REPORT ON AN ANALYSIS FRAMEWORK TO EVALUATE RESOURCE VALUES AND THE TRADE-OFFS BETWEEN THEM IN THE CRANBROOK TIMBER SUPPLY AREA

19 April 2007

Don Morgan, R.P.Bio, Ministry of Forests Research Branch, Smithers
S. Andrew Fall, PhD., Gowland Technologies, Victoria, and
Rob McCann, MSc., Consultant

Introduction:
The purpose of this report is to present an analysis framework designed to evaluate the supply of ecosystem services and their trade-offs, while explicitly accounting for uncertainty. It uses the Cranbrook timber supply area in south-eastern British Columbia as a case study and explores the question of how to maintain ecosystem services, mainly timber and wildlife habitat, as the area experiences an unprecedented Mountain Pine Beetle (*Dendroctonus ponderosae*; MPB; Taylor and Carroll 2003) outbreak. Ecosystem services, for this document, follow the definition used in the Millennium Ecosystem Assessment Report (MA 2005). Ecosystem services have three components; 1) provisioning services, such as food, fuel, fibre and fresh water, 2) regulatory services, such as the maintenance of air quality, climate regulation, erosion control and water purification, and 3) cultural services, such as spiritual enrichment, wilderness, recreation and aesthetic experiences (MA 2005).

Scenario planning has emerged as a robust technique to explore the supply of ecosystem services, particularly in the context of the uncertainty associated with complex dynamics of human and ecological systems (Peterson et al. 2003, MA 2005). Through the process of constructing scenarios of plausible futures, the interactions and uncertainties between human decision making and natural landscape dynamics can be illuminated. A scenario describes a possible situation, a structured account of a possible future (Peterson et al. 2003). They are alternative dynamic stories that capture the essence of our uncertainty about the future of a system and our ability to shape change. Through scenario planning, options for action and insights into drivers of change can be articulated. In general, a scenario planning process includes steps to identify issues, engage stakeholders, assess the current status of a coupled human-environmental system under investigation, identify the social and ecological drivers of change, build and test scenarios, and develop and analyse management policies. Scenario planning has its basis in social-ecological systems theory (Peterson et al. 2003). Social-ecological systems theory views human and environmental systems as an integrated system with coupled social and ecological components (Gunderson and Holling 2002). It uses state variables to describe the status of a system. The 'identity' of the system is dependent on the value of state variables (Cumming et al. 2005) and is analogous to a social-ecological 'regime' characterized by specific structures, functions and controls (Walker et al .2004). When the state variables cross a predetermined threshold the identity of the system is considered to have changed and a different social-ecological regime emerges.

Collaborative analysis has proven to be central to the management of complex social-ecological systems (Fall et al. 2001, Gunderson and Holling 2002, Walker et al. 2002, Peterson et al. 2003, Cumming et al. 2005). Fall et al. (2001) presented a collaborative analysis framework that has been extensively applied in British Columbia, including land use planning and MPB projects (Fall et al. 2001, Morgan et al. 2002, Fall et al. 2005, Eng et al. 2005). This framework, shown in figure 1, provides a nested, iterative collaborative process to engage stakeholders, collect relevant information, develop and test models and to conduct analysis of complex systems (Fall et al 2001). We have extended the Fall et al. (2001) framework to include more formal system state and state transition descriptions, and methods for assessing risk and uncertainty associated with landscape change and ecosystem service decision making. This extension is achieved by integrating the scenario planning approach promoted by Peterson et al. (2003), Cumming et al. (2005) and MA (2005) with the methods of Fall et al. (2001).

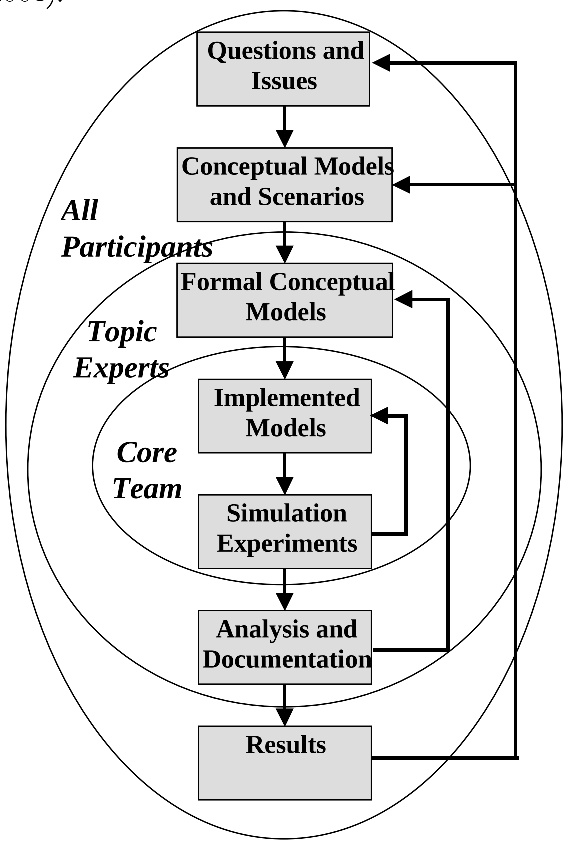

Figure 1. An analysis framework is a nested, iterative collaborative process that generates models and protocols to derive solutions to complex problems. Groups participate in all circles that surround them. All participants (stakeholders, decision-makers, domain experts, core team members) set objectives, select scenarios, develop conceptual models, and discuss model results. Domain experts and the core team develop and verify the formal models. The core modelling team is responsible for organizing workshops and communication, gathering required information, implementing models, ensuring equivalence to formal conceptual models, running simulations, analyzing outputs and documentation (from Fall et al 2001).

This report presents a general overview of the analysis framework followed by an outline of an application in the Cranbrook study area. It will be demonstrated how the analysis framework can be used to conduct scenario planning that allows participants to explore future forest condition and to assist in the development of their adaptive capacity to deal with managing the supply of ecosystem services.

Framework Overview:
Our analysis framework, integrating the methods of Fall et al. (2001), Peterson et al. (2003) and Cumming et al. (2005), has four basic steps titled Context, Current State, Alternate States and Scenarios:

1. Context: includes:
    a. identification of focal issues,
    b. specification of scale, including physical extent of study area and time horizon under consideration. As well, the spatial resolution, or granularity, and the finest temporal time step used in the analysis
    c. identification of ecosystem services, and
    d. establishment of a stakeholder, decision maker and scientist collaboration.
2. Current State: description of the essential system attributes of the current system:
    a. structural components,
    b. functional relationships and connectivity,
    c. sources of system innovation, and
    d. sources of system continuity.
3. Alternate States: description of the drivers, or forces, that may contribute to plausible futures and includes:
    a. scenario themes: identified by project participants,
    b. forces: social-ecological internal and external forces that may shape the study area, including an assessment of those that are partially controllable and those that are not, and
    c. likelihood: an assessment of the likelihood of ecological and management forces occurring.
4. Scenarios: definition of a set of scenarios of future social-ecological conditions and includes:
    a. Scenario definition: based on the current system and the forces that act on it, including management policies.
    b. Scenario testing: an evaluation of the plausibility and social-ecological consequences of a scenario.
    c. Management options and interventions: management interventions that may alter the trajectory of a scenario to a preferred future condition.

Case Study Outlining Framework Steps

1. Context

1a. Focal Issues

The focal question for this study is the impact that the current MPB outbreak in the Cranbrook Timber Supply Area will have on ecosystem services, in particular on forest derived services of forest products and wildlife. Local industry, government and conservation groups require information on what management action and land use polices are required to maintain values, such as a viable commercial forestry industry and meeting wildlife conservation targets. There are many other services that are impacted by the MPB outbreak, such as hydrology and viewscapes, but these are outside the scope of this study.

1b. Spatial and Temporal Boundaries

The geographic extent of the system is the boundaries of the Cranbrook Timber Supply Area, an area of almost 1.5 million hectares in extreme south-eastern B.C. The spatial grain chosen was 1 ha. Temporally, the study focuses on the short and long term. In the short term, the focus is on the current MPB outbreak and explores the past 30 years and the next 25 years. Over the long term, the study evaluates the implications of current decisions on the supply of ecosystem services over the next 200 years. The project evaluates system state on annual time steps.

1c. Ecosystem services

The main ecosystem services considered in this study are fibre, wilderness – status of mountain caribou (*Rangifer tarandus caribou*) and grizzly bears (*Ursus arctos horribilis*), recreation, and aesthetic appreciation.

1d. Collaboration

To establish a collaboration community, commercial, government and non-government groups have been invited to participate in the project. Invited participants include:

- Forest industry:
  - Canfor (Canadian Forest Products Ltd.),
  - BC Timber Sales, and
  - Tembec Ltd.
- British Columbia provincial forest planning and environment offices:
  - Integrated Land Management Bureau,
  - Ministry of Forests, and
  - Ministry of Environment.
- Conservation organizations:
  - Nature Conservancy, and
  - Nature Trust.
- First Nations
  - Kootenai First Nation.
- Recreation interest groups.

For our application, a series of workshop are being conducted to engage participants, identify issues and values, and to capture potential resource management interventions. A project web site and blog have been established to disseminate project results and to enable discussion among the project participants.

2. Current System

To describe the current system we used Cumming et al.'s (2005) concept of identity. A system's identity is dependent on "(1) the components that make up the system; (2) the relationship between components; and (3) the ability of both components and relationships to maintain themselves through space and time" (Cumming et al. 2005). In addition, identity is related to a system's capacity to be innovative and self organize under a range of perturbations (Cumming et al. 2005). Variables are used to describe a system's identity within a specific state space. When the limits of the state space, as defined by the state variables, are crossed the identity of the system has changed. Alternate future systems can be defined based on having a different identity. The concept of identity is analogous to the idea that a system can be described as occupying a multivariate space and that at any point in time the system occupies a stability domain around an attractor (Holland and Gunderson 2002), which represents the identity of the system. The advantage of using the concept of identity to describe a system is that it provides a more transparent separation of system attributes and their drivers (Cumming et al. 2005).

To describe the Cranbrook study area's identity four essential system attributes are described; 1) the system's structural components, 2) functional relationships and connectivity between the structural components, 3) system innovation, how the system changes, and 4) continuity, how the system maintains its current state. By exploring these four parts of the system, a descriptive picture of the system's current state can be drawn, including the variability in the supply of ecosystem services. Through an understanding of the system's current identity, changes in the long term supply of ecosystem services can be assessed and decision rules, based on changes in state variables, constructed that indicate when a new system identity, or regime, has been assumed. If a system maintains its identity under particular conditions and perturbation then it can be considered resilient (Cumming et al. 2005).

2a. Structural Components

The structural components of the system are split into their constituent social and ecological parts and form the "nodes" of the system. Figure 1 shows how the human actors in the Cranbrook study area are split into those that are internal to the area, such as local communities, and those that are external, such as the corporate shareholders. Further, the social domain is divided into individual people and institutions.

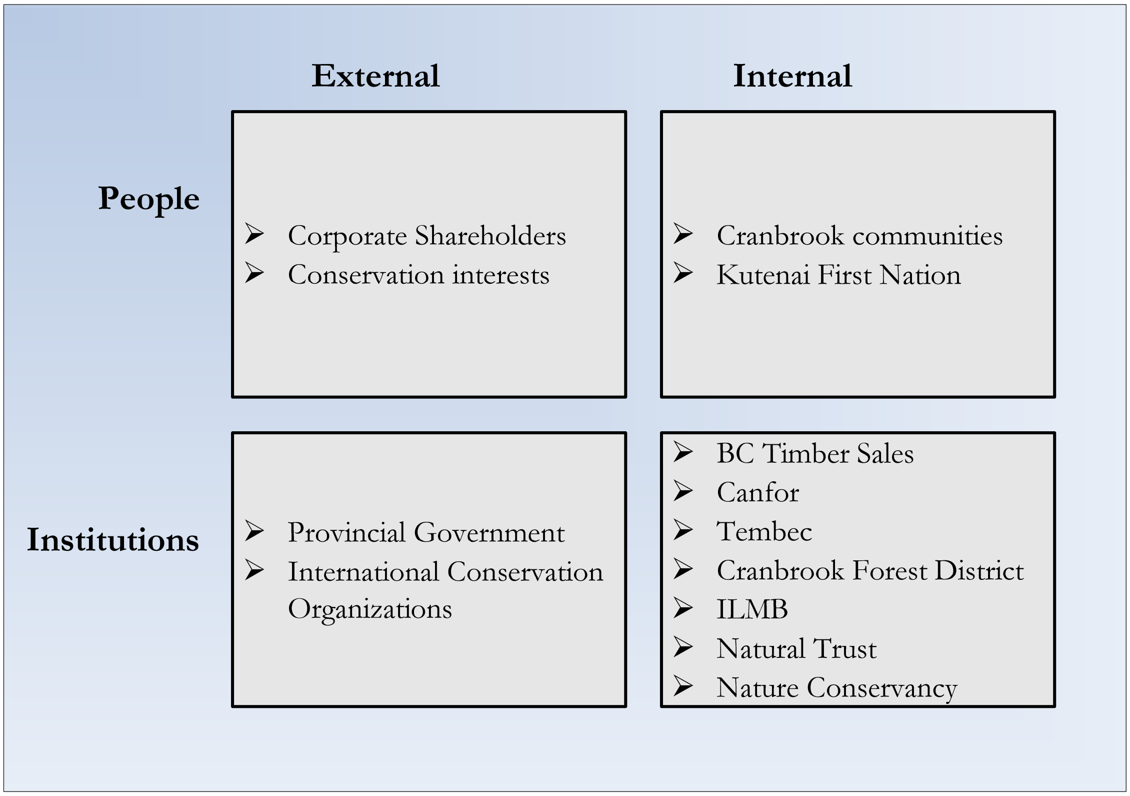

Figure 1. Human actors in Cranbrook study area, divided into internal, external, and people and institutions.

Figure 2 maps the Cranbrook ecosystems, mainly forests, water and grassland to the ecosystem services they provide. Further delineation of ecosystems is provided by British Columbia's Biogeclimatic Ecosystem Classification system (BEC; Meidinger and Pojar 1991) and include units such as wet, mesic, and dry forests, grasslands and alpine. Other ecological components include landscape features, such as avalanche tracks, riparian areas and steep terrain. Additional structural components, which result from human activity, include roads, settlement and agriculture.

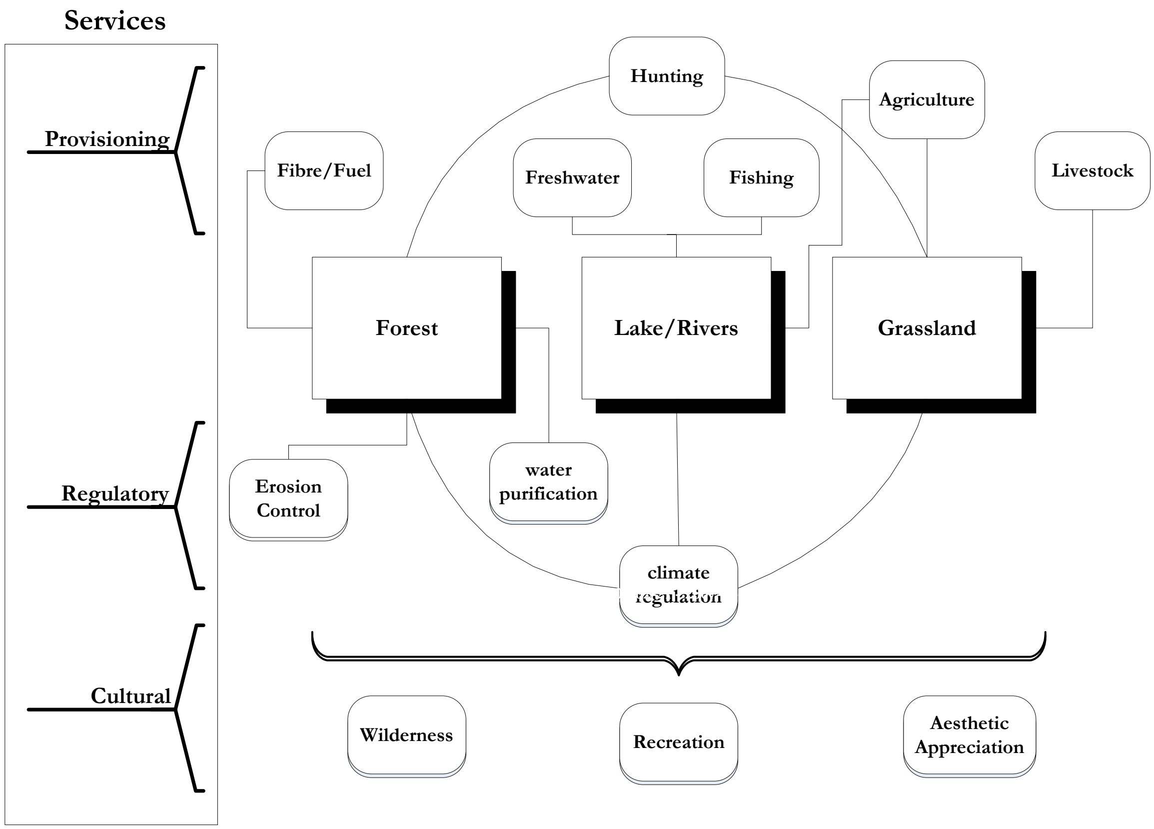

Figure 2. Ecosystems and the provisioning, regulatory and cultural services they provide.

State variables are used to capture the status of structural components of the system and correspondingly they can be used to evaluate the supply of ecosystem services. These variables reflect a combination of indicators that are generated from static and dynamic inventories, and generated from process models. Listed in Figure 3 are the ecosystem services and their associated state variables.

		Social State Variables		Ecological State Variables					
Ecosystem Service		**Human Population**	**Dominant Business**	**Land Cover**	**Forest State**	**BEC**	**Roads**	**Watershed Status**	**Wildlife - Grizzly Bear, Caribou, Ungulates**
Provisioning	**Fibre/Fuel**	high impact	Forestry	Forest	Age/Species	Forested ecosystems	Extent Density	Access	
	Hunting	low impact	Recreation	Forest Range			Extent Density	Access	Habitat
	Fishing	low impact	Recreation	Water			Extent Density	Access	
	Drinking Water	low impact	Settlement	Water	Age/Species			amount forested	

	Agriculture	high impact	Agriculture	Agriculture		Suitable for agriculture			
	Livestock	mod impact	Ranching	Range		Suitable for range			
Regulatory	**Erosion Control**	mod impact	All	Forest	Age	Link to disturbance	Extent Density	amount forested	
	Water Purification	mod impact	All	Forest	Age	Link to disturbance		amount forested	
	Climate Regulation	high impact	All	Forest	Age	Ecosystem type			
Cultural	**Wilderness**	low impact	N/A	Forest Range	Age		Extent Density	Access	Habitat
	Biodiversity	low impact	N/A		Age/Species	Ecosystem Distribution	Extent Density		Habitat
	Recreation	mod impact	Recreation	Forest Range	Age		Extent Density	Access	
	Aesthetics	low impact	Recreation	Forest	Age				

Figure 3. Cranbrook state variables and attributes relevant to ecosystem services.

2b. Functional relationships and Connectivity

Functional relationships are descriptions of the way that the structural components of the system are related. These relationships can be social, such as the economic relationships between tenure holders, or ecological, such as plant-animal interactions. Further, there is interaction between the ecological and social systems, such as timber growth and yield and the availability of timber for harvest. Of concern in the Cranbrook study are the relationships between MPB, forest harvesting, the long term supply of timber and wildlife habitat. As well, there are questions of shifts in trophic relationships between herbivores and grassland, and predator-prey relationships between mountain caribou, moose (*Alces alces*), wolves (*Canis lupus*) and cougars (*Puma concolor*). In the social domain there is resource extraction and preservation relationships between the various land tenure holders, such as private land holders, crown land and forest licensee operating area and First Nations traditional territories. Planning initiatives formalize these social relationships between the various interest groups and land tenure holders, and are expressed in the Kootenay Boundary Land Use Plan, Southern Rocky Mountain Sustainable Resource Management Plan and Sustainable Resource Management Plans. Human use of the landscape for settlement, agriculture or resource extraction, has implications for ecological systems, such as the fragmentation of contiguous forest or grassland by road and rail infrastructure and the loss and degradation of wildlife habitat by industrial activities such as agriculture and forest harvesting. Table 1 summarizes the functional relationships in the Cranbrook area that are being considered in this study.

Table 1. Cranbrook study area functional relationships

Ecological	**Social**	Social-Ecological

Ecological	**Social**	Social-Ecological
ecosystem dynamics: • succession • natural disturbance (fire, MPB)	**land tenure:** • **private land** • **crown land** • **First Nation Territories**	ecosystem fragmentation: • transportation • land use change
trophic level relationships: • **predator-prey dynamics** • **herbivory**	land management planning: • Government lead plans • Industry plans	land cover loss and degradation: • land conversion: o settlement, and o agriculture • unsuitable habitat due to natural and human disturbance

Some relationships are highly dependent, such as caribou's need for mature contiguous forest, where as others are less dependent, such as the species of tree required for timber extraction. There can be redundancy in the system, where alternative options are available, such as switching forest harvesting to different tree species. Other relationships are highly connected and are sensitive to perturbation of one element. For example, the loss of contiguous old forest, due to human or ecological disturbance, results in a decline in caribou due to shifts in predator prey relationships as moose increase in the younger forest, their predators, wolves and cougar, increase which also prey on caribou (Wittmer et al. 2005).

Describing how tightly elements and relationships are bound in the system gives an indication as to which parts may be most sensitive to change and which more resilient. Further, parts of the system may change, but the functional relationships may persist. For example, predator prey dynamics may persist, but instead of a caribou-wolf and cougar dynamic it may shift to a moose-wolf and cougar system, or forestry may persist but focus on Douglas fir (*Pseudotsuga menziesii*) instead of lodgepole pine(*Pinus contorta*), which has been lost due to MPB outbreak. Table 2 presents an overview of indicators used as measures of connectivity.

Table 2. Measures of connectivity of Cranbrook study area.

	Ecological	*Social*
Internal	Dominant overstory tree species Forest age structure Extent and arrangement of old forest Predator-prey dynamics Herbivory	**Employment diversity** **Transportation network**
External	**Provincial ecosystem rarity** **Hydrology:** • **headwaters**	**Rarity of local products** **Resident population vs. recreation and tourism population**

	Ecological	*Social*
	• **dams and diversions**	

2c. Innovation

Innovation captures those subsets of the system that generate change or novelty in the makeup of the system. For example, commercial forestry, natural disturbance and the expansion of human settlement alter the landscape configuration by changing the use of the land, through conversion or degradation of ecosystems and habitat. These changes may be benign until some critical threshold is reached when their cumulative impact causes the system to reorganize and express a different identity, such as forested land becoming grassland or wilderness becoming settlement. Innovation is a function of the amount of ecological diversity in an area. Further, the more connected an area is at various scales, the more likely animal and plan immigration and emigration can occur, providing sources of system innovation or continuity.

Socially, innovation is a function of the diversity in the skills of people in the area and the relationships people have with external sources of information and technology. Innovation may be guided through planning groups or advocacy groups. New economic opportunities may emerge, such as harvesting non-timber forest products, or novel recreation opportunities, for instance land conversion for golf or skiing. New technologies may trigger innovation, such as novel harvesting and silviculture practices that change the density or amount of industrial activity on roads. Table 3 provides some examples of sources of innovation in the Cranbrook area.

Table 3. Sources of innovation in the Cranbrook study area.

Ecological	Social

ecosystem dynamics:
• succession
• natural disturbance
   o MPB,
   o disease, and
   o fire
• climate change
	industrial activities:
	• commercial forestry
	• agriculture

Predator-prey shifts: • **wolf-moose to wolf-caribou.**	human expansion: • settlement • recreation

2d. Continuity

System processes may also act to maintain the system, such as natural succession or sustainable forest management planning. These processes may drive the system within its current regime and be a source of renewal. For example, ecological dynamics may provide novelty in the system over short time periods, but over the long term they help maintain ecological health by nutrient cycling, etc. Other sources of ecological continuity are seed banks, genetic diversity and post disturbance legacies, which contribute to maintaining the area's ecological identity.

A variety of planning initiatives in the Cranbrook area contribute to the continuity of the area. For example, sustainable resource plans and wildlife population monitoring and management try to maintain the historic flow of ecosystem services from the landscape. Similarly, through traditional ecological knowledge the Kutenai First Nation is able to integrate memory into understanding the continuity and novelty of the area.

Current System Description

As part of the analysis framework, influence diagrams are constructed to show system elements and relationships. An example is presented in figure 3 and shows the interaction of forest management planning in the social domain with the impacts of forestry and relationships to ecosystems and wildlife in the ecological domain.

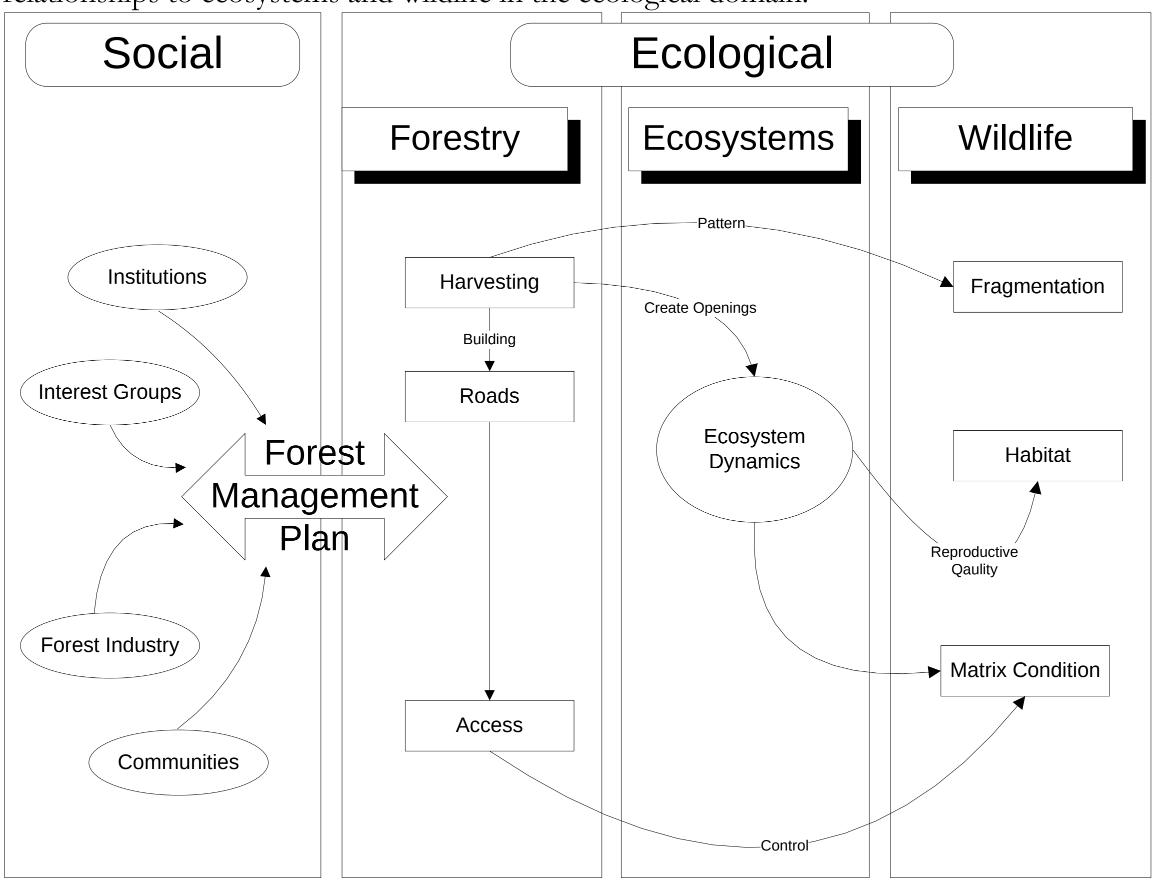

Figure 3. System diagram showing some interactions between forest management decisions, forests, ecosystem dynamics and wildlife.

3. Alternate States

This section presents major themes that participants have identified to be incorporated into the scenarios. The themes incorporate management interventions that could guide the system towards a desired or plausible future condition. Also presented in this section is a discussion of the ecological and human, internal and external, forces that may act on the

Cranbrook system and how they might direct the current system to alternate states. Landscape simulation models have been developed that model these processes and track the status of key state variables. The shift of the current regime to an alternative state is characterized by state variables crossing thresholds and results in the establishment of different ecological structures and functional relationships.

3a. Scenario Themes

Discussions among the project participants identified a number of themes that would contribute to a range of future systems (table 4). These themes are primarily focused on management interventions to minimize the impact of MPB on timber, ecological and recreation values, and include the management or ecological mechanism to address the theme and the state variables that would track the elements relevant state, such as change in land cover.

Table 4. Project participant scenario themes, mechanism to realize and state variable used to track.

Theme	**Mechanism**	**state variable(s)**
Agricultural Expansion:	Increase agriculture and range following MPB salvage with increased roads and removal of trees	Land cover - area of agriculture and range
Settlement Expansion:	Gradual increase settlement areas and permanent roads over time	Land cover - area of settlement
Quality Recreational Experience:	Limited salvage in visual areas and apply road closures for wilderness	visual areas, number of roads and density of roads
Mountain Tourist Lodges:	Limited salvage in mountain lodge visual areas	visual areas
Watershed Impacts	Minimize level of access and salvage in watersheds and riparian areas	watersheds - classed by level of development, amount of salvage in riparian areas
Access Management:	Track open/active roads by watershed	watersheds - classed by: number and density of active road, salvage area, Equivalent clear cut area, salvage in riparian
Optimized Ecological Values:	Minimize salvage in old growth management areas, high value conservation forests, riparian, Grizzly habitat, caribou habitat fringe	Old growth management areas (OGMA), high value conservation forests (HVCF), riparian areas, grizzly habitat, caribou habitat fringe - amount of salvage and disturbance
Rocky Mountain Trench Restoration:	Pine in trench replant/succession to other species (doug fir?)	Rocky Mountain Trench land cover
Ungulates:	minimize salvage in winter range and caribou fringe	ungulate winter range, caribou habitat fringe - amount of salvage and disturbance

Theme	Mechanism	state variable(s)
Mixed Species Planting:	Shift replant to non-pine	leading tree species - amount of each species, old and replanted
Patch Size:	Get in/get out, then close access	old forest patch size, watershed access
Small Scale Salvage/Sanitation:	Small scale salvage to delay spread	annual spread rate
Operability Line:	Salvage and harvest above operability line	inoperable area harvested
MPB Suppression Activities:	Harvest low quality pine stands to delay spread	low quality stands harvested
Cold winters:	Delay spread with cold winter	annual spread rate
Climate Change:	Climate change mode shift BEC impacting succession and disturbance	BEC distribution, change in leading tree species distribution, change in amount and extent of fire

3b. Human and Ecological Internal and External Forces

Any characterization of the future is subject to uncertainties in the behaviour of the actors and to unknowns of the system dynamics (Peterson et al. 2003, Cumming et al. 2005). By assessing past system behaviour with respect to fire, insects and forestry, some of this uncertainty can be reduced. We have conducted an historical reconstruction to evaluate past MPB disturbance events and the management policy to understand previous MPB outbreaks and management response.

This section focuses on the internal and external forces that shape the Cranbrook system (table 5). State variables identify the status of the system and are used to evaluate when the system has shifted to an alternative regime and to what type and extent of perturbation the system can withstand and still maintain its identity and be considered resilient.

Table 5. Internal and external social-ecological forces on the Cranbrook study area.

Scale	Force	Mechanism	State Variable(s)
Internal	***Natural***		
	Succession	Ecological succession transition	Land cover, Dominant tree species and age
	MPB	MPB spread	Land cover, Dominant tree species and age
	Fire	Fire ignition and spread	Land cover, Dominant tree species and age
	Human		
	Local Forest Management	Forest management policy - various rules restricting harvest	Dominant tree species and age within designated areas such as wildlife and visual zones
	Commercial Forestry: Harvest	Rate and extent of harvest	Area harvested

Scale	Force	Mechanism	State Variable(s)
	Commercial Forestry: Salvage	Rate and extent of salvage	Area salvaged
	Land conversion	Range land to agriculture Expansion of settlement	Land cover, area of settlement and extent and density of roads
External	***Natural***		
	Weather	Cold winters suppressing MPB	rate of spread of MPB
	Hydrology	Water availability and quality, upstream damns, etc	Extent of riparian area, volume of water
	Human		
	Provincial Forest Policy	Forest management policy – rate of cut	Species and age structure of forest
	Timber Market	Species targeted for harvest	Tree species and age
	Climate Change	Shift in climate envelopes shifting natural disturbance and succession	BEC distribution, change in leading tree species distribution, change in amount and extent of fire

3c. Likelihood of Alternative Futures

Scenario themes, and human and ecological drivers, have been presented in the previous two sections. The likelihood of a combination of these themes, and ecological and human drivers occurring, is dependent on the current state of the system, management decisions that are made and the plausibility of particular disturbance events either continuing, such as MPB, or occurring, such as extensive wild fire.

Models can be constructed to evaluate the long term availability of ecosystem services in the absence of stochastic events, such as natural disturbance. Alternately, natural disturbance can be included using only a mean rate or extent. These models can assist in understanding the maximum supply of ecosystem services that can be achieved from the landscape and to determine what management decisions would be best to realize that goal. The likelihood of maximizing the supply of ecosystem services is compromised by a number of constraining factors, such as the characteristics of the area's disturbance regime or by unanticipated impacts on other values that may curb the consumption of specific services, such as the decline of a wildlife species triggering a reduction in forest harvesting. Assigning a probability to these unanticipated factors is problematic due to either their stochastic nature or their unknown origin.

An understanding of the Cranbrook study area's disturbance regime can be informed by the rate and extent of past events. The study area was subject to an extensive MPB outbreak in the early 1970s. By studying the rate and size of the spread, as well as what forest structure remained after the outbreak, insights can be gained as to the impact and extent of the current outbreak. Further, fire history studies can be used to reconstruct what the historic fire cycle has been in the study area and used to inform an expected rate and extent of future fires.

There is, however, extensive variability in characteristics that describe an area's disturbance regime. In an effort to capture this variability the "Range of Natural Variability" (RONV) concept has been promoted as a tool to characterize disturbance regimes (Landres et al. 1999, Haeussler and Kneeshaw 2003). By using a framework that describes the range of conditions in an unmanaged forest system, the focus shifts away from looking only at the central tendency of the system but to its dynamics (Haeussler and Kneeshaw 2003). However, there remain two central challenges to this approach. First, there is no consensus on the time period for describing regional stability of disturbance regimes in unlogged forests. Prior to European contact, a traditional system of land use practices established by indigenous peoples probably played a significant role in determining landscape condition. This system was supplanted by a non-traditional system, where the influence of humans was less benign (Suffling and Perera 2004). The second challenge is that disturbance events are subject to stochastic and cyclical external drivers that modify the characteristics of the regime. For example, fire frequency in western North America is influenced by El Niñno / La Niña ocean temperature oscillations. External drivers cause the disturbance regime to drift over time, leading to a spatial, temporal and stochastic variability that result in the mosaic of forest ages. It is unclear how variable the historic disturbance regime was in south-eastern British Columbia. Despite the shortcomings of the RONV concept, it remains a useful framework for understanding landscape dynamics and their interaction with forest management decision making.

There are feedbacks between the human and ecological domains. For example, there can be changes in management direction due to an unforeseen circumstance, such as the rapid decline of a wildlife species. Internal feedbacks, where the actors in the system adapt to new information, make the assignment of likelihood to various management decisions challenging. However, through landscape modelling, the effect of different decisions can be explored. Thresholds can be identified, such as a critical amount of wildlife habitat required to support a species, that once crossed would trigger a new decision to constrain some human activity, such as forest harvesting. This exploration helps to build understanding of the system and social adaptability. Changes, such as an increase in human population, or recreation becoming the dominant economic activity, can be informed by recent trends in the study area and in other, similar jurisdictions. The resilience of the identity of the current system can be determined by how it can maintain its identity despite various perturbations. Further, management decisions can be identified that would best maintain a system's preferred identity.

4. Scenarios

Scenarios provided a structured account of a possible future. They are constructed based on known system composition and dynamics, and guidance from project participants. The information from the preceding sections on the system context, information describing its current state and alternate states, and system drivers, is used to compose the scenarios and includes:

- Structural components – the parts of the system under consideration,
- functional relationships and connectivity – how parts of the system are related,
- sources of system innovation – how the system may change,
- sources of system continuity – how the system may maintain itself,
- human and ecological forces – specific forces that act on the system, and

- management action – interventions that may change the trajectory of the system.

There are three components to the development of the scenarios:

1. Scenario definition: for convenience scenarios are given descriptive names, have a specific identity, and are the result of a particular combination of ecological drivers and human management decisions.
2. Scenario testing: testing is conducted to evaluate the plausibility of a scenario and to determine their consistency and the plausibility of dynamics. Testing reveals problems with scenarios and allows for their refinement.
3. Management options and interventions: the scenarios are used to test, analyze and to create policies. Policies can be assessed as to how they would fare in different situations. Elements of the current system state can be investigated as to their impact on future conditions.

This section presents an overview of the scenarios identified for the Cranbrook study area. The project is at the scenario definition phase and will begin extensive scenario testing in the next phase. After the scenario testing phase, the scenarios will be used to explore policy alternatives to meet the project goal of evaluating the supply of ecosystem services and managing the uncertainty associated with the current MPB outbreak.

4a. Scenario Definitions

Four scenarios have been identified for the Cranbrook study area. Each has been given a name and represents a plausible set of events that could lead to some future condition. Scenarios are evaluated to determine their credibility. All are anchored in the current system configuration, but follow different trajectories in their evolution leading to distinctively different states. Key variables are tracked that describe the system's state as the scenarios play out in time. Simulation models, currently in development, are used to model the scenarios through time and to report the key variables. The first scenario focuses on current business practices and management assumptions and would lead to a future similar to the present, whereas the subsequent three scenarios entail a re-organization of the current system to a different identity.

Business as Usual

The first scenario named "Business as Usual" assumes that the system would maintain its current identity. This future is described in the timber supply review III report (Robinson 2004) and in Canfor and Tembec's Sustainable Forest Management planning process. This future assumes some reorganization under the current MPB outbreak, but forestry continues to be the focus with extensive salvage while other values, such as wildlife habitat, are maintained. Under this scenario the current rate and extent of natural disturbance would continue into the future. Due to commercial forestry activities, using primarily clear-cut practices, the landscape pattern would become skewed towards smaller units than would have historically dominated the landscape, while the age-class distribution would become more uniform. As well, there would be an increase in road and road density. Due to these forest composition changes, the predator-prey dynamics, specifically caribou, and wolves and cougars, would continue to shift to a moose dominated system. It is also assumed that there would be a slight increase in tourism and recreation as community affluence increases as a result of high wage forest industry jobs. A description of the Cranbrook system's state variables for the "Business as Usual" scenario is given in table 6.

Eco-Garden

The second scenario, called "Eco-Garden", focuses on implementation of strict conservation targets based on the historic range of variability. It tries to reconstruct historic landscape patterns in the hopes of re-affirming historic predator-prey relationships. This scenario tries to maintain flexibility in the provisioning of ecosystem services in the face of future uncertainty in their supply. The overall identity shifts to more conservation bases and it minimizes road density. A general description of the state variables is given in table 6.

Playground

The third scenario, named "Playground", is a shift to a human amenity focus. A larger human population is assumed, with an increase in recreational use of the landscape. The dominant employment shifts from forestry to the service and recreation industry. There is an emphasis on maintaining values related more to landscape aesthetics than to commercial forestry. Under this scenario there is an increase in the area of settlement and land conversion to recreation infrastructure, such as golf courses. As well, the use of roads by backcountry enthusiasts increases, as does the occurrence of snow mobiles in the winter and all terrain vehicles in the summer. With the increase in human activity across the landscape there are more negative wildlife interactions. Table 6 show how the state variables would change for the Playground scenario.

Climate Shift

The fourth future centres on climate change, where there is an expansion of grasslands, the woodlands extend into the alpine and there is a reduction in water availability. This scenario, called "Climate Shift", bases biotic shifts on changes in the current climate envelopes, which are used to define the existing ecological classification system used in British Columbia (Meidinger and Pojar 1991). Under this scenario these ecological zones shift according to changes in temperature and precipitation forecasted in downscaled general circulation models (GCM; Hamann and Wang 2006). There is an expansion of agriculture and range and a decrease in area available for forestry. However, the majority of forest harvesting is targeted at salvage. An increase in human population is assumed with increased land use for crops and livestock. As well, with a general drying trend forecasted for south-eastern British Columbia (Hamann and Wang 2006), we assume that there will be more hydrological control. Table 6 summarizes the general trend in state variables for the Climate Shift scenario.

Table 6. State variable changes under four different scenarios.

		Scenario			
	State Variable	**Business as Usual**	**Eco-Garden**	**Playground**	**Climate Shift**
Social	**Human population**	stable	stable	increase	increase

		Scenario			
	State Variable	**Business as Usual**	**Eco-Garden**	**Playground**	**Climate Shift**
	Dominant Business	forestry	forestry/recreation	recreation	agriculture/range
Ecological	**Land Cover**	some land conversion to settlement	stable mix of land types	land conversion to recreation (golf, skiing, etc) and settlement	conversion of forest to settlement, agriculture and range
	Forest State - focus	sustainable timber supply	emulate natural disturbance	viewscapes	increased disturbance
	Forest State - pattern	increase fragmentation	decrease fragmentation	more continuous old forest, more linear corridors	increase fragmentation
	Forest State - age	more even age structure	uneven age structure	uneven age structure	increase in young forest
	BEC	stable	stable	stable	shift to drier units
	Roads	increase density	decrease density	increase density and use	increase density and use
	Watershed Status	open access	controlled access	open access	open access
	Wildlife	increase moose, elk, deer - decrease grizzly and caribou	less moose more caribou	increase moose, elk, deer - decrease grizzly and caribou	increase moose, elk, deer - decrease grizzly and caribou

4b. Testing Scenarios

Scenario testing will be conducted during the next phase of the project. Scenarios will be tested for their internal consistency and for the consistency between scenarios. As well, expert opinion will be sought from climate scientists, forest ecologists, foresters, wildlife ecologists and social planners for the plausibility of the four scenarios. In addition, we are implementing a 2 phase approach to modelling the scenarios. In the first phase we are building simple process models to evaluate the interaction between the system elements and drivers. Once we have captured the system with this simple implementation we will then draft the scenarios into more rigorous landscape simulation models to further evaluate scenario assumptions, behaviour and plausibility. The simulation modelling is geared towards capturing the transitions of forest states. The state of the system is monitored through a set of indicators and sub-models. Through this monitoring, the evolution of the system can be gauged. The results of the scenario implementation and testing are examined from each of the system actor's perspective through subsequent workshops to address issues of scenario interpretation bias

4c. Management Options

The final step of this analysis framework is to explore potential management interventions and policies and their influence on the trajectory of the system. Through this exercise management properties that perform well, in terms of guiding the system towards a preferred future condition, can be distinguished from those policies that give unintended results.

Discussion

This report presents an overview of an analysis framework designed to evaluate the supply of ecosystem services and their trade-offs, while explicitly accounting for uncertainty. The framework is being applied in the Cranbrook timber supply area to explore the question of how to maintain ecosystem services, mainly timber and wildlife habitat, as the area experiences an unprecedented MPB (Taylor and Carroll 2003) outbreak. The framework consists of four steps: 1) Context identifies the focal issues and establishes a collaboration between project participants and scientists, 2) Current State describes the essential system attributes of structural components, functional relationships and connectivity, sources of system innovation, and system continuity, 3) Alternate States outlines the human and ecological forces that could shape the system and their likelihood based on historic system behaviour, and 4) Scenarios uses information provided by the previous steps to construct plausible trajectories of future social-ecological conditions. The scenario step includes scenario testing to evaluate the conceivability of a scenario and policy testing to explore robust strategies for increasing the likelihood of preferred future condition.

The framework allows project participants to explore and contrast historic, current, and hypothetical management responses to MPB outbreaks at a variety of scales by capturing historical and expert knowledge. This provides insights into values that are likely to be vulnerable to changes in landscape and human condition resulting from the current MPB outbreak.

A formal publication will be drafted based on this document and include a more detailed examination of the theoretical basis of scenario planning. Next steps in the project will be to construct detailed system diagrams of the elements, their relationships and how they are influenced by the various human and ecological drivers. Preliminary landscape models have been constructed for the project and they will be extended to accommodate the exploration of the proposed scenarios. Scenario testing and policy analysis will then be conducted to address the central goal of the project of using historic information to guide MPB-related decisions through a strategic analysis that compares the consequences of historic responses to alternative management approaches.

Literature Cited

Bennett, E.M., Carpenter, S., Peterson, G.D., Cumming, G.S., Zurek, M., and Pingali, P. 2003. Why global scenarios need ecology. Front Ecol Enviorn. **1**: 322-329.

Cumming, G.S., Barnes, G., Perz, S., Schmink, M., Sieving, K.E., Southworth, J., Binford, M., Holt, R.D., Stickler, C., and Van Holt, T. 2005. An exploratory framework for the empirical measurement of resilience. Ecosystems. **8**: 975-987.

Eng, M., Fall, A.., Hughes, J., Shore, T., Riel, B., Hall, P., and Walton, A. 2005. Provincial level projection of the current mountain pine beetle outbreak. Victoria, B.C., Canada. [online] URL: http://www.for.gov.bc.ca/hre/bcMPB/BCMPB_MainReport_2004.pdf.

Eng, M., Fall, A., Hughes, J., Shore, T., Riel, B., Walton, A., and Hall, P. 2006. Provincial level projection of the current mountain pine beetle outbreak: Update of the infestation projection based on the 2005 provincial aerial overview of forest health and revisions to "the model" (bcmpb.V3). Victoria, B.C., Canada. [online] URL: http://www.for.gov.bc.ca/hre/bcMPB/BCMPB.v3.BeetleProjection.Update.pdf.

Gunderson, L., and Holling, C.S., editors. 2002. Panarchy: Understanding transformations in human and natural systems. Island Press, Washington, D.C., USA.

Hamann, A., and Wang, T. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. Ecology. **87** (11): 2773-2786.

Haeussler, S., and Kneeshaw, D.D. 2003. Comparing forest management to natural processes. Pages 307-368 *In* Towards sustainable forest management of the boreal forest. *Edited by* P.J. Burton, C. Messier, D.W. Smith, and W. Adamowicz. NRC Research Press, Ottawa, Ontario, Canada. pp. 307-368.

IPCC. 2000. Special Report on Emissions Scenarios. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Landres, P.B., Morgan, P., and Swanson, F.J. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications. **9** (4): 1179-1188.

Meidinger, D.V., and Pojar, J. 1991. Ecosystems of British Columbia. Research Branch, British Columbia Ministry of Forests, Victoria, British Columbia, Canada.

Millennium Ecosystem Assessment**.** 2005. Chapter 2 in ecosystems and human well-being: Scenarios. Island Press, Washington, D.C., USA.

Peterson, G.D., Cumming, G.S., and Carpenter, S.R. 2003. Scenario planning: A tool for conservation in an uncertain world. Conservation Biology. **17** (2): 358-366.

Robinson, C. 2004. Cranbrook Timber Supply Area Timber Supply Review #3 Analysis Report. Forsite Consultants Ltd, Salmon Arm, British Columbia.

Spittlehouse, D.L., and Stewart, R.B. 2003. Adaptation to climate change in forest management. BC Journal of Ecosystems and Management. **4** (1):

Suffling, R., and Perera, A.H. 2004. Characterizing natural forest disturbance regimes: Concepts and approaches. Chapter 4. Pages 43 to 54 *In* Emulating natural forest landscape disturbances: Concepts and applications. *Edited by* L.J.B. AH. Perera, and M.G. Weber. Columbia University Press, New York, New York. pp. 43 to 54.

Taylor, S.W., and Carroll, A.L. 2004. Disturbance, forest age, and mountain pine beetle outbreak dynamics in bc: A historical perspective. *In* Proceedings of the Mountain Pine Beetle Symposium: Challenges and Solutions, 30-31 October 2003, Kelowna, British Columbia. *Edited by* T. Shore, J.E. Brooks, and J.E. Stone. Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, Victoria, British Columbia. pp. 41-51.

Turner, B.L., Kaspersonb, R.E., Matsone, P.A., McCarthy, J.J., Corellg, R.W., Christensene, L., Eckleyg, N., Kasperson, J.X., Luerse, A., Martellog, M.L., Polskya, C., Pulsiphera, A., and Schiller, A. 2003. A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Science of the United States of America. **100** (14): 8074-8079.

Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G.S., Janssen, M., Lebel, L., Norberg, J., Peterson, G., D., and Pritchard, R. 2002. Resilience management in social-ecological systems: A working hypothesis for a participatory approach. Ecology and Society. **6** (1): 14. Available from: http://www.ecologyandsociety.org/vol6/iss1/art14/

Wittmer, H.U., Sinclair, A.R.E., and McLellan, B.N. 2005. The role of predation in the decline and extirpation of woodland caribou. Oecologia. **144**: 257–267.