causal network" conceptual model that was developed using the DPSIR conceptual framework (Niemeijer and de Groot 2008). Note that no societal response appears to be included in the network.

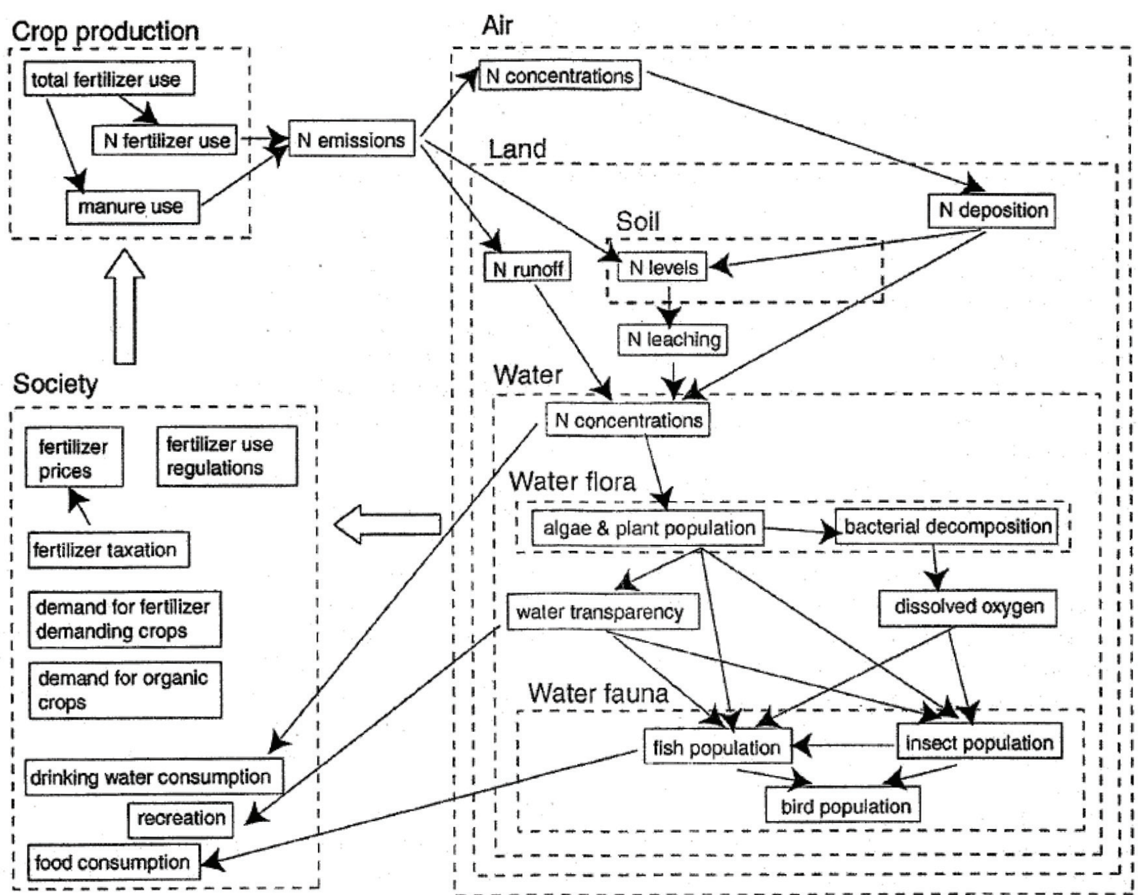

Figure 1. ***A conceptual model developed following the DPSIR framework (from Niemeijer and de Groot 2007). Key monitoring indicators would probably be developed for the state variables in the "Water" box and (or) the impact variables "drinking water consumption", "recreation," and "food consumption."***

Pressure-State-Response and Related Models:	
Most common application:	**Human impacts on the environment; monitoring and evaluation of environmental impacts**
Advantages:	Widely used and accepted for monitoring and evaluation projects; conceptually broad; strong emphasis on human impacts on environmental issues
Disadvantages:	Usually general in nature and focussed on broad environmental and social outcomes; seldom applied to wildlife monitoring and evaluation
Potential Applicability:	Moderate

2. *Ecological Causal Webs*

The conceptual framework most directly applicable to wildlife effectiveness evaluations may be the "ecological causal web" approach seen in recent publications from the United States Pacific Northwest and British Columbia (e.g., Marcot et al. 2006). The causal web is a set of nodes and links representing relationships in which the logical flow leads from individual biotic and other nodes called "key ecological correlates" (KECs), to summarized habitat nodes, and finally to nodes of population responses of the species of interest (Marcot et al. 2001) (Figure 2) . The KECs are important attributes of the environment that are known or expected to influence a species' habitat (e.g., the density of trees with cavities suitable for cavity-nesting birds). The summary habitat nodes represent the influence of two or more KECs that together determine the suitability of a particular type of habitat. Each node displays potential states (e.g., high, low) and the probability of the node being in that state (e.g., 50% probability). Additional elements may be added to models that incorporate ecological causal webs, such as the decision and utility layers seen in Figure 2.

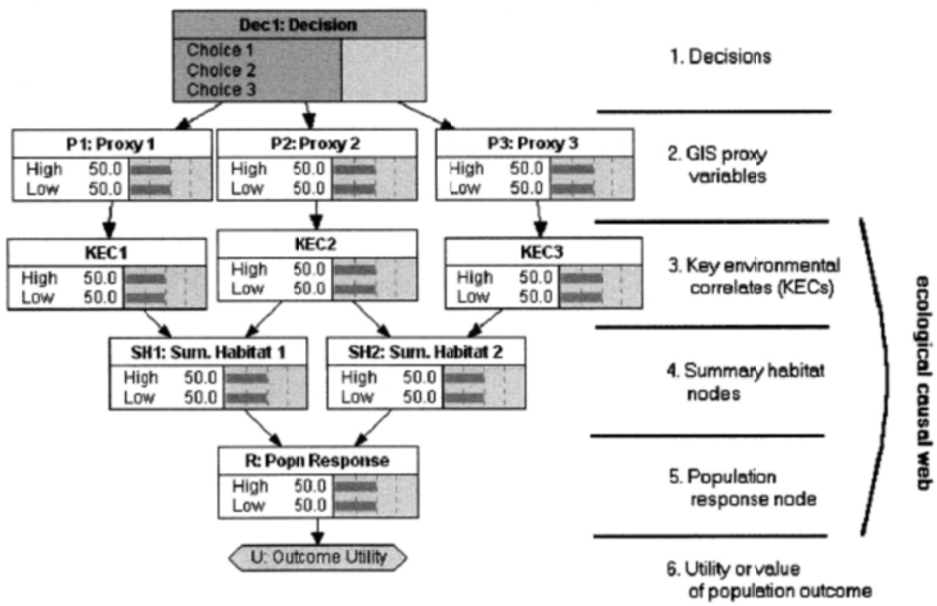

Figure 2. ***The general structure of a conceptual model for environmental impact assessments of fish and wildlife populations, including the ecological causal web at node levels 3–5 (from Marcot et al. 2001). Key monitoring indicators would probably be developed for the summary habitat nodes and (or) the population response node.***

Ecological Causal Webs:	
Most common application:	**Ecosystem dynamics; species responses to human activities or natural disturbance**
Advantages:	Commonly used for models of wildlife applications; links environmental inputs to habitat and species responses; can include human impacts and decision analysis
Disadvantages:	Usually little emphasis on broad driving forces or ultimate outcomes
Potential Applicability:	High

3. *Impact Hypothesis Diagrams*

Many adaptive management programs for natural resources use conceptual models in the form of "impact hypothesis diagrams" to guide program design. The conceptual framework for impact hypothesis diagrams typically includes system inputs and management actions, ecological and other processes, system responses, and valued ecosystem components. The framework also illustrates linkages between the elements in each of these categories (Figures 3 and 4). Indicators to be monitored in determining the effectiveness of the adaptive management program are usually drawn from the key system responses or valued ecosystem components.

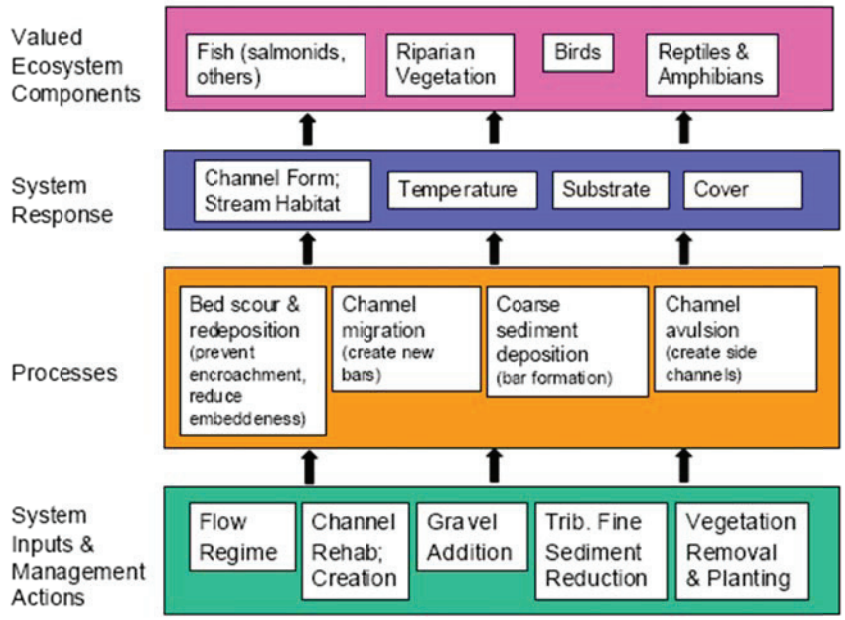

Figure 3. ***The general framework forming the basis for impact hypotheses in adaptive management of a watershed restoration program (C. Murray, ESSA Technologies Ltd., pers. comm.).***

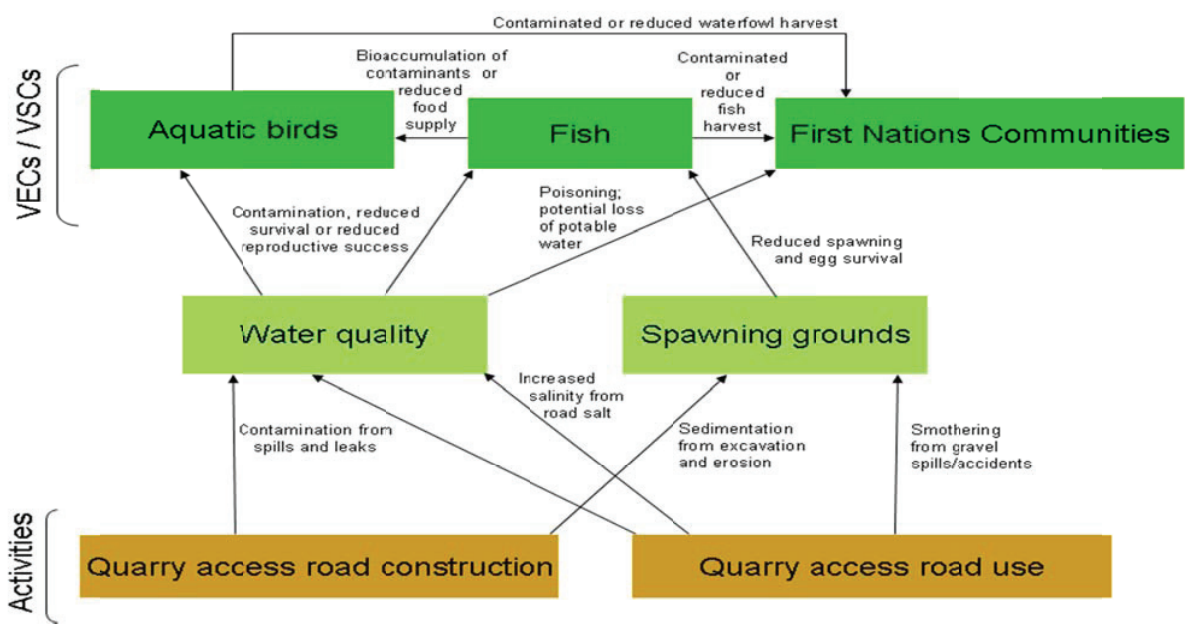

Figure 4. ***An example of an impact hypothesis diagram linking quarry access activities to valued ecosystem components and valued social components (C. Murray, ESSA Technologies Ltd., pers. comm.).***

Impact Hypothesis Diagrams:

Most common application:	**Ecosystem dynamics; species responses to human activities or natural disturbance**
Advantages:	Used in adaptive management to identify uncertainties, hypotheses, and indicator variables for monitoring
Disadvantages:	Few references available
Potential Applicability:	Moderate

4. *Program Logic Models*

Although not as directly relevant to natural resource monitoring and evaluation as the preceding three conceptual frameworks, the "logic model" or "program logic model" is prevalent in evaluation literature from other fields, including education, social science, and business.[3] The logic model has increasingly found its way into resource program management in British Columbia, as provincial ministries apply it in program planning associated with their service plans.

A logic model is "...a systematic way to present and share your understanding of the relationships among the resources you have to operate your program, the activities you plan, and the changes or results you hope to achieve" (W.K. Kellogg Foundation 2004). In a logic model, program components are usually described as inputs, activities, outputs, outcomes, and impacts. Inputs (program resources) and activities represent the work to be carried out. Outputs, outcomes, and impacts represent various aspects of the intended results. Outputs and outcomes are often split into short, medium, and long-term categories, with outputs representing tangible or direct consequences, and outcomes and impacts representing qualitative or indirect results (Figure 5). Many organizations simplify the model to include only inputs, outputs, and outcomes.

3 See http://www.uwex.edu/ces/pdande/evaluation/evallogicbiblio.html for an extensive bibliography on the logic model and its applications.

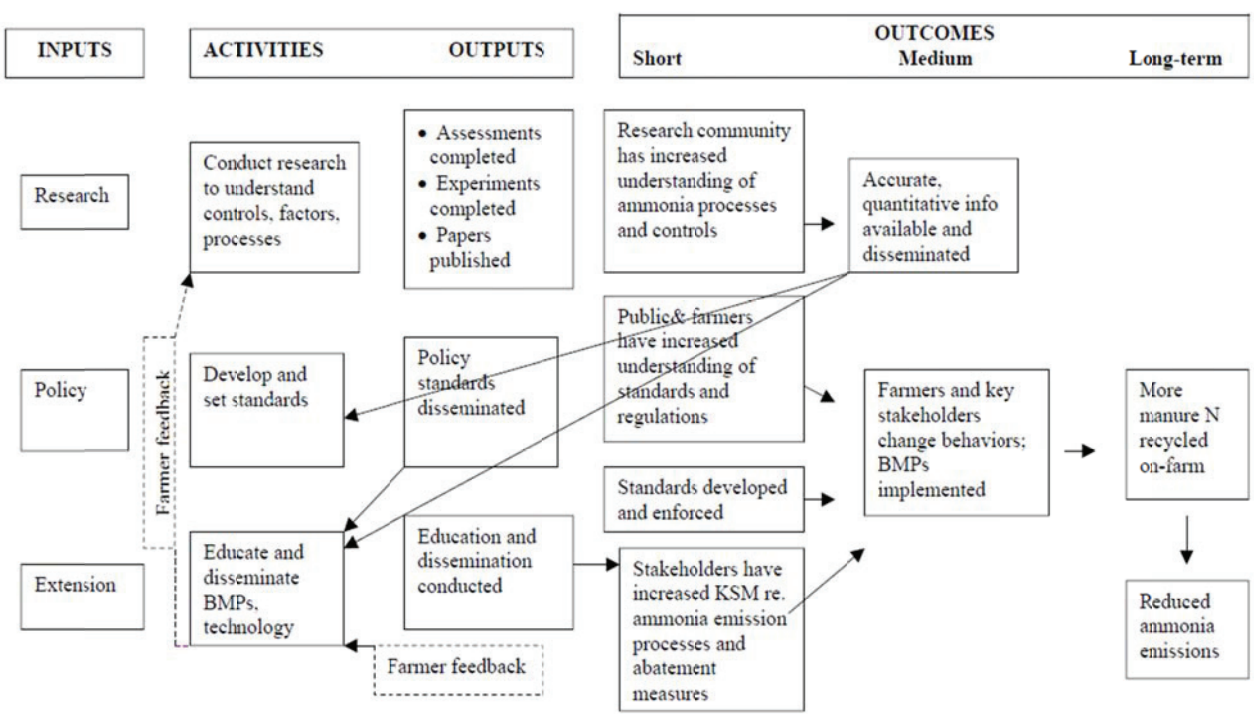

Figure 5. ***Outline for a logic model addressing a multi-agency partnership approach to abating ammonia emissions from dairy farms (from Powell et al. 2005). Key monitoring indicators would probably be developed for outputs and short- and medium-term outcomes.***

Program Logic Models:	
Most common application:	**Program planning and evaluation in business and government organizations**
Advantages:	Widely used and understood in the provincial government; strong emphasis on management decisions and their results
Disadvantages:	Tends to be process oriented, with little or no emphasis on the individual attributes of the modelled system and interactions among them
Potential Applicability:	Low

5. *Other Conceptual Frameworks*

Many conceptual models used in evaluation programs for wildlife and other resources are not based explicitly on one of the conceptual frameworks described above, but they usually incorporate some or all of the components seen in these frameworks. For example, in the effectiveness monitoring program for the Northwest Forest Plan in the United States, Noon et al. (1999) based their conceptual model on stressors (akin to pressures in the PSR framework), ecosystem resources or key system components (similar to key ecological correlates in ecological causal webs), ecological processes (as recognized in impact hypothesis diagrams), and system responses (as seen in all the frameworks). In their manual on designing, managing, and monitoring conservation and development projects, Margoluis and Salafsky (1998) based their conceptual models on activities (similar to activities in logic models), factors (akin to processes, pressures, or key ecological correlates in other frameworks), and target conditions (similar to outcomes in logic models and valued ecosystem components in impact hypothesis diagrams).

In addition, quantified (mathematical) relations between ecological variables can be considered conceptual models, and also draw on components seen in the broader frameworks described above. Quantified relations often represent functional linkages between activities and ecological correlates or population responses (Figure 6).

The benefits of quantitative approaches compared to qualitative ones are:

- quantitative models can help evaluation teams clarify the indicators requiring measurement, the level of confidence, and the effect size needed for detection; and
- quantitative models can estimate the predicted status and trend of indicators, test sensitivities, and evaluate the consequences of alternative decisions.

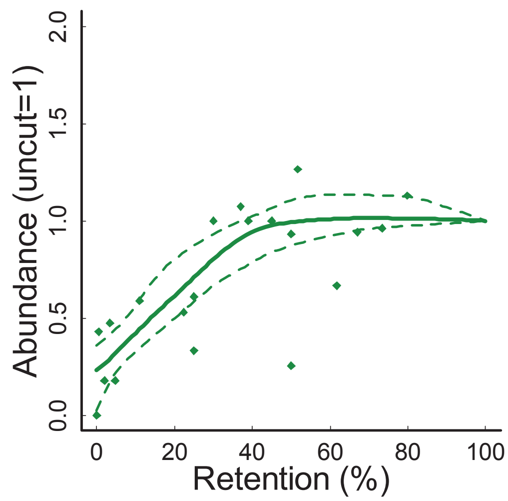

Figure 6. ***An example of a quantitative conceptual model linking a forest management action (tree retention in harvested stands) to an indicator of population response in Chestnut-backed Chickadees (Poecile rufescens) (from Huggard and Kremsater 2006).***

Presentation Formats

The formats used to display conceptual models in resource management and monitoring include text descriptions, diagrams, and complex mathematical equations. These formats usually incorporate some form of pictorial (graphic) representation of the modelled system components and the linkages among the components. Four main formats are recognized here.

1. *Diagrams*

A diagram, especially the “box-and-arrow” diagram, is by far the most widely used format for presenting conceptual models regardless of the conceptual framework (see Figures 1–5). Easily drawn whenever pen and paper are available, such diagrams are usually where people start when developing a conceptual model, regardless of the purpose or complexity of the finished model. Conceptual diagrams can start out quite simply (Figure 7) and gradually increase in the information captured until they become quite complex (Figure 8).

Box-and-arrow diagrams and their variations (such as influence or cycle diagrams) are well suited to presenting the basics of structure and linkages in conceptual models. They can present a great deal of information if elaborated using colours, bolded arrows and boxes, and supplementary text descriptions and annotations (see examples in Appendices 1 and 2). Box-and-arrow diagrams are not, however, amenable to illustrating large numbers of detailed functional relations and equations, as they then become overwhelmingly complicated.

At its simplest, an influence diagram is merely a box-and-arrow diagram that shows relations and influence among variables (Figure 9). However, to more informatively depict cause-and-effect relations, influence diagrams are expanded into quantitative models that can be tested, updated with new information, and used to assess probabilities, uncertainties, errors, and decision utilities, as described below (see "Mixed Diagrammatic and Quantitative Formats").

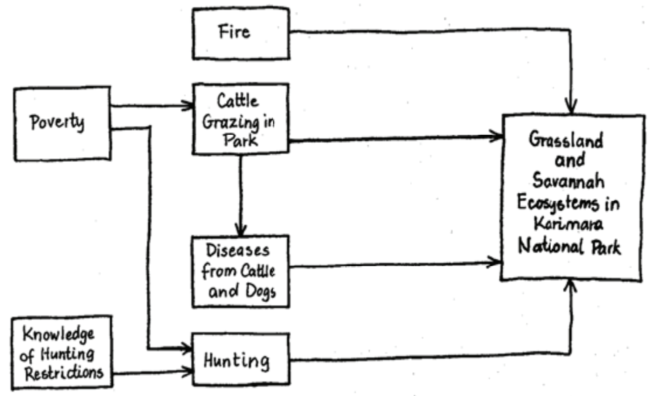

Figure 7. ***Initial conceptual model of factors influencing the state of ecosystems in a subtropical national park (from Margoluis and Salafsky 1998).***

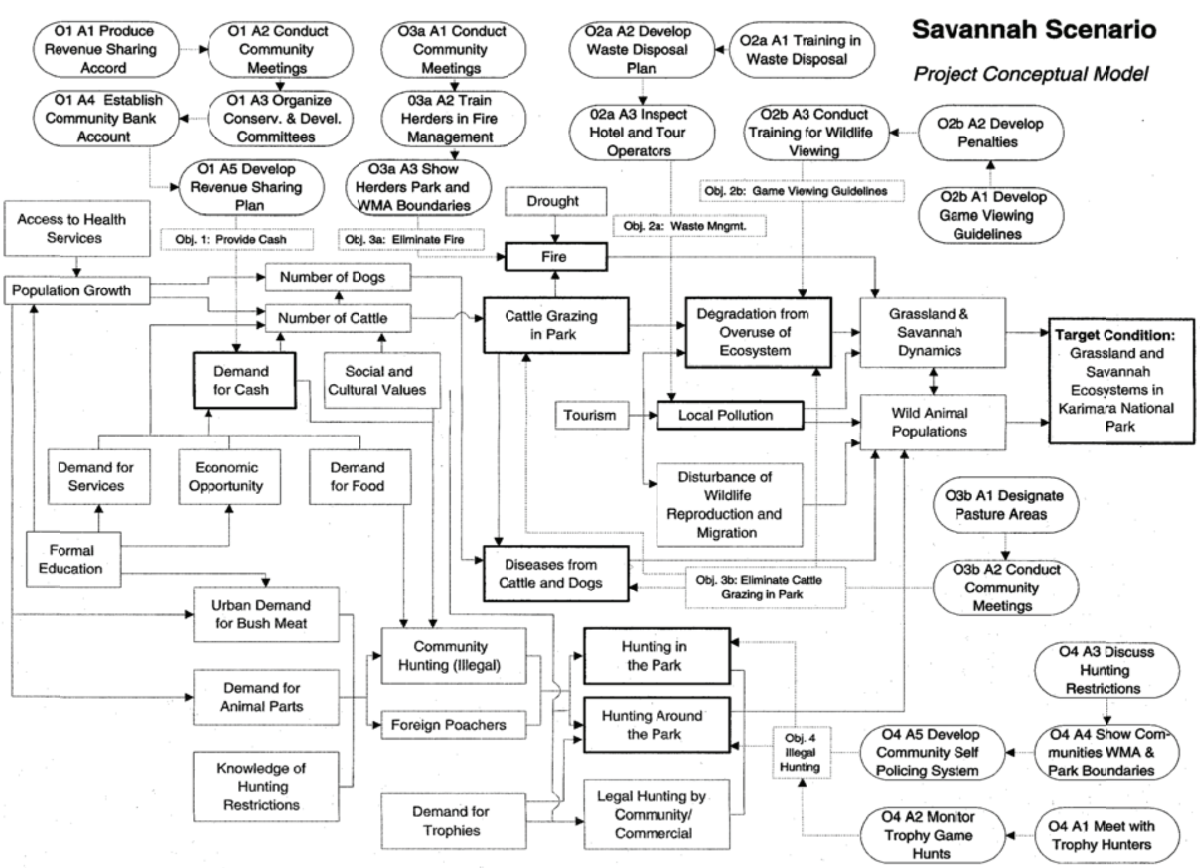

Figure 8. ***Complete conceptual model for a conservation and development project scenario in a subtropical national park (from Margoluis and Salafsky 1998). Key monitoring indicators would probably be developed for "Grassland & Savannah Dynamics" and "Wild Animal Populations."***

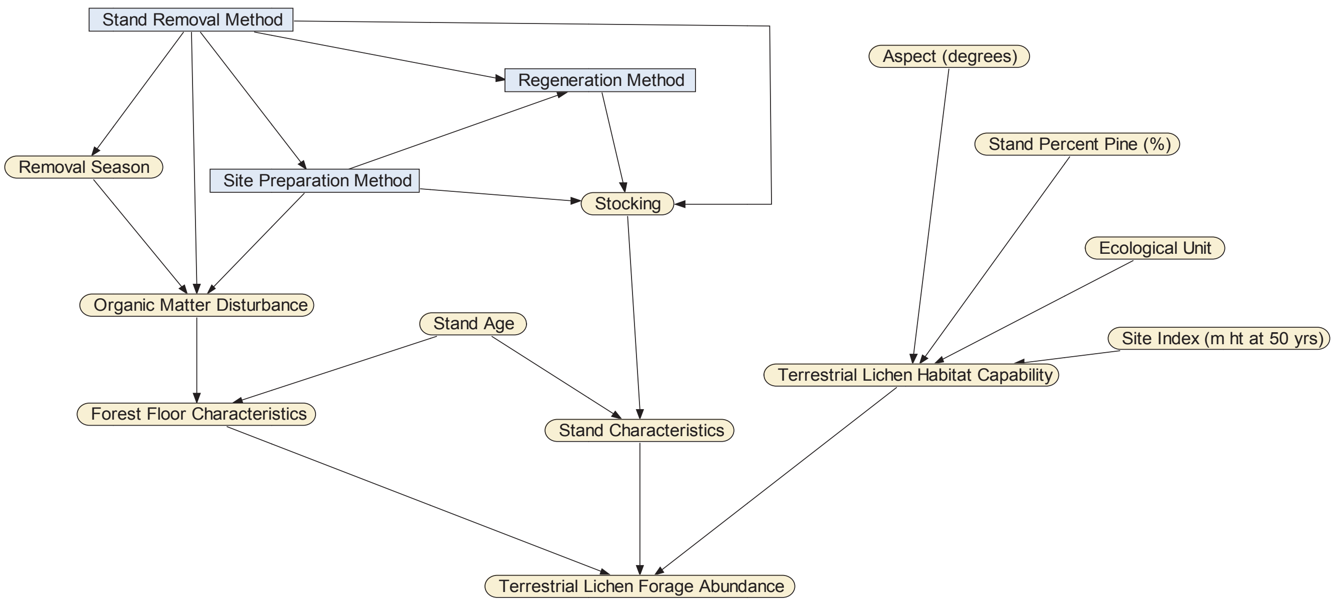

Figure 9. ***An influence diagram illustrating the factors that determine the abundance of terrestrial lichen forage on winter ranges of caribou (Rangifer tarandus) in the northern interior of British Columbia (from Nyberg et al. 2006).***

Diagrams:

Most suitable audience:	**All types**
Advantages:	Familiar to most audiences; intuitively easy to grasp linkages and interactions among model components; easy to draw in almost any setting, including workshops
Disadvantages:	Can become confusing if too many interactions are shown; may be too simplistic if no explanatory or supplementary information is provided
Potential Applicability:	

2. *Text and Tables*

Some conceptual models can be easily expressed in words, especially simple or general concepts such as “Logging old-growth forests removes nesting and foraging habitat for Spotted Owls (*Strix occidentalis*), which leads to reduced Spotted Owl populations.” Written descriptions of model components and linkages can also be structured as tables or charts (Figure 10).

Both text and tabular formats are effective means of communicating the details of conceptual models. For some non-technical audiences, text descriptions of models may be more meaningful than the pictorial formats familiar to resource specialists. Models written out in text and tables are, however, best kept simple so the amount of text required to describe them does not overwhelm the reader. Also, most people do not grasp the structure and hierarchy of a written model as quickly as they do a pictorial version of the same information. To capture all important ideas and enable thorough reviews, Margoluis and Salafsky (1998) suggest that conceptual models for conservation and development projects should be expressed both in words and as diagrams.

THREATS	POTENTIAL EFFECTS ON BADGERS		CANDIDATE INDICATORS	
	Habitat	Population	Habitat	Population
Habitat Loss and Degradation				
Urban development & Intensive agriculture	• Decreases available grassland habitat • Decreases potential burrowing area • Increases fragmentation of habitat • Destruction of burrows	• Displacement of badgers • Increases disturbance from human activity	• Area of grassland habitat lost • Area of "diggable" soil lost • Index of fragmentation • Burrow density	• Frequency of burrow use • # badgers using WHA
Highway construction	• Increases road densities	• Increases potential for road mortality	• Road density	• # of road mortalities
Highway maintenance	• Increases attractants to road rights-of-way	• Increases potential for road mortality	• Measure of vegetation on rights-of-way	• # of road mortalities
Forest in-growth and encroachment	• Decreases suitable grassland habitat	• Displacement of badgers	• Change in % canopy closure • Burrow density	• Frequency of burrow use • # badgers using WHA
Prey Loss				
Pest management	• Decreases prey abundance	• Increases energy required to find alternative prey resources	• Index of prey abundance	• Home range size
Poor range practices	• Decreases suitable habitat for prey • Decreases prey diversity	• Decreases in breeding opportunities and ovulation potential • Decreases in successful litters due to aborted implantation	• Index of prey abundance and diversity • Condition of grassland • Grazing intensity	• Presence of female or family • # and size of successful litters
Human-Caused Mortality				
Trapping and persecution		• Increases badger mortality		• # reported trapping mortalities
Traffic volumes and speed	• Decreases potential for safe crossing	• Increases badger mortality	• Road density (by road type)	• # of road mortalities

Figure 10. Tabular conceptual model identifying links between threats within Wildlife Habitat Areas and the populations and habitats of Badgers (from Hoodicoff 2006).

Text and Tables:	
Most suitable audience:	**Non-technical, or mixed technical and non-technical**
Advantages:	Familiar to all audiences; can be used to provide extensive description and detail; requires no expensive or specialized resources to compile
Disadvantages:	Relations between factors in the model are difficult to grasp quickly, especially if multiple interactions exist; can be very dense with information and therefore challenging to comprehend
Potential Applicability:	Moderate; best used to supplement other formats

3. *Mathematical Equations and Graphs*

Some quantitative models—or portions of them such as functional relations representing processes—can be written out as equations or numerical tables. Mathematical equations are a concise and precise format for representing certain kinds of information, and are indispensable in certain kinds of models and applications. However, this format may only be understandable to those with the required mathematical background, and therefore will need explanatory text or figures for more general audiences.

Mathematical Equations and Graphs:	
Most suitable audience:	**Specialists with advanced education in mathematics as used in ecology**
Advantages:	Concise and precise; require no expensive resources to compile
Disadvantages:	Minimal explanatory information included; multiple processes and interactions difficult to communicate; not suited to qualitative or categorical information
Potential Applicability:	Moderate; best used to supplement other formats

4. *Mixed Diagrammatic and Quantitative Formats*

As conceptual models become more quantitative in nature, they shift to serve additional purposes that depend on mathematical content such as predictive, statistical, decision-support, or simulation applications. For wildlife effectiveness evaluations, the most complex forms of quantitative models (e.g., simulations of populations or habitat change over long time periods) are probably unnecessary. Many evaluation project teams will, however, want to explain certain key relations between human impacts, habitat, and species population parameters in the form of x–y graphs (Figure 6), regression and correlation analyses, contingency or probability tables, and other standard methods used in biology and ecology. As noted earlier, these can be added as annotations to box-and-arrow diagrams and other formats.

Two mixed formats containing both diagrams and quantitative information should be considered for use in conceptual models for effectiveness evaluation purposes. These are path regression and Bayesian belief networks, both of which can be grasped relatively easily by most people with basic statistical training.

Path Analysis

A path analysis, or path regression model, is an effective way to display the partial correlation of various independent variables representing causal influences on a dependent variable of interest, such as the abundance of a wildlife population (Shipley 2002; Marcot 2006). Figure 11 presents a simple hypothetical path regression model, which shows that only 20% of the variation in a migratory bird population can be explained by breeding habitat—such as might be protected in a Wildlife Habitat Area (WHA)—while the rest of the variation is due to other known and unknown factors. This type of analysis can help to identify key uncertainties, guide selection of the scope indicators to measure in effectiveness evaluations, and interpret the resulting data.

Path analysis models depend on observational or experimental data from which correlations or regressions can be statistically derived. In wildlife evaluation applications, such data are often not available for many of the relationships between management actions, habitat attributes, and species responses. A full path analysis for the whole system to be modelled will therefore seldom be possible.

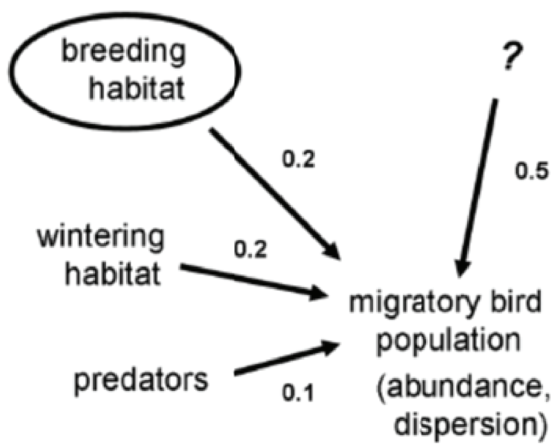

Figure 11. ***A hypothetical path regression model of abundance of a migratory bird species (from Marcot 2006). The key monitoring indicators probably would be variables representing the abundance and dispersion of the migratory bird population.***

Path Analysis:

Most suitable audience:	**Specialists with education in mathematics as used in ecology**
Advantages:	Powerful for evaluating partial regressions and identifying key uncertainties and causal factors; the general message of the diagram is easily grasped by most people
Disadvantages:	Depends on having quantitative data amenable to correlation/regression analysis
Potential Applicability:	Moderate

Bayesian Belief Networks

Although Bayesian belief networks (BBNs) were almost unknown to biologists 10 years ago, this format now seems to be experiencing irruptive growth in use for resource management and research (Marcot et al. 2001; Marcot 2006; McCann et al. 2006; and examples cited in this report). Three main reasons appear to underlie the popularity of this format.

1. BBNs have many powerful features that make this format particularly well suited to modelling ecological systems (see bullets below).
2. Most people quickly and intuitively grasp the key concept of conditional probability used in BBNs.
3. The software programs for BBNs are easily used by groups of people to draw and display computerized box-and-arrow diagrams and to progress from there to building fully specified BBN models.

A BBN is: "...a graphical network of nodes linked by probabilities... Nodes can represent constants, discrete or continuous variables, and continuous functions, and how management decisions affect other variables ...Nodes are linked with arrows to represent direct correlations or causal inferences" (McCann et al. 2006). Figure 12 illustrates a BBN based on the simple influence diagram in Figure 9. "Underlying each node is a modeller-defined table that specifies the unconditional (prior) probability of each state for input [parent] nodes, or the conditional probability of each state for child nodes" (McCann et al. 2006).[4] Table 1 provides an example of one of the conditional probability tables for a child node in the BBN. In this case, the probabilities were drawn from expert judgement based on local field experience, but they could have been based on empirical data alone or a combination of the two.

4 "Child" nodes are those with arrows coming in from their "parent" nodes.

Note that a BBN can be based on any of the conceptual frameworks discussed above, as the BBN is merely a mathematical and diagrammatic formalization of the concepts and knowledge held by those who construct it. Several recent publications have discussed the nature and use of BBNs at length (Marcot 2006; McCann et al. 2006; Nyberg et al. 2006; Pourret 2008). To summarize, the most valuable attributes of BBNs for ecological modelling are that they:

- clearly display major influences on wildlife populations and habitats, and their values and interactions;
- combine categorical and continuous variables;
- combine empirical data with expert judgement;
- express predicted outcomes as likelihoods, as a basis for risk analysis and risk management;
- explicitly incorporate probability and uncertainty;
- update easily with new data and through expert review;
- facilitate sensitivity testing that can be used to evaluate the relative influence of each of the modelled factors on the outcome;
- infer the most likely set of causal conditions for a given outcome; and
- permit effective communication of results of alternative conditions and decisions, and of cumulative effects.

Bayesian belief networks are now widely used for wildlife habitat and population modelling in British Columbia (McNay et al. 2006; Sutherland et al. 2007; Steventon 2008), and for other applications including ecological mapping (Walton and Meidinger 2006). Helpful guidance on constructing and using BBNs is available in Marcot et al. (2006).

Figure 12. ***Bayesian belief network showing the outcome of one set of "findings" (characteristics) for terrestrial lichen forage on caribou winter ranges in the northern interior of British Columbia (from Nyberg et al. 2006). Nodes representing decision choices are in blue, and input nodes representing environmental conditions are in gray. The numerical values associated with the states of the output nodes in the lower part of the network are the probabilities that the various states will occur, given the set of causal conditions represented in the upper nodes.***

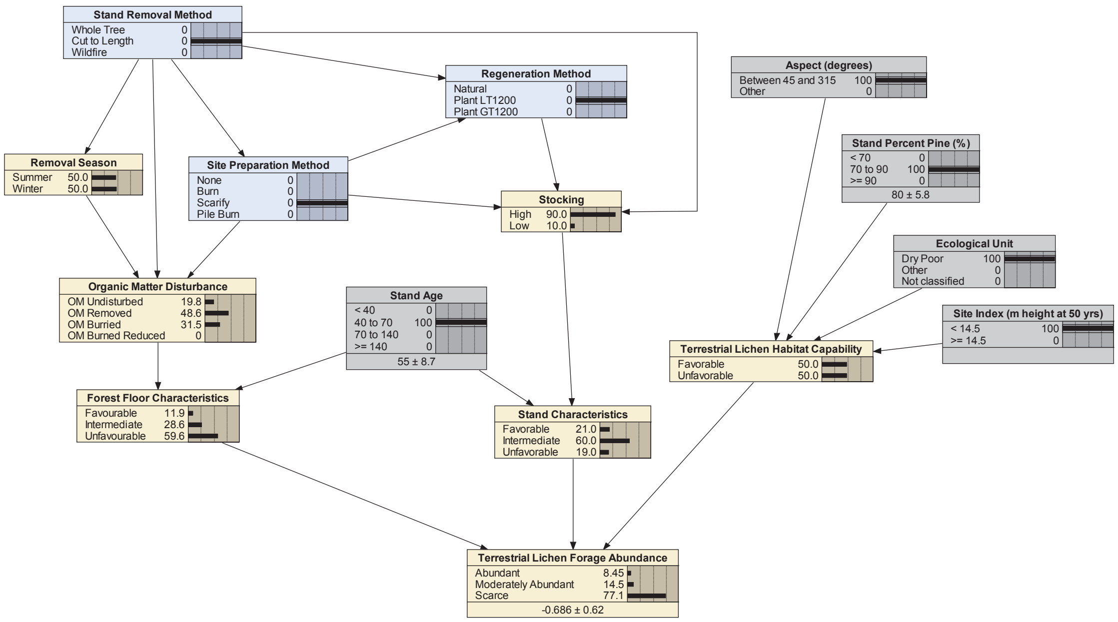

Table 1. ***Conditional probability table for node "Forest Floor Characteristics" in Figure 12 (Nyberg et al. 2006).***

Parent node states		**Conditional probabilities of outcomes**		
Organic Matter (OM) Disturbance	Stand Age (years)	Favourable	Intermediate	Unfavourable
OM Undisturbed	< 40	0.35	0.3	0.35
OM Undisturbed	40 to 70	0.6	0.3	0.1
OM Undisturbed	70 to 140	0.65	0.25	0.1
OM Undisturbed	≥140	0.15	0.35	0.5
OM Removed	< 40	0	0	1
OM Removed	40 to 70	0	0.4	0.6
OM Removed	70 to 140	0.5	0.2	0.3
OM Removed	≥140	0.15	0.35	0.5
OM Buried	< 40	0	0	1
OM Buried	40 to 70	0	0.1	0.9
OM Buried	70 to 140	0.1	0.1	0.8
OM Buried	≥ 140	0.05	0.1	0.85
OM Burned Reduced	< 40	0.1	0.2	0.7
OM Burned Reduced	40 to 70	0.35	0.3	0.35
OM Burned Reduced	70 to 140	0.65	0.25	0.1
OM Burned Reduced	≥ 140	0.15	0.35	0.5

Bayesian belief networks are also employed as conceptual models in the development of protocols for wildlife effectiveness evaluations in British Columbia. Appendix 3 presents an example illustrating the factors that determine the suitability of habitat as winter range for mountain goats (*Oreamnos americanus*) in the Kamloops Timber Supply Area (Nyberg and Hamilton 2007). The factors were drawn from the legal notice[5] that describes the amount, distribution, and attributes of that habitat.

Although BBNs have many useful traits, they also have drawbacks for some applications, particularly when compared to certain other types of sophisticated quantitative models. For example, BBNs are poor at handling temporal dynamics such as feedback between input and outcome variables. Modelling population trends over sequential time steps is cumbersome with BBNs because of the feedback between population size and fecundity and mortality rates at each time step.

By including decision nodes, where management choices are made, and utility nodes, representing the utilities or values of outcomes, BBNs can be elaborated further into Bayesian decision networks (Marcot et al. 2001; Nyberg et al. 2006) (see Appendix 5).

5 See http://www.env.gov.bc.ca/wld/frpa/notices/uwr.html

Bayesian Belief Networks:

Most suitable audience:	**Technical, or mixed technical and non-technical**
Advantages:	Clearly display factors (within nodes) and interactions between them (links); can combine categorical and continuous variables; can combine empirical data with expert judgement; express predicted outcomes as likelihoods, with error terms; explicitly incorporate probability and uncertainty; easily updated with new data and through expert review; facilitate sensitivity testing to identify key causal factors; permit effective communication of results of alternative conditions and decisions, and of cumulative effects; BBN software programs are relatively easy to use for building models in workshop sessions; software has many built-in analysis and presentation options
Disadvantages:	Requires specialized software and experience in its use; specifying the conditional probabilities can be time-consuming; poor for representing temporal dynamics unless combined with other methods
Potential Applicability:	High

CHOOSING AN APPROACH

Advice on choosing an approach to conceptual modelling for wildlife effectiveness evaluations is as simple as this: *Build a model—any model—and write it up*. The process of building a model forces its developers to think critically about the links between forest and range management and impacts on the habitat conditions and wildlife responses that might be monitored. Documenting a model allows it to be communicated to others who want to understand the knowledge and reasoning on which the resulting monitoring methodology is based. At the most basic level, then, choosing which modelling approach to use is less important than making the commitment to build one.

Once this fundamental decision is made, however, questions will arise concerning which approach is best for a given situation (i.e., which conceptual framework and presentation format to use). The summary comments in the preceding sections have already hinted at the recommendations provided in this section, but further explanation may be helpful.

The conceptual frameworks reviewed above share many common elements, but the program logic model appears to be least applicable to evaluating wildlife and other environmental values due to its focus on human actions, resources, and outcomes. It is thus best left to those interested in evaluating the success of "business" programs and projects within organizations. The remaining three frameworks (pressure-state-response, ecological causal webs, and impact hypothesis diagrams) are much alike—they suggest linking human policies and actions to environmental variables and, ultimately, to resulting ecological or other values of interest to the manager or resource user. Any of these frameworks could successfully be used as the structure of a conceptual model for wildlife evaluations.

Most people will, however, find it easiest to build on previously published examples and guidance from conceptual models used in monitoring programs for forest wildlife. The published examples most relevant to British Columbia's forests come from the United States Pacific Northwest. **This leads to the conclusion**

that the conceptual framework of choice for the FREP program should be the ecological causal web (Marcot et al. 2001) or the similar framework used in the effectiveness monitoring program for the Northwest Forest Plan in the United States (Noon et al. 1999).

After a conceptual framework is chosen, wildlife evaluators will decide on an appropriate presentation format. As noted above, diagrams and text play important roles in illustrating the linkages in any modelled system and in explaining the meaning of the system's various attributes and relations. However, quantitative content is critical for effectiveness projects to benefit from the full potential of conceptual model.

Quantitative information serves many important purposes in effectiveness evaluations, including the following.

- It can provide detailed information on the influences of threats, habitat associations, and other factors on wildlife species (e.g., how much they affect the species, at what levels, under what conditions, and how well we know this).
- Once indicators for monitoring are selected, quantitative relationships can illustrate how responsive the indicators are to management actions or natural disturbances, which is important when determining which management actions or policies require revision.
- Knowing the quantitative nature of the relations in the model can help highlight important indicators and eliminate others, based on the known or expected responses of the indicators to the factors influencing them. This includes determining the relative strength of the influence of various factors on an indicator in those many cases where multiple factors interact (Huggard and Kremsater 2006).

In reviewing the importance of quantitative information, Huggard and Kremsater (2006) state that: "The key issue is to specify a best estimate of the relationship between the indicator and the species (and the uncertainty of that relationship), based on direct and indirect information in the literature and expert opinion." They go on to say that "quantitative relationships are a basic feature of science. If we can't specify them for proposed indicators, then there's no point in collecting quantitative monitoring data—we won't be able to interpret a value or a comparison or a trend in an indicator."

Given the importance of quantitative information for wildlife evaluations, all FREP wildlife evaluation projects should strive to develop a quantitative conceptual model. Even limited datasets can be formally organized within a simple conceptual model, providing a good start towards building a quantitative model that can be parameterized and expanded upon as monitoring continues.

The most practical, informative, and powerful way to illustrate and document the necessary graphic and quantitative relations is with a BBN. **Therefore, BBNs should be the preferred format for conceptual models in wildlife effectiveness evaluations.** When it is not feasible to provide individuals responsible for developing evaluation protocols with the software and expertise required to develop BBNs, **a box-and-arrow diagram of the conceptual model can be drawn on flip charts or with computerized chart-drawing software. Relevant quantitative information should be included as annotations on the flip chart or in appendices.** The drawback to such models is that they can quickly become confusing and cluttered; furthermore, the nature of the interactions among various influences or factors cannot easily be shown. However, the goal of any conceptual model, whether BBN or box-and-arrow diagram, should be to focus on those key, testable relationships which will explain the greatest variation within the system and most simply elucidate the anticipated relationships between ecological attributes, stressors and outcomes. Conceptual models should be kept as simple as possible while maximizing their explanatory capabilities for the purposes of identifying good monitoring indicators. Models should avoid over-representing the state of available knowledge; BBNs consisting of three to five boxes can be as valid and valuable as those containing twenty, depending on the species, but if knowledge is particularly weak for a given species then an influence diagram or simple box-and-arrow diagram may be the best option.

As noted above, BBNs have many valuable features not seen in other modelling frameworks, including: the ability to combine empirical data with published quantitative relations and with expert judgement; explicit representation and analysis of uncertainty and probability; and incorporation of both categorical and continuous variables. For effectiveness evaluations, four other features of BBNs are especially important.

1. With a little explanation and by working through examples, non-modellers can easily comprehend BBNs and can contribute their local or expert knowledge to the model.
2. Most BBN software (e.g., Netica[6]) has sensitivity testing features that allow users to easily explore

6 Norsys Software Corp; see http://www.norsys.com/

the relative influence of the factors affecting an indicator of interest. This can help to identify which factors are the most important to monitor, which can be ignored, and which may need research or other studies to better define the relations.

3. Predicted outcomes are shown as both means (with variances) for continuous variables and as probabilities. This suggests not only how probable it is that a certain outcome will occur under various combinations of management and ecological conditions, but also how uncertain the prediction of the outcome is, based on the combination of factors (nodes) that influence it. This information is invaluable to design the monitoring program and to interpret the resulting data.
4. As monitoring data comes in, BBNs can easily be updated and the model revised. Sensitivity testing of the revised model may then lead to new insights about the relative influence of the various factors (nodes) determining the habitat or species outcome, and suggest changes needed in the monitoring protocol.

If BBNs are used frequently in effectiveness evaluations, challenging questions can be expected to arise that will require special expertise to solve. For example, the team that built the draft framework of an effectiveness model for the tailed frog (see Appendix 4) struggled initially with how to incorporate the threats posed by various human activities into the BBN, and had to develop its own solution to the problem (G.D. Sutherland, Cortex Consultants, pers. comm. August 2008). Fortunately, a number of biologists in British Columbia now have extensive experience in applying BBNs to wildlife issues, and should be able to assist with similar challenges faced by other evaluation teams.

A caution is necessary regarding the modelling approaches recommended for FREP wildlife evaluations. Although the standard approach should be an ecological causal web implemented as a BBN (the preferred standard) or an annotated box-and-arrow diagram (an acceptable alternative), some risk is associated with making these the only accepted methods. Other modelling approaches that could prove more useful may already exist or may arise in future. Therefore, FREP should allow or even encourage a certain amount of experimentation with other approaches. Ideally, this should take place as part of the continuous learning design for the effectiveness evaluation program.

BUILDING A BAYESIAN BELIEF NETWORK MODEL

Detailed advice on building and applying BBNs is available in the literature (see especially Marcot et al. 2006) and in the user manuals for BBN software such as Netica and HUGIN.[7] The following is an overview of the key steps required to build and apply a BBN to wildlife evaluations.

1. **Build a box-and-arrow diagram, the core of which should be an ecological causal web.** Most biologists, foresters, and ecologists are familiar and comfortable with box-and-arrow diagrams, so this is the obvious place to start building a conceptual model. Preferably, develop the diagram in a collaborative workshop session, with the evaluation team and a small number of experts in attendance. Use published literature, local knowledge, species experts, and other credible sources to identify causal factors influencing the habitat and species outcomes to be evaluated.
2. **Translate the box-and-arrow diagram into a draft influence diagram using BBN software,** preferably during the same workshop. Software such as Netica provides easily learned tools for drawing and displaying these diagrams.
3. **Using published information, empirical data, and expert judgement, construct the conditional probability tables (CPTs) associated with each "child node" in the BBN.** Be as specific as possible about the factors represented by the nodes, whenever possible making them measurable variables such as "density of terrestrial forage lichen per hectare" as opposed to abstract indices such as "winter forage." While doing this, use the annotation features of the software to document the source information (e.g., references for published studies, names of experts providing their best judgement), the exact meaning of the variable, and any assumptions or caveats that underlie the CPT.
4. **Compile, test, and adjust the BBN to ensure that it realistically represents the knowledge and judgement on which it is based.** For example, try different combinations of input values to observe the results for the key habitat and wildlife outcomes displayed in the BBN.
5. **Subject the BBN to review by one or more subject matter experts not involved in its development.** Based on this review, revise the model structure or CPTs as required and conduct further model tests.

7 HUGIN Expert A/S: see http://www.hugin.com/

6. **Apply the completed BBN to the evaluation project.** Identify the habitat and wildlife outcome nodes for which indicators may be useful. Test for sensitivities in the relationships between these nodes and those higher in the network that influence them. Decide which indicators will be measured, which uncertainties need to be resolved, and how monitoring data will be interpreted given the variance expected in the data.
7. **Finally, as monitoring data and other relevant information become available, use them to update the CPTs and revise the model structure if necessary.** Based on the revised model, re-evaluate the indicators to ascertain their continuing relevance and determine which uncertainties remain in the evaluator's understanding of the system and the responses of wildlife.

CONCLUSION

Evaluation of the success of wildlife conservation under the Forest and Range Practices Act (*FRPA*) will require an extensive and long-term monitoring program, even to track just a few species or habitat types. Such a program will require a substantial investment of time and money and should therefore be based on a solid foundation of synthesized knowledge and an analysis of the key questions. As important building blocks of this program, conceptual models help to organize knowledge and guide thinking about what to monitor and how to interpret the results.

The most significant benefit of conceptual models for evaluators lies in their ability to identify important wildlife effectiveness outcomes and the essential factors (e.g. stressors, ecosystem attributes) and processes that influence the outcomes. Once the outcomes, factors, and processes are clear, the variables for which monitoring indicators are needed should also become obvious. This knowledge is critical to design successful monitoring protocols. Other less-tangible benefits will also arise from the process of building conceptual models. For example, a common understanding is developed among each evaluation project team concerning the components and linkages in the monitored system. Current and future project members and other interested parties will also benefit as this understanding is documented and communicated.

At the core of all conceptual modelling benefits is the critical thinking that goes into building a model. This critical thinking, which can be supported and formalized in several ways, is the most important aspect of evaluation protocol design. A simple hand-drawn, box-and-arrow diagram is useful, for it requires evaluators to work through the process of model building and the associated implications for monitoring. Whenever possible, however, the BBN is the preferred approach in FREP wildlife evaluations as it is both a practical and powerful tool that fits the needs of evaluators very well.

Expertise in conceptual modelling is growing rapidly in British Columbia, including experience with the application of BBNs to many types of wildlife issues. By drawing on the assistance of advisors from the modelling community, evaluators should soon develop the skills and knowledge needed to apply conceptual models to every FREP wildlife evaluation project. This could also provide a precedent for the FREP program to apply in evaluations of other FRPA resource values.

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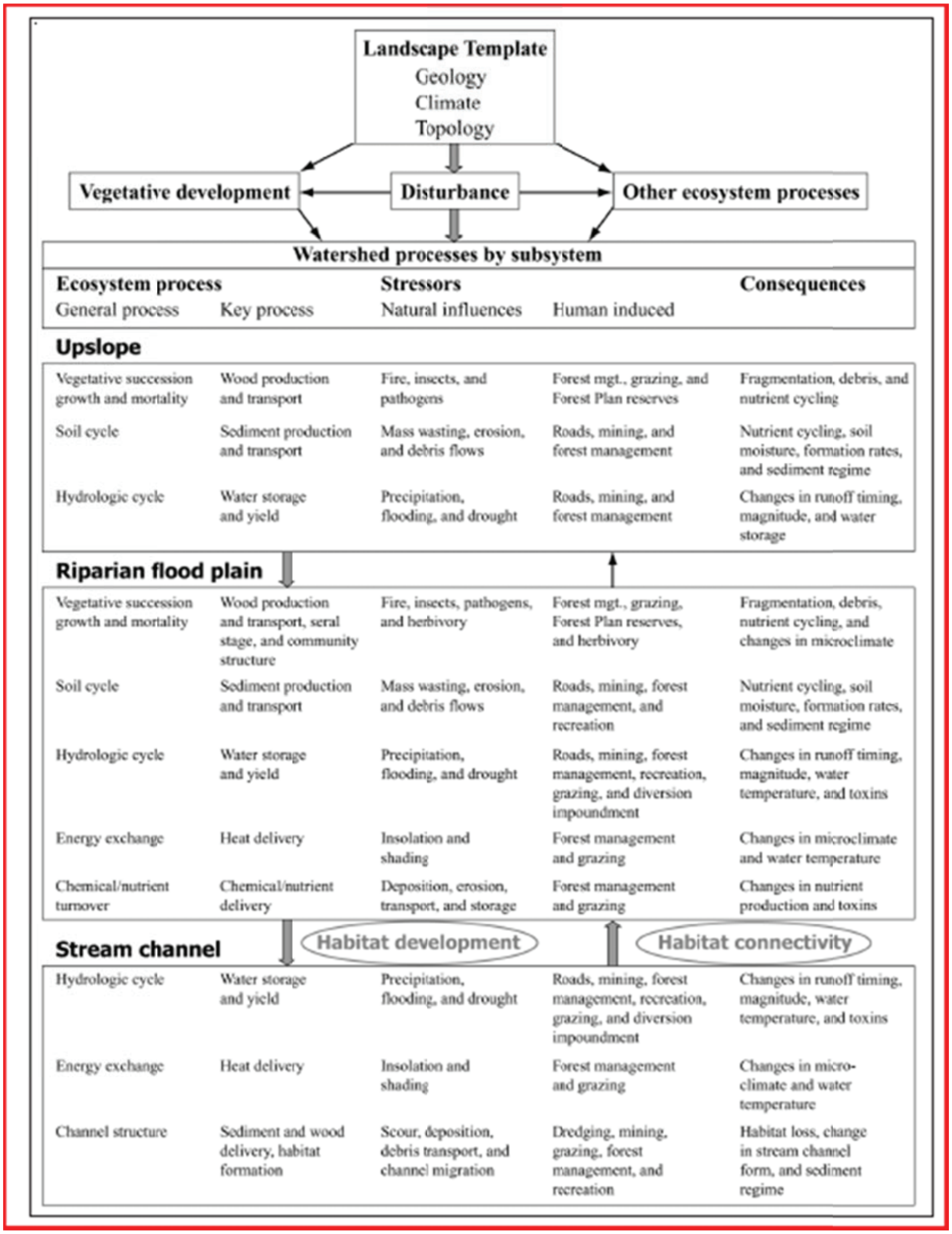
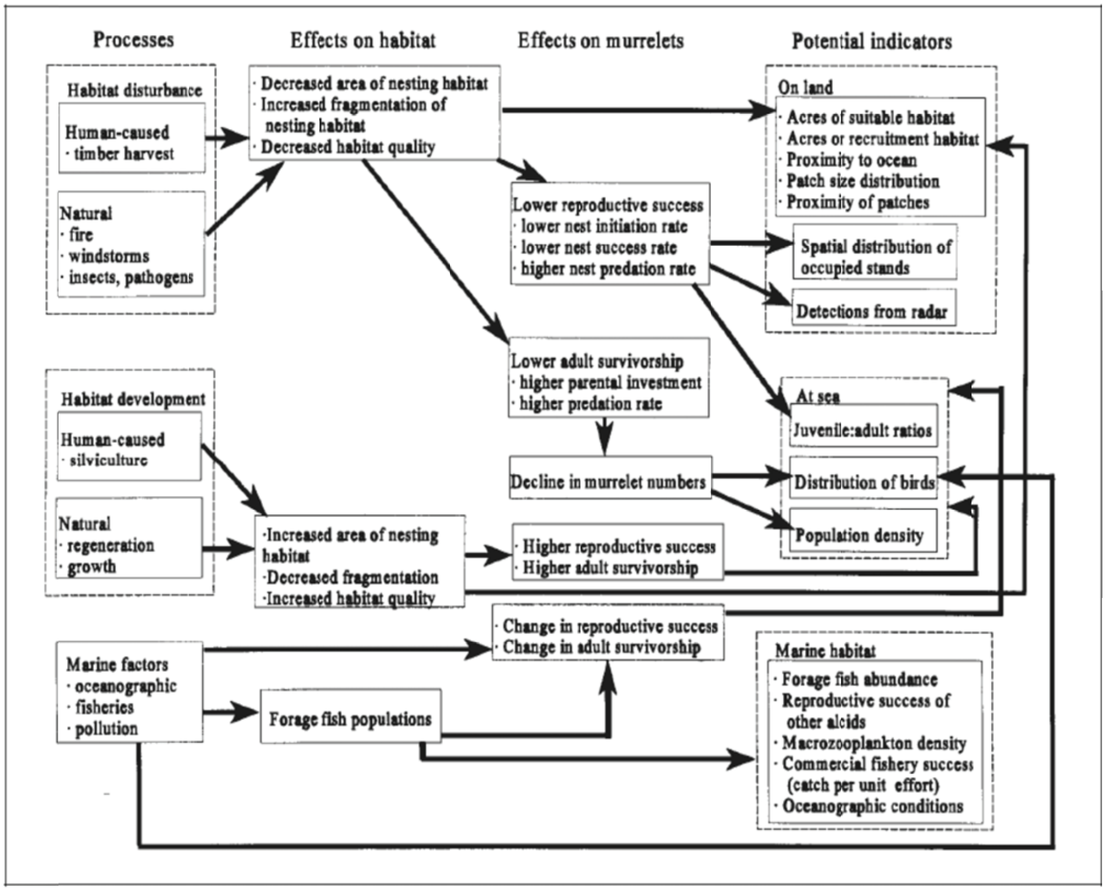
APPENDICES

APPENDIX 1. ***Conceptual model for riparian and aquatic effectiveness monitoring that combines tabular and pictorial elements (from Reeves et al. 2004).***

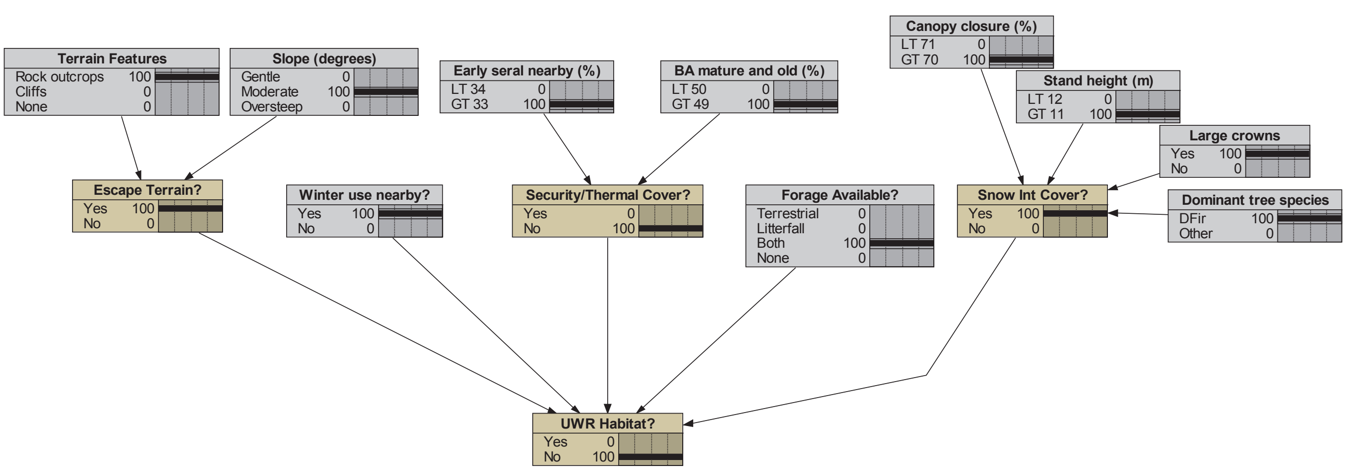


Ecosystem process: General process	Ecosystem process: Key process	Stressors: Natural influences	Stressors: Human induced	Consequences
Upslope				
Vegetative succession growth and mortality	Wood production and transport	Fire, insects, and pathogens	Forest mgt., grazing, and Forest Plan reserves	Fragmentation, debris, and nutrient cycling
Soil cycle	Sediment production and transport	Mass wasting, erosion, and debris flows	Roads, mining, and forest management	Nutrient cycling, soil moisture, formation rates, and sediment regime
Hydrologic cycle	Water storage and yield	Precipitation, flooding, and drought	Roads, mining, and forest management	Changes in runoff timing, magnitude, and water storage
Riparian flood plain				
Vegetative succession growth and mortality	Wood production and transport, seral stage, and community structure	Fire, insects, pathogens, and herbivory	Forest mgt., grazing, Forest Plan reserves, and herbivory	Fragmentation, debris, nutrient cycling, and changes in microclimate
Soil cycle	Sediment production and transport	Mass wasting, erosion, and debris flows	Roads, mining, forest management, and recreation	Nutrient cycling, soil moisture, formation rates, and sediment regime
Hydrologic cycle	Water storage and yield	Precipitation, flooding, and drought	Roads, mining, forest management, recreation, grazing, and diversion impoundment	Changes in runoff timing, magnitude, water temperature, and toxins
Energy exchange	Heat delivery	Insolation and shading	Forest management and grazing	Changes in microclimate and water temperature
Chemical/nutrient turnover	Chemical/nutrient delivery	Deposition, erosion, transport, and storage	Forest management and grazing	Changes in nutrient production and toxins
Stream channel				
Hydrologic cycle	Water storage and yield	Precipitation, flooding, and drought	Roads, mining, forest management, recreation, grazing, and diversion impoundment	Changes in runoff timing, magnitude, water temperature, and toxins
Energy exchange	Heat delivery	Insolation and shading	Forest management and grazing	Changes in micro-climate and water temperature
Channel structure	Sediment and wood delivery, habitat formation	Scour, deposition, debris transport, and channel migration	Dredging, mining, grazing, forest management, and recreation	Habitat loss, change in stream channel form, and sediment regime

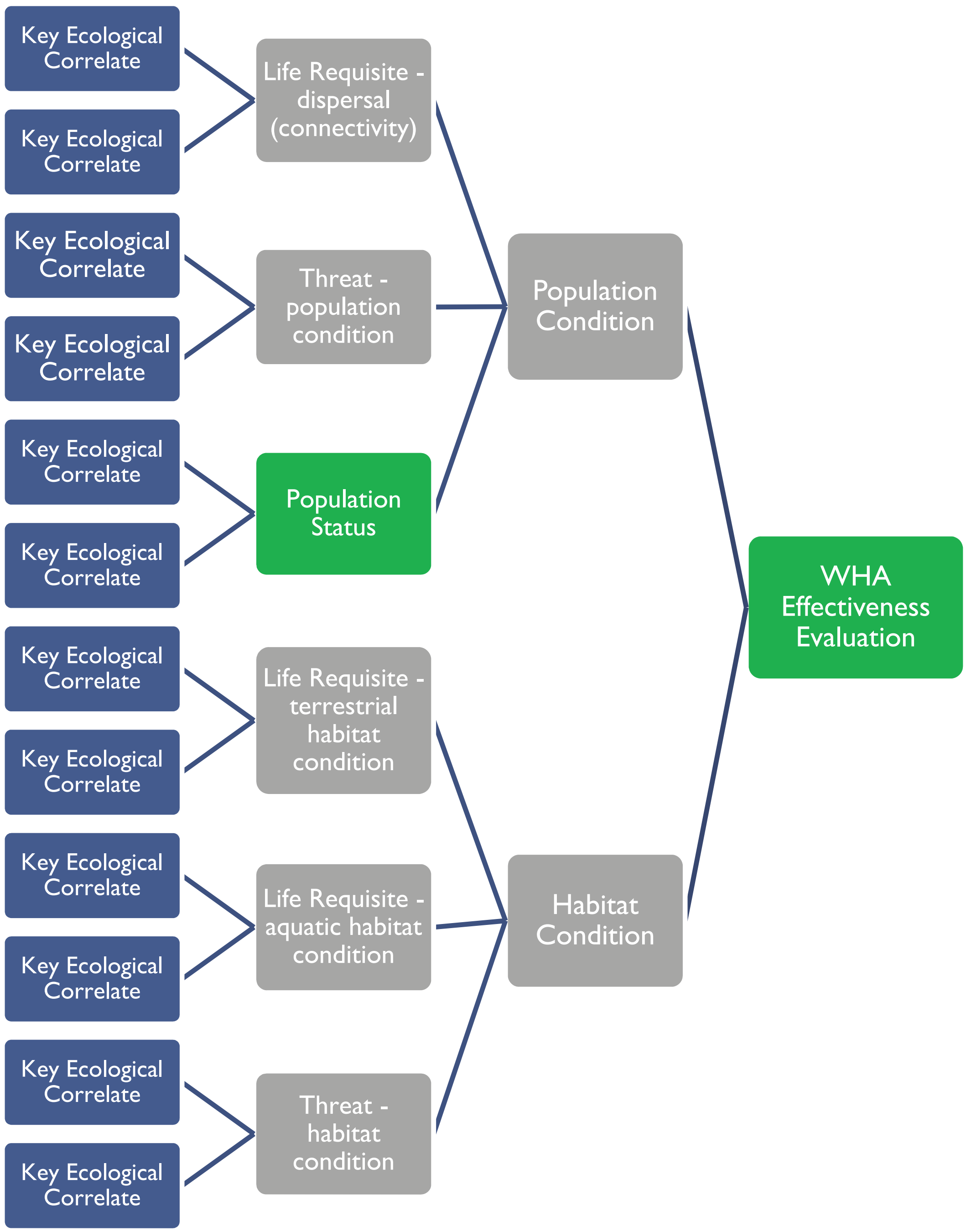
APPENDIX 2. ***Conceptual model to qualitatively depict effects of environmental processes at the landscape scale on Marbled Murrelet nesting habitat and populations and to identify potential indicators for effectiveness monitoring (from Madsen et al. 1999).***



APPENDIX 3. ***Bayesian belief network showing the outcome of one set of "findings" (characteristics) for winter range for Mountain Goats in the Kamloops, B.C. area (from Nyberg and Hamilton 2007).***



APPENDIX 4. ***Conceptual structure of a BBN for Tailed Frog WHAs for effectiveness monitoring at the scale of individual WHAs (recreated from Sutherland 2008). Blue indicates input nodes or ecological correlates that relate functionally to life requisites; intermediate summary nodes are indicated with gray; green indicates result nodes provide outcomes from the evaluation. Results may in turn become inputs to other BBNs at different scales.***



APPENDIX 5. ***Bayesian decision network model illustrating the most favourable combination of ecological conditions and forestry treatments for terrestrial lichen forage on winter ranges of Mountain Caribou in the northern interior of British Columbia (Nyberg et al. 2006). Decision nodes, where management choices are selected that best result in desired objectives and outcomes, are in blue; gray nodes represent environmental conditions; pink utility nodes represent the value of a particular decision or outcome. In this example utility nodes represent the business value, or cost in dollars per hectare, associated with particular management choices made within decision nodes. By linking this decision network, based on the terrestrial lichen forage model, to models of caribou population dynamics, utility nodes could be produced to reflect the value of the terrestrial lichen forage abundance outcome in terms of caribou population density or some other evaluative response.***