Science in Forestry: Why does it sometimes disappoint or even fail us?

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ABSTRACT

Society invests in science to advance human interests and limit human impacts on the environment. However, despite great progress in forest science, governments and forest companies remain reluctant to invest adequately in research. We believe this reflects the perception that forest science serves itself more than forestry, and that one determinant of this perception is a misunderstanding of science. Science involves knowing, understanding and predicting. Many feel that only the reductionist, disciplinary, hypothetico-deductively-derived understanding component is hard science. Inductively-derived knowledge and experience are often regarded as soft science. Predicting future states of forests involves complex hypotheses that are not amenable to traditional hypothesis testing and, according to some, this renders prediction of complex systems soft science. Science-based forest policy frequently employs hard science: the understanding component of science based on reductionist, jigsaw puzzle research. Necessary for the development of SFM, this is not sufficient for reliable prediction of possible forest ecosystem futures, for which knowledge and understanding must be synthesized into decision support systems at appropriate temporal, spatial and complexity scales. These should be linked to visualization software to create a common language by which to communicate to a diversity of audiences the available choices and their possible consequences.

Key words: science in forestry, forest policy, ecosystems, prediction, decision support systems, visualization, “jigsaw puzzle” science, hard science, soft science

RÉSUMÉ

La société investit dans les sciences afin de faire progresser les intérêts humains et de limiter les effets humains sur l'environnement. Cependant, malgré les grands progrès effectués en science forestière, les gouvernements et les compagnies forestières demeurent hésitants à investir adéquatement en recherche. Nous croyons que cela reflète la perception que les sciences forestières sont plus utiles à elles-mêmes qu'à la foresterie et qu'un élément prépondérant de cette perception réside dans l'incompréhension de ce que sont les sciences forestières. Les sciences portent sur la compréhension et la prédiction. Plusieurs personnes considèrent que seul les éléments de compréhension réducteurs, rattachés à une discipline, basés sur des hypothèses et des déductions constituent les sciences pures. Les connaissances acquises par induction et l'expérience sont souvent considérées comme des sciences appliquées. La prédiction des états futurs des forêts comporte des hypothèses complexes qui ne sont pas assujetties aux essais standards d'évaluation et, selon certains, cela transforme les prédictions portant sur des systèmes complexes en équivalant de sciences appliquées. Les politiques forestières dérivés des sciences utilisent fréquemment les sciences pures : les éléments de compréhension basés sur des recherches réductionnistes plus près des casse-tête. Nécessaires pour l'élaboration de l'AFD, cela n'est pas suffisant pour obtenir des prédictions fiables sur l'avenir envisageable des écosystèmes forestiers, pour lesquels les connaissances et doivent être synthétisées dans des systèmes d'aide à la décision en fonction d'échelles de temps et d'espace appropriées et complexes. Le tout devrait être relié aux logiciels de visualisation afin de créer un langage commun par lequel il est possible de communiquer avec plusieurs niveaux d'auditeurs les choix disponibles et leurs conséquences envisageables..

Mots clés : sciences en foresterie, politiques forestières, écosystèmes, prédiction, systèmes d'aide à la décision, visualisation, sciences « casse-tête », sciences, pures, sciences appliquées

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Introduction: The Role of Scientific Knowledge in the Evolution of Forestry

The very early stage of the relationship between humans and forests has generally been characterized by belief systems about nature (for a useful discussion of the various meanings of "nature," see Peterken 1996; nature as used here includes humans as a natural component of forest ecosystems). Events are ascribed to mythical powers, magic and/or the Deities. At this stage, there is usually little active management — the relationship is one of exploitation⁵ to satisfy the needs of the local population. Exploitation is sustainable if there are few people and their technology prevents them from causing significant ecosystem change (i.e., the impacts do not exceed the resilience of the ecosystems in question). Over time, belief systems may be modified by experience, and experience-based passive or active management may develop.

As the size of local or regional human populations and the power of their technology increased, human impacts exceeded the resilience of forest ecosystems and altered their character. Colonization of societies by technologically more advanced people from crowded and ecologically different countries generally resulted in the loss of local knowledge and experience ("indigenous knowledge"), and the moderating influence this experience had on the use of environment and resources (e.g., Koppes 1988, Brosius 1990). Both developments led to non-sustainable exploitation and ecosystem alteration. Resource depletion followed, creating the need and the political environment for the development of institutional forestry.

The first stage in the development of institutionalized forestry⁶ ("administrative forestry"; Kimmins 2004) is generally characterized by rules and regulations intended to sustain supplies of one or more resources. However, rules and regulations at this stage of forestry have rarely been based on adequate local knowledge, experience and understanding of the ecosystems and values in question. As a consequence, they have generally failed to respect and sustain biological diversity and ecosystem function, and related values and environmental services.

Forestry evolves as knowledge of particular forest stands and landscapes increases and is incorporated into the design of forestry activities. The first major modification of administrative forestry is the development of an ecological basis for timber-focused silviculture. This is followed in time by site-specific, "ecosystem-based management" (EBM) in which forests are managed for multiple values, largely from the perspective of biophysical science. Under EBM, individual values are often managed by different agencies under different management plans; there is a failure to manage all values as a system under a single integrated plan. The separate management of the individual components of the ecosystem generally results in suboptimal management of the overall ecosystem, and this often leads to conflicts between different resources and values. Only when the forest is managed as a system

⁵Exploitation is defined here as the utilization of a forest resource or resource value without any explicit action to ensure its renewal.

⁶Forestry is defined here as the art (skill), science, practice and business of managing forest stands and forested landscapes to maintain an ecologically sustainable and socially desired balance of values and environmental services. Such forestry is also referred to as stewardship.

under a single management plan that balances social and biophysical values in a sustainable, ecosystem management (EM) framework can we fulfill the fundamental intent of forestry — stewardship — as defined above (Fig. 1).

As forestry evolved, experience (the accumulation of empirical knowledge over time) continued to be the main foundation for decision-making; even today most forest planning tools are still experience-based. Experience is the most reliable basis for forestry as long as the future environmental and management conditions remain constant or change only slowly. It is an incomplete basis for forest planning in a future for which we lack experience. To cope with a changing and uncertain future we need to combine experience with an understanding of the ecosystem processes and structures that collectively determine the character of the forest and how it responds to management and natural disturbance. This understanding should be provided by the biophysical sciences, but the incorporation of science into forestry has not occurred to the extent that it should.

There are at least three impediments to the trend towards science-based forestry:

1. While the public has expressed the wish that land use policy and resource practice debates be science-based, all too frequently public groups (e.g., ENGOs) have brought "their" eminent scientist to the table, and industry "theirs." The two have presented science-based but often contrary arguments — both sides coming from published research in well respected journals. The result is conflict where science was supposed to help resolve conflict.

When scientists involved in controversial land use and forest practice planning processes disagree, they often present conflicting, science-based interpretations. With significantly different opinions, issues of "our science" vs. "their science" arise. This leads to confusion on the part of the public who generally believe that science should provide the definitive answer. This raises questions about the usefulness of science in resolving resource issues. Out of frustration, people may pursue a purely political process in place of a science-based process ("postural anti-scientism"; Medawar 1984), or simply assert their belief systems (Dasmann 1988). These belief systems are inappropriate if they fail to reflect our current understanding of the structure, function, dynamics and diversity of nature. This can force a return to an earlier stage of forestry (Fig. 1).

2. For many people "science" constitutes only the physical and biological sciences. The social sciences are often marginalized. From the definition of forestry given above, it is clear that forestry is about people — their values, needs and desires (Westoby 1987). While ecological and other biophysical sciences form an indispensable foundation, forestry problems cannot be resolved without an equal focus on people (Medawar 1984). Failing to address social issues adequately, biophysical science fails to address the complexity of issues in forestry.
3. There is a profound lack of understanding of what science is. Many people assume there must be a single, correct solution to a problem because problems can be explained and predicted by science. There is a general failure to recognize the uncertainty and risk in science-based predictions, factors that result in many different possible forest futures. There is also a failure to recognize that risk and uncertainty are aggravated when science that looks only at

individual subcomponents of ecosystems — “jigsaw puzzle science” — is used as the basis for policy and practice in the management of those ecosystems.

This third impediment is one reason why science has often disappointed forest planning processes and it is a major cause of the first impediment. We now discuss how the full engagement of social and biophysical sciences and their integration with human-defined value systems might be accomplished to achieve the goals of sustainable, multi-value, ecosystem management.

The Issue: What is Science and What Should Its Role be in Land Use Planning Decisions?

The three objectives and components of science

Science is a human activity that relates to our need to know, understand and predict the objects, conditions, processes and/or events that are the focus of the science. It is generally driven by the desire of society to address persistent problems⁷ — to make things better (Medawar 1984). These problems are usually complex and difficult to understand (sometimes referred to as “wicked problems”⁸), and they are generally beyond the ability of belief systems or experience to resolve them. Herein lies the rationale for science in general, and science in forestry in particular — a way of knowing, understanding and predicting, and thereby dealing with complexity.

Science can be reduced to three complimentary components or objectives that are related to the above three needs. Each of these three parts is necessary for the solution of complex problems and none is sufficient on its own. Only when all three parts are combined are we likely to achieve the objectives of science in forestry and provide an adequate basis for guiding the relationship of people to the forest. Communication is considered by some to be a fourth component of science. Science un-communicated does not contribute to the advancement of humankind and our quest to live sustainably with our environment. However, communication is required in all of the three components just identified, so we will not

⁷A problem is an issue that does not get solved; an issue that gets solved quickly is not a problem. Problem issues often persist because they are complex and only simple solutions are offered.

⁸The term “wicked problem” was originally proposed by H.J. Rittel and M.M. Webber (1973) in the context of social planning. Their discussion identified several characteristics of such problems, including: 1. They are complex and not easily defined. Lacking a clear description, 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 better or worse. They are more dependent on value systems than on 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. 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 choose between different alternatives. 8. Every wicked problem can be considered a symptom of another problem. Linkages between problems increase the complexity of finding a workable solution (this was a major finding of the Club of Rome study *Limits to Growth* (Meadows et al. 1972). For background on this topic, see Rittel and Webber 1973, Allen and Gould 1986, Rauscher 1999, Shindler and Cramer 1999, Salwasser 2002, Wang 2002, Conklin 2005.

deal with it as a separate category here. It is discussed in more detail later.

The thesis of this paper is that a principal source of confusion in the application of science in forest resource management stems from the misinterpretation of the role and the misuse of the understanding component of science. This second and central component should not be used as a complete scientific basis for solving problems⁹.

The first stage in resolving a problem issue is to know what the problem is. Knowing about a problem, object or condition requires that it be described and classified relative to other problems, objects or conditions. Creation of this level of knowledge (which we are choosing to call experience when knowledge is accumulated over time) by the process of induction (going from descriptions of many examples of the issue, object or condition to statements about specific examples thereof) will generally be more reliable as the basis for policy and practice than a simple belief system if the latter lacks a solid, inductively-derived foundation (i.e., an appropriate level of knowledge and experience) (Fig. 2). However, knowledge and experience always refer to the present and the past, respectively, whereas in forestry we want to know about the future. What should we do today to ensure a desired future for both us and our descendants? What policies and actions applied today will honour our intergenerational equity obligations and ensure that we practice multi-generational, ethical forestry?

Experience on its own is an adequate basis for predicting the future if the future is exactly like, or very similar to, the past. This is generally not the case. In fact, problems in forestry sometimes arise because the public wants forestry to change from the practices and policies of the past to new practices and policies for which we have little or no experience. This is bit like driving a car slowly down a freeway with the front windshield covered. If there is no other traffic on the freeway, one can navigate safely looking only in the rear-view mirror because the future direction of the road is changing slowly relative to the past direction and one's speed. The knowledge gained from the rear view mirror (experience of the past) will show you when you start to go off the road in sufficient time for a course correction (adaptive driving). Experience is “rear-view mirror driving”; reliable only when the future is the same as or is changing slowly relative to the past. Such a navigational procedure is not appropriate for driving on a winding mountain road where the future changes rapidly and unpredictably relative to the past. In such cases excessive reliance on experience (the “rear view mirror”) will probably result in your vehicle going off the road. This has implications for the adaptive management approach in forestry. If experience on its own does not give you the necessary feedback in sufficient time to avoid making significant mistakes, it cannot be relied on to prevent undesirable outcomes.

Understanding involves study of the component parts and processes of the problem, object or condition in question. The power of the inductive component of science (knowledge, experience) is that it is based on many examples or observations of reality that incorporate implicitly the complexity of the real world. However, the complexity of the

⁹See Forscher 1963.

Fig. 1. A model of the evolution of forestry. There is a progressive increase in the use of science in forestry as it evolves from administrative forestry to ecosystem management. However, excessive dependence on experience to the exclusion of understanding and prediction based on synthesis does not equip forestry to deal with a changing and uncertain future. Likewise, policy based on "jigsaw-puzzle" science or inappropriate belief systems can act to drive the evolution backwards (modified from Kimmins 2002).

Fig. 2. Knowing. The first stage of science is description and classification of the issue, problem or condition of interest. Policy and practice can be designed by the process of induction or through experience. However, this will only be a reliable basis for policy and practice if the future is similar to or is changing slowly relative to the past.

Fig. 3. The inductive-deductive, hypothesis testing loop (hypothetico-deductive science) is the indispensable central component of the science triad. A theory or postulate derived by induction is broken down into a series of hypotheses that are tested in experiments based on the scientific method. The experimental results are then used in an inductive process to evaluate the theory or postulate, either supporting it or rejecting it. This may lead to modification of the theory or postulate (which is now both inductively and deductively derived) and/or new hypotheses for testing, and eventually to scientific principles and laws.

knowledge and data that constitute “experience” is often so great that we cannot be confident that we have fully described and correctly interpreted the reality that is represented in our experience. Was the gathering of the data on which induction and experience are founded biased in some way? Was it sufficiently complete to have accurately described the object of the scientific activity and its full complexity and variability? Are we able to perceive, observe and measure the object of our experience — are our cognitive abilities sufficient for us to have created a sufficiently complete knowledge base? Two additional types of scientific activity are required to provide sufficient confidence in our induction-based interpretations so that they can be a reliable foundation for effective policy and practice. The first is critical testing of the descriptions (i.e., experience) of, and hypotheses about, the components and processes that are the focus of the scientific study. The second is a synthesis of the results of this testing to provide a basis for reliable prediction, or at the very least a set of “limited and contingent generalities” (Rescher 1998).

It is a basic tenet of science that it is not possible to prove an idea, concept or interpretation (hypothesis) as correct — only to disprove incorrect ones. Failure to disprove builds confidence in an idea or interpretation, but it can never be proven definitively. The process of induction is used to go from the descriptive foundations of science (knowledge as described above) to initial theories or postulates (assertions)

about the object of investigation. The understanding component of science involves reductionism — the breaking down of the complexity of these initial theories or explanations into their component parts. The process of deduction is then used to derive hypotheses about these components that can be tested (Fig. 3).

In basic science (that which is not related to policy and resource management practice), experimental results are typically added to the growing body of knowledge that becomes the foundation for revised or new theories or postulates (an inductive process). After sufficient cycles round this inductive-deductive loop, the theory (now deductively as well as inductively derived) may be raised to a Scientific Principle. If this withstands a prolonged period of testing it may become a Scientific Law. However, such principles and laws are generally sufficiently theoretical and/or reductionist that it is difficult to apply them directly as the basis for solving “wicked” problems in forest policy and practice (Fig. 4). For those who believe that “understanding” is what constitutes science (that it is the only “hard science”), the direct application of results from reductionist, hypothetico-deductive experimental science is not only justified; it should be the scientific foundation for policy and practice (Fig. 4).

Understanding the individual components and processes of a problem, object or condition is essential (necessary) to science, but is not enough (sufficient). The results of reduc-

Fig. 5. The relationship between levels of biological organization and biological integration, and understanding vs. prediction. Ecology and forestry deal with individuals, populations, communities and ecosystems, but of these only the ecosystem level permits reliable prediction of future events and conditions within an ecosystem.

hypothesis testing loop (understanding; Fig. 3). Many would argue that prediction is the fundamental objective of science; others would suggest that knowledge and understanding for their own sake are sufficient rationalization for this human activity. Regardless, the application of science to address an issue or problem invariably involves some form of prediction based on a synthesis of knowledge and understanding of the components of the issue or problem.

Navigating into the future in a sustainable and ethical manner depends on our capacity to forecast the possible consequences of alternative policies and practices in complex systems. While the reductionist or analytical approach to science works well for predicting response in relatively simple systems, it is insufficient for application to complex systems where the old adage “the whole is greater than the sum of its parts” usually applies. To adequately address the “wicked” problems associated with management of forest resources requires a *systems approach* in which an understanding of the linkages and interactions of an ecosystem’s key components and processes provides the basis for prediction. This biophysical activity must then be linked to social values in order to predict (though scenario and value trade-off analysis) the interactions between social and biophysical components of forests and forestry.

The need for adequate complexity in theories and explanations was recognized long ago. William of Occam¹⁰, a 14th

century English logician and Franciscan friar, asserted that explanations, theories and solutions to problems should not be more complex than necessary. This principle (called the principle of parsimony, and adopted by science in the form of Occam’s Razor) has become a basic tenet of reductionist science (the hypothetico-deductive understanding component of science — Fig. 4); it encourages the use of the simplest hypothesis available. However, Occam’s Razor has two “edges” — as simple as possible, but as complex as necessary. This idea was echoed by Albert Einstein in his admonition to keep theories and explanations “as simple as possible but no simpler.”

Progress in understanding requires the simplification of complex issues, theories etc, but achievement of prediction of complex systems requires the synthesis of “scientific bricks and two-by-fours” into explanations of sufficient complexity to reflect the characteristics of the object(s) of scientific activity and source(s) of “wicked” problems. The Club of Rome study, reported in *Limits to Growth* (Meadows *et al.* 1972), concluded that science and society are probably capable of solving any single problem that they face if it can be isolated from other problems. However, all major problems are linked in complex ways, so that solving one problem exacerbates other problems and/or reduces the possibility of solving them. Our ability to understand, predict and derive solutions to complex problems is generally limited more by our unwillingness or inability to synthesize reductionist, disciplinary knowledge up to the level of complexity of the issues than by our lack of detailed knowledge of the components and processes of the problem, the continuing incompleteness of this knowledge notwithstanding.

In the field of ecology, the issue of complexity and prediction was addressed 70 years ago by Tansley (1935) when he coined the term and described the concept of ecosystem. Rowe (1961) pointed out that biological knowledge is organized into levels of biological organization that are indispensable for the description and understanding of events and conditions at each of these levels. However, prediction of future

¹⁰The 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 must not be multiplied beyond what is necessary. This principle is known as Occam’s Razor or the principle of parsimony. It asserts that problems should be stated in their most basic and simplest terms. In science, Occam’s Razor asserts that the simplest theory that fits the facts of a problem is the one that should be selected. This rule is interpreted to mean that the simplest of two or more competing theories or hypotheses is preferable.

Fig. 6. Mechanistic computer modeling is a means of synthesizing disciplinary knowledge and understanding into systems whose complexity reflects that of the system being investigated, thus conferring more reliable powers of prediction for a changing and uncertain future. The most practical and powerful of these decision support systems are those that incorporate both inductively-derived knowledge and experience, and our understanding of ecosystems structure and function derived from hypothetico-deductive experimental research.

events and conditions at any of these levels can only be successful in the context of the next level of biological integration above (Fig. 5). Individual levels of biological organization define only a subset of the processes that affect future conditions and events at that level. Only the next true level of integration above in the hierarchy of system complexity defines the key determinants of the future for the level of interest. Thus, the fate of an individual organism cannot be defined solely on the basis of knowledge of the biology of that individual, or of the population or even of the biotic community in which it finds itself. The population level fails to identify all the biotic factors influencing that individual, and neither the population nor the community level address the climatic and edaphic (soils) factors and the physical natural disturbance events that play such a key role in defining the future for that individual.

How can the results of synthesis — complex hypotheses — be tested? One answer lies in the development and testing of mechanistic computer models (decision support systems), which represent complex hypotheses about the structure and function of these ecological systems. Testing complex hypotheses involves comparisons between model forecasts and historical records of the behaviour of the systems in question (retrospective and chronosequence research), or with the results of long-term field studies (validation). This is analogous to the reductionist loop of understanding, but it deals with complexity rather than simplification (Fig. 6).

As noted above, the traditional basis for prediction in forestry has been experience. Growth and yield models and the timber supply models based thereon are “rear-view-mirror” forecasting systems. They are reliable and often the best overall basis for navigating into a future that is very similar to the past, or when the future is expected to change slowly so that

adaptive management will act as an adequate “navigational course corrector.” However, such experience-based, inductive models (also called historical bioassay models; Kimmins 1988) based on knowledge but not on understanding are unsuitable for rapidly changing futures or situations in which society is requiring foresters to change to management policies and practices for which there is inadequate experience to build new experience-based models. Historical bioassay decision support systems are likely to be more useful for short-term than for long-term predictions, because the short term is often much more similar to the past than to the long-term future. They will probably continue to be valuable for short-term tactical decision-making, but are generally unsuitable for long-term strategic decision support.

Purely mechanistic (process simulation) models that represent many of the key processes and components of forest ecosystems and the “wicked” problems that confront forest policy makers and field foresters tend to be very complex. As a consequence, either they have been calibrated for relatively few forests, or they are not widely and freely available, or they are so expensive to calibrate and complex to use that they have not been widely adopted by forest companies as decision support and scenario analysis tools. Exceptions to this generalization exist, and with the growing power of computers, the growing need for flexible decision support tools (Korzukhin *et al.* 1996) and the increase in knowledge and understanding, the use of purely process models may be expected to increase in the future.

An alternative approach is to combine experience and understanding into hybrid simulation models that are able to predict for both unchanging futures on the basis of inductive science, and changing futures for which we lack experience based on our understanding of the system’s components and

processes. This approach to forecasting is gaining acceptance as one of the best ways to conduct scenario analysis of complex problems in forestry. It combines the strengths of the two component approaches, while reducing the problems associated with the complexity of purely process simulation prediction systems and the inability of experience-based systems to deal with changed futures.

Communicating Science to the Public and Non-scientific Stakeholders

The genesis of this paper were: 1) what is science, and 2) how can science be used appropriately as a component of decisions in forest land use planning and forest practice? In a democracy, it is essential that all interested stakeholders be involved in these processes. However, democracy only serves society well when all those contributing to decision processes are well informed. This requires that both the choices and the possible outcomes are communicated effectively to stakeholders.

Forest ecosystems and their management are complex. In fact, an ecosystem is one of the most common examples given to explain the concept of complexity in the literature on complex systems (e.g., Hauhs *et al.* 2001, Johnson 2001, Wu and David 2002, Levin 2003, Mitleton-Kelly 2003). In forest management this biophysical complexity is accompanied by social complexity. The latter generally frames discussions of the former. For example, what are our goals, how do we conceptualize and represent our values as they determine our visions of desired future forest conditions, and how do we monitor our effectiveness at achieving desired outcomes (Kimmins *et al.* unpublished)? One of the complexities of forest ecosystems is that they are always changing. Social complexity is also characterized by continuing change in our values, and by the process of selecting individual values that are to be sustained from the myriad of values that the forest has to offer. Both of these complexities — the social and the biophysical — pose significant challenges in discussions of forest management. As Bunnell (1999) noted, "Forestry is not rocket science: it is much more complex."

Complex systems can be conceptualized in many different ways, and our experience and belief systems influence our perception of them. Different disciplinary experts frequently bring different terminology and mental models to discussions of issues in forestry. This often results in debates over semantics rather than substance (facts as we know them), which limits progress towards problem resolution. This emphasizes the need to develop communication mechanisms that can provide a common language through which to examine problems. In this case, the single most easily shared medium for communication is information visualization (Meitner and Gandy 2004).

The complexity of the problems that we face is one of the impediments to understanding problems by disciplinary scientists, and to the understanding of science by non-scientists. Meaningful public involvement in the forestry debate is often hampered by the fact that we often deliver much of our scientific understanding of problems as individual pieces of a scientific jigsaw puzzle without the "picture on the box" (the larger context for disciplinary information) to refer to. The results of experimental testing are generally presented in terms of graphical, tabular and statistical information: analytical information that does not communicate well to the aver-

age non-scientist. Non-technical people tend to think more in terms of mental and conceptual models based on experience and images that can be interpreted by the senses — mainly visual. Consequently, there is a need to compliment analytical presentations with visual models. However, static (snapshot) images are often an unreliable guide to the future state of dynamic, ever-changing systems such as forests. What is needed are representations of the dynamics of forest stands and landscapes (i.e., movies of forest change under alternative natural disturbance and management scenarios) based on the best knowledge (experience) and understanding, synthesized within simulation models of sufficient complexity and appropriate spatial and temporal scales, and projected using advanced visualization systems.

Visualization is a very powerful tool for communication and furthering understanding of complex scientific information because it takes advantage of our innate ability to absorb and interpret visual information. A majority of the information processed by sighted human beings is visual in nature, and as a result of our species' reliance on our visual sense we have evolved a visual perception system that can rapidly process immense amounts of data with very little cognitive effort. Visualization extends our power of perception by providing a representation of the consequences of non-visual processes (e.g., the effect nutrient cycling rates on tree growth and on the competitive ranking of different species). We can also represent very large- and very small-scale conditions and events that are beyond the range of perception and comprehension of most. For example, a time-lapse movie of a flower blooming compresses the temporal scale so that we are able to observe events that are normally too slow to perceive. This temporal compression is extremely important because of the long time scales and large spatial scales involved in forestry. We must often make decisions today whose consequences will persist for many human generations. By bringing the future to life and encompassing spatial scales that the average person cannot comprehend, science-based visualization can facilitate personal decisions with regard to inter-generational equity questions; we can more easily make ethical decisions with regard to balancing our present day desires against those that we think our grandchildren may want. Visualization can also communicate the need to make local stand decisions in the context of landscapes, and landscape decisions in terms of what this means at the stand level. This is important as decisions that seem appropriate when made at the stand level may have undesirable consequences when applied at the landscape level if both scales and their interactions are not sufficiently scrutinized.

The last aspect of visualization in the context of communication is translation. Bringing disciplinary experts together can be assisted by this technology, but it is equally important to think of visualization from the perspective of simplifying complex scientific information for communication to non-scientists. Visualization provides a two-way communication mechanism because it can be used to represent the values and mental models of all the different stakeholders, thereby simplifying the social complexities of the debate.

On casual inspection, visualization appears to be a fairly straight forward undertaking, as evidenced by the plethora of tools for creating purely data-driven visualizations of future environmental states. However, this final stage of scientific activity (communication) involves several important ques-

tions. Is it possible to present visual and non-visual information on an equal, unbiased basis? What are the strengths and weakness of different approaches to visual representations for generating a deeper understanding of the information represented? How do the knowledge, experience and understanding of observers influence their perceptions of the visualization? What is the effectiveness of different visualization systems in engaging different audiences? What are the ethical implications of using these powerful communication tools in a decision-making context? How can we prevent the misrepresentations of the present state and possible future conditions of a forest by selective use of photography that is frequently used by various parties to the environmental debate in forestry to persuade the public to their point of view? What is the best way to convert snapshot visualizations of short-term ecosystem condition into dynamic representations of possible forest futures? These are just a few of the significant concerns raised by the increasing use of ever more realistic visual depictions of present and future conditions. We would agree that they need to be addressed, but would also argue that the pressure of environmental concerns prevents us from

awaiting complete answers to these questions. It is important that these technologies be applied now as a component of the land management decision-making process, and thus contribute to a deeper understanding and questioning of the underlying concepts. We should proceed with caution, guided by interim principles or a code of ethics (Sheppard 2001), while continuing to evolve our ability to deliver unbiased land management information through visual means.

A Suggested “Complete Science” for Forestry

All three of the components of science — knowledge, understanding, and prediction — are necessary in forest management. Because forest science is so young and there is so much that we do not yet understand, inductive, descriptive science should play a much larger role than in some of the more mature sciences. However, induction in forest science is incomplete — it must be complimented by rigorous testing of the subcomponents of the complex issues faced in forestry and forest science, and this requires a substantial investment in the understanding component of science based on the inductive-deductive hypothesis testing loop.

Forest science has filled knowledge warehouses (libraries) with the products of inductive/ descriptive and deductive/ experimental science. For our intellectual legacy to make a major contribution to the advancement of forestry, this jigsaw puzzle of experience and understanding needs to be assembled into decision support systems for scenario and value trade-off analysis. Such systems cannot provide THE answer, because there is no single correct answer — only a variety of choices with a variety of consequences. And such decision support tools cannot be completely reliable as predictors of these consequences, because they are only representations of reality, not reality itself, and we can never predict the future with complete confidence. It is too stochastic and unpredictable. However, foresters must make decisions and choices every day, albeit on the basis of incomplete knowledge and ability to predict the future. These choices should be as well informed as possible and based on the best available synthesis of what we know and what we understand today, knowing full well we will know and understand more in the future.

Fig. 7 presents our concept of how science, both biophysical and social, could better serve forestry. We believe that this model of science is the best way of informing the inevitable choices that are faced in forestry. We also believe that the democratic process and equitable involvement of all stakeholders requires that a major effort be invested in the communication of science-based choices to scientists and non-scientists alike, and that this should involve that most powerful of human communication devices — visualization.

Conclusion

Forest policy and practice developed on the basis of “individual pieces of the jigsaw puzzle” rather than the whole picture are frequently unsustainable. Even when the whole picture is examined, generally only a snapshot or short-term assessment of the dynamic forest system is generated, rather than a “movie” of how the system and associated values change over time. Policy that is limited to a snapshot of the present, even when this is based on acceptably complete representations of current spatial, structural and functional complexity, can lead to very undesirable outcomes — the result of the failure to account for temporal diversity.

For science to serve society in the cause of developing a more sustainable relationship with nature in general and forests in particular, we must employ all three components of science, and deliver the results as alternative scenarios and value trade-off analyses. These must incorporate uncertainty and risk, and show that there are many alternative possible futures, each with a different temporal pattern of supply of different values and environmental services. Predictive decision support tools cannot predict the future with complete accuracy, but when used appropriately can provide us with the best currently available vision of what the future could be under different ways in which we could conduct forest management.

There is no single “answer” that can be provided by science, and science cannot decide what values society should support. But it can, if used in the manner described here, provide the best available science-based “guess” about the possible consequences of alternative land-use plans and management practices. By identifying possible trade-offs of different

values over space and time, it can contribute to decisions about how to manage forests to sustain the desired range of values. Communication of trade-offs and choices can most usefully be based on advanced visualization software driven by ecosystem management and social value models.

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