Bulkley Valley Centre for Natural Resources Research & Management

www.bvcentre.ca

Strategic Research Framework for Landscape Ecology in West-Central BC

Liz Osborn MRM, MSc

Prepared by:

Liz Osborn MRM, MSc

Wildland Nexus

Phone: (250) 847-9303

Email: wildland@nexusbc.ca

Smithers, BC

Prepared for:

Bulkley Valley Centre for Natural Resources

Research and Management

Smithers, BC

Prepared: March 2003

Contents

List Of Tables

Executive Summary

This research framework for landscape ecology in west-central forests of British Columbia provides a strategic focus for research that is anchored in furthering broad scientific development while addressing the knowledge priorities of BC resource managers. It also takes into account methodological considerations and identifies research opportunities that efficiently build on infrastructure already in place.

The landscape characteristics most relevant to BC forest management are fragmentation, old growth forest attributes and disturbance. Research priorities for these are best addressed with a diverse set of tools including field studies and modeling. Particular attention, however, must be paid to temporal and spatial scale and to integrating disciplines.

The landscape ecology research priorities for west-central BC involve three broad areas:

- Functioning of natural systems.
- Limits to ecological functioning.
- Ecological responses to forest management.

Two issues currently of particular concern are the impacts of mountain pine beetle disturbance and developing relevant indicators of ecosystem functioning.

Opportunities to enhance understanding of these include improving synthesis of and access to existing research results, developing interdisciplinary research field sites, and building on existing landscape modeling. The research framework suggests how these opportunities can be applied to build the science required for enhancing landscape management in west-central BC forests.

Acknowledgements

Funding for developing this research framework was provided by the BC Ministry of Sustainable Resource Management. Many scientists and resource managers in west-central BC provided expertise which contributed substantially to forming the framework. These are Don Morgan, Andrew Fall, Jim Pojar, Kevin Kriese, Sybille Haeussler, Carl vanderMark, Doug Steventon, Dave Coates, Ken White and Laurence Turney.

1.0 Introduction

This document presents a strategic framework for research into landscape ecology. While based on general principles of landscape patterns and processes, the framework's scope is sub-boreal forests of British Columbia with emphasis on terrestrial ecosystems of the west-central portion of the province. The framework combines scientific ideals with practical imperatives to address three main objectives:

- Furthering the science of landscape ecology.
- Addressing resource use priorities for west-central BC.
- Efficiently producing quality research results.

The focus of the framework is on advancing scientific understanding of ecosystems, particularly to support achievement of sustainability. Due to the extensive influence of forest management on ecosystems and associated human communities in this part of the province, an applied approach and practical application of research is emphasized. Influential contexts for this work are prevalent research funding requirements and the need for quick, relevant results.

Since the framework has been developed based upon broad scientific views of landscape ecology, the most germane concepts are briefly described. Research needs for these disciplinary components are discussed next. This is followed by an overview of critical methodological considerations. This information is then brought to bear on present management challenges facing west-central BC, resulting in identifying research priorities and opportunities for this area. The framework does not attempt to provide a review of research findings nor a status report on research underway. Instead, the emphasis here is forward looking at a strategic level. The final section summarizes the research framework, with a coalescence of priorities, methodological considerations and opportunities in the west-central BC context.

2.0 Overview of Essential Landscape Ecology Principles

Landscape ecology can be summarized as the study of ecosystem mosaics, focusing on three elements and their linkages, for areas covering 5,000 to 100,000 hectares (D'Eon 2002, Eng 1998, Forman and Godron 1986). The three main elements of the field are:

- Structure - including distribution patterns and spatial relationships of ecosystems.
- Functioning - particularly ecological processes and interactions among ecosystems.
- Change - spatial and temporal characteristics resulting from disturbance and succession.

Three landscape characteristics are generally recognized as significantly affecting ecological sustainability and are considered most relevant to forest management in BC:

- Fragmentation.
- Distinctive components of old growth forests.
- Effects of disturbances.

These are discussed further below as components of landscape composition and landscape change.

2.1 Fragmentation

According to many in the scientific literature, fragmentation of habitats is potentially presenting the most serious threat to biological diversity (Eng 1998, Harrison and Voller 1998). Fragmentation involves the breaking up of large patches of forest, which are homogenous in species and age composition, to form smaller discrete patches interspersed with different seral stages. While some species benefit from this type of mosaic, fragmentation is detrimental to species which are unable to move between patches, or which require large tracts of uniform habitat (Steventon 1994). Key components of fragmentation involve:

- Characteristics of remnant patches including size, shape, interior habitat conditions, time since isolation and the amount and sharpness of edges.

- Spatial context of remnant patches including distance from other remnants, degree of similarity with surrounding habitat and connectivity with similar patches.

Connectivity is an important feature of fragmented landscapes. Ecologically it means the degree of flow of energy, nutrients, water, and organisms between landscape habitats or patches (Harrison and Voller 1998). One form of connectivity is corridors, which are continuous strips of habitat linking ecologically similar patches.

2.2 Old Growth Forest Attributes

The distribution and extent of successional stage pattern is most critical as it relates to the amount and distribution of old growth forest habitat. Some species are heavily reliant on old growth features. Yet this habitat type is affected most by large-scale disturbance, particularly timber harvesting.

Old growth habitat has been analyzed to determine which components are distinctive and fill critical habitat needs. These are large, old, live trees; coarse woody debris (CWD), and snags (MacKinnon 1998). In northwestern BC, for instance, 120 species use dead trees with about half of those probably requiring CWD or snags (Radcliffe et al. 1994, Keisker 2000). Also important is a diversity of vegetation structure, both vertically and horizontally, achieved through a rich presence of shrub and herb understory layers, and multiple layers of tree canopies and canopy gaps (Holt 2000). These critical structural features, along with patch connectivity, stand complexity and landscape heterogeneity are considered the most reliable indicators of biodiversity (Lindenmayer et al. 2000).

2.3 Disturbances

Changes to landscape composition occur over time as a result of successional processes until these are interrupted by disturbance. Disturbances are generally considered to be events that result in making growing space available (Oliver and Larson 1996) and have the critical elements of disrupting ecosystems or population structures, along with changing the allocation of resources within ecosystems (Rogers 1996). In forests, disturbances can cause an increase or decrease in biological diversity (Parminter 1998) by changing:

- Seral stage distribution.

- Spatial distribution of patches.

- Connectivity between patches.

Some disturbances are initiated and controlled by ecological forces and influenced by human activity. These are referred to as natural disturbances and include wildfire, insect infestations, pathogens, flooding, windthrow and landslides. Disturbances initiated and controlled by humans, and influenced by ecological factors are generally termed management or development, and include forest harvesting, silvicultural activities, prescribed burning, road building, dam building, open pit mining and agriculture. Disturbances can create impacts at any of the regional, landscape, stand and canopy gap levels.

The type and frequency of disturbance, along with disturbance intensity (proportion of forest impacted) and magnitude (area covered) are all important variables (Turner et al. 2003). Disturbances can also have antagonistic or synergistic effects on subsequent disturbances (Parminter 1998) resulting in the interactions of different kinds of disturbances on a landscape or stand. For instance, a mountain pine beetle (MPB) infestation can result in high fuel loading conducive to wildfire, or harvesting may quickly follow a MPB epidemic to salvage timber before decay sets in. Disturbances may occur in rapid succession, creating cumulative impacts. In turn, landscape pattern influences the susceptibility of forests to disturbance (Perry 1988, Whitehead et al. 2001).

Over-riding successional patterns and disturbance disruptions is the process of global climate change. Historically in BC, climate change has substantially altered biogeoclimatic zone boundaries and the frequency and intensity of natural disturbances (Hebda and Walker 1999, Brown and Hebda 2002). This adds another layer of complexity to landscape ecology change, issues and research.

3.0 Research Priorities for Landscape Ecology

The critical theoretical underpinnings of landscape ecology lack substantial empirical supporting evidence and are currently subjects of considerable debate (Wu and Hobbs 2002). Two general areas of landscape ecology research stand out in the context of this framework:

- Ecosystem processes, functioning and change at all spatial and temporal scales (National Science Foundation 2002). There is limited understanding of these aspects of forested ecosystems (Nelson 2003).

- The interactions of human and natural systems, particularly human impacts on ecosystems (National Science Foundation 2002, Wu and Hobbs 2002).

These provide the overall context for the following discussion of research to address the essential elements of landscape composition and change from a broad scientific perspective, but with an emphasis on forest ecosystems. Research needs identified in the literature are also summarized in Table 1.

3.1 Fragmentation

The theoretical framework for understanding fragmentation has yet to be adequately tested with empirical research (D'Eon 2002). What is apparent from fragmentation research conducted so far is the lack of consistency in findings (Debinski and Holt 2000). It is not yet possible to generalize about the effects of forest fragmentation on a species (Eng 1998) nor across ecosystems.

The effects of forest fragmentation on all aspects of ecosystem functioning requires investigation. Research is needed to examine fragmentation impacts by comparing ecosystems before, during and after fragmentation occurs (Harrison and Voller 1998). As well, species-specific population responses, including dispersal and movement across landscapes, require further investigation (Debinski and Holt 2000). Edge influences on ecosystem function and structure are another important component of fragmentation identified for further research (Voller 1998).

Whether connectivity plays an essential role in forest ecosystems is also a subject of debate due to a paucity of empirical evidence (Holt 2000). When assessing the influence of landscape structure on landscape connectivity, researchers have concluded that as a concept, connectivity is still poorly defined (Goodwin and Fahrig 2002).

In the few long-term (10 to 20 years) fragmentation studies conducted, processes have been revealed that were not evident during shorter investigations (Debinski and Holt 2000). Long-term fragmentation research is therefore essential.

In summary, empirical fragmentation research is a widely identified need. Fragmentation studies of most value include comparative analyses, long-term field observations and investigations into the role of connectivity and edges in ecosystem functioning.

3.2 Old Growth Forest Attributes

Scientific understanding of successional patterns and processes needs building with an emphasis on determining at what point seral forests contain old growth attributes, particularly those features meeting critical habitat needs (MacKinnon 1998). The dynamics of how these features develop and decay, and are distributed spatially in both managed and natural stands, is not yet well enough understood (Lofroth 1998, Ruggiero et al. 1994). As well, better information on the species requirements for these habitat features is needed (Keisker 2000). In the context of using these features as indicators of ecosystem health and functioning, empirical testing is also required (Lindenmayer et al. 2000).

3.3 Disturbances

Regarding disturbance, research questions mainly concern the effects of disturbances on ecosystems and landscapes, particularly fragmentation and seral stage characteristics. Some types of disturbance are better understood than others. For instance, research into natural disturbances has focused largely on wildfire ecology and blowdowns, while landscape level and stand level patterns and processes resulting from insect infestations is relatively poorly understood (Parminter 1998). Scale is an important consideration in disturbance research. For instance, most of the fire-effects research has been conducted at small scales, with relatively little data about interactions among physical and biological characteristics and the critical aspects of spatial and temporal dynamics of fire at large scales (Schmoldt et al. 1999). The interactions of consecutive disturbances and cumulative effects of disturbance also need further attention (Hobbie 2003), particularly for various forest management activities following disturbance.

Human initiated disturbances dominate land cover change and these in particular require more research effort into their causes (including socioeconomic forces), processes and ecological consequences (Wu and Hobbs 2002). As a part of this, the optimization of landscape pattern for various purposes, such as biodiversity conservation, is a fundamental research priority for landscape ecology (Wu and Hobbs 2002). Of particular management concern is identifying the threshold levels at which forest ecosystems are capable of absorbing disturbance while maintaining healthy functioning (Nelson 2003).

Table 1 Research Priorities Identified in the Literature

Topic	Context	Reference
Land Management		
Ecosystem processes under different management regimes	N BC	9
Ecological legacy post beetle-proofing	N BC	2
Integration of MPB ecological impacts into forest land planning	N BC	2
Integration between basic landscape ecology research and land management applications	Global	10
Causes, processes and consequences of land use change	Global	10
Optimization of landscape pattern	Global	10
Assumptions behind choosing particular forest attributes as management targets	NA	1
Cost-effective harvesting practices consistent with ecosystem-based management	N BC	7
Interrelationships of human resource use and natural systems	US	6
How major biogeochemical cycles are affected by human activities	US	6
Forest management impacts on dynamics and ecosystem value of dead wood	BC	15
Managing forests to provide habitat necessary for species dependant on old-growth forests	BC	14
Comparison of various managed and natural forest interior conditions	BC	14
Natural Disturbances		
Characteristics of natural disturbances	N BC	7
Effects of natural disturbances over time	BC	11
Relationships between landforms, landscapes and natural disturbances	BC	11
Role of pathogens as natural disturbance agents	BC	11
Impact of MPB on stand dynamics and natural forest succession	N BC	2
Comparison of MPB harvest pattern and size with natural disturbance	N BC	2
Impact of MPB on mature pine site ecology and habitat characteristics	N BC	2
Impacts of MPB infestation on streams, aquatic systems and hydrology	N BC	2
Ecological value and impacts of burn, green and beetle-killed stands	N BC	2
Effects of spatial/temporal landscape management on MPB risk	N BC	2
Identification and spatial mapping of factors reducing decay rate (salvageable shelf life) of MPB killed trees	N BC	2
Effects of large-scale wildland fire disturbance on natural resources	US	8
Physical and biological environmental characteristics relevant to large-scale wildland fire	US	8
Spatial and temporal dynamics of wildland fires at large scales	US	8
Fragmentation		
Studies of systems before and after fragmentation	BC	16
Long-term studies of habitat fragmentation impacts	Global	3
Managing for fragmentation at various scales	BC	12
Landscape options to reduce mature pine continuity	N BC	2
Effects of fragmentation on biota of forested environments	BC	12
Interactions between fragmentation and individual wildlife behaviour	Global	3
Model population response to fragmentation spatially and temporally	BC	13
Mechanisms behind species population patterns resulting from fragmentation	Global	3
Sizes of forest fragments required for species habitat	N BC	4
Optimum dimensions of connectivity corridors	BC	13

Topic	Context	Reference
Fragmentation		
Monitor species use of corridors	BC	13
Critical features, number and distribution of travel corridors	N BC	4
Influence of edges at different spatial and temporal scales	BC	16
Long-term impacts of edges on various species populations	BC	16
Old Growth Attributes		
Species, especially non-vertebrates, associated with old-growth forests	BC	14
Nature of species dependency on old-growth forests	BC	14
Habitat requirements of certain obligate or frequent CWD and wildlife tree users	N BC	4
Relationship between dead wood and dead wood obligate species	BC	15
Importance of dead wood in ecosystem processes	BC	15
Dynamics of dead wood (e.g. snags, wildlife trees, CWD)	BC	15
Levels of CWD recruitment in natural and managed forests	N BC	4
Maximum spacing of habitat types for CWD and wildlife tree users	N BC	4
Ecology of critical features of various wildlife tree types	N BC	4
Biodiversity Conservation		
Biodiversity and species at risk knowledge and modelling	BC	5
Thresholds for maintaining ecosystem integrity	N BC	7
Processes that create, sustain or reduce biodiversity	NA	1
Relationships between biodiversity and ecosystem dynamics	US	6
Landscape ecological guidelines for biodiversity conservation	Global	10
General Ecology		
Conceptual and theoretical development of landscape ecology	Global	10
Ecological flows in landscape mosaics	Global	10
Ecosystem structure and function	US	6
Geographic range and potential extremes of climate variability	US	6
Range of natural variability in various ecosystem attributes	BC	12
Identifying and testing practical criteria and indicators for ecosystem and SFM monitoring	BC, N BC	5, 7
Synthesis of ecosystem indicators by forest/ecosystem classification	N BC	2
Interior forest habitat	BC	14
Habitat requirements and basic ecology of poorly known vertebrates and keystone species	N BC, BC	9, 13
Comparisons of vertebrate diversity and productivity in different forest types	N BC	9
Wildlife use of various ecosystem structural components (e.g. CWD, herb layer)	N BC	9
Methods		
Transferring understanding from one spatial or temporal scale to another	Global	10
Adaptive management applications	BC	5
Ecologically representative network of permanent research plots	N BC	2
Modelling natural disturbances	BC	5
Spatially explicit forest modelling involving stakeholders and forecasting outcomes of management alternatives	BC	5
Incorporate empirical data into wildland fire-effects models to improve predictive capability	US	8
Models for dead wood cycle dynamics	BC	15

Context Key, Table 1
N BC = Northern, including west-central, BC
NA = North America

Reference Key, Table 1
1 = Bunnell 1998
2 = Canadian Forest Service 2002
3 = Debinski and Holt 2000
4 = Keisker 2000
5 = FORUM 2000
6 = National Science Foundation 2002
7 = Osborn 2002
8 = Schmoldt et al. 1999
9 = Radcliffe et al. 1994
10 = Wu and Hobbs 2002
11 = Parminter 1998
12 = Eng 1998
13 = Harrison and Voller 1998
14 = MacKinnon 1998
15 = Lofroth 1998
16 = Voller 1998

4.0 Research Approaches for Landscape Ecology

A diverse, integrated research tool box is recognized as the requisite approach to landscape ecology (Wu and Hobbs 2002). This means combining field measurements, experimentation, GIS and modeling. The science of landscape ecology grapples with an interdisciplinary complexity of landscape systems, multiple scales, spatial heterogeneity and lack of replicability. These require new scientific approaches to testing hypotheses (Wu and Hobbs 2002).

Two complimentary approaches to scientific investigation relevant to biological ecology have been described by Holling (1998):

- Analytical, experimental, reductionist, disciplinary, and eliminates uncertainty.
- Integrative, interdisciplinary, multiple competing hypotheses, exploratory, incorporates uncertainty.

Both have a role in landscape ecology, with the analytical approach to research providing a foundation for the wider-ranging integrative approach necessary for the interdisciplinary understanding that landscape ecology requires. For landscape ecology, field studies tend to take an analytical approach, whereas modeling uses either. Scale and disciplinary scope are important considerations with either approach. These are discussed in more detail below.

4.1 Field Studies

Basic biological understanding acquired through data collection is a necessary foundation for building an understanding of landscape structure and function (Wu and Hobbs 2002).

Collection of ecological field data can unveil historic patterns of disturbance through dendrochronology or lake sediment sampling. Impacts of disturbances can be uncovered through intensive site study to examine process and species responses to various events (Rogers 1996). As mentioned previously, long-term empirical research plays a strong role in developing scientific comprehension of landscape ecology.

4.2 Modeling

Technical advances in computers over the last decade have enabled integration of landscape considerations with forest-level models (Nelson 2003). Landscape models are used for testing research hypotheses or used as decision support tools by providing simulation, with specific models better suited to one function than the other (Fall et al. 2001, Rogers 1996). Theoretical models are built to understand ecological systems and can involve numerous submodels and large data requirements to address the wide array of ecological variables involved (Rogers 1996, Landsberg 2003).

Simulation modeling is used to predict outcomes of disturbance or succession (Rogers 1996, Bunnell 1998). Simulation models can be constructed to explore management options, evaluate consequences of various management approaches, and determine the sensitivity of a system to a particular disturbance (Landsberg 2003). These models need only the complexity required to provide the level of accuracy desired for predictions (Rogers 1996). Indeed, the simpler the model, the more value it has as a management and decision-making tool (Landsberg 2003). Furthermore, these predictive models need not be based upon complete scientific understanding, but instead can be modified through adaptive management (Bunnell 1998). Nevertheless, the scientific credibility of data is often a severe limitation for complex forest ecosystem models run over large spatial and temporal scales (Nelson 2003).

Modeling techniques can be used to drive an adaptive management approach to hypothesis testing (FORUM 2000). Applying adaptive management to landscape simulation modeling has been used by Fall and colleagues (2001) to develop decision-support modeling in BC and elsewhere. This iterative process involves collaboration of an array of stakeholders in constructing a conceptual model. A core team of modeling specialists then builds the model, and conducts sensitivity analyses, tests hypotheses and evaluates scenarios. The results are then presented to all participants with the opportunity for them to suggest improvements and raise additional questions to be addressed. This provides the modeling team with direction on refining their model. Iterative model building is a step towards addressing the research need identified for BC forest management of developing multi-scale spatial and temporal forest landscape planning models that incorporate ecological, social and economic values to support land use and management planning (FORUM 2000).

4.3 Interconnected Diversity of Scales

Spatial and temporal scales are important contexts for understanding landscapes. Research needs to use a spectrum of scales suitable for the process or pattern examined. Scales in which past research has tended to be most deficient are for large areas and lengthy time periods. Long-term studies and monitoring to more fully understand landscape structure, function and dynamics is emphasized as an important need by many authors (Wu and Hobbs 2002, Debinski and Holt 2000, Ruggiero et al. 1994, Hobbie 2003, Turner et al 2003). Large scale studies are particularly important for research involving large disturbances such as fire (Schmoldt et al. 1999) and wide-ranging vertebrates (Ruggiero et al. 1994).

Ecosystem as the research scale is considered more relevant now instead of discrete species and population studies (Noon 2003). This means making inferences about the effects on ecosystems resulting from changes to species populations. Principles and techniques for extrapolating results from one scale or hierarchy to others, particularly broader levels, is a methodological issue largely unresolved for landscape ecology (Wu and Hobbs 2002).

4.4 Interdisciplinary Scope

Landscape ecology is considered an interdisciplinary science which involves the integration of research with applications in resource management and land use planning (Wu and Hobbs 2002). Integration works both ways, with research informing managers and planners, but also with results from practical research contributing to development of the science.

The influence of humans on landscape cannot be ignored since this has become the dominant factor. Consequently, to fully reveal landscape issues, human demographic, social, political and economic factors need to be incorporated as variables in landscape level research (Wu and Hobbs 2002, Noon 2003) along with the more traditional environmental sciences.

Adaptive management is an approach enabling interdisciplinary and applied research. It is a formal systematic and rigorous approach to learning from outcomes of management actions, then accommodating change and improving management (Nyberg 1999). The application of adaptive management to forestry is relatively new (Nyberg and Taylor 1995), however it has considerable potential to not only further science, but to also facilitate quick incorporation of research results into practices. Forest management topics particularly suited to adaptive management include:

- Testing various harvesting and silvicultural techniques (Nyber and Taylor 1995).
- Landscape and stand-scale practices for maintaining biological diversity and wildlife values (Nyber and Taylor 1995).
- Integrating land use and the validity of structure-based indices of biological diversity (Lindenmayer et al. 2000).

Additional approaches to interdisciplinary research involve the synthesis of literature across many disciplines (National Science Foundation 2002). Meta-analyses whereby existing data from diverse disciplines and sources are assessed is another component of building interdisciplinary understanding through synthesis (National Science Foundation 2002, Wu and Hobbs 2002). This methodological frontier can be facilitated through cyberinfrastructure (National Science Foundation 2002). The US Long Term Ecological Research Network has already taken steps in this direction by making all data from research at their field sites available on the internet (Hobbie 2003).

5.0 West-Central BC Context

Sustainable Forest Management (SFM) and Ecosystem Management entail managing landscapes to simultaneously meet goals for commodity production and healthy ecosystem functioning. This paradigm is explicitly embraced by Lakes LRMP (Land and Resource Management Plan) (BC Ministry of Forests 2000) and Morice-Lakes IFPA (Innovative Forest Practices Agreement) (2002). Sustainable forest management is in part based upon employing an understanding of natural disturbance regimes to develop management strategies that will maintain healthy ecosystems. The current MPB epidemic has presented a natural disturbance of unanticipated proportions and character. These factors have created the context for west-central BC's landscape-level research needs to address land use planning and forest management concerns.

5.1 Research Priorities

Priorities for research into forest landscape ecology in west-central BC were identified in the literature and through interviews with local scientists and resource managers. These topics are summarized in Table 1 and discussed further here. This section also elaborates on two components of particular priority in this area: mountain pine beetle and ecosystem indicators. To conclude, a conceptual hierarchy summaries the critical elements of landscape ecology requiring future research.

BC's sub-boreal ecosystems, because of their remoteness, have received relatively little research attention compared with other parts of the country or province (Radcliffe et al. 1994, Keisker 2000). Consequently there are numerous gaps in basic understanding of species distribution, habitat requirements and their ecological roles and functioning. Among old growth attributes, knowledge gaps are particularly extensive for coarse woody debris including its natural abundance, distribution, and decay rates, as well as the impacts of forest management on CWD availability, and the habitat requirements of obligate CWD users (Keisker 2000).

As a result of their assessment of biodiversity in the Prince Rupert Forest Region, Radcliffe et al. (1994) highlight the need for comparative analyses of ecosystem processes under different natural and management disturbance regimes. They also identify the need for research into wildlife values of specific habitat components for various successional stages following disturbance.

Local forest managers and scientists perceive these research needs as still relevant priorities nearly ten years later. The main areas for landscape ecology research in west-central BC relate to understanding ecosystem components and their functioning, particularly the role of natural disturbances, and the impacts of human activities on the landscape. The change factors dominating the landscape and therefore requiring greatest research attention are the current MPB epidemic and forest harvesting and related activities.

Mountain Pine Beetle

Despite current interest in understanding natural disturbance regimes, these appear to have received almost no attention for high-impact insects such as MPB. What little research has occurred has been in the US and southeastern BC, in ecosystems which have many fundamental ecological differences from those found in west-central BC. In response to the current epidemic, the Canadian Forest Service (CFS) (2003) in consultation with resource managers and researchers, established priorities for MPB research funding, including topics related to forest ecology. These ecological research priorities concern the:

- Impacts of MPB on hydrology, biomass, ungulate winter range, tree insects and other ecological components.
- Dynamics of subsequent disturbances from fire in beetle-killed stands.
- Linkages between ecosystem processes and functioning with harvesting for salvage and beetle control.
- Integration of MPB impacts with planning and management of various resource values.

Current forest composition of sub-boreal west-central BC is a result of extensive human manipulation of the landscape during the last 100 years producing large homogenous stands dominated by a single mature seral species. The extent of these stands is likely beyond the range of natural variability (Carroll and Linton 2002), contributing to the current dilemma of massive-scale tree mortality from MPB. Forest management has the potential to break this pattern by introducing a wider range of seral conditions into these stands (Sullivan et al. 2002). Research also needs to address how various harvesting, silvicultural and other management techniques can be employed to create a more diverse array of forests across these landscapes.

Ecosystem Indicators

With public concern for biodiversity conservation and forest certification requirements, there is considerable interest in identifying and using efficient and effective surrogate measures of ecosystem health. Even where these indicators have been identified, however, much remains to be learned about measuring their role in ecosystem functioning. The assumptions that underlie choosing particular forest attributes as management targets (Bunnell 1998) continue to require research. Of paramount concern, from a forest management perspective, is identifying threshold measures at which these indicators show a critical decline in ecosystem functioning.

Monitoring indicators is a key feature of sustainable forest management plans developed for the Lakes and Morice TSAs (Timber Supply Areas) (Petterson 2002). Old growth attribute indicators in these TSA SFM plans, comprising the number of large live trees, number of snags, and volume of CWD, need to be calibrated against conditions associated with various natural disturbance regimes. Impacts from MPB on SFM indicators is another priority for research identified by CFS. Indicators to assess connectivity and fragmentation by landscape unit still need to be developed and calibrated. This includes identifying appropriate indices and methodologies for measuring and analysis, including patch definition.

Summary

The following hierarchy provides a conceptual summary of research priorities for west-central BC.

Summary of Research Priorities in Landscape Ecology Identified for West-Central BC

1. Functioning of Natural Systems
    a. Characteristics of natural disturbances
        i. Understory habitat vegetation and structural components at various seral stages following disturbance.
        ii. Impact of MPB on ecological processes and functioning including natural forest succession.
        iii. Comparisons of ecological impacts of various disturbances.
    b. Habitat requirements and basic ecology of poorly known vertebrates
        i. Comparisons of vertebrate diversity and productivity in different forest types.
        ii. Wildlife use of various ecosystem structural components.
2. Limits to Ecological Functioning
    a. Critical species requirements
        i. Sizes of forest fragments required by individual species.
        ii. Critical features, number and distribution of travel corridors required for species habitat
        iii. Maximum spacing of habitat types for individual species.
        iv. Habitat requirement of obligate or frequent users of old growth attributes.
        v. Thresholds for maintaining ecosystem integrity.
    b. Indicators
        i. Developing efficient and effective ecosystem indicators.
        ii. Synthesis of ecosystem indicators by forest ecosystem classification.
        iii. Indicator thresholds for maintaining ecosystem integrity.
3. Ecological Responses to Forest Management
    a. Comparisons of natural and managed ecosystems
        i. Levels of CWD recruitment in natural and managed forests.
        ii. Comparison of MPB harvest pattern and size with natural disturbance.
        iii. Ecosystem processes under different management regimes.

b. Landscape management implications

   i. Integration of MPB ecological impacts into forest land planning.

   ii. Landscape options to reduce continuous extent of mature pine.

   iii. Effects of spatial/temporal landscape management on MPB risk.

5.2 Research Opportunities

Relevance to Forest Management

With forest road building, harvesting and silviculture comprising the dominant human forces changing west-central BC's landscape in the foreseeable future, research linkages with these activities are essential. Research that leads to improved forest management is consistent with landscape ecology's emphasis on integrating research with land use. Coordinated research using an adaptive management approach is particularly valuable in this context. For instance, testing the validity of structure-based indicators as measures of biological diversity is best conducted through adaptive management (Lindenmayer et al. 2000).

Research Information Synthesis and Access

Noon (2003) describes research in conservation biology as an "eclectic collection of individual studies lacking a common theme." This situation is exacerbated in BC by insufficient up-to-date information coordination and synthesis of research results. In interviews conducted during preparation of this framework, many researchers and resource managers expressed concern about the lack of timely information exchange and coordination amongst the various forest research initiatives in this region. This requires support for identifying opportunities for synergistic collaboration and avoiding duplication of efforts amongst the universities, federal and provincial government research groups, the Morice-Lakes IFPA, and the various forest research funding programs.

A priority also ought to be made of making greater use of the research already conducted by synthesizing it, making interdisciplinary connections and enhancing accessibility to the results. For instance, no up-to-date literature review exists for mountain pine beetle research despite the considerable contributions to MPB knowledge that have been made in the last decade. In response, Industrial Forestry Service Ltd. (2002) of Prince George has been contracted by the Ministry of Forests to develop a database of MPB research publications. Provisions are still needed for maintaining the database, facilitating access, and creating meaningful consolidation of the results.

As another example, habitat models have been developed for a variety of species by many BC researchers and others. Although the need for a central database that coordinates modeling information in BC has been recognized, this has not yet been established. Consequently, knowledge dissemination about these models is ad hoc and inefficient. Some topics have received useful synthesis in the context of west-central BC over the last ten years, for instance Keisker (2000) on wildlife use of CWD and wildlife trees and Radcliffe et al. (1994) on biodiversity. Both these works, however, incorporate literature only up to the mid-1990s.

There is much that can be gleaned by reviewing the disparate research already conducted. Topics requiring such treatment for west-central BC include natural disturbance processes and patterns, seral stage structures for various ecosystems, responses of old growth attributes to various management treatments, and wildlife biology and habitat requirements. The Canadian Forest Service's (2003) research topics for MPB also include synthesis needs for:

- Ecosystem indicators by forest ecosystem classification.
- Stand rehabilitation options.
- Ecological characteristics of burned, beetle-attacked and undisturbed stands.

An organizational review of BC forest research (FORUM 2000) also found a lack of research results coordination. They recommend developing a spatial model to inventory scientific knowledge applicable to specific forest areas. Emphasis on regionally-based coordination of BC research information is supported by resource managers and scientists due to the substantial geographical scale and ecological variability of the province. Research synthesis will help focus prioritizing of research needs, support extension activities and provide new insights into landscape ecology.

Interdisciplinary Research Sites

Long-term, interdisciplinary and integrated studies in established research areas have proven to be a particularly effective way of addressing many aspects of landscape ecology (Turner et al. 2003, Hobbie 2003). Complexities of ecosystem functioning and responses to various forest management approaches have been productively investigated through integrated large-scale studies in BC at Date Creek near Hazelton in an ICH (Interior Cedar-Hemlock) forest, and at the Sicamous Creek Silvicultural Systems project in a southern BC ESSFwc2 (Engelmann Spruce-Subalpine Fir wet cold) forest. Carnation Creek on Vancouver Island is the site of long-term, interdisciplinary investigations into the effects of forest harvesting on a coastal watershed's physical and biological processes. Results from these studies have shaped many forest practices regulations and guidelines.

Installations of this magnitude have not been developed for all of BC's major west-central forested ecosystems, including SBS (Subboreal Spruce) and northern ESSF forests. Research sites are best established where they can capture impacts of natural disturbances and a range of forest management activities over scales appropriate for larger vertebrate studies. Due to the opportunity for interdisciplinary integration of management treatments with ecological responses, adaptive management is a well-suited research approach on these settings. To ensure transferability of the results, areas should be chosen that are comparable to significant portions of west-central landscapes. Both applied and scientific research questions involving successional pathways following various disturbance and management influences can be addressed with long-term and multi-scale integrated research sites.

The Canadian Forest Service (2003) has also identified a need of establishing permanent research plots to monitor and research ecosystem responses to MPB and various management approaches. A similar recommendation arose from an expert panel workshop in Burns Lake on MPB implications for landscape unit planning principles (Stadt 2002). The current west-central BC MPB infestation has affected large tracts of both managed and unmanaged forests since 1994 (Garbutt and Vallentgoed 1995), offering a rich opportunity for comparative analyses of ecosystem dynamics over time. An example of a disturbance research matrix for west-central BC is provided in Table 2.

Table 2 Disturbance Research Matrix: An Example for West-Central BC

BEC Subzone	Initial Disturbance	Subsequent disturbance	Disturbance Intensity	Example
SBSdk	Fire	None	Ground fire	
			Crown fire	Swiss fire
			Complete burn	Swiss fire
		Harvesting, tree planting	Clearcut	Swiss fire possibly
		Snag knockdown, tree planting	Complete snag removal	Swiss fire possibly
	MPB	None	High mortality	
		None	Medium mortality	
		None	Low mortality	
		Harvesting	Clearcut	
		Harvesting	Partial cut[1]	
		Fire 1 year after MPB	Crown fire	Blk G Lakes, 2003[2]
			Complete burn	Blk G Lakes, 2003
		Fire 10 years after MPB	Ground fire	Tweedsmuir Park 2003+ possibly
		Fire 20 – 50 yrs after MPB	Complete burn	
	Spruce bark beetle	None	High mortality	
		None	Medium mortality	
		Harvesting	Partial cut	
		Harvesting	Clearcut	
		Fire	Crown fire	
		Fire	Complete burn	
	Harvesting, tree planting	None	Clearcut	
		None	Partial cut	
	Harvesting	Broadcast burn, tree planting	clearcut	
SBSmc	As above	As above	As above	As above[3]
ESSFmc	As above	As above	As above	As above[4]

[1] Partial cutting intensity can be varied by harvesting pattern and proportion of stems taken.

[2] Research and operational trials proposed by Dave Marek.

[3] See Table 3 for examples of existing permanent research plots involving harvesting + broadcast burn.

[4] Swiss fire and Block G are not applicable to ESSF. See Table 3 for examples of existing permanent research plots involving harvesting + broadcast burn.

Modeling

SELES (Spatially Explicit Landscape Event Simulator) enables model building to forecast spatially and temporally the changes in vegetation cover and pattern over an area of any size to a resolution of one hectare. Modeling of MPB spread using SELES has been conducted for MOF Forest Practices Branch to assess various management options for minimizing MPB timber losses for the Lakes TSA (Fall et al 2002) and will be completed March 2003 for the Morice TSA. The MPB/SELES model is considered the best available simulation of MPB spread. Other than Kamloops Forest District, this is the only area where MPB/SELES has been used. Issues concerning MPB and harvesting impacts on wildlife habitat, biodiversity and other ecological values are not being addressed in these model runs except in an unfinished report by Oikos Ecological Services Ltd. investigating landscape-level impacts for the Lakes TSA using SELES results on edges, roads and stream crossings. Further MPB/SELES runs are anticipated for 2003, including addressing Morice LRMP planning questions.

The establishment of a landscape pattern model for west-central BC creates opportunities for further investigating natural disturbance responses. While SELES is mainly employed as a management decision-making tool, it can also function as a research tool. The MPB/SELES model is capable of addressing landscape questions by using data already incorporated for the Morice and Lakes areas. For instance, the model can be used for predicting and spatially identifying forest patches most likely to be skipped or less intensely impacted by future spread of the current MPB infestation. Further analyses can be done on the location and forest characteristics of unsalvageable MPB-killed stands. Forecasts with MPB/SELES can also be used to determine landscape patch distribution implications from the MPB epidemic and various harvesting responses.

SELES is also a tool for building other complex spatial and temporal process models, using only data essential to addressing the question posed. For instance, Steventon (2002) has used SELES to explore the age composition of trees for BEC variants, spatially and temporally, to estimate historic large disturbances in Morice and Lakes TSA forests. The cumulative and synergistic impacts of various types of disturbances can be further addressed using SELES through linking of various types of disturbance models. In another example, models were developed using SELES to conduct a multi-scale assessment of the degree of connectivity of late seral forest patches (Fall 2001). This enabled evaluation of mountain caribou habitat in BC's Columbia Forest District. This model can be further refined and broadened to assess landscape connectivity across a range of scales.

For landscape analysis, SELES offers advantages of being established in west-central BC, being spatially and temporally adaptable, and enabling relatively quick and strategic approaches to modeling. Involving stakeholders in developing hypotheses and reviewing model design and outcomes, through an iterative process, will enhance the management relevance of the research.

Much landscape-level modeling is an amalgamation of stand-level understanding. The MPB component of the MPB/SELES model is a prime example of this, being based on a stand-level MPB model derived from field and laboratory research of MPB biology. SELES enables the MPB stand model to be run at a landscape scale. Until the composition of seral ecosystems and successional dynamics are similarly understood and modeled, SELES cannot be used to track distributions of forest structural components and wildlife habitat across a landscape. With further development, stand models, such as SORTIE (Coates et al. 2002) that forecasts tree population dynamics, can be linked to SELES for landscape-level simulations.

At more detailed levels of modeling, the sparse availability of empirical data is a severe limitation for this part of the province. For instance, data are nonexistent for successional processes and characteristics following various types of disturbances, particularly how these impact various wildlife habitat needs and SFM indicators. These features include shrub and herb layers for forage availability, existence of biological legacies, and the existence of structural attributes critical for wildlife habitat. Parameterization of existing wildlife habitat models and SORTIE is also required in response to the MPB epidemic.

Quick and Efficient Results

Current research funding realities are such that grant competitions favour annual deliverables with some funding opportunities even limited to one year (Forestry Innovation Investment 2003, Canadian Forest Service 2003). Additionally, imperatives for land use planning, forest management and biodiversity conservation require answers sooner rather than later. This creates a difficult climate for investigating long-term ecological responses. Strategies to quickly gain insights on longer-term processes include building on existing research. Approaches involving modeling and research synthesis are relevant in this context and have already been discussed. Opportunities for new field research into long-term phenomena include revisiting field sites subject to studies in the past. Examples of such sites in west-central BC are listed in Table 3. Retrospective studies to gain insights over longer temporal scales, where the history of a site can be deduced is another approach. The level of precision required for studies needs to be assessed on a case-by-case basis to determine the best approach for meeting requirements for scientific rigour.

Table 3 Examples of Permanent Research Plots Established in West-Central BC

Site	BEC Sub-zone	Site Description	Site History	# Plots	Plot Size	Years Data Collected	Type of Data Collected[5]
Swiss Fire Ecological Reserve 81	SBSdk	70 – 80 yr pine on flat, gently rolling till; Aspen, spruce on slopes to river; Mature spruce, cottonwood on river terrace.	Wildfire May 1983, 8 plots complete burn, 1 canopy, 1 skipped. unlogged	10; 7 still located	Trees, tall shrubs 25 m x 5 m; low shrubs 3 m x 3 m; herbs lichen 1 m x 1 m.	1983 (post fire) 1984 1985 1986 1987 1989 1992 2001	Trees, tall shrubs: species, canopy cover, average ht.; Low shrubs; Herbs, bryophytes, lichens; Photos. No mensuration, no CWD
Walcott Exp Project 953	SBSmc2	830 m	Clearcut, broadcast burned 1982, planted pine 1983	3	Soils 30 m x 30 m	1982 1987 1992 others	Slash & soils pre and post burn Tree foliar nutrients, growth Vegetation succession
Helene Lk, NE Burns Lake	SBSmc2	1050 m	Clearcut, broadcast burned 1982, planted pine 1983	3	Soils 30 m x 30 m	1982 1987 1992 others	Slash & Soils pre and post burn Tree foliar nutrients, growth Vegetation succession
Herron	ESSF	1335 m	Clearcut, broadcast burned 1983, planted pine 1985	3; 2 still located	Soils 30 m x 30 m	1983 1988 1993	Slash & Soils pre and post burn Tree foliar nutrients, growth Vegetation succession
Echo	ESSF	1250 m	Clearcut, broadcast burned 1984, planted pine 1987	3	Soils 30 m x 30 m	1984 1989 1994	Slash & Soils pre and post burn Tree foliar nutrients, growth
McKen-drick	ESSF	1150 m	Clearcut, broadcast burned 1985, planted pine 1986	3; none located now	Soils 30 m x 30 m	1985 1990 1995 others	Slash & Soils pre and post burn; Tree foliar nutrients, growth; Vegetation succession

[5] Results of first 10 years of data collection for soils, tree growth and foliar analyses are presented for all sites except Swiss Fire in Kranabetter and Macadam (1998).

6.0 Research Framework for Landscape Ecology in West-Central BC

The research framework presented below summarizes how research opportunities can be optimally applied to build the scientific understanding most critically required for enhancing landscape management in west-central BC forests.

6.1 Research Context

- Coordination of research priorities and activities.
- Integrating ecological understanding with human land use.
- Long-term vision with short-term results.

6.2 Research Tools and Approaches

- Interdisciplinary synthesis of research results.
- Network of field monitoring sites.
  - ➢ Located to capture a range of ecological conditions, disturbance history, and seral stages.
  - ➢ Established to provide long-term results.
  - ➢ Provide data on ecosystem functioning, for indicator calibration, and for developing stand-level and landscape-level models.
  - ➢ Where possible make use of existing sites and retrospective opportunities.
- Interdisciplinary field research installations.
  - ➢ Located in representative sites of major forest ecosystems.
  - ➢ Opportunities for interdisciplinary and long-term research.
  - ➢ Emphasis on forest harvesting alternatives.
  - ➢ Adaptive management research involving a range of harvesting and silviculture techniques.
- Modelling.
  - ➢ Further develop and use existing models such as MPB/SELES.
  - ➢ Build other landscape models using SELES.
  - ➢ Further parameterize and improve on existing models (e.g. SORTIE, wildlife habitat models) with field study data.

6.3 Functioning of Natural Systems

- Long-term field monitoring of key ecosystem attributes and functioning including structural components, vegetation layer composition and succession.
- Hypothesis testing through field studies.
- Model development, parameterization and verification.
- Research synthesis.

6.4 Limits to Ecological Functioning

- Indicator calibration and monitoring using network of field monitoring sites.
- Testing of ecosystem thresholds and indicator responses to forestry activities through adaptive management and field studies.
- Iterative model development.
- Research synthesis.

6.5 Ecological Responses to Forest Management

- Adaptive management research at interdisciplinary field research installations.
- Long-term field monitoring and retrospective studies following various management activities under the range of ecological conditions.
- Model development, parameterization and verification.
- Research synthesis.

References

British Columbia Ministry of Forests. 2000. Lakes District Land and Resource Management Plan. Province of BC. Victoria, BC.

Brown, K.J. and R.J. Hebda. 2002. Origin, development, and dynamics of coastal temperate conifer rainforests of southern Vancouver Island, Canada. Canadian Journal of Forest Research 32: 353-372.

Bunnell, F.L. 1998. Setting Goals for Biodiversity in Managed Forests. *In* F.L. Bunnell, and J.F. Johnson eds. The Living Dance: Policy and Practices for Biodiversity in Managed Forests. UBC Press. Vancouver, BC.

Canadian Forest Service. 2003. Mountain Pine Beetle Initiative Inventory of Topics Identified in Scoping Sessions. Pacific Forestry Centre. Victoria, BC.

Carroll, A. and D. Linton. 2002. Managing Mountain Pine Beetle Populations in British Columbia. Forest Health and Biodiversity News 6 (1). Canadian Forest Service, Atlantic Forestry Centre.

Coates, K.D., C. Messier, B.E. Grover, D. Kneeshaw, D. Greene, J. Poulin, B. Harvey and C.D. Canham. 2002. Development, Parameterization and Use of a Spatially Explicit Individual-Tree Model (SORTIE) to Explore the Implications of Patchness in Managed Ecosystems of Canada. Proceedings of the 2002 Sustainable Forest Management Network Conference. Sustainable Forest Management Network. Edmonton, AB.

D'Eon, R.G. 2002. Forest Fragmentation and Forest Management: A Plea for Empirical Data. The Forestry Chronicle 78 (5): 686-689.

Debinski, D.M. and R.D. Holt. 2000. A Survey and Overview of Habitat Fragmentation Experiments. Conservation Biology 14(2): 342-355.
Eng, M. 1998. Spatial Patterns in Forested Landscapes: Implications for Biology and Forestry. Pp. 42 <ETH> 75 *In* J. Voller and S. Harrison (eds). Conservation Biology Principles for Forested Landscapes. BC Ministry of Forests and UBC Press. Vancouver, BC.

Fall, A. 2001. Assessing Critical Scales of Late Seral Forest Connectivity in the Northern Columbia Mountains. Unpublished report.

Fall, A., D. Daust, and D.G. Morgan. 2001. A Framework and Software Tool to Support Collaborative Landscape Analysis: Fitting Square Pegs into Square Holes. Transactions in GIS 5(1): 67-86.

Fall, A., D. Sachs, T. Short, L. Safranyik and Bill Riel. 2002. Application of the MPB/SELES Landscape Scale Mountain Pine Beetle Model in the Lakes Timber Supply Area. Final Report. Forest Practices Branch. Victoria, BC.

Forestry Innovation Investment. 2003. Forest Research Program Guide. Forintek Canada Corporation. Vancouver, BC.

Forman, R.T.T. and M. Godron. 1986. Landscape Ecology. John Wiley and Sons. New York.

FORUM Consulting Group Ltd. 2000. Moving Ahead: Science and Technology in BC Forest Resource Management. Prepared for the Committee of Forest Research Agencies (COFRA). Victoria, BC.

Garbutt, R. and J. Vallentgoed. 1995. Forest Insect and Disease Conditions Prince Rupert Forest Region 1994. Canadian Forest Service. Pacific and Yukon Region. Victoria, BC.

Goodwin, B.J. and L. Fahrig. 2002. How Does Landscape Structure Influence Landscape Connectivity? Oikos 99(3): 552-570.

Harrison, S. and J. Voller. 1998. Connectivity. Pp. 75-97 *In* J. Voller and S. Harrison (eds). Conservation Biology Principles for Forested Landscapes. BC Ministry of Forests and UBC Press. Vancouver, BC.

Hebda, R. and I. Walker. 1999. Longterm Natural Disturbance Regimes of the ESSF. Forest Renewal BC Research Program Final Report. Victoria, BC.

Hobbie, J.E. 2003. Scientific Accomplishments of the Long Term Ecological Research Program: An Introduction. BioScience 53(1): 17-20.

Holling, C.S. 1998. Two Cultures of Ecology. Conservation Ecology 2(2): 4. URL: http://www.consecol.org/vol2/iss2/art4

Holt, R. 2000. Inventory and Tracking of Old Growth Conservation Values for Landscape Unit Planning. Habitat Program, BC Ministry of Environment, Lands and Parks. Victoria, BC.

Industrial Forestry Service Ltd. 2002. Proposal to Identify Operational Research Opportunities in the Lakes Forest District. Industrial Forestry Service Ltd. Prince George, BC.

Keisker, D.G. 2000. Types of Wildlife Trees and Coarse Woody Debris Required by Wildlife of North-Central British Columbia. Working Paper 50. Research Branch, BC Ministry of Forests. Victoria, BC.

Kranabetter, J.M. and A.M. Macadam. 1998. Ten-year Results From Operational Broadcast Burning Trials in Northwestern British Columbia. Research Branch, BC Ministry of Forests. Victoria, BC.

Landsberg, J. 2003. Modeling Forest Ecosystems: State of the Art Challenges, and Future Directions. Canadian Journal of Forest Research 33: 385-397.

Lindenmayer, D.B., C.R. Margules and D.B. Botkin. 2000. Indicators of Biodiversity for Ecologically Sustainable Forest Management. Conservation Biology 14(4): 941-950.

Lofroth, E. 1998. The Dead Wood Cycle. Pp. 185-214 *In* J. Voller and S. Harrison (eds). Conservation Biology Principles for Forested Landscapes. BC Ministry of Forests and UBC Press. Vancouver, BC.

MacKinnon, A. 1998. Biodiversity and Old Growth Forests. Pp. 146-184 *In* J. Voller and S. Harrison (eds). Conservation Biology Principles for Forested Landscapes. BC Ministry of Forests and UBC Press. Vancouver, BC.

Morice & Lakes IFPA. 2002 Project Summary. The Sustainable Forest Management Plan: Public Involvement and Adaptive Management. Summary No. 5. March 2002. Morice & Lakes IFPA. Prince George, BC.

National Science Foundation. 2002. A 10-Year Agenda for Environmental Research and Education at NSF: Draft for Community Comments. Arlington, VA.

Nelson, J. 2003. Forest-level Models and Challenges for Their Successful Application. Canadian Journal Forest Research 33: 422-429.

Noon, B.R. 2003. New Pathways for Conservation Science. The 2003 Leslie L. Schaffer Lectureship and Jubilee Lecture Series. Faculty of Forestry, University of British Columbia. Vancouver, BC.

Nyberg, J.B. 1999. An Introductory Guide to Adaptive Management for Project Leaders and Participants. Forest Practices Branch, BC Ministry of Forests. Victoria, BC.

Nyberg, J.B. and B.S. Taylor. 1995. Applying Adaptive Management in British Columbia's Forests. Pp. 239-245 *In* Proceedings of the FAO/ECE/ILO International Forestry Seminar, Prince George BC, September 9-15, 1995. Canadian Forest Service.

Oliver, C.D. and B.C. Larson. 1996. Forest Stand Dynamics. Update edition. John Wiley & Sons. New York, NY.

Osborn, L. 2002. Forest Ecosystem-Based Management in Northwestern BC: A Status Report. Forest Ecosystem Management Conference Oct 2-4, 2002. Smithers, BC.

Parminter, J. 1998. Natural Disturbance Ecology. Pp. 3-41 I*n* J. Voller and S. Harrison (eds). 1998. Conservation Biology Principles for Forested Landscapes. BC Ministry of Forests and UBC Press. Vancouver, BC.

Perry, D.A. 1988. Landscape Pattern and Forest Pests. The Northwest Environmental Journal 4(2): 213-228.

Petterson, K. 2002. Morice Timber Supply Area Sustainable Forest Management Plan. Morice and Lakes Innovative Forest Practices Agreement. Prince George, BC.

Petterson, K. 2002. Lakes Timber Supply Area Sustainable Forest Management Plan. Morice and Lakes Innovative Forest Practices Agreement. Prince George, BC.

Radcliffe, G., B. Bancroft, G. Porter and C. Cadrin. 1994. Biodiversity of the Prince Rupert Forest Region. Land Management Report No. 82. Research Branch, BC Ministry of Forests. Victoria, BC.

Rogers, P. 1996. Disturbance Ecology and Forest Management: A Review of the Literature. General Technical Report INT-GTR-336. USDA Forest Service, Intermountain Research Station. Ogden, UT.

Ruggiero, L.F., K.B. Aubry, S.W. Buskirk, L.J. Lyon, W.J. Zielinski. Technical editors. 1994. The Scientific Basis for Conserving Forest Carnivores American Marten, Fisher, Lynx and Wolverine in the Western United States. General Technical Report RM-254. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO.

Schmoldt, D.L., D.L. Peterson, R.E. Keane, J.M. Lenihan, D. McKenzie, D.R. Weise, and D.V. Sandberg. 1999. Assessing the Effects of Fire Disturbance on Ecosystems: A Scientific Agenda for Research and Management. General Technical Report PNW-GTR-455. USDA Forest Service, Pacific Northwest Research Station. Portland, OR.

Stadt, J.J. (ed). 2002. Landscape Unit Planning Principles in the Lakes Forest District: Does the Mountain Pine Beetle Change Things? Ministry of Sustainable Resource Management, Skeena Region. Burns Lake, BC.

Steventon, J.D. 1994. Biodiversity and Forest Management in the Prince Rupert Forest Region: A Discussion Paper. Land Management Report No. 82. Research Branch, BC Ministry of Forests. Victoria, BC.

Steventon, J.D. 2002. Historic Disturbance Regimes of the Morice and Lakes Timber Supply Areas. Draft Discussion Paper. Prince Rupert Forest Region, Smithers, BC.

Sullivan, T.P., D.S. Sullivan, P.M.F. Lindgren and D.B. Ransome. 2002. Old-Growth Attributes in Intensively Managed Forests: Integration of Stand Productivity with Mammal Diversity. Sustainable Forest Management Network Conference Proceedings. Nov 13-15, 2002. Edmonton, Alberta.

Turner, M.G., S.L. Collins, A.L. Lugo, J.J. Magnuson, T.S. Rupp and F.J. Swanson. 2003. Disturbance Dynamics and Ecological Response: The Contribution of Long-Term Ecological Research. BioScience 53(1): 46-56.

Voller, J. 1998. Managing for Edge Effects. Pp. 215-233 *In* J. Voller and S. Harrison (eds). Conservation Biology Principles for Forested Landscapes. BC Ministry of Forests and UBC Press. Vancouver, BC.

Whitehead, R., P. Martin and A. Powelson. 2001. Reducing Stand and Landscape Susceptibility to Mountain Pine Beetle. BC Ministry of Forests. Victoria, BC.

Wu, J. and R. Hobbs. 2002. Key Issues and Research Priorities in Landscape Ecology: An Idiosyncratic Synthesis. Landscape Ecology 17: 355-365.