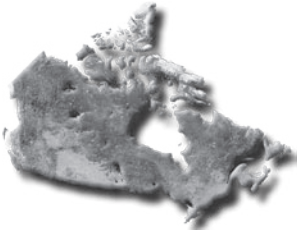

Possible Forest Futures: Balancing Biological and Social Risks in Mountain Pine Beetle Epidemics

J.P. (Hamish) Kimmins, Brad Seely, Clive Welham and Anliang Zhong

Mountain Pine Beetle Initiative
Working Paper 2005–11

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Abstract

Despite the fact that its severity and extent may reflect past fire control and contemporary human-enhanced climate change, the current mountain pine beetle (MPB) epidemic in British Columbia is part of the natural disturbance ecology of B.C.'s interior forests. The epidemic is more of a social issue than an environmental issue, although widespread salvaging of beetle-killed timber would raise the environmental profile of the epidemic. The complexity of questions involved in MPB policy development renders this issue a classical "wicked" problem, with all that this entails. Unless the complexity is explicitly addressed, policy with respect to the epidemic may raise as many problems as it solves. Policy should be developed in the context of a comprehensive conceptual model of the many facets of the issue and their inter-relationships. It should also reflect an understanding of the uncertainties concerning the future development of beetle-killed forest stands, because patterns of stand development will influence the temporal flow of values and environmental services from these stands.

Comprehensive decision-support systems that explicitly address both social and environmental dimensions of the MPB issue are essential for coping with the complexity and uncertainty associated with policy development. Many of the components of such systems are available, but MPB policy-related research should be targeted to fill critical information gaps and support the development, validation and application of these decision-support systems for scenario and value tradeoff analyses. Successful application and use of these tools will require their linkage to user-friendly interfaces, output visualization systems, and data management systems to handle the diversity of predictions. Research should be targeted at their development.

These MPB decision-support systems should be applied in a comparison of three possible policy paradigms: 1) a minimizing biological risk paradigm; 2) a minimizing social risk paradigm; and 3) a balanced risk approach involving zonation of forest lands into areas where biological risk would be minimized through management intervention, and areas where nature's natural cycles of disturbance would be permitted to operate largely unmanaged, and the associated social risks addressed through institutional arrangements and reforms. The first of these paradigms suggests "ecological engineering" through silviculture and management to "beetle proof" the affected forests and minimize the risks of other natural disturbances. This is very unlikely to be successful and would be very demanding on human and financial resources. It would threaten a variety of other forest values. The second paradigm accepts natural disturbance and modifies community economies and institutional arrangements to facilitate community and provincial response to the consequences of the disturbances in a way that minimizes negative social impacts. It is unlikely that a "social license" (public acceptance) could be obtained for this paradigm. The third paradigm combines the first two paradigms based upon a zonation of lands best suited to each of them. It balances biological risk and social risk. Evaluation of the optimum and socially acceptable balance would require scenario and value tradeoff analyses, which in turn would require the type of decision-support tools mentioned above.

Résumé

Bien que sa sévérité et son étendue puisse découler des pratiques passées de contrôle des incendies et des changements climatiques actuellement intensifiés par les activités humaines, la présente épizootie de dendroctones du pin ponderosa (DPP) en Colombie-Britannique fait partie des perturbations naturelles qui affectent régulièrement les forêts de l'intérieur de la province. L'épizootie est plus un problème social qu'un problème environnemental, bien que la récupération à grande échelle du bois provenant des arbres tués par le scolyte puisse éventuellement accentuer son profil environnemental. La complexité des questions posées lors de l'élaboration des stratégies liées au DPP fait que le problème est loin d'être simple à résoudre. Si cette complexité n'est pas abordée de front, les stratégies mises en place pour lutter contre l'épizootie pourraient bien faire jaillir autant de problèmes que de solutions. Les stratégies doivent être élaborées dans le contexte d'un modèle conceptuel détaillé tenant compte des multiples facettes du problème et des liens qui les relient. Elles doivent également refléter la prise de conscience des incertitudes concernant le développement futur des boisés ravagés par les scolytes car le mode de développement de ces boisés influencera le flux des valeurs et des services environnementaux qui leur seront associés.

Il est essentiel de mettre sur pied des systèmes décisionnels détaillés permettant de traiter explicitement les dimensions sociales et environnementales du problème des DPP si l'on veut surmonter la complexité et les incertitudes associées à l'élaboration des stratégies. De nombreuses composantes sont déjà disponibles pour de tels systèmes mais la recherche axée sur les stratégies associées au DPP doit être axée sur les lacunes critiques en matière d'information et soutenir l'élaboration, la validation et l'application de ces systèmes décisionnels pour les analyses de scénarios et des compromis en matière de valeurs. L'application et l'utilisation efficaces de ces outils nécessiteront leur intégration à des interfaces conviviales ainsi qu'à des systèmes d'affichage des résultats et de gestion des données de manière à pouvoir traiter toute une gamme de scénarios. Les travaux de recherche devraient être axés sur leur développement.

Ces systèmes décisionnels pour le DPP devraient être appliqués pour la comparaison de trois paradigmes stratégiques : 1) la minimisation des risques biologiques; 2) la minimisation des risques sociaux; 3) l'équilibrage des risques consistant à zoner les terres boisées en secteurs où le risque biologique pourrait être minimisé par des mesures de gestion et en secteurs où on laisserait s'opérer les cycles naturels de perturbation sans interventions de gestion, les risques sociaux étant gérés par des réformes et des arrangements institutionnels. Le premier de ces paradigmes suggère d'utiliser le « génie écologique » par l'intermédiaire de la sylviculture et de la gestion pour débarrasser les forêts touchées des ravageurs et minimiser les risques d'autres perturbations naturelles. Il est peu probable qu'une telle approche aboutisse et les ressources humaines et financières nécessaires seraient astronomiques. Elle menacerait par ailleurs toute une gamme d'autres valeurs forestières. Le second paradigme consiste à accepter les perturbations naturelles et à modifier les économies communautaires et les structures institutionnelles pour aider les communautés et les gouvernements à s'adapter aux conséquences des perturbations d'une façon qui minimise les impacts sociaux négatifs. Il est peu probable que l'on puisse obtenir du public qu'il accepte une telle voie. Le troisième paradigme est une combinaison des deux premiers et met en jeu un zonage des terres équilibré. Il

cherche à équilibrer les risques biologiques et les risques sociaux. L’évaluation de l’équilibre optimum et acceptable sur le plan social nécessite d’effectuer des analyses de scénarios et de compromis en matière de valeurs, ce qui ne peut se faire qu’à l’aide des outils décisionnels mentionnés précédemment.

Executive Summary

1) Forestry, one of the most interdisciplinary of human endeavors, is characterized by complexity. As a consequence, issues in forestry tend to belong to the category known as “wicked problems”. Amongst other things, these have no single correct “answer” or solution; have no “stopping rule” (it is often difficult to tell when the issue has been resolved); and they tend to be unique, so that experience is an incomplete basis for the design of acceptable solutions.

2) Problem issues typically exist as part of a system of linked issues. The Club of Rome *Limits to Growth* study concluded 33 years ago that the failure to address complexity and account for such linkages were two major impediments to solving problem issues. The current mountain pine beetle epidemic in British Columbia constitutes a “wicked” problem and is intimately linked to a variety of other issues, which makes it difficult to identify a single best policy option. There are only several policy alternatives, each lacking empirical experience of their possible outcomes, and each involving a different balance of value outcomes and tradeoffs.

3) The mountain pine beetle (MPB) is a component of the native fauna of B.C., and periodic population irruptions of this species are part of the disturbance ecology that has been responsible for the natural range of variation and the biological diversity of the interior forests of the province. However, the combination of a series of warm winters and large areas of mature lodgepole pine due in part to the history of fire control have combined to create a “perfect entomological storm” – an epidemic that is of unprecedented proportions within the recorded history of the province. The scale of the outbreak threatens a variety of social values and will cause a degree of change in the affected forests that is unacceptable to many people.

4) Selection from amongst a range of policy options to deal with a complex issue requires a foundation in both social and biophysical sciences and experience. However, science has frequently failed to satisfy society’s expectations concerning its ability to help solve complex problems. Much of contemporary science is disciplinary in nature and is limited to the first two of the three main components of science – knowing and understanding. The third component, prediction (which is indispensable for the development of decision-support systems that are essential for the design of effective policy and practice in resource management) has received much less attention. While decision-support systems and their underlying modeling frameworks cannot be developed in the absence of knowing and understanding, these first two components of science generally do not provide an adequate basis for selecting effective policy solutions and management strategies for problem issues. They are necessary but not sufficient. There must be synthesis at the level complexity and the temporal and spatial scales of the issue in question if policy is to serve the multiple interests and values involved.

5) Development of alternative policy solutions to complex forestry issues such as the MPB epidemic should commence with a conceptual model of the complexity of the

problem. The MPB epidemic is an ecosystem disturbance phenomenon, the comprehension of which requires an understanding of the ecology of ecosystem disturbance; the role of climate and climate change; the impacts of forest harvesting; the values and environmental services that forest ecosystems provide to human society; and the relationships between human communities and forests.

6) The direct impact of MPB and the subsequent impact of salvage logging in MPB-killed stands depend on many factors. There are few useful generalizations. Unless the type of ecosystem and the seral stage, age, disturbance history and current condition of the affected stands and surrounding landscape are accounted for, predictions about the outcome of the MPB epidemic and of various strategies to manage affected stands are likely to have limited utility for effective policy development.

7) Policy response to the MPB epidemic can be classified into three major paradigms. 1) a low biological risk paradigm; 2) a low social and community risk paradigm; and 3) a balanced paradigm based on a zonation approach in which a low biological risk strategy is developed for some areas, and a low social risk approach used for the remaining area.

8) The low biological risk paradigm involves minimizing the risk of future MPB epidemics, while at the same time minimizing all other significant biological and physical disturbance risks. This is somewhat akin to other natural risks over which humans have relatively little or no control, the ultimate example of which would be the risk of an earthquake or tsunami; it is likely to be very expensive at best and impossible at worst, and to have a low probability of success.

9) The low social and community risk paradigm involves minimizing the risks to community organization and social values caused by inevitable biological and physical forest disturbance events. This is achieved by diversifying the economies of forest-dependent communities, and modifying resource policy tools and institutional arrangements to make them more flexible in the face of natural disturbances and ecosystem change. It is based on recognition that the forces of “nature” frequently exceed human ability to produce a stable environment that serves the human goal of constancy of values and environmental services. The difficulty with this paradigm is the rigidity of human institutional structures and the difficulty in gaining a social license for the flexibility in response that is required. Constraints would be required on the flexibility allowed to sustain other values. A major feature of this paradigm would be a focus on prediction of risks and early detection of conditions favoring the initiation of biotic epidemics, their spread and potential spatial extent. Such an early warning system would be linked to policy and community responses.

10) The hybrid or balance of risks paradigm involves a zonation approach in which productive and resilient ecosystems close to communities and timber processing facilities are intensively managed in a manner that minimizes biological risk (paradigm 1). These areas would provide a relatively stable supply of resources and

social values to the local community and the province. Management for this biological stability must protect soils and watershed values, but would not be constrained to sustain all the values offered by an extensively-managed and naturally-disturbed forest. The remaining areas would be managed under paradigm 2, responding to natural disturbance cycles as much by salvaging values after disturbance as by managing to prevent disturbance. This hybrid paradigm would have all the requirements noted under paradigm 2 above, but would only apply to a subset of the landscape.

11) There are many ethical issues involved in development of policy with respect to MPB epidemics. These issues range from aspects of human ethics to the complex field of environmental ethics, and policy must seek a balance between often contradictory ethical imperatives. Employment, government revenues, community stability and a variety of environmental issues all require attention. Development of policy in the face of conflicting demands requires scenario and value tradeoff analyses. To conduct these in a comprehensive manner requires the use of multi-value decision-support systems and their underlying frameworks that are able to project possible forest and social futures for a variety of forest policy and management responses. Because the MPB affects ecosystems, and because the multiple social and environmental values of concern are ultimately dependent on the forest ecosystem, these decision-support systems should include stand level, ecosystem management simulation models. Because many aspects of the MPB epidemic are landscape and large spatial scale issues, these stand level models should be linked to large landscape, regional and provincial-scale models. The "bottom-up" ecosystem management models should be linked to "top-down" economic and social models if the policy responses to the epidemic are to be ethical and balance the needs of all sectors of society.

12) To communicate to the variety of technical and non-technical forest "stakeholders" the possible implications of different policy responses to the MPB epidemic, the decision-support systems noted above should include a variety of visualization and other presentation formats. These should render the questions, the policy alternatives and the possible outcomes understandable to this diverse "public" so that they can participate in a meaningful and informed manner to the challenge of addressing this "wicked" problem.

1. Introduction

The current mountain pine beetle (*Dendroctonus ponderosae* Hopkins; MPB) epidemic in the lodgepole pine (*Pinus contorta* var. *latifolia.* Dougl.) forests of the interior of British Columbia (Shore et al. 2004; Wilson 2004) is without precedent in the recorded history of forest management in the province. Epidemics on this scale may well have occurred before when the climate was changing from a colder to a warmer period, but we have no written record of such events. The present epidemic is not a problem for "nature". Large scale disturbances are a feature of Canadian forests, and insects have periodically "re-cycled" large areas of Canada's forests, from spruce budworm epidemics in the east, to hemlock looper, spruce beetle and other insect outbreaks in the west. These have altered forest composition, seral stage, susceptibility to fire and fire severity, wildlife habitat, hydrology, and the availability of forest values to human communities. The biological diversity of our forests and the widespread existence of continuous forest cover are a function of the disturbance history in many cool and humid northern forest ecosystems. The major issue raised by such outbreaks of insect "pests" is not whether they are natural but whether or not humans accept them. A second issue is whether or not we can do anything to stop them or mitigate their impacts if we do not accept their consequences.

In thinking about possible forest futures in the area of the present outbreak, there is a dichotomy: should foresters attempt to "beetle-proof" the forest through silvicultural treatments and harvesting methods; should we invest our limited resources in modifying the forest to render it inhospitable to the mountain pine beetle and thereby avoid the social risks that such an outbreak poses? Or should the inevitability of biotic and other disturbance events be accepted as a part of the ecological character of our forests, and human resources invested in developing institutional mechanisms that permit human communities to adapt to and adsorb the economic and social consequences of such events? Alternatively, one could pursue an intermediate strategy, in which some portion of the forest landscape is put into as "beetle-proof" and other "biological risk-proof" a condition as possible, while biotic (and possibly other) disturbances are accepted in the remainder of the landscape such that forestry and other human activities would be organized to function around them.

The review will start with a consideration of the nature of complex problems such as the current MPB epidemic. A conceptual model of the elements of the complexity will then be presented to illustrate the need to consider this complexity in the context of policy development. The complexity is further illustrated by presenting some possible responses of stand-level tree species composition to MPB-induced pine mortality. Some aspects of the three alternative approaches outlined above are then discussed, and the report closes with some thoughts on limitations on policy development, the response of the research community, and a series of recommendations.

This report deals with risk, of which two main types are germane in this discussion: 1) the risk of physical and biotic disturbance events that are part of the ecological character of Canadian forests (e.g., fire, wind, insects, diseases) but which disturb our social order and human economies and prevent us from achieving management, social and political objectives; and 2) risks posed by the political and social demands and aspirations of society and the institutions that have been put in place to provide for such needs and desires, but which prevent human adaptation to the consequences of "natural" or human-exacerbated ecosystem disturbance. The key question with respect to policy responses to the MPB epidemic is which type of risk should be the main focus of attention, or should there be a balance between the management of these two major risk categories?

2. The Nature of Complex Problems: Ghosts of the Club of Rome, Occam and Einstein

> *A problem is an issue that does not get solved. An issue that gets solved is no longer a problem. Problem issues often persist because they are part of a complex, interacting system of issues, and only simple solutions are offered: solutions that ignore the context of the problem in question and its interaction with other issues, many of which are also problems.*

The Club of Rome Study, presented in *Limits to Growth* (Meadows et al. 1972), concluded that there are probably no individual problems for which the solutions are beyond the technical ability of humans. However, the authors of the study also concluded that because most problems are linked to other problems, and because the solution of one problem may 1) exacerbate other problems, 2) expropriate the human, economic and material resources required to solve these other problems, or 3) create new problems, there are limits to the growth of the human population and to human activity. Finally, solutions to individual issues are frustrated by their existence in an interlinked and interacting system of issues. Unless individual problem issues are considered in the context of the overall system of issues within which they occur, solutions to individual problem issues typically remains elusive.

Society is organized along disciplinary lines. Education divides knowledge into individual subjects to facilitate learning, and this is a very successful strategy for imparting to students disciplinary packages of knowledge and understanding. Governments are organized into Ministries and Departments or Branches to facilitate policy, regulation and the administration of society. This disciplinary structure is frequently successful at focusing on individual issues or groups of similar issues, but is frequently inefficient at solving complex problems; it may result in the exacerbation of other problems or may create new problems, often unexpectedly.

The complexity of the systems associated with problem issues led to the concept of *wicked problems* (Rittel and Webber 1973, 1984; Allen and Gould 1986; Rauscher 1999; Wang 2002; Salwasswe, H. 2002). These are characterized by several features, including the following:

1) they are complex and not easily defined. Lacking a clear description of what the problem is, finding a solution is difficult;
2) they have no clear stopping rules – it is often difficult to tell when the problem has been solved;

3) solutions are not right or wrong; they are only better or worse. They are generally more dependent on value systems than on science, especially biophysical science;
4) there is no immediate and objective test of a solution to a wicked problem. The solution simply has to be tried, and its success or failure monitored over a considerable period of time (but see discussion of forecasting and decision-support systems below);
5) every wicked problem is more or less unique, limiting the possibility of learning from experience and applying general rules and guidelines;
6) there is an almost unlimited number of potential solutions, making it difficult to evaluate and chose between alternatives. Such choices inevitably involve scenario and value tradeoff analyses. Unless one can forecast possible outcomes of alternative choices, there is little logical basis for making any particular choice;
7) every wicked problem can be considered a symptom of at least one other problem. Linkages between problems increase the complexity of finding a workable solution.

The issue of complexity bedevils science as well as politics and the organization of society in general. Science has three major components: *knowledge* (which over time becomes experience), *understanding*, and *prediction* (Kimmins et al. 2005). Inductively-derived knowledge is descriptive. It leads to postulates, explanations, theories and/or conceptual models about the object or system of interest that are untested (and frequently un-testable by "conventional" scientific methodology). It is, however, the foundation on which the second component of science – understanding – is based. In order to assess the veracity of conclusions based on inductively-derived knowledge and experience, the complex explanations, theories and conceptual models that have been produced by the first stage of science are broken down into their component parts. These are then evaluated in rigorous experiments using the hypothetico-deductive scientific method and statistical tests. This "jigsaw puzzle" science is the *sine qua non* of science, and it engages, and should engage, the majority of scientists and scientific endeavor.

For most people, this second component is what science is all about: it is "hard science", inductive science generally being considered "soft science" or, by some, as non-science. However, reductionist ("jigsaw puzzle") science generally fails to address the complexity of the multi-dimensional problems, issues or phenomena that are the ultimate progenitor of scientific activity. Only when knowledge, experience and understanding are combined in a synthesis at the level of complexity and inter-disciplinarity, and at the temporal and spatial scales of the problem issue being addressed, does science fully serve society and provide a reliable basis for policy and regulation (Kimmins et al. 2005).

When science is incorporated as a component of policy development, it is generally the "hard" (understanding) component of disciplinary science that is used. When this occurs, it contributes to the development of "jigsaw puzzle" policy, which is frequently ineffective in solving problems which, by definition, are complex (Figure 1). This is particularly true in resource policy and management which deals with complex human-biophysical systems that are characterized by "wicked" problems, of which the current MPB epidemic is an example.

Recognition of the problems of unaddressed complexity in science and in the conduct of society in general occurred long ago. The writings about knowledge, logic and scientific inquiry by William of Occam (1284-1347; an English philosopher and theologian from the village of Ockham) played a major role in the transition from medieval to modern thought. Occam stressed the Aristotelian principle that *entities should not be multiplied beyond what is necessary*. This principle, known as Occam's razor or the Law of Parsimony, asserts that problems should be stated in their most basic and simplest terms. In science, Occam's razor states that the simplest theory that fits the facts of a problem is the one that should be selected; the simplest of two or more competing theories or hypotheses is preferable. Unfortunately, Occam's Razor has often been used as the basis for rejecting complexity in science: for many scientists, *as simple as possible* has become the guiding rule. However, Occam's Razor has two "edges"; *as simple as possible, but as complex as necessary.* This conclusion was echoed by Albert Einstein in his admonition to keep explanations and theories *as simple as possible, but no simpler.*

Point #4 in the discussion above of "wicked" problems – that there is no immediate and objective test of a solution to a wicked problem; the solution simply has to be tried, and its success or failure monitored over a considerable period of time – reflects the fragmented way in which science has approached complex problems. However, as noted in Figure 1, *if* the diverse products of disciplinary science can be synthesized with inductively-derived knowledge to appropriate levels of complexity, space and time, forecasts can be made (scenario analysis) about the possible range of outcomes of alternative potential solutions. Evaluation of these alternative outcomes can be a valuable guide to policy decisions with respect to "wicked" problems until sufficient experience has been gained to base policy on a more empirical foundation. In most cases we cannot wait for the significant period of monitoring of the outcomes of alternative choices to provide this empirical foundation: policy has to be made and acted on over much shorter time periods. In many cases, by the time the empirical evidence of consequences has been gathered, the problem has gone away.

The conclusion drawn from this discussion is that policy with respect to the current MPB epidemic should be as simple as possible but as complex as necessary to deal with the multiple dimensions of this "wicked" problem. Scientific support for policy development should involve: 1) knowledge and experience (inductive, descriptive) and 2) understanding (deductive, analytical) of the key social and biophysical aspects of the MPB epidemic, and 3) the synthesis of this knowledge and understanding into predictive decision-support tools of appropriate complexity and temporal and spatial scales that can facilitate scenario and value tradeoff analyses. Policy development should be supported by such analyses until appropriate long-term experience is available (recognizing, however, that by that time the problem may have resolved itself), and science in support of policy development should be focused on the development of such tools. These should be ecosystem-level because although tools based on studies of the individuals, populations and biotic communities of forest ecosystems can provide knowledge and understanding, they are generally poor predictors for futures about which we lack experience (Figure 2). It has been the frequent stalling of science at the understanding, "hard science" stage, rather than proceeding to the synthesis stage required for reliable prediction that has led to point #4 of the characteristics of "wicked" problems listed above.

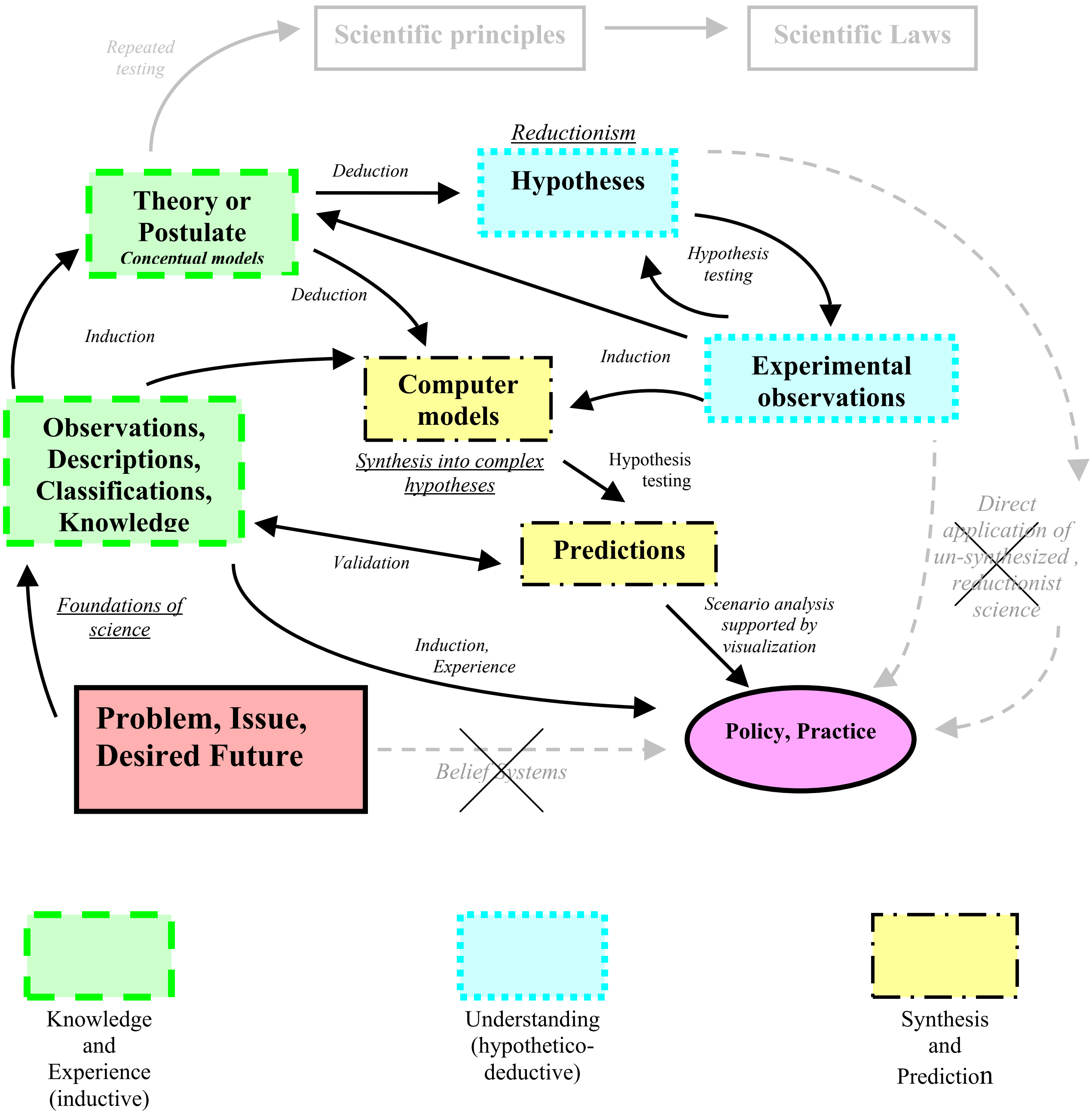


Figure 1. Conceptual model of the three major components of science. Belief systems unaided by knowledge and understanding are generally a poor foundation for forest policy. Similarly, direct application of un-synthesized, reductionist, hypothetico-deductive science is generally an unsuccessful basis for solving complex and “wicked” problems in forestry, although the understanding that it creates is an indispensable component of such solutions.

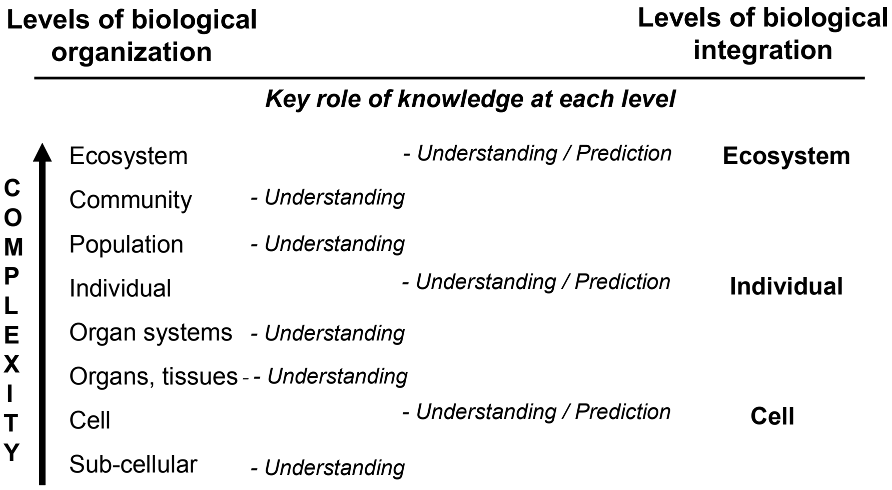


Figure 2. The relationship between levels of biological organization and understanding vs. prediction of those levels. Prediction of future states at any level of biological organization should be made in the context of the next true level of biological integration above. Only when this is done are all the key antecedent determinants of future states of the level of interest identified and factored into predictions of these futures.

3. Conceptual Model of the Context for MPB Epidemic Policy

Before exploring possible policy responses to the current MPB epidemic, the dimensions of the MPB issue will be examined in the context of a conceptual model. The objective is to remind the reader of the complexity of the system within which MPB policy must operate; it is intended to set a context for policy discussions. Many readers will already be familiar with this complexity and may wish to move directly to the next section (Section 4). The conceptual model is explored in some detail here, however, to provide a frame of reference for both technical and non-technical readers alike. The major components of the MPB issue represented within the conceptual model (Fig. 3) include the following:

1) the forest ecosystem, which is the combination of the physical environment (atmosphere [climate], geology, topography, soil, and physical disturbance – fire, wind, etc.) and the biota (plants, animals and microbes) in a functional and temporally dynamic system;
2) climate, which as a component of the ecosystem plays a major role in defining the "*ecological stage*" (this term is used here in the context of the metaphor of "*ecological theatre*", Kimmins 2004) – the physical setting which constrains the type of biota and therefore the type of ecosystem that can develop. Climate is considered

as a separate model component even though it is part of the ecosystem because of its key role in triggering MPB epidemics;

3) disturbance, which contributes to ecosystem change over time and determines to a considerable extent the "*ecological play*" (the sequence of biotic communities and associated ecosystem conditions that successively occupy and are replaced in a particular ecosystem over time). Disturbance includes both human-caused and non-human-caused events. However, as was the case with climate, harvesting is treated as a separate model component in recognition of its importance in the MPB issue;
4) the multiple values and "environmental services" provided to human society by forest ecosystems;
5) the harvest of products from the ecosystem, including hunting, trapping, fishing, mushroom and berry picking, collection of other non-timber products, and timber harvesting;
6) the human communities that depend on and benefit from harvesting activities in the forest ecosystem, and enjoy the un-harvested values and environmental services.

Each of these six components will now be examined in more detail to identify the wide diversity of considerations that the policy response to the MPB epidemic should take into account.

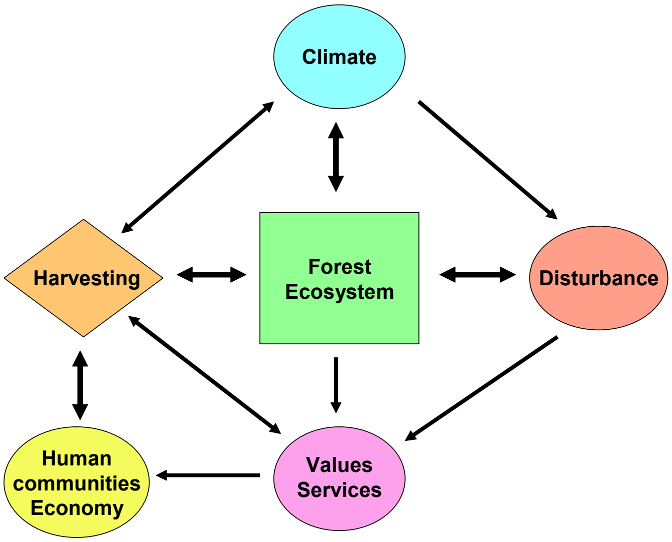


Figure 3. Conceptual model of the six major components of the MPB epidemic issue.

3.1. The Forest Ecosystem

Forest ecosystems (Figure 4) are ecological systems that can be defined at a wide variety of spatial scales, from local stands of a few hectares, to landscapes of millions of hectares. By definition, an ecosystem is any biophysical system with the following attributes: structure, function, interaction of its components and processes, complexity, and change over time:

Structure: Ecosystems consist of a physical component – atmosphere (and its temporal characteristics that define climate and climate change), topography, geology, water and soil; and a biotic component - plants, animals (including the mountain pine beetle) and microbes.

Function: A key characteristic of ecosystems is the capture of solar energy, its conversion to biomass, and the subsequent transfer of that biomass energy through the various trophic levels of the ecosystem, including herbivores, carnivores and detritivores (decomposer organisms). Regulation of the water cycle is another key function of terrestrial ecosystems.

Interaction of its components and processes: A characteristic of all systems, including ecosystems, is that their components and processes are interconnected and thus interdependent to varying extents. A component or process that is not interconnected and does not interact with other components and processes is not part of the system.

Complexity: The multiple structures, processes and interactions make it extremely difficult to predict the future state of ecosystems unless these attributes are identified, understood and accounted for. Even when a good understanding of the key components and processes is available, prediction is still difficult. Ecosystems often behave in a non-linear manner, they may develop “emergent” properties that cannot be predicted from an understanding of individual ecosystem components, and the frequently unpredictable and stochastic variability in components such as climate render accurate long-term prediction challenging at best. Nevertheless, the greater the knowledge and understanding of the key components, processes and interactions, the more accurate predictions are likely to be.

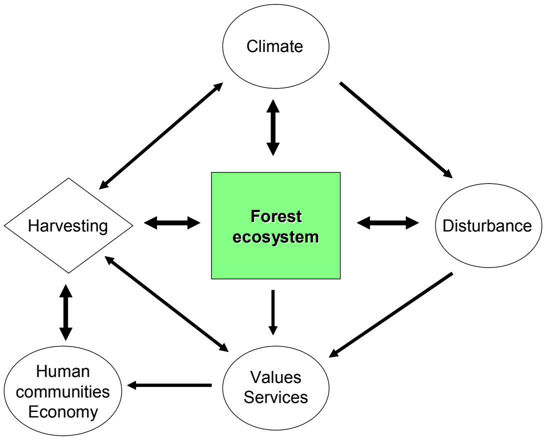
Change over time: Structure, function, interactions and level of complexity are all subject to change over time due to ecosystem disturbance and post-disturbance ecosystem development.

Note that there is no mention of size in this definition. Ecosystems are functional, dynamic systems that can be considered from a small local scale up to vast regional scales. However, to be an ecosystem, the geographical unit being considered must satisfy the above criteria.

As we shall see in Section 3.3, disturbance at some spatial scale, severity and frequency is a feature of all forest ecosystems, the pine-dominated forests or pine mixedwoods affected by the MPB epidemic in particular. These forests have been undergoing disturbance-induced change since they first established as the glaciers retreated at the end of the last Ice Age, and MPB is a component of this natural disturbance process (Gawalko 2004, Dalman 2004). The dramatic change currently being effected by the

MPB is probably within the natural range of variation (NRV) over that period, although it is possible that forest fire suppression and the resultant reduced fire frequency over the past century may have exacerbated the problem by increasing the age of the forest (Taylor and Carroll 2004, Li and Barclay 2004). Human-induced climate change may also have taken this event beyond the NRV, but in the absence of long term records and appropriate empirical research, we do not yet know this. The introduction of forest roads, soil compaction where it occurs, and the removal of large volumes of tree stemwood and associated nutrients constitute a step outside the NRV of these forests, although fire can remove more nutrients than logging (Wei et al. 2003). Considering the historical variation in these forests it is probable that there is no single set of landscape and stand conditions that could be considered "correct" and "natural", apart from the issues of roads and soil compaction, coarse woody debris (CWD) and periods of high abundance of standing dead trees (snags). Environmental aspects of salvaging pine trees killed by MPB should be considered in the context of a "temporal fingerprint" of change (Kimmins 2002, 1990) in ecosystem structure, function, complexity and interactions of the components. This fingerprint could be chosen to reflect NRV or some other desired forest future.

The MPB epidemic is altering the structure, function, complexity, interactions and change over time of the affected ecosystems. Killing of the pine trees does not "destroy" the ecosystem, even when the forest is a natural pine monoculture; it only alters its characteristics until domination of the ecosystem by trees is re-established. The MPB is acting as an agent of ecosystem change as it has done for millennia. Processes of ecosystem development will move the ecosystem back towards its pre-disturbance condition or to some new condition, just as the forests being affected by MPB are the consequence of an earlier disturbance.



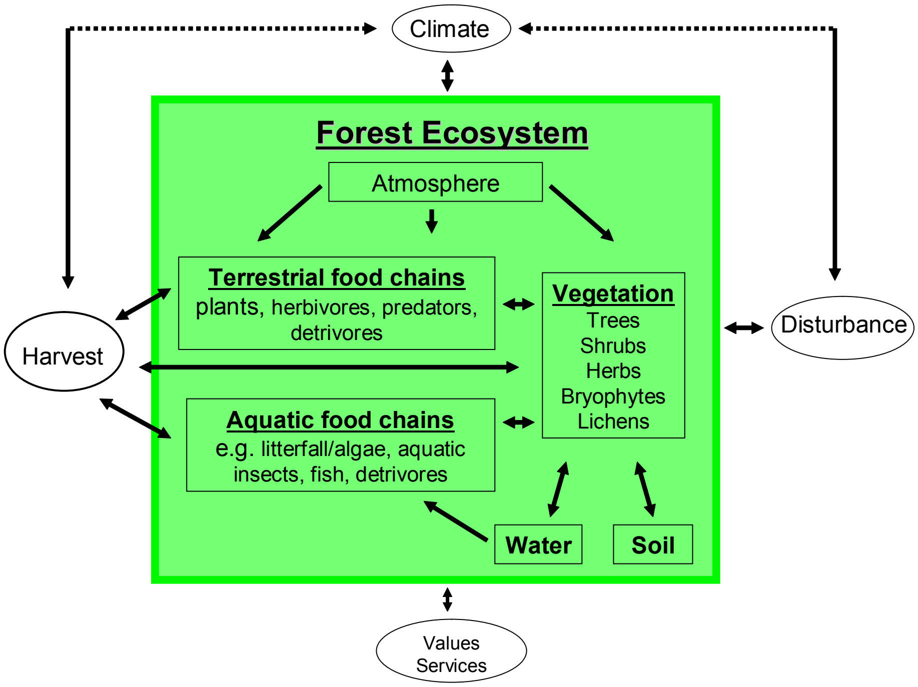


Figure 4. The major components of the forest ecosystem: vegetation and the food webs of animals and microbes that depend thereon, interacting with the atmospheric, soil and water components of the system. The ecosystem is strongly influenced by disturbance, of which harvesting is a particular type, and by temporal patterns of change in atmospheric conditions (climate).

3.2 Climate

The climate of a given region may be defined as the annual pattern of variation in atmospheric conditions and the change in this pattern with time (seasonal climatic variation and climate change, respectively). It is a major component of forest ecosystems as noted above, but is considered as a separate component in the conceptual model because of its importance in creating the conditions under which the present MPB epidemic occurred (Figure 5). Climate plays a key role in determining what species are capable of living (fundamental niche) and surviving under the stress of resource competition and other biotic interactions (realized niche) in a particular region and associated site types (a function of slope position, aspect and edaphic conditions). It also has a strong influence on the physical and biotic disturbance factors that will affect different species and lead to successional ecosystem change (See Section 3.3).

Temperature regimes (summer and winter air temperatures, length of frost-free season, soil temperatures), wind, rain and snow, water balance and other climatic features determine, in large part, the vegetation potential (plant species and growth rates) of the ecosystem. Any consistent, directional, change in the amplitude and/or seasonal variation of annual climate regimes ("climate change") may result in substantial shifts in ecosystem function and long-term alterations in ecosystem structure. Specifically, climate change will likely affect the following: species distribution ranges at both large (regional) and small (site series) spatial scales, reproductive capacity, growth rates, nutrient uptake and cycling, inter-specific competition, and resistance to pests and diseases. As in the case of the MPB epidemic, climatic variation can lead to epidemics of insects and diseases, especially if the forest condition promotes an irruption of their population (see below). Because trees are long lived and experience considerable climatic variation over their lifetime, climate change may affect tree reproduction and natural regeneration more than the growth and survival of established trees. Moreover, the effect on the ability of trees to resist diseases and pests may be greater than the direct effect of climate change on growth. In addition, through its effect on water balance and forest hydrology, climatic variation has a major impact on the aquatic ecosystems within forests: streams, rivers and lakes that are considered to be an integral component of the forest landscape.

Climate exerts a substantial influence on our ability to harvest material products from the forest through soil moisture, temperature effects and fire danger. The period of frozen soil is a key factor in timber harvesting in many northern forests because logging on unfrozen soil creates too much soil damage or is simply not possible. Winter logging using ice bridges may be the only way to access flat to gently rolling forest landscapes that have many small streams or areas of saturated soils. In contrast, excessive snow depth and duration and extreme cold may limit winter logging in some areas. Hot dry summers create fire danger that may restrict tree harvesting and fire may destroy economic timber and other values.

Insects such as the MPB respond strongly to variations in climate, and trees may be less able to repel insects and diseases when climatically stressed by drought and increasing temperatures. The recent history of several years of warm winters and hot, dry summers is believed to have played a key role in facilitating the current MPB epidemic (Carroll et al. 2004). Low winter temperatures are believed to be the primary cause of over-wintering MPB mortality. Summer climatic conditions that favor more than one MPB brood per year and cause moisture stress in trees (which were potentially declining in vigor because of advanced age) have also contributed to the build up of the MPB populations (see, for example, Shore et al. 2004).

While it may be tempting to design and plan for future forest conditions with a primary focus on reducing the risk of future large-scale MPB outbreaks (e.g., beetle-proofing the forest), forest management policy should not be developed without an in-depth analysis of the potential ecosystem consequences of plausible future climate change scenarios. For example, if species other than pine are to be planted to reduce the risk of future MPB outbreak, careful consideration must given to potential shifts in the geographical distribution of climate envelopes within which a given species is likely to survive and grow reasonably well. Such shifts must be considered regionally as well as locally to account for edaphic and other site factors (site series). The potential for climate change to increase the risk of other biological disturbance agents (e.g., spruce budworm, hemlock looper, Douglas-fir bark beetle, etc.) should also be taken into account when selecting species for revegetating salvaged MPB-killed stands.

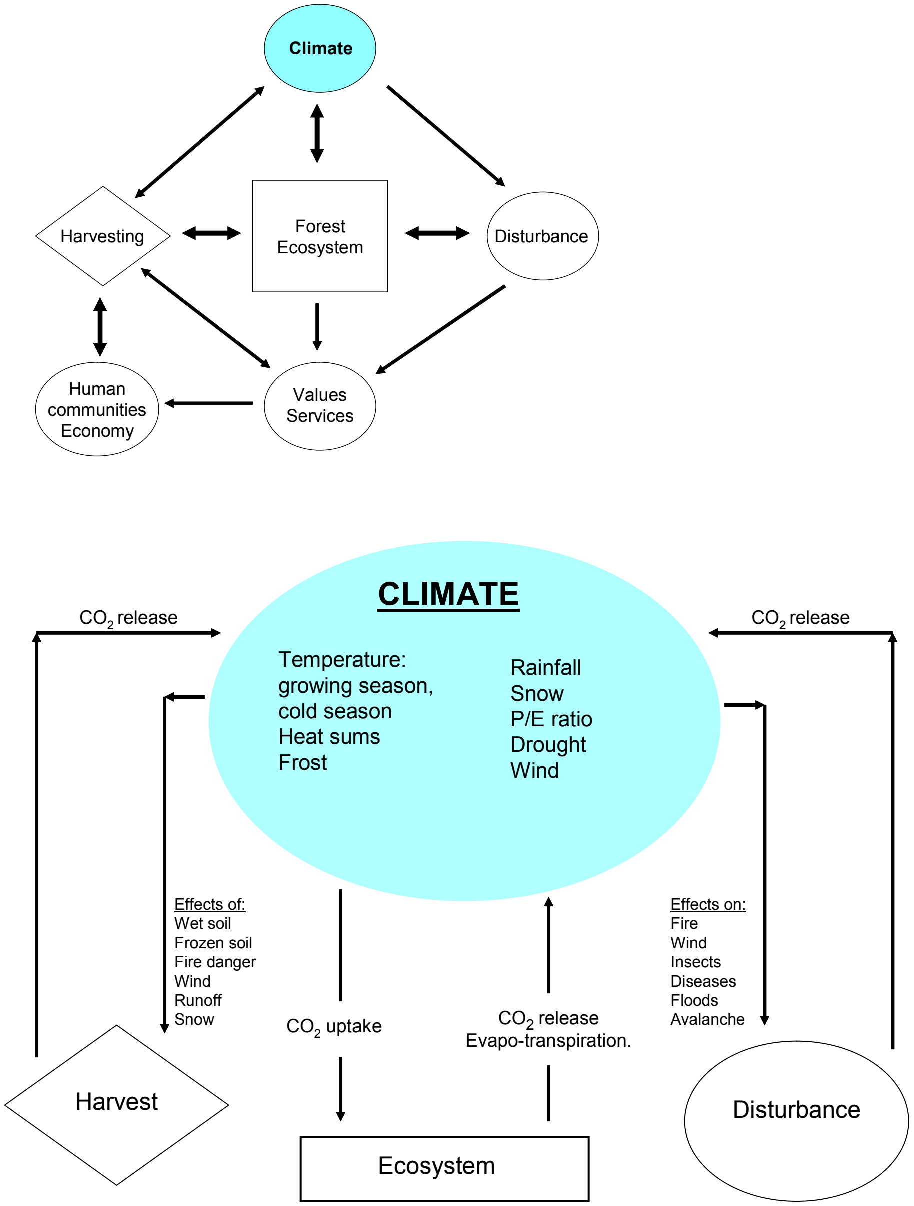


Figure 5. The multiple interactions between climate and ecosystems, either directly or through disturbance factors. Forest harvesting and, mainly in the tropics, deforestation and other forest disturbances, can contribute to changes in atmospheric chemistry (CO_2 and other greenhouse gasses) which affects climate. However, the major driver of climate change is believed to be the release of fossil fuel carbon.

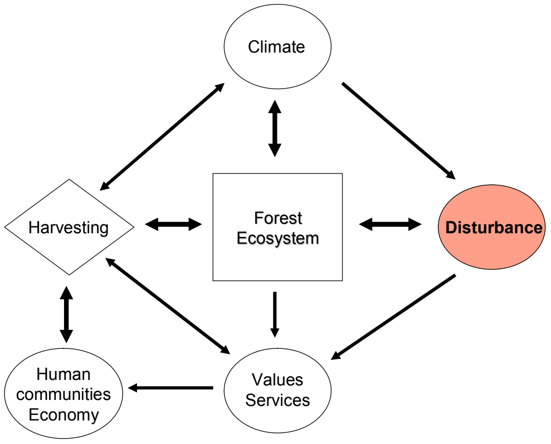
3.3 Disturbance

Disturbance in a forest ecosystem context may be defined as any event that changes the direction, rate, pattern and/or process of change in ecosystem structure and function from that which would have occurred by internal ecosystem biotic processes (Kimmins 2004, Perrera et al. 2004). It is both time and space-dependent. For example, the loss of all the foliage of a deciduous forest in the late summer/early fall by insects or some other agent would constitute little or no disturbance, whereas a similar loss in the early summer would 'disturb' the ecosystem significantly. In contrast, the loss of all the foliage of an evergreen forest would constitute disturbance whenever it occurs. With respect to spatial scale, the loss of an individual leaf or branch in that evergreen forest would not qualify as a forest-level disturbance and represents only a minor tree-level disturbance, but to the epiphytic moss or lichens on that leaf or branch, or the insects living on them, this would be a catastrophic disturbance.

It is helpful to consider disturbance in the context of succession (sequential changes in community composition). While processes such as seed production and dispersal, seedling establishment, resource competition, and age-related mortality may result in changes in ecosystem structure and function, they themselves do not constitute disturbance (according to the definition provided above). Rather, these processes and the resultant sequences of biotic communities that replace each other over time represent autogenic (self-generated) succession. Although a disturbance event may reset the pattern of autogenic succession, the fundamental processes of autogenic succession are not dependent upon disturbance. In contrast, other types of succession are disturbance driven. Allogenic (external) succession occurs when dramatic changes in ecosystem structure and function originate from physical (abiotic) agents such as strong winds, fire, harvesting, etc., or from biological agents (excluding endemic populations) including invasions of non-native species, diseases and epidemics or irruptions of otherwise endemic herbivores ('pests"- largely insects). Changes caused by this biological subset of disturbance agents are commonly referred to as biogenic succession. The present MPB outbreak in BC would be included in this category.

There are many different types of disturbance in forest ecosystems (Figure 6). Some are related to human activity. Fires set by indigenous peoples have affected most of the forests of the world for millennia and for most people these fires would be considered "natural". Similarly, tropical and temperate shifting cultivation and other forms of agro-forestry have played an important role in molding many of the world's forests – they have been part of the ecology of many of these forests for many centuries or millennia. (Willis et al. 2004) Exploitative hunting (e.g., the prairie buffalo) and alteration in historical predator-prey systems through predator control or the introduction of herbivores without their predators (e.g., the introduction of deer to the Queen Charlotte Islands - Haida Gwai) has altered herbivore pressure on vegetation leading to biogenic succession. Forest harvesting for timber and firewood, while listed here as a type of human-caused disturbance, is also treated as a separate component of the conceptual model (Section 3.4) because of its importance in the MPB epidemic issue.

A major consequence of disturbance is to alter the storage of carbon in forest ecosystems, generally (though not always) resulting in large releases of CO_2 to the atmosphere, with potential consequences for future climates. The post-disturbance rate of CO_2 release from carbon stored in biomass pools depends to a large degree on the type of disturbance. For example, fire results in an instantaneous release of CO_2 while the rate of release following pest-related mortality is much slower as the carbon contained within the biomass is transferred to slowly decomposing litter and soil pools. If harvested tree biomass is manufactured into long-lived wood products, this can have a similar effect of increasing carbon storage, as long as the quantity of fossil fuel carbon released in the harvesting, transport, manufacturing and "storage" (e.g., construction of buildings) is not excessive.



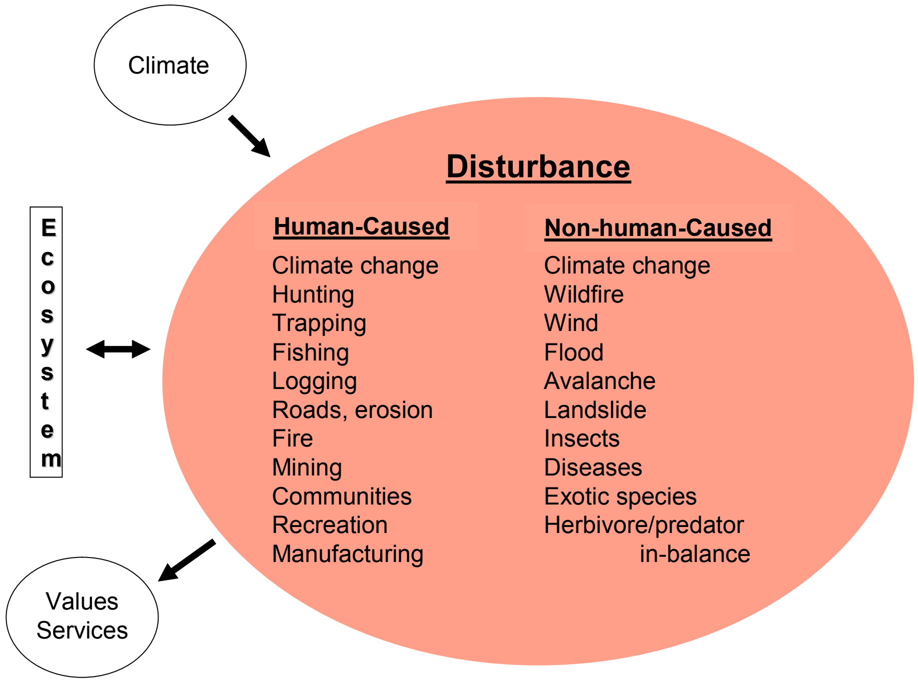


Figure 6. Ecosystem disturbance can take many forms, and be related to human activity or non-human causes. Whatever the cause, disturbance plays a fundamental role in the ecology of the majority of the world's forests, and is a dominant feature in the forests of interior B.C. where the present MPB epidemic is occurring.

3.4. Forest Harvesting

When people think of forest harvesting today they generally assume timber harvesting, and, in many people's minds, clearcut harvesting. However, harvesting can take many forms. Indigenous societies harvested food and medicinal plants and mushrooms, firewood (dead trees, branches and other smaller tree parts), roots, tree bark, and some tree stems for boats, buildings, defense and other needs. When human populations were relatively small and there was a lack of mechanical harvesting technology, tree harvesting was generally limited to individual trees or small patches of trees. However, forests were often burned or temporarily cleared to promote the harvest of non-timber forest products, to improve wildlife habitat and hunting, to facilitate travel, or to reduce the risks of predators. Indigenous people also harvested fish and wildlife for food, and a variety of forest animals for other purposes.

Natural disturbance, particularly large-scale events, can have both positive and negative impacts on the type and relative abundance of harvestable forest products. Typically there is a period of increased abundance of variable duration for some products (e.g., dead tree stems for salvage harvesting, honey and berry production, certain species of mushroom, and game populations such as deer that benefit from the minor vegetation response to disturbance), followed by a period of reduced local resource availability while the forest closes canopy and begins transitioning through the stem exclusion phase of stand development. For other products, there may be an immediate reduction until the forest age and condition associated with these products has re-developed. Some species of insects, birds and mammals undergo temporary, disturbance-related population increases; others are decreased. The total species diversity in a disturbed area can go up or down or show little response to disturbance, depending on the measure of diversity, the temporal scale at which it is evaluated, and how long after the disturbance the assessment is made.

Harvesting is restricted by society's value system. Ecological reserves, parks, protected areas, hunting and gathering restrictions, recreation, aesthetics and spiritual values may all limit harvesting of wood and non-wood forest products, as well as evidence of non-sustainable past management. Policy responses to the MPB that are intended to capture the social and economic values of trees killed by the MPB will be limited by public concerns about other values (e.g., Eng 2004). Policy must ultimately balance the variety of values that can be harvested from a forest after such a biotic disturbance against threats to other values that may be posed by salvage harvesting. In doing so it must recognize the spatial and temporal variability in post-disturbance values, balancing short and long-term human and environmental considerations.

Much of the ecosystem impact of timber harvesting has been related to roads and the associated access for hunters and predators that roads have created. Roads (particularly those poorly designed or constructed) are also largely responsible for the negative effects of harvesting on hydrology, water quality and streams. A major consequence of the MPB epidemic may be the accelerated development of road systems to access killed stands for salvage harvest. This can substantially alter the impact that MPB-related tree mortality has on forest ecosystems if no salvage is undertaken.

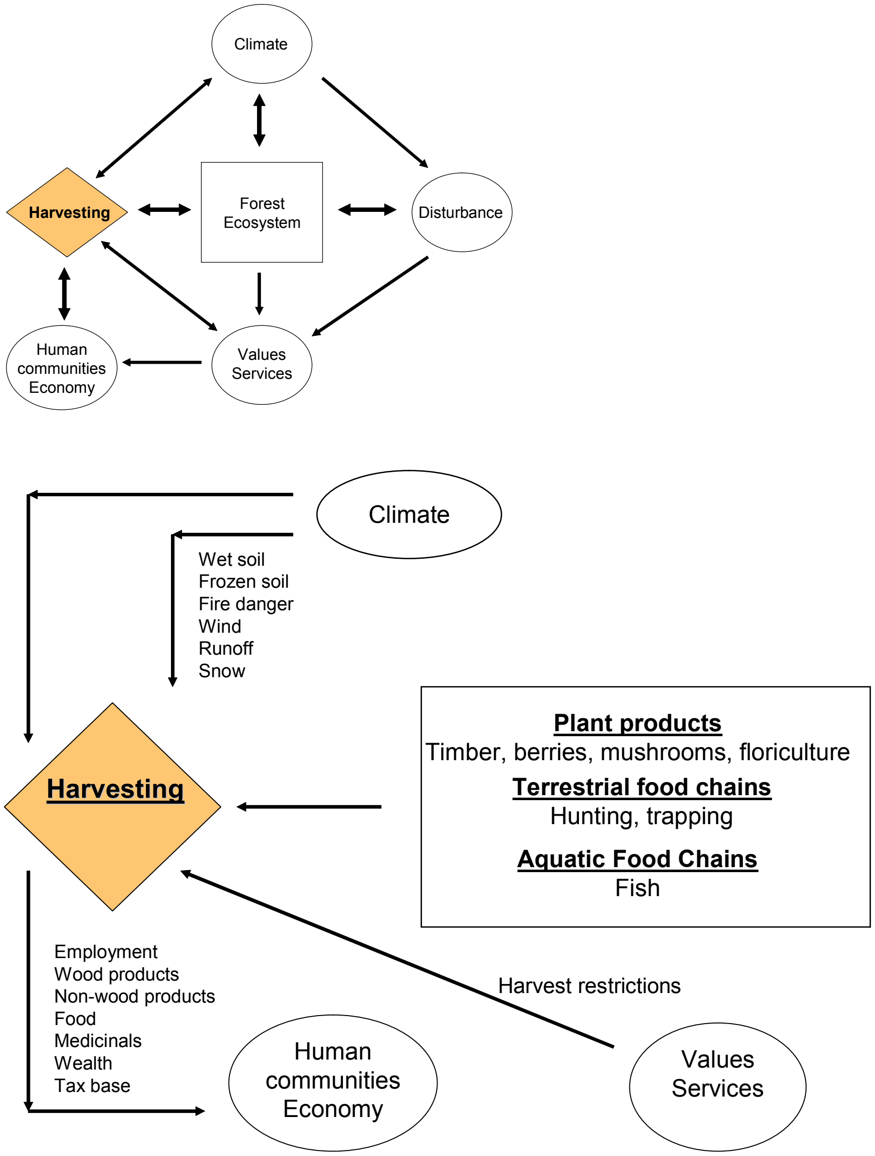


Figure 7. Forest harvesting involves many different products including terrestrial plants, animals and mushrooms, and aquatic plants, fish and other aquatic animals. While timber harvesting has dominated and will continue to do so in many areas, harvesting of non-timber forest products is expected to increase in importance.

3.5 Forest Values

The difficulty with forestry is not ultimately related to biophysical issues, but to the values and environmental services that forests provide to people. No matter how much issues such as biodiversity, climate change/forest carbon and environmental ethics are featured in public debates, without a human community to evaluate these issues, they would not exist. While existence value and the ethics and rights of individual species and even individual organisms are promoted by some, these largely constitute an extension of human ethics and moral concerns about human domination of other species. They are all human-centric. As has been noted many times, forestry is first and foremost about people, their values, needs and desires.

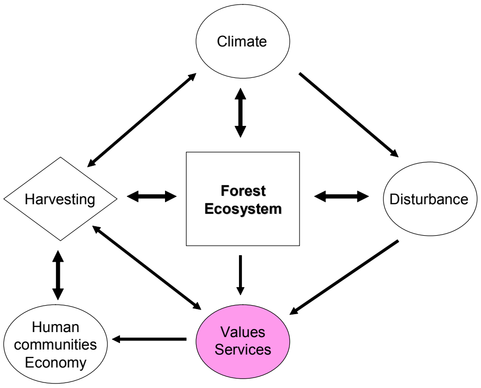
Forests provide a wide variety of environmental and social values and services, as noted in Figure 8. As the habitat and environment for much of the world's terrestrial vertebrate and invertebrate animals and the biota in forest streams and rivers, forests play a key role in biodiversity, hunting and fishing values. As a reflection of global precipitation patterns, closed forests play a key role in water balance and hydrology, regulation of snow accumulation and melt, stream flow regimens and water quality; they are a major source of water for human consumption and use. They stabilize slopes, control soil erosion and limit avalanches. The high leaf area of forests creates an efficient air filtering system, removing fog and dust. The shade and the cooling effect of trees reduces temperature extremes, and the roughness of the forest canopy and high leaf area reduces wind velocity. Tree litter production promotes soil development and soil fertility.

Complementing these environmental services, forests provide recreational and aesthetic values. They play an important role in cultural and spiritual values of societies that value forests, and for urbanites and others far removed from forests and who may never even go to a forest, they have important existence values. Simply knowing that they are there and that they are providing diverse values and services is a value in itself.

The environmental services provided by forests vary as their age and condition change over time. They also vary as society changes what it wants from forests. Centuries ago few would have thought of maintenance of biodiversity as an environmental service provided by forests; today it is one of the most popular public concerns about forests. Carbon storage and climate regulation has only recently been identified as an important environmental service of forests – perhaps one of the most important at a global scale in the face of profligate release of fossil fuel carbon. As society evolves, so will the list of services we want from forests.

Similarly, the values associated with forests are not constant – they evolve with the evolution of society. Early societies may value forests for shelter, food and spiritual values. Forest values in a developing country tend to focus on wealth creation, employment and resource supplies, whereas in a post-industrial society, aesthetics, recreation and spiritual values may dominate. The present MPB epidemic is threatening many contemporary values and environmental services and this is a major source of public concern.

The complexity of human-defined values and environmental services requires that forest policy and planning tools be multi-value and include social as well as biophysical forecasting capabilities.



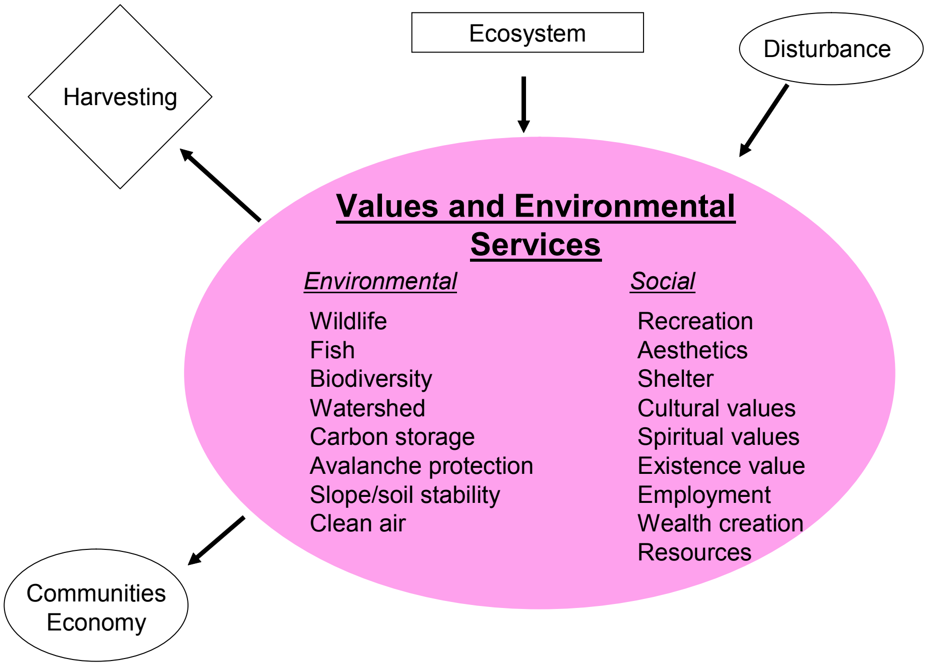


Fig 8. There is a wide diversity of values and environmental services that should be considered in designing forest policy and management. The challenges of managing forests sustainably have as much or more to do with human-defined forest values and human–desired services from the forest as with biophysical characteristics of the forest itself.

3.6 Human communities and the economy

Some of the most important values traditionally provided by forests are wealth creation, employment and harvested products of various types, all of which have been vital for forest-dependent communities and the economies of forest-rich nations. In a province like British Columbia where much of the landscape is dominated by trees, these social values have had an overwhelming influence on government policy. While some of the other sectors of the economy have grown faster than forestry, forest-related economic activity continues to be the main or one of the main drivers of B.C.'s economic engine. Many communities remain highly dependent on forestry and wood-products.

The economic value of B.C.'s wood products currently runs at $18.6 billion, compared with about $9.2 billion for tourism. Forestry jobs pay about $17,000 a year more than the B.C. average salary. Two hundred seventy thousand people are employed directly or indirectly – about 14% of the workforce – and more than 200 communities are directly dependent on the forest industry (COFI). The export value is $14.4 billion – about 50% of B.C.'s total export value; about 80% of total production is exported (B.C. Ministry of Forests Forest Facts 2004). The return to the government in terms of stumpage is about $1.5 billion, and forestry contributes about 20% of the total provincial revenue. Clearly, forestry continues to play a key role in the provincial economy and the economic support of B.C. communities. Because so much of B.C.'s tourism is forest-related, and because the forest sector is the major single user of high technology in B.C., the indirect contributions of forests and forestry to the provincial economy significantly augment the direct contributions.

In the past, much of B.C.'s wood products have been exported as primary products, but with the increase in tariff barriers on such materials and the greater economic returns that are possible with value-added manufactured wood products, the value-added sector is increasing, as is the market for non-timber forest products. New manufacturing technologies will increase the value of forest products, and values such as carbon credits have the potential to increase the economic returns of B.C. forests once the Kyoto Protocol is expanded to consider total carbon budgets, including biofuel–displacement of fossil fuels and the carbon savings when non-wood materials are displaced by wood-based products (Watson et al. 2001, P. McFarlane 2003 - www.cwc.ca/environmental/sustainable_buildings/green_by_design/3).

There is a need to diversify the economies of heavily forest-dependent communities. Forestry has always experienced cyclic fluctuations in markets and values for wood products, and international pressures to reduce the "social engineering" of forestry in B.C. will tend to exacerbate the effects of such fluctuations on these communities. In addition to these social risks, there is the continual risk of large-scale forest disturbance events, such as wildfire and the current MPB epidemic. Both these considerations suggest the need for increased institutional, social and economic diversification, or at the least an increased flexibility in the way communities are able to adapt to risks. The impact of the MPB on B.C.'s economy is expected to be very significant and this will be one of the major consequences of the epidemic. Increased allowable cuts and large quantities of dead pine may depress the value of wood; this will be followed by periods of reduced harvesting and possible wood price increases.

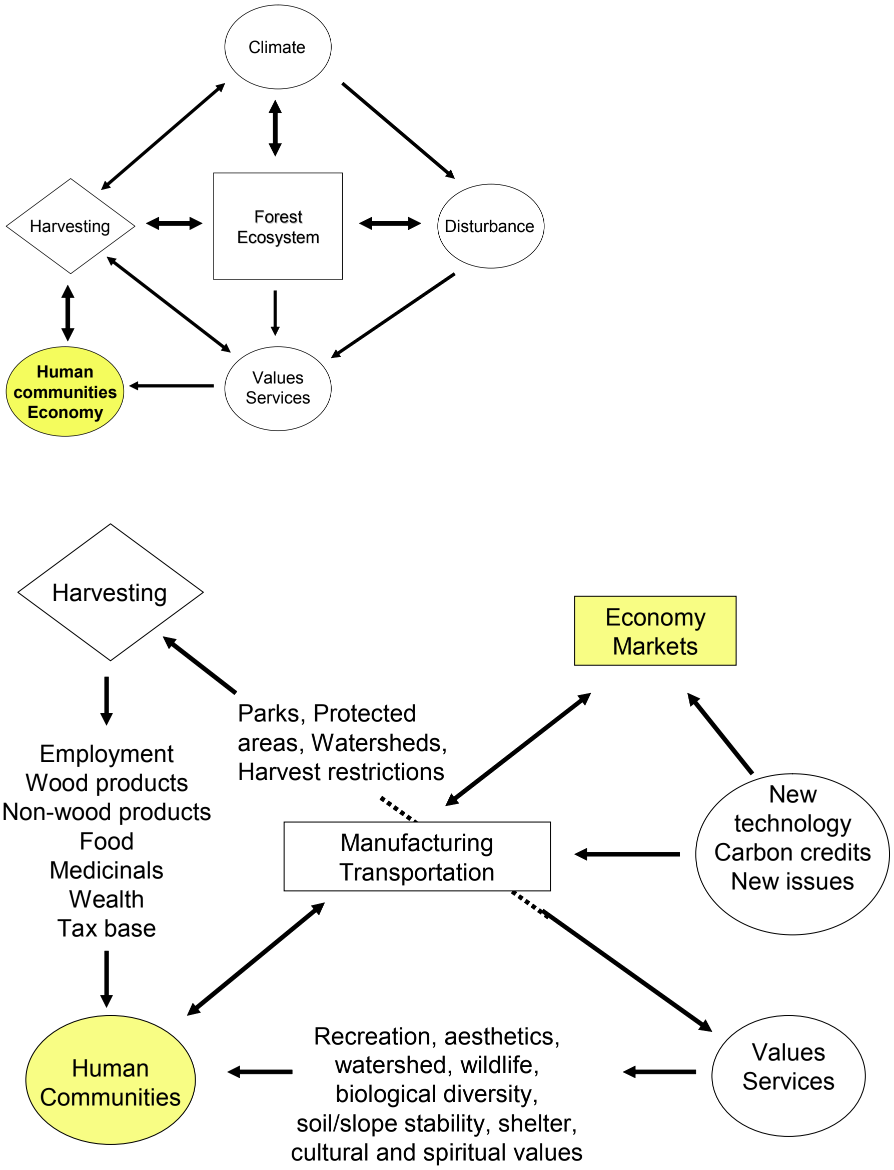


Figure 9. Most human communities have a dependence on forest ecosystems, whether this is for employment, wealth creation and products, or for the many other values and environmental services that forests provide. The value of the forest to communities is strongly influenced by regional, national and international markets and economies.

4. Impacts of the MPB Epidemic on Forest Vegetation

The driving force of forest ecosystems is the capture of solar energy, mainly by trees, and its conversion into biomass. By killing lodgepole pine trees, MPB significantly reduces ecosystem productivity until leaf area and the functional efficiency of the tree canopy are re-established. In the interim, ecosystem productivity is dominated by the response of understory vegetation and tree regeneration following overstory mortality. The pattern of vegetation development (succession, see Section 3.3) is also affected, and there may be greater variation in tree species composition and sequences of change in this composition than the variation in ecosystem function.

A wide variety of forest community types are affected by the MPB epidemic, and many different post-disturbance pathways (sequences) of ecosystem development may occur. Figures 10-16 present some of the diversity of tree communities in which MPB-related mortality may occur and some of the variety of possible successional outcomes that could result. This diversity and variability reflects the variety of biogeoclimatic zones and subzones affected, the diversity of ecosystem types within these ecological classification units, and variations in forest plant communities on any particular site type due to variations in stand history and stage of successional development. The successional pathways will vary according to the ecosystem type and pre-disturbance condition, the severity of pine mortality, the landscape pattern of mortality and its effect on availability of seeds of different species, competition from minor vegetation, and several other factors. The diversity of pathways is increased (not shown) by variation in the distance to seed sources, the availability of seedbeds and bud banks, and the density of surviving live trees; the type and density of the herb and shrub community that were present before disturbance and develop afterwards; and the presence and composition of advanced tree regeneration. Other stand types in which lodgepole pine are killed by MPB include pine/western larch stands in southern and southeastern BC. The impacts of MPB on stand dynamics are reported by Hawkes et al. (2004).

The diagrammatic models illustrated in Figures 10-16 ignore variation in soil and site type. On summer-dry and nutrient poor sites, the successional sequence may be of the “relay floristics” type (Egler 1954; succession in physically unfavorable environments with respect to soils and microclimate in which there is a more or less obligatory sequence of communities which successively modify the site and by so doing make possible the invasion by the species of the next seral stage) which will restrict which species can recruit following pine removal. Where the soil is richer and moister, many different species may be able to recruit following the mortality-induced reduction in competition for site resources. This reflects the “initial floristics” model of succession (Egler 1954; succession in favorable environments in which many different species can invade, the sequence of communities observed being a function of the timing of their arrival at the site and their tolerance of competition). Furthermore, if there is a well developed understory of herbs and shrubs prior to the MPB-induced mortality and if they survive the disturbance, they may prevent recruitment of seed-based regeneration, creating an “inhibition” successional pathway, and leading to long-lived and invasion-resistant shrub or herb communities.

Predicting the possible successional outcome of MPB epidemics and how to manage the subsequent stand succession to produce a desired range of future forest conditions will require decision-support systems that can be used to project the combined effects of the determinants of succession suggested above. This requires ecosystem-level models and planning tools; population and even community-level models will generally not address the complexity involved. Experience-based forecasts of successional pathways may be more reliable and useful than complex models *if* the experience exists and accounts for all the key determinants, and *if* the future remains essentially similar to the past. Where such experience is lacking and/or the future is expected to be different in ecologically significant ways, process-based ecosystem management stand models may play a useful role (Korzukhin et al. 1996; Johnsen et al. 2001).

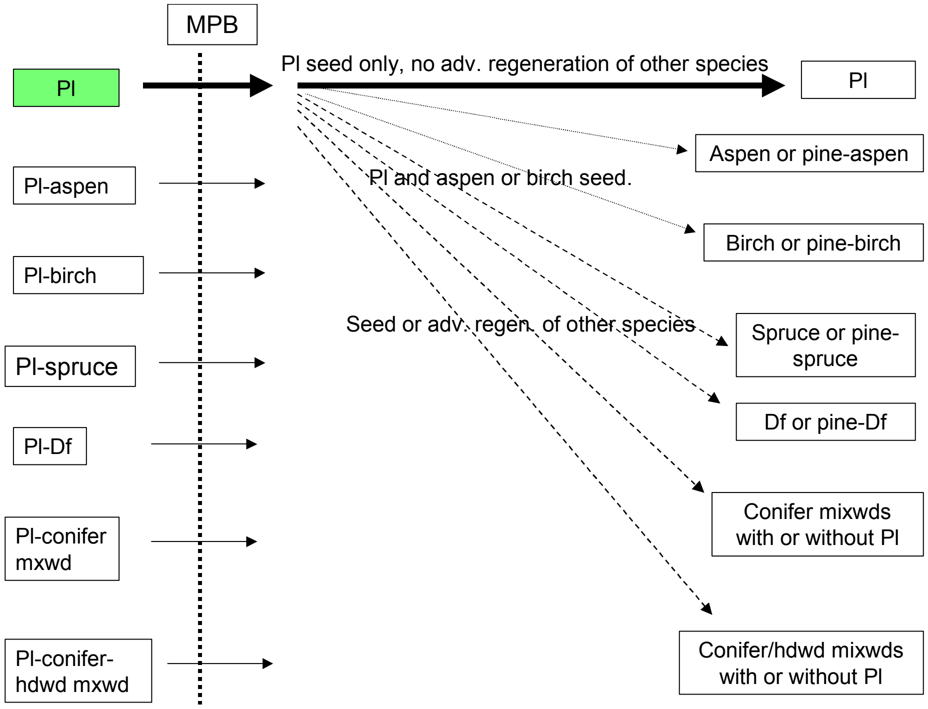


Figure 10. Possible pathways of forest cover type development following MPB-related mortality in monoculture lodgepole pine stands. Serotinous cones providing a canopy seed bank will generally ensure a return to monoculture pine stands in areas of extensive pure pine stands unless competition from minor vegetation is very severe. Where the soil is appropriate, where there are suitable seedbeds and a source of aspen or birch seed, the stand may develop into a pine-aspen or a pine-birch stand. The invasion of other species will be more likely if salvage harvesting creates mineral soil seedbeds. (Pl = pine; Df = Douglas-fir; mxwd = mixed wood; hdwd = hardwood.)

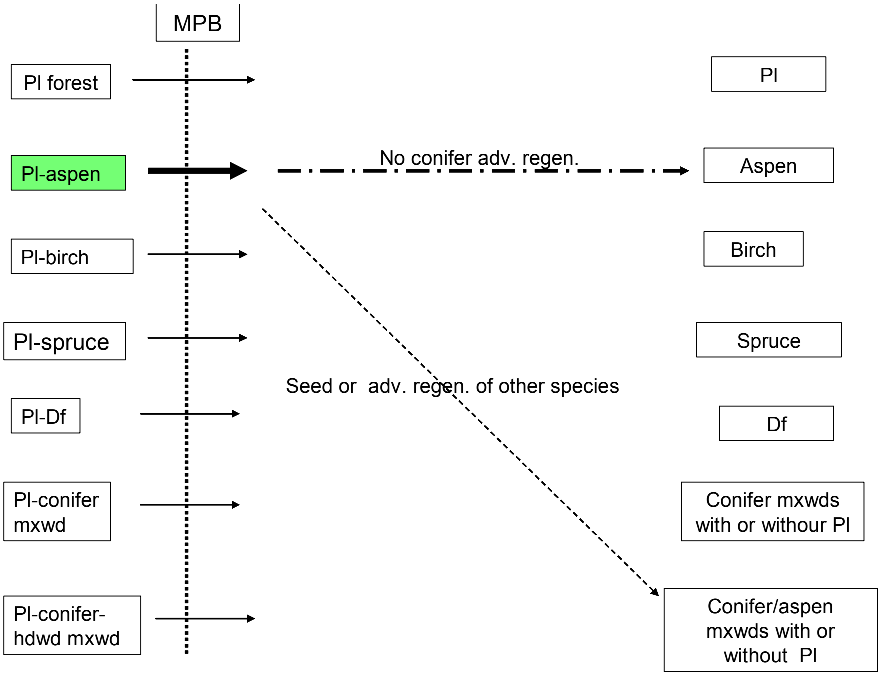


Figure 11. Possible pathways of forest cover type development following MPB-related mortality in lodgepole pine-aspen mixed stands. The aspen will take over to form pure aspen stands if there is no advanced regeneration of other species. If there is such advanced regeneration or seed rain of other species, the stand may develop into a conifer-aspen mixedwood, with or without lodgepole pine. Re-establishment of pine or invasion of other conifer species by seed rain will be limited by light competition and competition for soil resources posed by the established aspen population. If the aspen density is low and seed of conifers is available, development of mixedwoods is likely, subject to soil and site type, seedbeds and other environmental factors.

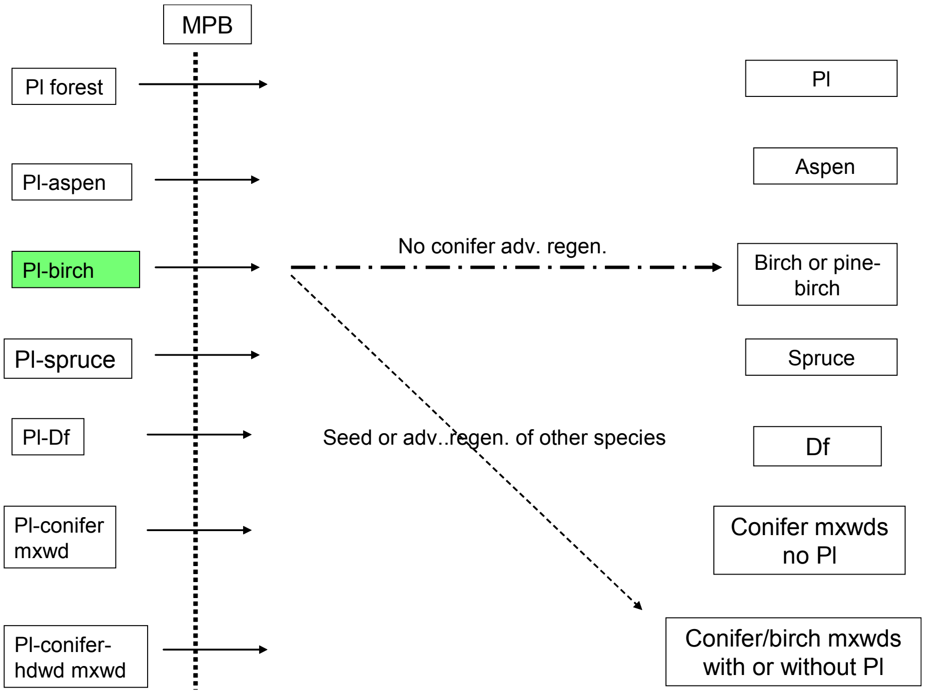


Figure 12. Possible pathways of forest cover development following MPB-related mortality in lodgepole pine-birch mixed stands. The birch may take over to form pure birch stands if there is no advanced regeneration of other species and the density of birch is high, thus excluding the shade-intolerant pine regeneration, or a birch-pine or pine-birch stand may develop. If there is such advanced regeneration or seed rain of other species, the stand may develop into a conifer-birch mixedwood, with or without lodgepole pine.

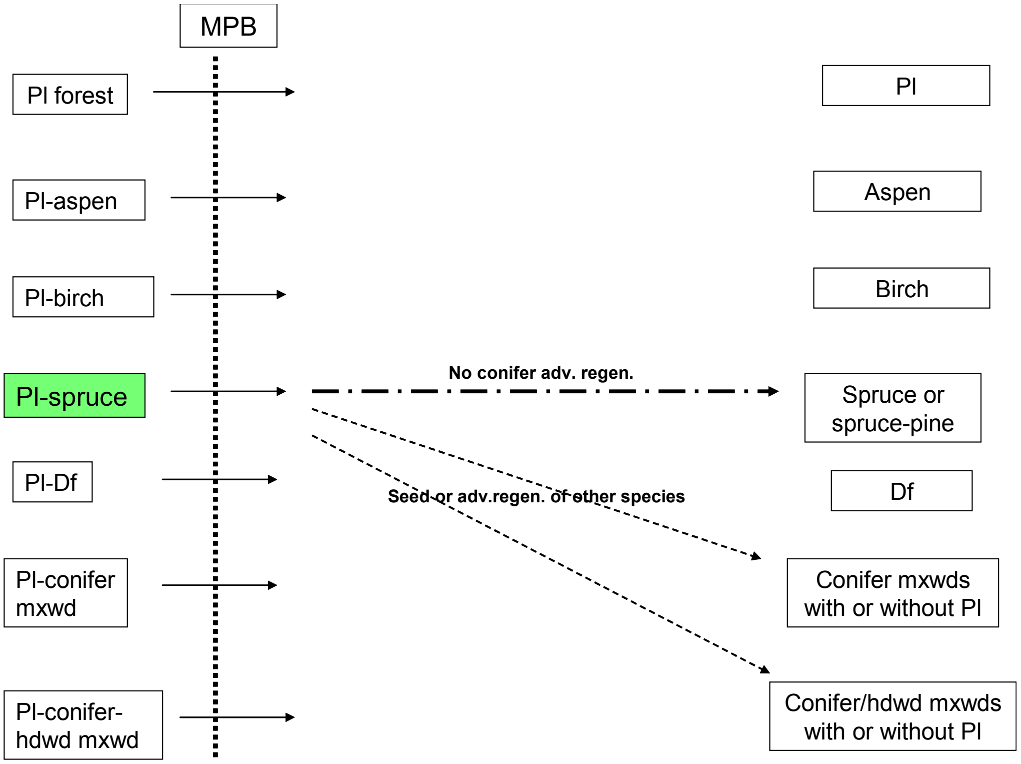


Figure 13. Possible pathways of forest cover development following MPB-related mortality in lodgepole pine-spruce mixed stands. The spruce may take over to form pure spruce stands if there is no advanced regeneration of other species and the spruce density is high, thus shading out the shade intolerant pine regeneration; alternatively, a spruce-pine stand may develop if seedbeds, light and other factors are favorable. This outcome would be promoted by the presence of the spruce leader weevil which would restrict the height growth of spruce regeneration. If there is advanced regeneration or seed rain of other species, the stand may develop into a conifer or a conifer-hardwood mixedwood, with or without lodgepole pine.

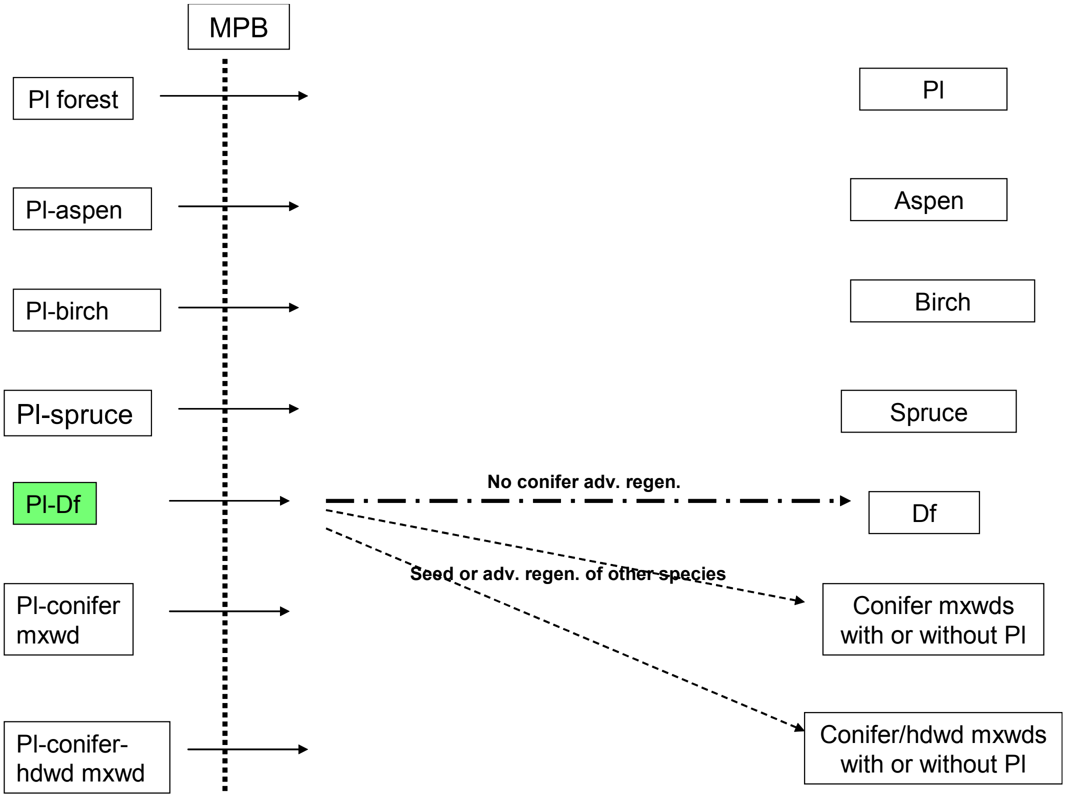


Figure 14. . Possible pathways of forest cover development following MPB-related mortality in lodgepole pine-Douglas-fir mixed stands. The Douglas-fir may take over to form pure Douglas-fir stands if there is no advanced regeneration of other species, or a Douglas-fir-pine stand may develop depending on post-disturbance stand density, seedbeds and competition from minor vegetation. If there is advanced regeneration or seed rain of other species, the stand may develop into a conifer or a conifer-hardwood mixedwood, with or without lodgepole pine.

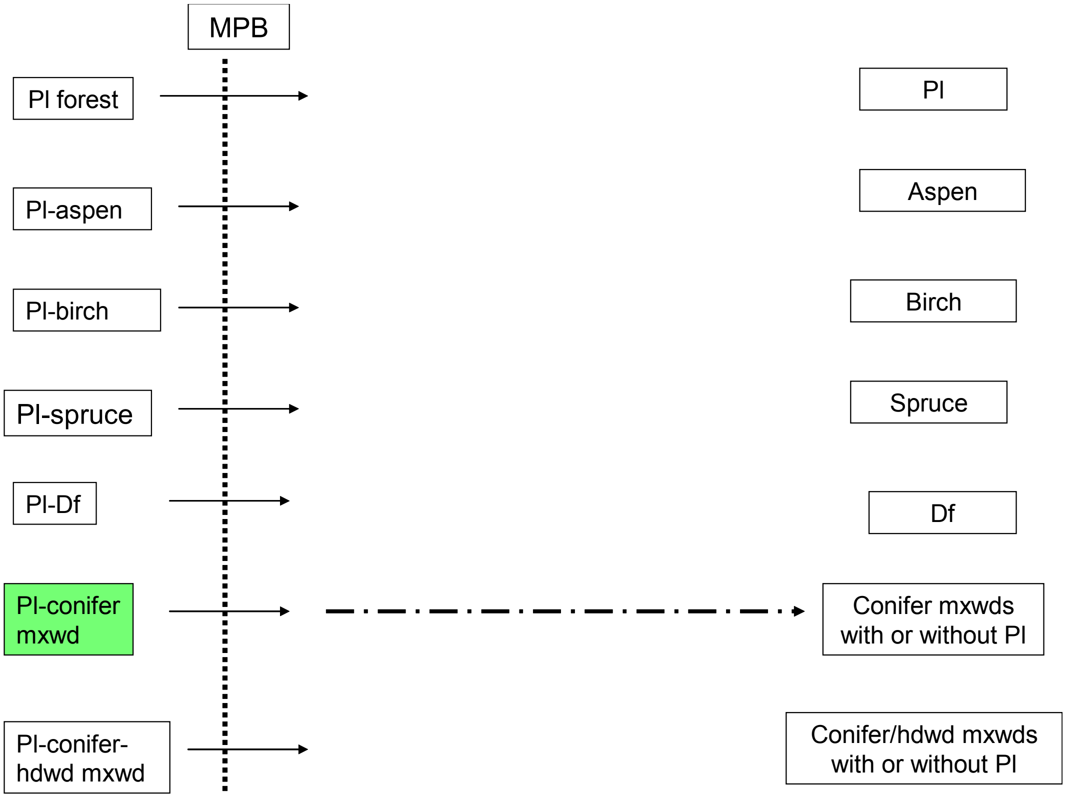


Figure 15. Possible pathway of forest cover development following MPB-related mortality in lodgepole pine-conifer mixed stand. Mortality of the pine would probably maintain the conifer mixed stand, possibly with some pine recruitment, depending on post-mortality stand density, seedbeds and competition from minor vegetation. Relatively little change is thus expected in such stands, although species composition would trend towards dominance by the most shade tolerant species.

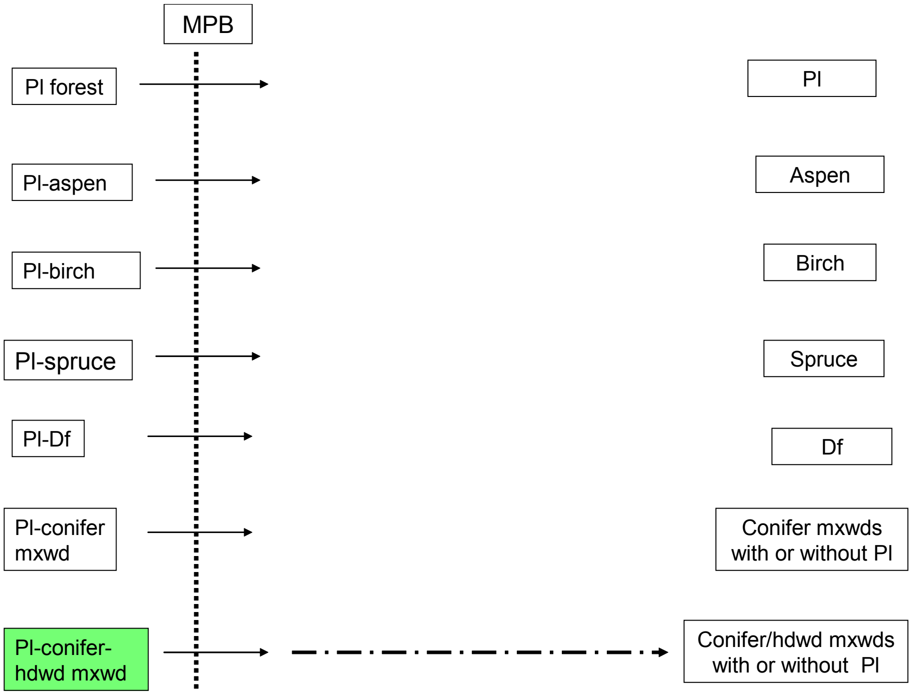


Figure 16. Possible pathway of forest cover development following MPB-related mortality in lodgepole pine-conifer-hardwood mixedwood. Mortality of the pine would probably maintain the mixedwood, with the tree species most able to take advantage of the reduced stand density being favored initially. Ultimately, such mortality would favor shade tolerant species. Pine may or may not recruit depending on seedbeds, minor vegetation competition and stand density. Thus, in the short run, the fast growing deciduous component of the mixedwood may be promoted. In the long run, the pine mortality may permit the establishment of the more shade tolerant species which would therefore be promoted.

The conclusion of this analysis is that policy with respect to MPB epidemics like the present one should reflect the diversity of ecosystem types affected, and the diversity of possible future stand types that could develop on a particular site type. On some site types in some biogeoclimatic subzones, many different stand types could develop depending on a variety of factors. On others the range of potential forest cover types will be much more limited. Planning tools at the stand level should have the capability to address this diversity of ecosystem-response; planning tools at the landscape scale should be driven by such stand-level tools.

Because so many other forest values will depend on the post-MPB successional pathways, it is important to be able to make reliable forecasts of possible post-disturbance forest development. Silvicultural planning will require forecasts of which silvicultural strategies in the wide variety of post-MPB situations could result in desired forest futures. The best basis for such forecasts would be experience. In the absence of appropriate experience over appropriate time and spatial scales, process-based models linked to expert systems and available experience is probably the most effective policy decision-support systems.

The difficulty in forecasting post-disturbance successional pathways in the face of the complexity of determinants that are involved must be recognized. However, landscape models driven by stand-level ecosystem management models that in combination account for the key determinants of succession should prove useful in policy evaluation until long-term empirical data on successional trends are available.

5. Possible Paradigms for MPB Policy Responses.

Predicting the future is fraught with uncertainty. The best one can do is to make forecasts on the combined basis of experience, the best available scientific understanding of the biophysical components of the target systems, and informed opinions about possible trends in human populations, values, politics, economies and actions.

Prediction of future trends in the biophysical components of forestry in the MPB outbreak area are constrained by uncertainties about future climates, successional pathways followed by disturbed ecosystems, and the occurrence and severity of future forest disturbances. However, if appropriate, knowledge-based assumptions are made with respect to data gaps, a variety of projections of plausible biophysical scenarios can be made. Future trends in human populations, values, economies and communities are harder to predict, yet some trends are apparent. There is a world-wide trend towards urbanization and the decline of small rural communities. Countering this is a movement of recent retirees to favorable environments away from growing cities (but many of these individuals return to centers with good medical care as age-related health problems take their toll). The replacement of relatively young working communities (with families and mortgages) by retirement communities changes the values that are sought and community acceptance of different forest practices and policy responses to events like the MPB epidemic. If these trends persist, the desired forest of the future will probably change from the previous desired future. Similarly, over the life of the forest that replaces the dead pine stands there is predicted to be a major shift in world politics and economies, with China and India emerging as major economies and markets, and the US dominance of the past 50 years waning. This will likely lead to a change in the type and variety of wood products desired from these forests. Technical advances in wood processing and engineering will similarly change the profile of usable forest products. And non-timber forest products will probably gain in economic importance.

Land uses will change as B.C. continues to be a desired destination for retirees from colder climates in Canada and as urbanites from the larger cities move, albeit temporarily, out into rural retirement situations. First Nations treaties will play an increasingly important role in the interior forests that have been so affected by MPB, with a different value set and different perceptions of the forest accompanying this land manager transition. Forest practices will continue to change under public pressure to manage for a set of values and environmental services that differ from those of the past. However, with the increasing evidence of the benefits of using natural range of ecosystem variation (NRV) and the partial emulation of natural disturbance as a guide (but not a rule) for forest management, and as some of the more fundamentalist environmental non-government organization (ENGO) groups acquire a deeper understanding of ecosystem function and the ecology of desired values and services, the trends in forestry of the past decade will probably be modified once again. While the desired outcomes may remain, the methods to achieve them will probably change from those recently or currently advocated by some ENGO groups.

The following scenarios are investigated against this background of diverse possible futures, and the considerable uncertainty surrounding such scenario analysis. Full scenario analysis requires a combined top-down-bottom-up modeling of the systems involved (human and biophysical) so the scenarios examined here are limited to a qualitative, conceptual analysis of three philosophically different approaches or paradigms that could be adopted.

Significant efforts have been made to describe (inductive), understand (deductive) and predict (synthesis) the course of the current epidemic, including some of its possible environmental consequences, and the expected social costs (see the conceptual model presented in Section 4). There has been an emphasis on how to "beetle-proof" the affected forests (an ecosystem-centric view; e.g., Whitehead et al. 2004), and how to utilize the dead timber (a social values-centric view). Alternatively, measures to prevent the wholesale salvage of as much wood as possible have been advocated based on wildlife habitat considerations (e.g., Eng 2004; a biocentric and conservation-centric view).

Much of this emphasis appears to reflect the desire to prevent future MPB epidemics in order to provide for social and ecosystem stability. There is a sense that the MPB beetle epidemic is an environmental and social tragedy if not a catastrophe. While much of the area affected by the present outbreak has long had a high risk of natural disturbance (by MPB and agents other than the MPB), the social consequences of the epidemic will be very hard for individuals and communities that depend on the affected forests for their livelihood. Part of the present problem appears to relate to past efforts to reduce the negative social effects of forest fire. There appears to be an understandable, though perhaps unrealistic, desire for a low-risk future forest (low MPB risk, low fire risk, and low social risk). However, other paradigms are possible and should be examined. We will examine three:

1. Low biological risk paradigm – an approach based on "ecosystem engineering" to create a desired condition that does not pose social risks associated with fluctuations in ecosystem condition.
2. Low social and community risk paradigm – acceptance of ecosystem risk and minimization of associated social risks by adaptation to ecosystem fluctuations; an

approach based on “social engineering” to maximize the ability of communities to adapt to the fluctuations of nature.

3. Balanced risk paradigm – limited management of ecosystem risk to create a balance between social values and the inevitability of environmental and biotic fluctuations in the forest of the interior of B.C. This approach involves zonation of the landscape into biotic risk management zones for the purpose of human community stability, and zones in which fluctuations in nature are accepted and institutional arrangements created to facilitate human community adaptation to them.

Paradigm 1 has some parallels with agriculture, in which natural variability is controlled to produce a regulated supply of agricultural products; soil variability is controlled by plowing, fertilizing and the location of fields on certain types of soil; biotic disturbances are controlled with agricultural chemicals or cultural techniques; climatic variability is controlled to some extent by irrigation and frost amelioration techniques. Paradigm 2 has some parallels with natural disturbances such as earthquakes, tsunamis, storms and major forest fires – events that are beyond the ability of humans to prevent or manage. The best we can do is to have early warning systems, mitigate damage through engineering of structures, and maximize the resilience of human communities to these events through modification of social, political and economic institutions. Paradigm 3 suggests a combination of early warning, harm reduction and institutional flexibility to promote adaptation of communities where the disturbance cannot be controlled and direct investment in disturbance management where this can be successful – a zonation approach.

5.1. Low Biological Risk Paradigm

A future forest that has a low risk of large-scale disturbance would be one in which there was low risk of insect epidemics, low risk of fire, low risk of disease, low risk of wind damage, and low risk of adverse effects on tree growth due to possible climate change. It would also have low risk of failure to gain a social license to harvest timber values. Not only would the future forest need to be beetle-proof, but also other insect-proof, fire-proof, disease-proof, wind-proof and have aesthetic and wildlife characteristics that constitute sustainability in the eyes of the public.

What type of forest would this be? Monoculture lodgepole pine grown to the age at which it is prime MPB habitat, coupled with predicted warming of the climate, would appear to be incompatible with a low risk forest. In the absence of fire, and particularly if uneven-age or variable retention (VR; complex stand structure; Franklin et al. 1997, Arnott and Beese 1997) and long rotation management systems were to be practiced, the pine mistletoe could become a serious risk to timber values and increase the risk of fire. Extensive areas of even-age pure spruce or Douglas-fir would pose risks, including spruce leader weevil, Douglas-fir beetle, spruce budworm, Douglas-fir tussock moth, or frost damage. Depending on how these forests were harvested in the future, pure stands of disease-susceptible tree species would pose increasing risks of root and stem fungal diseases and parasites (e.g., mistletoe; Thomson et al. 1997, Geils et al. 2002) unless subjected to disturbances (e.g., fire) that would reduce this risk.

How could these biological risks be reduced? MPB risk might be minimized by harvesting lodgepole pine at a younger age, but this poses problems of harvest and milling economics, wood quality, and marketability of products. It would also increase the area of young forest with implications for habitat of some wildlife species. This strategy would not reduce the risk in parks, protected areas and the non-contributing land base (areas where epidemics have sometimes been initiated) unless pine were to be removed from these areas. Fire risk could be reduced by cleaner logging on shorter rotations, but this would reduce the abundance of snags and coarse woody debris (CWD) in harvested areas, unless significant retention was applied in VR systems. Significant retention in the absence of fire would pose risks of mistletoe. The silvicultural strategy of lower stand density poses risks to wood quality (wide rings and branchiness) and incomplete stand stocking because of additional tree mortality agents. The alternative strategy of higher densities reduces tree size, lengthens rotations and may reduce tree vigor. Other possibilities include the following:

- Extensive stands of pure, even-age spruce may pose risks of leader weevil damage which can degrade stem values, slow early stand development (lengthening the period of licensee obligations), lead to plantation failure, and will lengthen rotations in comparison to pine stands.
- Extensive stands of even-age Douglas-fir can experience frost damage in some areas and this may delay or prevent such plantation establishment. They may become susceptible to Douglas-fir beetle.
- Extensive stands of hardwoods – aspen or birch according to BEC zone and site type – would avoid many of these risks, but may offer lower economic values and have lower value for some species of wildlife.

Mixedwoods have much to offer for a lower biological risk scenario, but are more difficult to manage and harvest according to what concept of mixedwoods is applied. Tree-by-tree mixedwoods pose many silvicultural and harvesting challenges but might offer the lowest overall stand-level biological risk. However, there are other mixedwood concepts. Mixedwoods as a mosaic of patches of individual species pose lower silvicultural and harvesting difficulties, the scale of the mosaic that still constitutes a mixedwood depending on the dimensions of the ecotones between the patches. A mosaic of monoculture patches in which >50% of the stand area is in this ecotone is a mixedwood. There are also temporal mixedwoods – the alternation of monocultures of different species constitutes a temporal mixedwood. If the sequence of monocultures, or monocultures and mixedwoods, approximates characteristic successional sequences for the site and region, such temporal mixedwoods will emulate nature much more closely than any attempt to maintain any particular mixedwood stand condition unchanging over time – which usually is not possible anyway. Major challenges with a mixedwood scenario include economics, the difficulty in conforming to management regulations, the greater difficulty in inventory and predicting growth and yield, and problems in planning timber supply to meet mill requirements and respond to market opportunities. Mixedwood stands may yield a greater variety of log sizes as well as the variety of wood types, posing challenges for milling and drying, respectively, unless the component species of the mixedwood go to different mills. This tends to support separate licenses for the conifer and hardwood components of mixedwoods, with all the management problems attendant on mixed licenses in the same stand. Mixed evergreen/deciduous stands may also result in larger branches and knot sizes and longer live crowns for evergreen conifers, which has implications for wood quality and value.

Development of low-risk forests would almost inevitably move the forest out of its NRV as we know it and would alter “natural” pathways of ecosystem development in the wake of large scale disturbances. This has implications for a variety of values, including some measures of biodiversity and landscape patterns of variation. Before attempting to achieve such a low biological risk forest condition, careful value trade-off analysis would need to be undertaken to identify the cost for any one forest value of attempting to achieve stability and low risk for other values.

5.2. Low social and community risk paradigm

An alternative to minimizing biological risk through management is to accept such risk and deal with the consequences. This approach is clearly unacceptable in the case of risks such as fire, which can destroy property and threaten lives and livelihoods. The social consequences of accepting biological risks may also be unacceptable. This was the case in New Brunswick where the forest industry and forest-dependent communities would have collapsed if the balsam fir forests had not been protected from the spruce budworm for decades by spraying. However, the situation with MPB is different. Spraying is not an option, and it appears that MPB epidemics cannot be stopped when there is a conjunction between beetle-favorable climatic conditions (which foresters cannot control) and the age/condition of pine stands and pine-dominated landscapes (MPB habitat). Converting such vast landscapes of MPB habitat to a low beetle-susceptibility condition would require several centuries and/or enormous investments. Alternatively, affected stands could simply be salvage logged (to varying extents) when there is an outbreak, with investments with respect to MPB being put into early detection and the ability of human communities to adapt to the consequences. Moreover, a significant proportion of the revenue generated during periods of elevated salvage harvest should be invested to sustain communities through periods of reduced harvest following such disturbance events. The objectives of such investments may include diversifying the local economy and generating revenue from interest, etc.

Adaptation to risk involves the ability to predict the future occurrence of risk in sufficient time to make the necessary social, economic and technical adjustments. Where risk is closely related to stand structure and species composition and to landscape patterns of stand variation, acceptably accurate predictions should be possible using pest population dynamics and risk models at stand and landscape scales. Where risk is largely related to climate change, the ability to predict risk will be much lower, with negative consequences for adaptation planning. However, as climate change modeling becomes more sophisticated, predicting the climatic component of MPB risk may become more reliable.

Key facets of social adaptation will involve the ability to make temporary adjustments to AAC and tenure arrangement to provide the flexibility to respond to nature’s variations.

Union contracts will similarly need to have the flexibility to respond to unmanageable disturbance events. There will need to be flexibility in milling, manufacturing and marketing to ensure that wood products and associated social values resulting from natural disturbances can contribute positively to local communities and the provincial economy. A flexible and adaptive marketing strategy will be required to ensure that the flood of salvage harvested wood products can find and reach willing markets. All this poses significant social challenges, but no greater than challenges associated with trying to prevent events such as the present MPB epidemic.

The key to this scenario is willingness on the part of all involved in the forest resource sector to accept risk and be prepared to adapt to it. Once a social license for such an approach is achieved, policy makers and planners will need to invest significant resources on an on-going basis in order to plan for the rapid-response changes that may be required. Just as forest fire requires constant monitoring and response planning, risks such as MPB epidemics will have to receive similar investments under this paradigm. Planning the multi-value response to these risks will require sophisticated risk prediction models, linked into multi-value, meta-modeling frameworks and accompanied by field monitoring of MPB population dynamics and spread as an on-going check on the accuracy of the predictive models. These would become the core of the planning process; they would be used to examine value tradeoffs expected to accompany alternative adaptive responses. The tools would require linkage to public communication vehicles (e.g., visualization systems) that can address all of the key resource values and present the options and predicted tradeoffs to the various different “forest stakeholders” in an understandable format. Success in gaining public support for this approach is expected to be closely related to the success of these communication tools. The approach is expected to fail unless the planning process can involve the key “publics” on an on-going basis. When such support is sought at the 11th hour, public support is unlikely since public health and safety and personal property values are unlikely to be threatened (other than declining real estate values if MPB epidemics result in declining economic activity and employment) the way they are by forest fire.

In summary, this paradigm is somewhat analogous to the recent Pacific tsunami. The event could not be stopped or even managed. The best that could have be done would have been to have an early warning system and the organization of the local communities and economy to be prepared for such an eventuality and thereby to reduce harm (e.g., by not locating housing and economic activity in the high danger zone). It appears unlikely that another MPB epidemic on scale of the current outbreak could be prevented once conditions favor it, and unlikely that landscape age-class patterns and stand species composition could be changed on a scale that would significantly lower the future risk. On the other hand, the risk of the next major MPB epidemic can probably be predicted in advance with reasonable accuracy; indeed, entomologists had been warning for some time about the risk of the present outbreak. They already have predictors that have been shown to be an acceptable early warning system (refs. in Shore et al. 2004). What is required in this paradigm is for governments and communities to evaluate the social risks and develop institutional responses that permit adaptation to future events. Unlike forest fire, MPB epidemics develop over several years and the early warning systems can give sufficient advanced notice such that community adaptation to the event would be possible. This is only feasible if all parties are willing to be flexible and open to change and adaptation.

5.3. Balanced Risk Paradigm

This paradigm represents a compromise between the "biological risk avoidance" approach of the first paradigm and the community adaptation approach of the second paradigm. It would involve lower investment in reducing biological risk than in the first paradigm, and lower political, social and technical constraints on success implicit in the second paradigm. Thus, it should have a higher probability of success in achieving its objectives.

The balanced management of risk in this third paradigm involves identification of ecosystem types at appropriate locations (productive sites relatively close to human communities and wood processing centers) on which intensively managed stands could be established that would provide a relatively low risk source of quality wood, accounting for a significant proportion of the fiber supply requirements for the local economy. Such plantations would vary in species composition and age class to provide the desired product with minimum biological risk. Their focus would be on fiber production while sustaining soil and water quality. By increasing the productivity of these stands through management, pressure to maintain constant fiber supply from other areas would be reduced. This paradigm would allow for community stability by providing a relatively steady base level of employment and wood supply. The intensively managed areas would be established as a mosaic within less intensively managed stands which would provide for other values, such as wildlife habitat. Outside of these intensive areas, natural patterns of forest development and succession would be permitted, with only modest investments to address future timber supply. Such extensively managed areas would have a strong emphasis on non-timber values.

This third, balanced management of risk paradigm includes the following elements:

- Identification of management objectives, including a desired future forest condition, specific to BEC zones and subzones, to site types within subzones, and to locations relative to communities and wood processing centers. This zonation would identify the areas in which biological risk would be minimized, and areas where it would be accepted. This zonation would be based on local knowledge and circumstances.
- Consideration of possible climate change and its potential effects on zone/subzone boundaries, the vegetation potential by site type, and the risk of biological and physical disturbance.
- Development of strategies to move towards the management objectives and desired forest futures for the different management zones, allowing for the effects of climate change such that traditional successional pathways may be preserved. These strategies should work with natural processes as much as possible so as to remain within the realm of economic possibility.

- Development of institutional mechanisms that permit local communities and the various levels of government to adapt to disturbance events in the risk-acceptance zone. These mechanisms would be designed to reduce social risk.
- Renewal of lodgepole pine forest should be accepted where this is the best species for the site, even if MPB may require its harvest at an earlier age than would be chosen without MPB, or simply accept the need to "chase beetle" – the MPB sets the timing for future harvest.
- Where ecologically appropriate and economically feasible, move monoculture stands towards mixed species stands, but only after considering harvesting, milling, management, biodiversity, wildlife, employment, economic and other factors, and conducting value trade-off analysis to ensure that this is the most desirable option. Conducting such analyses requires the use of hierarchical decision-support systems including ecologically based stand and landscape level harvesting and disturbance risk models. Such meta-modeling frameworks would act as an early warning system to identify biological risk probabilities to facilitate social adaptation. Such systems should include visualization and other communication tools to facilitate dialogue with the public and specific forest stakeholders.

5.4 Discussion of the paradigms

> "A thing is right when it tends to preserve the *integrity*, *stability*, and *beauty* of the biotic community. It is wrong when it tends otherwise"
>
> "The evolution of a land ethic is an intellectual as well as emotional process. Conservation is paved with good intentions which prove to be futile, or even dangerous, because they are devoid of critical understanding either of the land, or of economic land-use"
>
> (Aldo Leopold, The Land Ethic)

The first of these two quotations from *The Land Ethic* (Aldo Leopold 1966) has contributed to the widespread belief that ecosystem integrity is preserved by creating a stable condition in which none of the components, relationships and processes of the ecosystem change, and the result is a beautiful forest and landscape. It has been used to promote the idea that disturbance which causes a change in species, ecological relationships and processes and converts the "beauty and order" of undisturbed nature into "ugliness and untidiness" threatens ecosystem integrity.

The second quotation warns that development and implementation of a land ethic, and thereby the fulfillment of our sustainability and intergenerational obligations, requires an understanding of both ecosystems (the "land") and human valuation and utilization of them. Leopold clearly understood that stability and integrity in ecosystems and biotic communities involves non-declining patterns of change over time and space scales that match the natural dynamics of the ecosystems and species in question. He understood the need for humans to achieve reasonable stability in the supply of products and services from forests, but equally that we must respect the natural ecological role of change in ecosystems and must adapt to the way nature works.

Leopold probably would not have supported the first paradigm – there are limits to the extent that humans can "tame" nature and create "stability" without enormous inputs of energy and materials, and without creating new environmental problems. He would probably have accepted that society has limitations on the degree to which it can adapt to the wilder fluctuations of nature, and so he would probably not have accepted the second paradigm without modification. As a farmer, forester, fisher and hunter, he understood that management is necessary to permit human uses of nature to be sustainable. He would probably have accepted the intent of the third paradigm.

There are abundant examples from around the world of the futility and/or enormous energy and financial costs of trying to "engineer" natural ecosystems to fit human objectives when these are inconsistent with the ecological characteristics of the ecosystems in question.

- Intensive farming of marginal and infertile farm land; irrigation of deserts in various countries and the removal of eucalypt forests in Australia for sheep farming that led to soil salinization;
- excessively short tree crop rotations coupled with burning to control weeds in China leading to massive yield decline;
- herbicide control of aspen in boreal mixedwoods to release spruce growth leading to the killing of spruce due to competition by grasses;
- urban development in floodplains or on steep, unstable slopes; subdivisions in fire-prone forests and shrublands.

In all these examples, land use and management practices were applied based on one or more of the following: an incomplete assessment of the situation, the application of strategies from ecosystems where they may have been sustainable to ecosystems where they were not, the use of management practices that damage key ecosystem processes, and the development of policy to meet a narrow set of objectives. Great care must be taken in developing the policy responses to the MPB epidemic to avoid repeating such errors. Based on these considerations, "beetle-proofing" the forest is probably unachievable within current economic realities and would probably have unacceptable consequences for other values. Political and social constraints on community adaptation to unfettered natural variation would probably prevent the *laissez faire* approach of relying entirely on community adaptability. Most communities and economies require a certain level of stability to function. Consequently, the third paradigm may be the most attractive of the three.

6. Limits to Policy Response

Perhaps the greatest barrier to developing an effective policy response to the MPB epidemic is the complexity and multi-value characteristic of the issue. This complexity manifests in the interdependent biological and social systems within which the MPB issue exists (Section 3), but also within provincial and federal institutional structures tasked with the development of policy.

The current B.C. government web site lists the following ministries that presumably have significant interests in the issue: Finance, Treaty Negotiations, Forests, Human Resources, Provincial Revenue, Small Business and Economic Development, Sustainable Resource Management, Water, Land and Air Protection, Community, Aboriginal and Women's Services, and Tourism BC. Undoubtedly, other ministries will have interests in the issue and its resolution. Moreover, responsibilities within the Ministry of Forests (MoF) are further distributed between a series of branches and other institutional structures. The Forest Analysis, Forest Practices, Research, Tree Improvement, Compliance and Enforcement, Strategic Policy and Planning, Aboriginal Affairs, Economics and Trade, Resource Tenures and Engineering, and Revenue Branches are all likely to have an interest in the MPB epidemic issue. This complexity of institutional structures that have connections to the issue, and therefore should have an interest in policy developed with respect to the MPB epidemic, poses difficulties in addressing the issue in a comprehensive, systems analysis manner. Additional complexity derives from its linkage to the political system of government which almost guarantees change over time. This complexity poses formidable policy development challenges.

A second major limitation on policy development is uncertainty and incomplete knowledge. While much remains to be learned about the ecology and biology of the MPB and the effects of the present epidemic on ecosystem characteristics, a great deal is known, thanks to the work of researchers and the experience of field foresters, First Nations and others. Less certain is the cumulative effect on the provincial ecosystem of policies and practices related to salvage of dead pine and how to manage the forest with respect to possible future epidemics. Even less is known about the over-riding effects of possible climate change, which could frustrate attempts to create a desired future forest condition. The politics of trade such as the softwood lumber dispute with the US also poses uncertainties and political constraints on various aspects of the government response to the epidemic.

Conclusions that can be drawn from this complexity and uncertainty are: 1) the need to focus investments in research on resolving the key uncertainties (to the extent that this is possible), and 2) the need to harness the knowledge and understanding so gained into multi-value systems analysis tools (decision-support systems) that would have the capability of providing input to decision making by most or all of the key branches in MoF and to other key ministries.

Dealing with uncertainty and information exchange between branches of the MoF and other ministries is not new of course; it happens all the time. There are long established mechanisms to deal with such issues. However, history suggests that these mechanisms are not very efficient with the result that government policy developed in one branch of one ministry, or by one ministry, is often in conflict with the conclusions of other branches or other ministries, respectively. The politicians are then left with making choices between competing recommendations from different bureaucratic institutions; choices that are often not optimal because the full range of trade-offs between alternative policies for multiple values has not been adequately investigated. The organization of governments around the world suffers from the same problem; an inability to deal adequately with the complexity of "wicked" problems. The government of B.C. is no different. Unless this institutional shortcoming is addressed, it is almost certain that policy responses to the MPB epidemic will entail internal conflicts and contradictions, and will fail to balance short and long term considerations, competing values, and local vs. regional concerns.

One is reminded of the origins of the Clayoquot Sound debacle. The political desire to extinguish old tenures (Timber Licenses (TLs)) or to raise the rental on these tenures led one branch of government to impose decisions that had very significant consequences for forests and forestry in the area. The Ministry of Forests should have been the lead agency, but was not fully involved in the decision making until after the TLs had been logged, and then was not supported financially at a level that could resolve the environmental damage that had been done. It was only pressure of public protest that arrested the sequence of events that was occurring largely because of inadequate information exchange and linkage of policy development between all the key ministries. Another example is the decision in the late 1960s to raise more government revenue to pay for the Columbia River Treaty dams. This led to "third band" wood (there were other considerations in this, including development of the interior saw milling and pulp industry), a great increase in AAC and an acceleration of harvesting. These decisions were clearly not subject to careful analysis to examine all significant implications. Once again, it was public concern (in the form of the published concerns of a Kelowna architect John Woodworth) that led to a re-examination of the issue and contributed to the beginnings of the 5-year Timber Supply Review process. Other examples of inadequate policy development linkages within the MoF include the "zero tolerance of waste" regulation, and the "10 ft (3 m) rule" on snags. Both of these regulations were targeted at a specific, narrow question or issue, and were implemented without a comprehensive analysis of their implications for other values or the interests of other forest stakeholders.

Clearly, there are many examples of the failure of forest policy development to account for the complexity of issues. The same policy limitations that led to these undesirable past policies/regulations still exist today and must be overcome if policy with respect to MPB is to be optimal and effective.

7. Research Perspectives: Past, Present and Future

Research efforts with respect to MPB over the past few decades have been led by entomologists who have accumulated much useful information about MPB population biology and have arguably provided the most valuable insight towards dealing with the MPB problem to date (e.g., Carroll and Safranyik 2004; Safranyik 2004). While much remains to be discovered through research, advances in entomological knowledge and understanding have provided the basis for risk assessment and predictions about the likely course of the outbreak under different climate scenarios. Amongst all the uncertainties associated with this complex issue, MPB biology is probably the lowest thanks to their work.

What is uncertain is how the forests affected by the MPB epidemic will respond if no action is taken, or if a variety of management interventions are imposed. Even more uncertain is how such interventions will affect the social and political aspects of the issue. The wood science side of the issue is paying considerable attention to the issues of "shelf life" of dead trees, how to utilize the salvaged wood, and how to market the products. However, much remains to be done in this area, and there is always uncertainty about markets – the unstable value of the dollar, international trade barriers, and public perception of the products.

There are many biophysical and socioeconomic aspects of the epidemic that require more detailed analysis. Examples of key biophysical questions that must be addressed include the following:

- What will the successional pathways be following MPB–induced mortality, and how will these be affected by alternative salvage and post-disturbance management?
- What will the effects be on wildlife habitat and various measures of biological diversity (Chan-McLeod and Bunnell 2004)?
- How will MPB disturbance of pine forests affect soil processes and how will this compare with fire and harvesting (e.g., Wei et al. 2003)?
- How will all these impacts vary over time as a result of within-ecosystem (autogenic) processes of succession?
- How will ecological succession and other stand-level aspects of the post-disturbance ecosystems be affected by landscape-level processes and anticipated climate change?
- How might the dynamics of beetle dispersal and impacts change as the MPB moves into Alberta and begins to inhabit forested landscapes (including jack pine) with no history of MPB attack?

The large number of variables involved (e.g., soil, site series, accessibility for salvage, salvage method, stand condition and tree species composition, size of mortality patch, distance to seed sources, frequency of seed production and dispersal distances, climate change and other factors) make biophysical generalizations difficult, especially if the policy and practice decision-making process lacks, or does not use, tools that are capable of incorporating many if not all of the key determinants. Difficulties posed by inaccurate forest inventories add to the challenge.

In addition to the many research needs in the biophysical domain, as much or more work is needed in the political, economic and social aspects of the issue. These include the following:

- What will be the long term effects of AAC fluctuations for forest-dependent communities?

- How will the glut of dead pine wood affect lumber prices and softwood tariff negotiations?
- What transitional economic strategies will be needed for communities that have expanded their economic activity and population during the AAC "uplift" period when the AAC is reduced?
- How will a social license be obtained for various different post-epidemic management options given the lack of trust between various environmental non-government organizations (ENGOs) and forestry, and the dedication of some ENGOs to block any AAC uplift and to impose far-reaching restrictions and a rigid regulatory approach on forestry?
- How will social and environmental value conflicts be resolved?
- How will the outbreak affect treaty negotiations?

Having identified the many well known specific questions that constitute information gaps or inadequacies in terms of policy development, what is the priority for research? What are the key limitations with respect to policy? There is no single answer since there are many significant uncertainties and information shortcomings, and research is needed in many areas to address these. However, one of the most important needs is seen to be the creation of multi-value decision support systems that can be used both to synthesize existing knowledge and understanding and the products of new research, and to facilitate scenario analysis. Such systems would span from expert-systems based approaches including meta-analyses and summary reviews (e.g., Bunnell et al. 2004) to hierarchical meta-modelling frameworks (e.g., Seely et al. 2004). As a broad generalization, human action is often limited as much or more by our failure to apply what we already know as by what we don't know. Thus, a major component of research should be to create a framework for integrating the diverse knowledge set required to untie this particular Gordian knot. This framework should not be permitted to develop separately from research. Unless the research includes a mechanism for feeding into decision support systems, its value with respect to policy development would be significantly diminished.

MPB-related modeling work over the past decade has resulted in useful advances, especially in the biophysical modeling of MPB risk and spread across the forest landscape. *The Provincial Level Projection of the Current MPB Outbreak* (Mountain Pine Beetle Initiative, Canadian Forest Service and BC Ministry of Forests) appears to be a very useful development, addressing probabilities of the spread and duration of the current outbreak, and the effects on timber supply under varying "shelf life" and management constraint relaxation scenarios. This projection activity is very much focused on the present outbreak and its implications for wood-based resources. Concerns have been raised about the conservation implications of various salvage policy scenarios (Eng 2004, Lindenmayer et al. 2004), but it appears that these have not yet been explored in stand- level ecosystem management models, or in landscape models driven by such ecological stand-level models.

The current MPB modeling effort appears to be relatively limited in terms of dealing with stand-level ecosystem processes, the mechanistic projection of possible successional pathways under alternative management scenarios, and the important consequences of climate change for multiple values. These topics, which have not yet received adequate attention, have implications for many values, including long-term employment, future timber supply, First Nations involvement in forestry, the diversification of tenures, community stability, wildlife, conservation, water supply and fish habitat, and recreation. The recommendation with respect to research is that greater efforts should be made towards the development of multi-value decision support systems (and the underlying modelling frameworks) for scenario analysis and value tradeoff analysis across the many different sectors of BC forestry to capitalize on and complement all the useful research activity focused on the MPB and timber. This does not imply the development of a mega model. Rather, it suggests that a series of sectoral models be linked in a meta-modeling framework that has the capability to examine the ramifications of the MPB epidemic and society's responses to it for the many different values that our forests provide to BC society, the rest of Canada and the world. This meta-modeling framework should adhere to Occam's Razor and the admonition of Albert Einstein – it should be *as simple as possible but as complex as necessary*. Its output should be in formats that facilitate communication of scenario and tradeoff analysis results to the many different arms of government and the many different forest stakeholders in BC and Canadian society. Existing models such as the MPB/SELES model (Fall et al. 2004) and the FPS ATLAS-based UBC Model (Nelson 2003a, b) and others should be evaluated to assess their potential for use as frameworks within which to create such meta-models. Seely et al. (2004) provide an example of the linkage of landscape, stand and wildlife habitat suitability models into a framework suitable for examination of the multiple impacts of MPB. Stockdale et al. (2004) note the need to link landscape models to stand-level models.

A difficulty with very large models is that of communicating the results and their uncertainties to a wide variety of audiences that have a wide variety of technical backgrounds. They also pose challenges to information handling. Because there are many possible policy choices and many values and environmental services affected by the choices, such models can overwhelm their users with their prediction-based information. In developing the comprehensive management decision and policy support systems suggested above, a considerable portion of the effort should be invested in the development of communication vehicles, involving the work of psychologists and other social scientists trained in human perception and communication (Sheppard and Harshaw 2000). Considerable attention should also be focused on developing user-interfaces, and information management systems to handle the large arrays of value tradeoffs that must be considered. Without these communication and user interfaces, the value of decision support systems will be significantly diminished.

8. Summary and Recommendations

1. Policy with respect to the MPB epidemic should address the social and environmental complexity of the issue and should not be based on narrow sectoral considerations. Furthermore, it should reflect the wide range of values and environmental services provided by the forests affected by MPB based on an integrated, systems analysis of

central issues. Short-term considerations are obviously important, but these should be balanced against long-term issues.

2. A choice could be made between minimizing biological risks such as MPB epidemics by maximizing ecosystem stability vs. accepting the dynamics of nature and investing in maximizing the capability of human communities to adapt to such dynamics. A hybrid between these two approaches might be a better choice, involving a zonation of forest lands into those suited for minimizing biological risk, and those where disturbance will be accepted as a driving factor in harvest patterns and rates. In the latter case, a focus should be placed on facilitating community adaptation to minimize social risk.

3. Development of policy with respect to the present and future economic, social and environmental aspects of the MPB epidemic should be based on comprehensive scenario and value-tradeoff analyses. It is very unlikely that there is a single "correct" policy choice: only many alternative plausible choices, each associated with a different range of potential outcomes and resulting in a different balance of values and environmental services. Analysis of alternative policies would benefit greatly from the use of decision-support systems that are capable of addressing the complexity and the temporal and spatial scales of the issue.

4. Comprehensive decision-support systems suitable for this purpose already exist (to varying degrees) as modeling frameworks involving the linkage of sectoral sub-models. Because the issue is fundamentally one of forest ecosystem dynamics and disturbance, such decision-support systems should be (where possible) driven by "bottom-up" ecosystem management models (e.g., models that capture knowledge and experience, then combine these with products of process-level research that provide understanding of the key determinants of the issue). However, in the absence of appropriate experience with such a large-scale MPB epidemic and in the face of climate change, there is a risk that decision-support systems based solely on knowing and understanding will prove inadequate.

5. Combined experience/process-based ecosystem management models should be linked to large-scale landscape management and natural disturbance models in a hierarchical structure to provide biophysical assessments of possible outcomes of forest management policy with respect to MPB as well as flows of forest products and conditions to facilitate an examination of tradeoffs between biophysical and social values.

6. Decision-support systems in forestry in general, and in the MPB epidemic in particular, should include visualization (where appropriate) and other communication media to facilitate the involvement of a wide variety of technical and non-technical stakeholders in the debate about policy options and choices. In the absence of such components, the complexity of the issues acts to limit their informed involvement. User interface and information management systems should be developed to ensure

that these tools are accessible, understandable and useful to a wide variety of interested parties.

7. Research in support of MPB policy should continue to identify and fill information gaps, but this should be done in the context of the decision-support systems (of all types) that will use the resultant knowledge and understanding. All too often scientific research that is proximally or ultimately intended to contribute to a more sustainable management of forests is conducted in the absence of such an explicit linkage, and this reduces its effectiveness in the policy arena. While basic research unfettered by policy considerations should always be supported, the urgency of issues like the MPB epidemic requires that wherever possible this research-policy linkage be made explicit and used to guide the design of the research.

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