CONTEXT TO A CONVERSATION:
THE CONTRIBUTION OF SCIENCE TO SUSTAINABLE FORESTRY

by

GEOFFREY HAROLD CUSHON

B.Sc.F.(Hons.), Lakehead University, 1980

M.Sc., University of British Columbia, 1985

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ABSTRACT

The currently topical problems of forest management are issues of trans-science. They can be framed in the language of science but they cannot be resolved in the language of science. They involve historically contingent phenomena for which predictive certainty is not possible *and* they involve issues of moral, aesthetic and economic value. What is the role of science in contributing to the public debate on what are fundamentally social issues such as clear-cut logging or the preservation of old-growth forests?

A history and philosophy of science, in general, and ecological science, in particular, is presented that traces the transition, over the last half century, from a positivist science of universal, timeless, predictable order to a science that attempts to interpret local, particular aspects of nature. The former relies on identifying restricted spatio-temporal scales that facilitate prediction while the latter focuses on an understanding of the causal relations within interrelated systems that facilitate explanation of system properties. A kind of contextual or dialectical holism is advocated wherein system components are considered in the context of the whole and the whole is considered as an epiphenomenon resulting from causal interaction of the parts.

A history of forest science is presented that identifies sustained yield forestry as a construct of positivist science. Recent insights by ecological science, into the complexity and contingency of forest ecosystems, reveal the limitations of this simplified view. Moreover, the application of a single large-scale strategy such as sustained yield forestry to managing forests in British Columbia contained value assumptions that no longer reflect the full range of values that the public express.

The currently topical debates on clear-cutting, logging in municipal watersheds and over-cutting are offered as examples of how questions of fact and questions of value become linked. Although these debates have been carried on in the language of science they are essentially social issues and cannot be resolved by science.

The role of science in contributing to the resolution of social issues, such as the development of a sustainable forestry, is not to develop specific solutions but to contribute to the social dialogue in a subservient fashion. Science can characterize the context in which disagreements about matters of value take place. Science can use its experimental protocols to help society construct living experiments that allow us to learn our way into the future. Science can take part in an equitable conversation on sustainable forestry that will facilitate a better understanding of the beliefs and values of the human component of forested ecosystems.

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1. INTRODUCTION

Humans are cognitive and social animals with the capacity to plan individual and collective actions. Accordingly, we seek to establish grounds or constraints to guide what these actions might best be. There are, in general, two approaches to defining such grounds. The oldest is the process of forming and understanding interpersonal beliefs and values and constructing a moral code by which to guide our actions. On the Christian view, for example, acting in accordance with the Ten Commandments promises rewards in the afterlife for whatever discomfort we might have to bear here and now.

The second approach to grounding *right action* is based, not on beliefs and values, but on ostensible facts, on *what is*. This is the world of science. The scientific world-view engendered a profound shift in our approach to life. The older moral systems were concerned with helping us to bear our fate, but science brought with it the promise that we might control destiny. If we could classify the objects of sense and determine formulae describing their relations, we could predict their future states and manipulate them to suit our desires. Science promised a kind of tangible foresight.

There are different kinds of knowledge, but in the modern world the kind of knowledge we invariably seek, when faced with a dilemma concerning the material and circumstantial world around us, is scientific knowledge. While we tend to think of science as being complementary to moral beliefs, our desire for certainty here and now and for material well-being in a perilous world lends disproportionate influence to the promise of certainty apparently offered by science. When questioned about the development of a government policy on global warming, the then American President George Bush was quoted as saying "what we need is facts, the stuff that science is made of". Similarly, the British Columbia Minister of Forests was interpreted, in a 1991 newspaper article, as saying that "environmentalists who want to stop logging ... should make their arguments based on science rather than emotion"[1].

It is easy to imagine everyday problems of which the resolutions lie within the domain of science. If I feel ill I can visit a doctor who has a battery of clinical tests developed by medical scientists that can determine if I am infected by a pathogen. On the other hand if I am trying to decide whether or not my religious beliefs allow me to accept the medication the doctor prescribes science will have little bearing on my decision.

How I choose to deal with illness is typical of most, if not all, of the important issues society faces. They are characterized by a blend of ostensible facts, and beliefs and values. This medicine may kill the pathogen but is that an approach I want to take in attempting to cure my illness? A chemical pesticide may kill a potentially destructive insect but do I want chemical pesticide-use as part of my way of life? Can science show that logging can be environmentally benign and, even if it can, would I rather have an undisturbed natural forest?

All the currently topical issues of environmental management display this characteristic blend of ostensible fact and value. They lead to two distinct but complementary questions. How can we manage our environment, and how do we want to manage our environment? Using forestry as an example, the central question of this thesis will be to explore the role of science, both historical and current, in the broader cultural issue of determining public policy. What kind of knowledge can science offer about the first question and how does it bear on the second? What is the role of science when fact and value become interwoven?

The scientific tradition we have inherited has been profoundly influenced by the empiricism of Francis Bacon, the rationalism of Descartes and by the positivist philosophy expounded by Comte, Mach, Spencer, Pearson and others. The positivists believed that

[1] "Activists rally to save B.C. trees", the Vancouver Sun, Monday, December 16, 1991, page B6.

knowledge was to be exhausted in a description of the co-existence and succession of the objects of sense. The aim of science was to predict the future by making inferences from regularities evident in observable phenomena.

On the positivist view, science was the only legitimate means to gain knowledge of the world and consequently the means by which to determine our collective actions in the world. As there is

> ...no way to gain knowledge of the universe except through the gateway of scientific method... (Pearson 1892 [1957 ed.], p.17)

we must await the contribution of science to resolve conflicting arguments about the world and the environment around us.

The positivist philosophy was an extension of the rationalist program of Descartes. Toulmin (1990) suggests that the triumph of rationalism was an intelligible response to an historical crisis.

> [Descartes]...opened up for people in his generation a real hope of *reasoning* their way out of political and theological chaos, at a time when no one else saw anything to do but continue fighting an interminable war. (Toulmin 1990, p.71, author's italics)

Descartes' rationalist program and its offshoot, scientific positivism, promised a means of resolving the conflict between different belief systems and providing the foundation for a rational reorganization of human society. It was believed that the application of scientific method to all aspects of human society would improve the quality of life.

On the positivist view, then, social problems must be translated into the language of science for their effective resolution. In Richard Rorty's (1979, p.316) words:

> Residual disagreements will be seen to be "non-cognitive" or merely verbal, or else merely temporary - capable of being resolved by doing something further.

For some the truth claims of science are tied to methodology which removes them from the influence of social and historical context. This has allowed scientific knowledge to be portrayed as objective, value-neutral and absolute.

In recent times perceptions of science and the role science plays in determining human affairs have changed. The controversy over spraying insecticide for the Gypsy moth in British Columbia has been offered as one example of the growing distrust of scientific authority[2]. In contrast to the positivist claims for science, the scientific world-view has been portrayed as a relativist position that is inherently bound up in the project of exploiting and dominating nature (Leiss 1972) or more generally as a tool for legitimating various ideological positions. Aronowitz (1988) argues that the norms and methodology of science are not self-evident and that science is best understood as a socially constructed discourse that legitimates its power by presenting itself as truth.

Yet while there is academic questioning of the legitimacy of scientific knowledge and of the disproportionate influence of science in human affairs, and a growing public distrust of scientific authority, there is also a growing demand for more and better scientific knowledge to solve the profound difficulties society faces. There is a persistent public outcry for improved scientific understanding of health issues such as AIDS and cancer, and environmental issues such as pollution and resource depletion. Even those who take the position that science is simply a manifestation of the ideology of exploiting nature clamor for scientific knowledge that shows the harmony and sanctity of nature, and thus justifies their own ideological position.

The growing public awareness of environmental health issues, engendered in part by the environmental movement that began in the fifties and sixties, roughly surrounding the publication, in 1962, of Rachel Carson's *Silent Spring*, has focussed attention on scientific ecology as the means by which to resolve such issues as renewable resource depletion, air and water pollution, and global warming:

> ...ecologists, like doctors...are not just scientists enquiring into natural systems but...have...become - and society has forced them to be - the custodians of those systems. (Sagoff, 1982, p.17)

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[2] "Growing distrust of authority shows through the spray, professors say", the Vancouver Sun, Thursday, April 16, 1992, page A1.

Ecology, like medical science, economics, sociology, and other integrating sciences, has come face to face with the obstacle of producing the tight causal proofs or experimental evidence that are generally considered to constitute scientific knowledge while providing remedies for the ills of the environment.

The reductionist approach and the predictive ideal advocated by scientific positivism have not proven successful in developing predictive models for ecological phenomena. As most ecologists recognize, ecological systems are open, complex, contingent and evolutionary, producing interactive processes that cannot be predicted from an understanding of their component parts. It is extremely difficult, arguably impossible, to produce the kind of certain, predictive knowledge that society has come to expect. The deterministic ideal of scientific positivism hangs over the head of scientific ecology in spite of expanding scientific understanding of ecological uncertainty.

One manifestation of the growing scientific, social and political awareness of environmental issues has been the introduction, by the World Commission on Environment and Development (WCED) of the concept of *sustainable development* and subsequent dialogue thereon. The basic premise of sustainable development is that economic development must be considered in relation to, and constrained by environmental issues:

> From space, we see a small and fragile ball dominated not by human activity and edifice but by a pattern of clouds, oceans, greenery, and soils. Humanity's inability to fit its doings into that pattern is changing planetary systems fundamentally. Many such changes are accompanied by life-threatening hazards. This new reality, from which there is no escape, must be recognized - and managed. (WCED 1987, p.1)

The concept of sustainable development as advanced by WCED contains a tacit recognition of the failure of science and technology to resolve social issues such as the growing number of poor and hungry people on the planet, the stability and resilience of local communities, and the rights of future generations in the debate on what to do now. This recognition is not an indictment of science but a questioning of the manner in which science can be applied to the resolution of social issues. It suggests that we must address social issues in a social context and redefine the role of science in informing the dialogue. Scientific understanding of the ecological systems we depend on is critical but it must be used in the context of

> ...our cultural and spiritual heritages [which] reinforce our economic interests and survival imperatives. (WCED 1987, p.1)

The social and environmental problems that the World Commission on Environment and Development hoped to address with a philosophy of sustainable development are similar to those faced in the early part of this century when sustained yield forestry was introduced to North America. These problems included unchecked exploitation of forests with no attention to renewal, community instability, uncertain timber supplies and the destruction of non-commodity environmental values. The development of sustained yield forestry, in Germany in the last century, and its introduction to British Columbia in this century, will provide the context for my discussion of the role of science in addressing social issues.

Sustained yield is part of what has been called scientific forest management. The idea of scientific forest management has its roots in positivist philosophy in the 19th and early 20th centuries and in the progressive conservation movement evident at the turn of this century for advocacy of which Theodore Roosevelt is remembered. At the heart of the progressive conservation movement was the positivist ideal that science, and its handmaiden technology, could decide the course of resource development. Conflicts over resource use could not be resolved politically, as "partisan debate could not guarantee rational and scientific decisions" (Hays 1959, p.3).

> Conservationists envisaged, even though they did not realize their aims, a political system guided by the ideal of efficiency and dominated by the technicians who could best determine how to achieve it. (Hays 1959, p.3)

When the WCED published its report, *Our Common Future*, in 1987, the Association of British Columbia Professional Foresters (ABCPF) responded with a memo to British

Columbia politicians. The response was that through policies of sustained yield and multiple-use forestry

> B.C. Professional Foresters have been practicing sustainable development long before it became popular for others to be interested in this concept. (ABCPF, 1988)

Sustained yield forestry is a kind of attempt to address economic development in the context of ecological sustainability. Set in its historical context it represents a rational attempt to prevent resource degradation. More recently, recognition of ecological complexity and contingency and of the inability of science to address issues of value expose flaws in the strategy of sustained yield forestry.

North American models of sustained yield in forestry and fisheries have been based on the concept of maximum sustained yield as deduced from single-species population models (eg. Larkin 1977, Chambers and McLeod 1980). Decisions regarding the management of whole ecosystems have been made by determining the maximum rate of production of the commodity species, while ignoring the dynamics of the underlying system that engender productivity.

While sustained yield forestry was adopted to address social as well as technical concerns, the assumption was that social concerns would be met as a consequence of producing the maximum volume of wood fibre. Other products and values associated with the forest were considered secondary to this overriding goal. As a narrow technocratic solution, sustained yield forestry imposed the belief that managing forests for the maximum continuous supply of wood fibre would satisfy all other values that people hold with respect to the forest.

Our human desires for certainty and material well-being encourage the positivist quest for predictive certainty. But ecological phenomena have a creative element as a consequence of evolution and contingency. A sense of certainty in nature, the ability to accurately forecast its future states, is an illusion, rather than a reality. The assumption that we can understand and resolve problems of environmental management in the language of a reductionist, mechanistic science of certainty requires re-evaluation. Science has made great strides toward an understanding of complex systems through stochastic modelling, through simulation and through a general acceptance of the complexity and interconnectedness of natural systems. These strides suggest that the degree of certainty by which we can forecast the consequences of our interventions in nature is limited.

To the unpredictability inherent in nature, in its most fundamental and most integrative states, we must add the uncertainty of human individual and social behavior. Over the last century the province of British Columbia has been settled largely by European peoples with an agrarian background. The descendants of these people are in the process of constructing a forest-dwelling culture, developing beliefs, values and relationships with nature that bear on how they may choose to manage their environment.

John Dewey described a *spectator theory* of knowledge, of which science is the prime example, as being concerned with the search for what is foundational, and thus, eternal in nature. On the other hand, he noted that:

> The realm of the practical is the region of change, and change is always contingent; it has in it an element of chance that can not be eliminated. (Dewey, 1929, p. 16)

In the abstract, certain knowledge may be possible, but in the real world, we can never know for certain the outcome of our actions. We must manage for the unexpected. The complex, contingent and evolutionary nature of ecological systems, including the notable unpredictability of their driving weather systems, and the thinking, dreaming human populations embedded in them, make these systems fundamentally unpredictable. To resolve the conflict between a notion of certain, abstract knowledge, and the art of practical living in the face of a variety of kinds of uncertainty, science and society must seek a new relation between an expanding knowledge of ecological complexity and the social problems we face.

Forestry, and resource management science in general, are in a state of flux as we approach the twenty-first century. This state of flux is related in part to changes in our conception of science and its role in the broader cultural milieu. The concept of sustainable development implies that there is a social dimension and a broader time frame to be considered in economic development activities such as forest management. Gifford Pinchot recognized this social dimension, in a sense, when he recalled his studies in France and Germany with his mentor, Dr. Dietrich Brandis:

> Dr. Brandis never let his pupils forget a great truth which most German foresters had never grasped - in the long run Forestry cannot succeed unless the people who live in and near the forest are for it and not against it. (Pinchot 1947, p.17)

Positivist science has failed to resolve forestry issues because of its inability to incorporate ecological uncertainty and because it fails to recognize that the goals and aspirations of people cannot be formalized and resolved in a scientific context. The contribution of ecological science to resource-use issues, such as forestry, has been limited in the past by its inability to provide the kind of predictive model held as the standard of positivist science. Were it possible for ecology to provide predictive certainty it would entail reducing the problem far below the level of social relevance. An acceptance of the integrated nature of ecological phenomena, and the uncertainty engendered by contingency indicate that forests must be managed as whole entities. People comprise an important component of ecosystems and environmental issues are not strictly scientific issues.

Stephen Toulmin sees science at the end of the 20th century as beginning to loosen its positivist ideals:

> Claims to certainty...are at home within abstract theories, and so open to consensus; but all abstraction involves omission, turning a blind eye to elements in experience that do not lie within the scope of the given theory, and so guaranteeing the rigor of its formal application. (Toulmin 1990, p.200)

> ...scientific inquiry will increasingly shift from abstract laws of universal application to particular decipherments of the complex structures and detailed processes embodied in concrete aspects of nature. (Toulmin 1990, p.204)

I will begin this study by examining the ideals of science and the kind of knowledge science can offer. In Chapter 3, I will consider the science of ecology in the light of this re-evaluation of science, consider why its application to resource-use issues has been limited and illustrate why it is the necessary grounding for managing nature.

Toulmin's perceived shift in the ideals of science can be discerned in the evolution of forest science and in its application in British Columbia. Chapter 4 will focus on the history of forest science and, particularly, the concept of sustained yield forestry, from its roots in 18th and 19th century Germany, to its introduction and development in British Columbia. Sustained yield forestry provides a useful and well-studied example of the traditional technocratic approach to the problems of resource management. It also exemplifies the miscast relation between science and society. Chapter 5 will include a critique of the main assumptions of sustained yield forestry and recent developments that signal a change in our perception of forests and the consequences of human agency on them.

In Chapter 6 I will describe three current issues in British Columbia that science is expected to resolve. While science may have much to contribute they are all essentially social issues that must be addressed in a social context. In what manner can science be mandated to assist society in resolving these issues? How do questions of fact and questions of value become linked in our attempts at resolution?

The ideal that science could improve the quality of life is a noble one. The resolution of environmental issues in the practical world, in the world of doing, requires that science be responsive and subservient to the dialogue on appropriate action rather than attempting to create illusory models of certainty that predetermine social and political decisions. Science can provide background information, maps, inventories, explanations of what has occurred and possibilities of what might occur that can provide context to the social process but not, in context, assured predictions. Science can use its critical attitude and its methods of modelling and experimental design to help us design living experiments that yield knowledge as we move into the future. We can use science to live adaptively in an evolving world.

Science cannot determine what it is right for us to do, but it can play an important part in the democratic dialogue on appropriate action. Science can provide not certain knowledge, but clues as to how our story will proceed into the future. These clues enlighten the dialogue by suggesting options, by providing an understanding of nature's capacity to respond to our needs, by providing context to the conversation.

2. WHAT IS SCIENCE?

What kind of knowledge does science produce? How can and how should scientific knowledge be used to inform decision makers and influence human affairs? What is science?

Before considering the arguments pertinent to answering these questions it seems reasonable to wonder why the questions are relevant in the first place. Do competing projects claim the name science? Is there a social dimension to the production and use of scientific knowledge such that we must place bounds on what we call science and scientific knowledge? While the question *what is science* has, for the most part, been addressed in the context of the former question, seeking, for example, to separate physics from astrology, let me suggest that the latter question is by far the more critical. Science is immensely influential in the construction of 20th century society. Any attempt to analyze and address the nature of social issues must look at the contribution of science and the nature of scientific inquiry and knowledge.

Science has come under fire, in recent times, as being a socially constructed discourse for legitimating the influence of certain ideological positions: for example, by socialists who claim that science is a tool for legitimating capitalism, by feminists for whom science is the means of legitimating patriarchy, and by environmentalists who claim that science is a tool for legitimating the domination of nature.

A defense against these claims might be along the lines that science is merely the pursuit of understanding and this is inherently a good thing, it is human and natural. This line of reasoning seems acceptable but it is not clear that this is what is at stake when science is attacked as ideology. It makes sense to me to consider two aspects of science, science as the pursuit of understanding, and science as a tool for using nature to satisfy our needs. Francis Bacon, who championed science for its practical merits, as a means of mastering nature, was aware of this distinction:

> Just as the vision of light itself is something more excellent and beautiful than its manifold use, so without doubt the contemplation of things as they are, without superstition or imposture, without error or confusion, is in itself a nobler thing than a whole harvest of inventions.[1]

The problem then seems to be to define science in a way that emphasizes this *nobler purpose* while clarifying its mandate in influencing the course of human affairs. Science may be inherently *good* but still have *bad* consequences.

The objective of science is to find pattern in nature, to suggest some order that enlightens us regarding the phenomena we experience each day. Aristotle distinguished between essential and accidental behavior in nature. Traditionally science has acknowledged the latter, but the efforts of science have been focussed on characterizing the former. The project of modern science has been to abstract general principles from specific facts in order to explain and make predictions about the phenomena we observe in the natural world. Quantum theory, for example, is an attempt to generalize the behavior of nature at the molecular, atomic and sub-atomic level. Evolutionary theory attempts to generalize the processes of natural selection and organic evolution. The generalization or theory serves as a framework to organize and relate observations of actual sense data.

Consider, again, President Bush's comment, "What we need is facts, the stuff that science is made of". That there are facts pre-supposes there to be an objective world outside us that has a pattern, an order that can be discerned. President Bush's claim also implies that science can achieve some immutable truth, an ideal of certainty upon which rational action can be based. While the first idea is necessary for any conception of science, the ideal of certainty has been increasingly compromised in the last half century. But while Chalmers reports that

> ...modern science has replaced the utopian aim for certainty by the requirement of continual improvement or growth (Chalmers 1990, p.36),

the political desire for certainty is still imposed on scientists.

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[1] As quoted in Thomson (1922).

The ideal of predictive certainty based on a deterministic world order is a cornerstone of a positivist view of the world. Positivism is grounded in the rationalism and mechanical philosophy of Descartes and the empiricism of Hume (Bhaskar 1989). The term *positivism* was coined by Comte in the first half of the nineteenth century and elaborated on by Mach, Spencer, Pearson and others. Positivism has taken many forms, including the logical positivism developed in Vienna, in the 1920s, by Schlick, Carnap, Neurath and others (Hacking 1983). For my purposes I will consider positivism as a philosophy of science that has the following features:

1. Knowledge consists in, and only in, the description of the co-existence and succession of the phenomena of sense. A statement is meaningful only if it can be verified empirically. Consequently all statements that have no means of verification are metaphysical, metaphysical statements are meaningless, and scientific method is the only source of correct knowledge about reality.

2. There is no causality in nature, only what Hume called constant conjunction, the constancy with which one event follows another. The goal of science is to develop laws describing such regularities.

3. Explanation and prediction are symmetrical (Harre 1985). Given an acausal view of the world, science cannot explain why an event occurs except to say that it does occur in some regular way. Science is either entirely unconcerned with explanation, its goal being to predict the future states of a phenomenon by describing its succession with law-like generalizations (eg. Pearson 1892) or, alternatively, to explain a phenomenon is simply to be able to predict its future states as a necessary consequence of the laws that govern it, the so-called deductivist model of explanation (eg. Hempel 1966).

The positivists made explicit that the aim of science was to provide knowledge of what happens but not why, skepticism about the existence of causes rendering the latter question moot. In Comte's words:

> Our business is - seeing how vain is any research into what are called *causes*, whether first or final - to pursue an accurate discovery of these laws, with a view to reducing them to their smallest possible number.[2]

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[2] As quoted in Hacking (1983, p.47).

But descriptive knowledge is vaguely dissatisfying; we also want to understand why. While Comte was concerned with the question *why* as the search for first or ultimate causes he ignored the possibility that events might be explained by purely physical causal antecedents. The goal of reducing scientific laws to their smallest possible number is also a dismissal of the possibility of causal interactions that create contingencies such that new phenomena arise out of the interaction of prior phenomena.

By *why* I mean the set of causes and antecedent conditions that result in a phenomenon. What series of events lead to this event occurring here and now. While in a somewhat different sense than Comte, we recognize, now, that science can and does provide explanations of natural phenomena and many philosophers and scientists believe the primary goal of science to be that of understanding why things happen in this restricted sense.

My discussion will consider assumptions made by science regarding the way in which the world is constructed. I will begin with a discussion of how science attempts to describe the objects of sense and then, through discussions of causation and scientific reduction, consider how science can characterize relations between the objects of sense. I will then consider the issue of whether the goal of science is to predict or to explain and the importance of that issue for the social role of science. The third major topic in this chapter will be an exposition of scientific method. I will address the question whether science can be legitimated solely by its method. I will close with some comments on the social context of science. To what extent can science be construed as an objective, value-free mode of inquiry and in what sense is its objectivity constrained by its place in the broader sphere of human culture. My purpose here is to develop a view of science that will enlighten the subsequent discussion of ecology as science and ecology as a source of knowledge for managing human agency in the environment.

2.1 Ordering the Objects of Sense

Knowledge begins with the recognition of differences and of similarities. The first step towards knowledge is to provide a systematic description of the circumstances in which recognitions will occur:

> ...the first step in wisdom is to know the things themselves; this notion consists in having a true idea of the objects; objects are distinguished and known by classifying them methodically and giving them names. Therefore, classification and name-giving will be the foundation of our science.[3]

The classification of the objects of sense into categories of like and unlike may be relatively discrete and obvious. To make a crude example, it seems unproblematic to say that a tree is different than a newt (although a biologist can tell us much about their similarity). In many cases, a useful classification requires the interposition of some conceptual structure that influences the perception of difference. It would be difficult to understand how a caterpillar and a butterfly could be the same being without an understanding of the process of pupation. The species is the basic unit of taxonomic classification, generally referring to a group of organisms capable of producing viable offspring as a result of breeding among themselves. Species of organic life often appear similar but are classified differently based on interpretations of morphology, physiology, ecology and/or gene structure. Some different species of newt, for example, can physically mate and reproduce, but are excluded from doing so by the evolution of a convoluted mating dance in which the male must follow the female precisely in order to fertilize the eggs.

Other species of life appear to have evolved from the same strain following their separation by the exigencies of geology, and have continued the process of evolution for greater or lesser periods of time. The jack and lodgepole pines (*Pinus banksiana* Lamb. and *Pinus contorta* Dougl. *ex* Loud., respectively) of North America are believed to have been separated by the uplift of the Rocky Mountains causing their isolation and different evolutionary pathways. More recently these two species have been found to form natural

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[3] Linnaeus in the *Systema naturae*, as quoted in Lesch (1990, p.75).

hybrids in Alberta, Canada (Fowells 1965) creating a conundrum for the botanical systematist.

That the objects of the material world are less discrete than as they were viewed in the immutable pre-scientific world or the mechanistic world of scientific positivism, becomes clearer when we consider more complex entities such as soil formations or plant assemblages. These may be relatively discrete, if separated by the effects of landform, or relatively continuous, when for example occurring on the same mountain slope. The issue of classification, in the latter case, entails defining arbitrary boundaries, based on functional changes, that are not discrete in space or time. While there may be real differences between different soil types there will also exist soils that encompass characteristics of two or more classes. How such anomalies are classified will depend, to a large degree, on the conceptual or theoretical framework the classifier brings to the system, and in some cases on practical concerns related to the problems of classification or the purpose of the classification. Our perception of the fact, i.e., the individual soil, is constrained by the language theory affords us for interpreting it. In other words we cannot see a humo-ferric podzol until we have created the category within our theories of soil genesis.

What we come to experience is a dialectic between what is really there and what we expect to see, between objective reality and theoretical interpretation, between perception and the language of representation. Consider Hanson's (1958) oft-quoted example. Did Tycho Brahe and Copernicus see the same sun? One believed it to be moving across the horizon while the other believed it to be fixed in the sky, the earth a spinning ball in orbit around it.

2.2 The Causal Structure of the World

The attempt to understand relations between the objects of sense has led to a long debate about the nature of causation. The failure to discern what Hume called a *necessary connection* between cause and effect led him to postulate that causes are only constant conjunctions. When an event of type A occurs, say striking a redball with the cueball, an event of type B always ensues, in this case motion is imparted to the redball. The positivist view was that we should not seek for causes in nature, but for regularities or constant conjunctions. We cannot, on this view, explain why an event occurs, that is, answer the intuitive question *why* with a *because*, but only describe the antecedent conditions that precede it.

> To say that we have found the explanation of an event is only to say that the event can be deduced from a general regularity.[4]

In everyday life, we seek to understand why things happen, and an appropriate answer to a why-question begins with the word "because".

> ...causal explanations have truth built into them. When I infer from an effect to a cause, I am asking what made the effect occur, what brought it about. No explanation of that sort explains at all unless it does present a cause. (Cartwright 1982, p.114)

The shattering of a window pane is caused by a ball striking it. Turning a light switch releases a causal process, the transmission of electrical energy, that explains why a light appears. The evolution of morphological characteristics in a species of plant or animal is caused by that species' interactions with a changing environment over relatively long periods of time.

Skepticism about the reality of causes and an acceptance of a constant conjunction attitude to causation was encouraged, unintentionally perhaps, by the success of Newton's theory of gravitation. Although Newton's theory successfully described the phenomenon of gravity it offered no tangible connection between cause and effect. Liebniz's rejection of Newtonian mechanics was motivated by his objection to the occultist idea of action-at-a-distance. The positivist solution was, rather than accept the theory as incomplete, to decide that all causal laws are mere regularities. Discovering the connection between cause and effect was a matter beyond the scope of human inquiry.

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[4] This characterization of the positivist view is provided by Hacking (1983, p.47).

The specter of action-at-a-distance was subsequently removed by Einstein's theories of relativity:

> Gravitational fields have physical reality, and gravitational influences are propagated as waves traveling at a finite velocity through such fields. (Salmon 1984, p.242)

Although gravitational waves have not been detected as yet, there seems to be sufficient indirect evidence to justify our belief in their existence[5]. Hertz's experimental detection of electromagnetic waves, which removed the problem of action-at-a-distance in Maxwell's electromagnetic field theory, provides additional evidence that we can expect to discover causal explanations, in the macroscopic world at least[6].

The idea of a causal process propagated through time and space provides the necessary connection between cause and effect.

> Causal processes transmit energy, information, structure, and causal influence; they also transmit propensities to enter into various kinds of interactions under appropriate circumstances. (Salmon 1984, p.261)

Some causes may be deterministic, that is they may be sufficient and/or necessary to the effects they precipitate, but others seem clearly to be probabilistic. When we say that cigarette smoking causes cancer we recognize that smoking does not always cause cancer and that non-smokers also contract cancer. The evidence that more smokers than non-smokers contract lung cancer suggests that smoking has a propensity to cause lung cancer. Smoking, by itself, is neither a necessary nor a sufficient cause of lung cancer.

While smoking may be found to be part of a set of sufficient causes of cancer, there are many examples of what appear to be irreducibly stochastic processes at work in the universe. A carbon 14 atom has, *a priori*, a probability of 1/2 of emitting an electron and being transformed into nitrogen within a period of 5,730 years. Similarly, experiments in

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[5] See, for example, Davies (1980).

[6] Action-at-a-distance in quantum physics forces us to recognize the possibility that some events may not be completely determined by preceding causes. For a discussion see Salmon (1984, pp.242-259).

Mendelian genetics illustrate how cross-fertilization of, for example, pea plants produce 3/4 red blossoms and 1/4 white blossoms.

A probabilistic view of causation is suggested for two reasons. First, there appear to be ineluctably stochastic forces at work in the world. Second, for a wide range of complex phenomena it may be logically possible but practically unfeasible to determine the nexus of causes relevant to an effect. We can characterize only the likelihood for a certain event to occur.

The constant conjunction view of causality should be discarded, I believe, for two reasons. Salmon's explication of a causal process that can propagate causal influence through space and time provides the necessary connection that Hume failed to discern between cause and effect. Second, viewing causes as propensities, as giving us an understanding of the likelihood for an event to occur, allows us to view causes as neither sufficient for nor necessary to their effects. A constant conjunction cannot be inferred from an effect, but we can use scientific generalizations to consider the range of causes having a propensity to result in the observed event. We might, in principle, find the full set of causes of a given case of lung cancer, but it seems to me needlessly restrictive to say that the only legitimate causal explanation is one that would predict every case of lung cancer.

2.3 A Critique of Scientific Reductionism

The idea of a causal process and of multiple, interacting causal processes is important in relation to the idea of scientific reductionism. The positivist ontology of atomistic events and closed systems supposes that phenomena can be explained by reducing them to their constituent parts and ultimately to the level of physico-chemical processes. On this view, complex systems display no *emergent* properties relevant to an understanding of the system, understanding ensuing solely from a description of the functional properties of the constituents.

From a positivist point of view the biological sciences may be merely *provincial* sciences, having generally failed to produce deterministic, law-like generalizations like those of the classical sciences. The theories and explanations of biology will ultimately be reduced to the laws of physics and chemistry. For the scientific positivist, the ideal of science was

> ...to define phenomena in terms of movements and forces that obeyed universal laws - that is, laws which were not in any way restricted in time or space nor subject to any exceptions. (Mayr 1988, p.9)

The biological and social sciences and, arguably, even the physical sciences, with their acceptance of probabilistic laws and irreducibly stochastic processes, have failed to live up to this ideal. This failure suggests that a different grounding for science is required.

Hempel, in 1966, noted that

> ...it is clear that at present, at any rate, the description of biological phenomena requires the use not only of physical and chemical terms, but of specifically biological terms that do not occur in the physico-chemical vocabulary. (Hempel, 1966, p.102)

However, he concluded that

> ...mechanism...as a heuristic maxim, as a principle for the guidance of research...enjoins the scientist to persist in the search for basic physico-chemical theories of biological phenomena rather than resign himself to the view that the concepts and principles of physics and chemistry are powerless to give an adequate account of the phenomena of life. (Hempel 1966, p.106)

In the 19th and early 20th centuries, biologists had posited metaphysical *vital forces* or teleological explanations, in order to account for the uniqueness of organic life (Mayr 1988). It now seems possible to account for the phenomena of the living world on a causal view of the world. Biological and ecological phenomena conform to the laws of physics and chemistry but display unique behavior that cannot be fully explained by the concepts and principles of physics and chemistry. Salmon's explication of causal processes, propagating and interacting through space and time, gives us the means to acknowledge the uniqueness of the biological world.

The uniqueness of the biological world is the result of four factors:

1. The capacity of living things to propagate causal influence via historically acquired information encoded in their gene structure,

2. Their organization into hierarchical structure and the propagation of new causal influence through causal interactions at each level of organization,

3. The subjection of biological entities and systems to causal influence from irreducibly stochastic processes operating throughout the universe, and

4. The capacity of living things to propagate causal influence in response to contingent information acquired via sensory processes.

Physical systems appear to conform to points 2 and 3. Astronomical galaxies and the earth's crust, for example, appear to evolve in contingent ways. They share the ability to store historically acquired information. Biological systems have the additional features of DNA-programmed responses to stimuli and at higher levels of organization the novel processes of behavior.

An individual organism is the result of the interaction of genetically coded historical information with its environment. Understanding or explaining the occurrence of an organism requires knowledge of not just its functional characteristics but of the historical context in which these characteristics developed. The process of natural selection, by which change as an adaptation to environment can be encoded and propagated causally through time, lends an additional historical aspect to biological phenomena not present in the inanimate world.

The organic world is organized into complex and homeostatic, hierarchical systems:

> The hierarchical structure within an individual organism arises from the fact that the entities at one level are compounded into new entities at the next higher level - cells into tissues, tissues into organs, and organs into functional systems. (Mayr 1988, p.14)

Other levels of organization include organs into organisms, organisms into populations, populations into communities and communities into ecosystems. Counter to the assumptions of positivism, biological systems are open systems that, in spite of inputs and outputs, display elaborate feedback mechanisms that result in internal homeostatic control. In a simple predator-prey system, for example, predation provides negative feedback that may counter high fecundity in the prey species and maintain the system within some domain of stability. Purely physical systems share this feature in an elementary way. For example, a water reservoir stores information and its response, outflow, is contingent upon the storage. This represents a homeostatic tendency.

Biological and ecological systems are composed of many interactive parts. They are themselves contingent, in that a perturbation in one part of the system will have consequences throughout the system. Unique effects are caused by the interactions between components. For example, the population dynamics of a species of bacteria that breeds in owl pellets will depend on the interaction between owls and mice[7]. To go one step further, the abundance of a certain species of plant might depend on the availability of some trace mineral made available by bacterial breakdown of the owl pellets.

Given that interactions between entities have causal efficacy, causal processes will be propagated, in integrated systems, that cannot be understood from an understanding of their component parts alone, without considering how components interact with each other and with their environment. This suggests a kind of dialectical holism between component and system that is distinct from obscurantist holistic views such as vitalism or finalism. There is no need to posit some ideal organizing force. As Levins and Lewontin point out, idealistic holism shares a common fault with reductionism:

> ...they see "true causes" as arising at one level only, with other levels having epistemological but not ontological validity. Clementsian idealism sees the community as the only causal reality, with the behaviors of individual species populations as the direct consequence of the community's mysterious organizing forces... Reductionism...sees the individual species, or ultimately the individuals (or cells, or molecules...), as the only "real" objects, while higher levels are again descriptions of convenience without causal reality. (Levins and Lewontin 1985, p.135)

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[7] The example is from Levins and Lewontin (1985, pp.135-136).

In order to understand ecological systems or social systems, we need to recognize that causal efficacy is not limited to some fundamental unit. Both reductionism and idealistic holism fail to recognize the emergence of new properties at each level of organization and that the whole exerts causal influence on the parts as the parts influence the whole.

This complex, contingent and evolving biological world is then subject to interaction with the seemingly stochastic forces of weather, geology and galaxy. Random events impose on the order in a way that cannot be understood or predicted from an understanding of the entities composing the system. Even with complete biological understanding, which appears impossible to achieve given the contingent and evolutionary qualities of biological systems, the unpredictability of weather patterns and other environmental effects make the complete reduction of biological phenomena to physico-chemical laws an unachievable ideal.

In nature the arrow of time is real. Higher level organisms alter their behavior through cognition and learning and behavioral adaptations may be encoded through natural selection. The interaction of causal processes results in emergent properties that lend a creative and unpredictable element to biological phenomena. We can comprehend a great deal about geological formations or the appearance of new organic species by retrodiction, but we cannot predict, for example, the shape of Mt. St. Helens after the next eruption or the appearance of a new strain of virus. To have any understanding of these phenomena requires a holistic and historical view. The whole influences the parts as the parts influence the whole and the system must be understood as a dialectical whole that is changing its configuration through time in no simple pattern.

The reductionist program has proven extremely successful in certain branches of science, notably physics, chemistry, molecular biology and microbiology. Understanding of a system requires an understanding of its components and of the immanent forces to which it is subject. But at any level of organization new phenomena may arise as a result of contingencies. Contingencies are propagated by the interaction of causal processes. By breaking the system into parts these interactions are obscured. A reductionist program is critical to understanding complex phenomena but can never provide more than part of the puzzle.

2.4 Explanation and Prediction

The aim of science, for the scientific positivist, is to find universal, deterministic laws which allow absolute prediction:

> The Laws of Nature are man's descriptive formulae of uniformities of sequence, which enable him to say, "If this, then that". (Thomson 1922, p.1168)

The test of a scientific theory, on this view, is its ability to make reliable predictions. On a positivist view explanation and prediction are symmetrical. Explaining a phenomenon is to predict its occurrence as a necessary consequence of one or more law-like generalizations, the so-called deductivist or covering law model of scientific explanation (Hempel and Oppenheim 1948). Prediction follows as a consequence of successful explanation.

On a causal view of scientific explanation asymmetries appear between prediction and explanation. In ecology and the social sciences, for example, we seem to be able to explain why things happened the way they did, by retrodiction, without necessarily being able to predict their future occurrences. On the other hand statistical correlations that are not based on causal relations allow us to make predictions without any understanding of why the predictions will hold. Although prediction will always be an important aim of science, predictive certainty as the ideal of science belies the reality of nature. Endeavoring to explain, to seek an understanding of the phenomena we experience, allows us to recognize the limits of our ability to control nature while giving us some capacity to anticipate and act in the face of fundamental uncertainty. In the following discussion I will illustrate the differences between explanation and prediction and argue that explanation is a more fundamental goal of science than prediction.

In the biological and social sciences, universal, deterministic laws have been elusive[8]. Generalizations in these disciplines tend to be probabilistic, often having numerous exceptions, and tend to apply to geographically or otherwise restricted contexts. Generalizations might describe, for example, the basic process of evolutionary change, the habitat requirements of a species of animal or the dynamics of interaction between species. As these generalizations are conditional, habitat requirements may be slightly different at different geographic locations or within different populations. Anomalies may occur such as the observation of a species occupying a hitherto unknown habitat[9]. Similarly, the two-species interaction may be different in different habitats and/or may be profoundly influenced in certain settings by a third, fourth or fifth species. These kinds of generalizations are subject to change via specific processes of evolution and/or the emergence of particular contingencies.

Such *conditional* generalizations identify a regularity or cause "without knowing what the conditions are which are necessary for its causal efficacy" (Scriven 1959, p.481). By identifying the relevant conditions a past event may be successfully explained and the conditions that might lead to future occurrences anticipated.

To say that the extinction of the Irish elk[10] is to be explained by the swamping of its habitat, is to say that given a relevant set of circumstances, flooding caused the extinction. These circumstances might include aspects of climate and terrain, and morphological features of the animal that prevented it from coping successfully with its altered habitat. Other contingencies, such as the presence of a predator, could have caused the extinction had they happened to occur. But in this specific case we suppose that we have an explanation that

[8] For a useful discussion of the nature of generalizations in the biological sciences see Mayr (1988) and in the social sciences see MacIntyre (1984).
[9] An interesting but unsubstantiated example is provided by a logger's report of a spotted owl found nesting in an abandoned automobile. Preservation of the spotted owls' preferred habitat, old-growth forest, has reduced the area available for commercial forestry in Oregon and Washington, USA, creating a lively conflict between loggers and environmentalists.
[10] This example is from Scriven (1959).

fits the facts as we know them. In the future, if we were to perceive a similar species of animal, having similar habitat requirements, in circumstances similar to those of the Irish elk at the time of its extinction, we might anticipate a similar event. In this new situation, however, we face an assortment of new ecological contingencies including, perhaps, an animal that has developed behavioral and morphological features different than the Irish elk. Thus, extinction may not occur in this new case, while an extinction may occur in other circumstances beyond our experience.

The account given above suggests that the attempt to develop fixed, deterministic laws may have limited application in at least some branches of science. Knowledge of the living world must continue to grow and change as organic systems keep changing and slipping away. Our inability to make firm predictions, in such circumstances, seems to bear little on the quality of our knowledge. To explain the inability of a science to produce predictive tools as indicative of its *immaturity* as a science is facile. While the ability of a scientific discipline to forecast the future improves as the discipline develops, the limits of predictive power are ultimately imposed by the complex, contingent and evolutionary nature of the phenomena, towards an understanding of which biology and ecology have made enormous strides.

While I have argued that valid scientific explanations are possible with no guarantee of prediction, it seems equally clear that prediction is possible without explanation. Given the elevation of the sun, for example, we can predict the height of a flagpole from the length of its shadow[11]. Clearly, the shadow does not explain the height of the flagpole. To explain involves identifying the causal process involved, light from the sun passing or being blocked by the flagpole before casting a shadow when it reaches the ground.

In antiquity the tides could be reliably predicted. But not until Newton proposed a constant conjunction with the cycles of the moon, and the mechanism of gravity, was it

[11] The flagpole example is attributed to Sylvain Bromberger by Salmon (1984).

possible to explain *how* they occurred. Even still, there was little reason to believe that we could explain *why* the tides occurred in terms of proximal causes, until the theoretical proposal, in the 20th century, of gravitational fields that provided a causal connection.

For an example from ecological science consider the use of empirical correlations with lake processes such as eutrophication. The correlation between phosphorus loading and biomass production can statistically account for the variation in productivity in lakes in the north temperate zone. But predictions for a particular lake may be substantially wrong. Moreover the statistical correlation ignores other system properties that may be critical to understanding a particular lake. Lehman (1986) describes an example wherein scientists used empirical models to predict phosphorus concentrations in Northern Manitoba lakes subject to hydro-electric development. While the models may have successfully predicted phosphorus concentration, the actual ecosystem alterations included fishery collapse, unacceptable mercury contamination, and excessive shoreline erosion. The model used could neither predict nor explain the unexpected results. In Lehman's (1986, p.1161) words:

> ...if we do not know why a particular relationship conforms to the data, we cannot guess when it will fail or if the failure would be catastrophic.

Prediction requires only consistent correlation, not an identification of causes, although prediction may follow on causal explanation. Prediction, as the ideal of science, encourages us to ignore the openness and uncertainty in nature, and to look only for certainty, for constant conjunction. Simple correlation produces a kind of illusion, a superficial knowledge that overstates our ability to influence and control natural processes. The quest to answer why deepens our understanding of the way the world works and forces a recognition that contingencies create the opportunity for unexpected results.

In an important book on the philosophy of biology, Elliot Sober argues that even though improbable events may be explained and that indeterminism may be a reality, our standard of explanation should still be oriented toward a deterministic ideal:

> ...an explanation need not be a prediction, but one property that makes an explanation good is that it facilitates prediction. (Sober 1987. p.146)

The deterministic ideal of predictive certainty is a poor and potentially dangerous standard for science for two reasons. First, there are numerous examples of low probability events that appear to be ideally explained. Second it encourages us to favor explanations with a high degree of predictive certainty when, in fact, explanations with low predictive power may provide far more realistic characterizations of the phenomena in question. I will address first the issue of low probability explanation, leaving the latter question to the end of this section.

There are numerous examples, from physics and biology, of relatively improbable events that appear to be completely explained. Radioactive decay events in long-lived isotopes, for example, are highly unlikely statistical events that nevertheless occur with measurably high precision.

Irreducibly stochastic events occur in the biological world as well. Suppose a Mendelian genetic experiment employing pea blossoms produces 3/4 red blossoms and 1/4 white blossoms. Exactly the same circumstances explain both events, although no individual event can be predicted with certainty. Is the occurrence of a red blossom better explained than the occurrence of a white blossom because it is more likely? In this case we apparently know exactly why the 3:1 ratio occurs. There are no additional circumstances that might complete our explanation in a fashion that would allow absolute prediction of individual events. It appears that the occurrence of a white blossom is as well explained as a red blossom.

A deterministic ideal encourages the view that science is not concerned with the explanation of individual events but only with identifying regularities. This view is unacceptable for two reasons. First, it is by the anomalous event that we expand our understanding of nature. Searching for regularity leads us to reduce *noise* although variation in perceived regularities frequently leads to the discovery or confirmation of additional causal processes.

Consider an example, again from Salmon (1984, p.118):

> ...the famous electron diffraction experiments of Davisson and Germer gave rise to statistical distributions of scattered electrons that were quite puzzling and quite out of harmony with the results Davisson predicted on the basis of his theory.

These experiments were conducted in 1923 and repeated in 1925 before the puzzled Davisson, at a conference in Oxford, heard Born cite them as confirmatory evidence for de Broglie's electron waves.

Salmon documents another example from genetics, involving controlled breeding of red-eyed male fruit-flies with white-eyed females. In 200 of the matings, the expected distribution of 1:1 white-eyed progeny to red was observed. But in six matings almost all the progeny were red-eyed. The investigators, rather than accepting that the regularity still held, recognized that an explanation of the anomalous phenomenon required "an investigation of the chemical mechanisms of the 'cheating genes'" (Salmon 1984, p.118).

The second objection to the argument that science is not concerned with the explanation of individual events is simply that it ignores a major aspect of the scientific enterprise.

> We want to know why a particular dam collapsed, or why a particular airplane crashed, or why a particular soldier contracted leukemia, or why a particular teenager became a juvenile delinquent. (Salmon 1984, p.119)

To say that science is not concerned with specific events but only with regularities, is discordant with a major motivation of science and, moreover, with the important role science plays in human affairs.

Placing the onus on science to produce predictive tools places it in a paradoxical position with respect to reality. The reality is that generalizations in the biological and social sciences may inherently be predictively weak and that no law-like generalizations may be obtainable. To the complexity, contingency and evolutionary qualities of biological systems, MacIntyre (1984) adds four kinds of systematic unpredictability in human affairs:

1. Our capacity for radical conceptual innovation.
2. The unpredictability of my future by me.
3. The game-theoretic nature of social interactions.
4. Contingency in social systems.

Under such circumstances I see no reason to suppose that generalizations with high predictive power should be inherently better than those with lower predictive power. MacIntyre cites an example from economics that makes the point clear:

> ...forecasts produced on the basis of the more sophisticated economic theory for OECD since 1967 have produced less successful predictions than would have been arrived at by using the common-sense, or as they say, naive methods of forecasting rates of growth by taking the average rate of growth for the last ten years as a guide or rates of inflation by assuming that the next six months will resemble the last six months. (MacIntyre 1984, p.89)

Simple correlations may provide better predictive tools but they lead us no further toward an understanding of the dynamic nature of the system and of why its properties are difficult to predict. While useful as practical tools they beg the question of why the predictions hold and cannot explain the circumstances under which predictions will fail. Predictive power as the sole standard for science encourages us to remain naive and search for statistical regularities with high predictive power in the short-term but negligible explanatory power in the long-term.

This is not to imply that more complex, *realistic* models are preferable under all circumstances. Predictive power is still an important criterion for evaluating the adequacy of scientific models. Ludwig and Walters (1985) provide an example from fisheries management where a simpler, less realistic model provides better estimates of surplus production because of inadequate information for parameter estimation in a complex, more realistic model. The less complex model may perform better as a forecasting tool because it makes fewer incorrect assumptions about noise in the system. In this case it still describes a basic causal relation between surplus production and catch per unit effort that reflects the state of knowledge with respect to a specific fishery and provides a useful management tool. An increase in model complexity unjustified by adequate knowledge of its significance creates an illusion of knowledge where in fact additional research is required.

The search for correlation, for laws that could predict future events, without asking why, has produced much mischief. The attempt to correlate race with intelligence creates a dangerous illusion of racial superiority even though more insightful research suggests that the correlations are due, in large part, to social and environmental factors and to the nature of the tests of intelligence used. The turn of the century science of eugenics was regarded as a valid scientific enterprise in its time, appearing on many university curricula. Eugenicists supported a hereditarian view of such characteristics as drunkenness and simplemindedness, and sought correlations between such features and a statistical analysis of physical measurement that might lead to selectively breeding out these characteristics (Farrall 1985).

Around the turn of this century, Karl Pearson, for example, advocated measures to encourage England's better *stock* to have larger families and prevent its degenerate *stock* from multiplying. The goal was to increase the *national efficiency* and improve England's chances in the "struggle of race against race and nation against nation"[12]. In retrospect we can see that a hereditarian view fails to account for the full range of causes of intelligence or sobriety, for the causal interactions with society and environment that alter human behavior such that some characteristics are passed on and some not. The ideal of certainty encourages the eugenicist kind of view over one that might say it is less clear that we can predict such traits as intelligence or sobriety. The consequence can be a gross restriction of basic human rights.

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[12] These are Pearson's words as quoted in Farrall (1985, p.303).

The search for predictive power in forestry produced the concept of the normal forest which will be discussed in more detail in Chapters 4 and 5. The concept of the normal forest began as an abstraction for the purpose of simplifying the problems of forest measurement. From this grew the idea of simplifying the forest itself for economic reasons and to simplify yield forecasting (Lowood 1990). The potential losses in biodiversity accompanying a simplification of the spatial and temporal diversity of the forest, prior to any inquiry into its importance, may create long-term problems for the integrity of forest ecosystems.

We live in a perilous world where the contingencies of population growth and environmental limits require us to act and science provides the most accessible information to guide that action. We want to predict the harvest of farms, forests and fisheries, the incidence of disease, trends in the economy and the outbreak of wars. We can, and do, make use of predictive indices that have little explanatory power. But the predictions we produce rarely match ideally the real world we face:

> ...long-term prophecies can be derived from scientific conditional predictions only if they apply to systems which can be described as well-isolated, stationary, and recurrent. These systems are very rare in nature; and modern society is surely not one of them. (Popper 1963, p.339)

We need to develop our understanding of natural systems in order to understand the circumstances in which our predictions fail. We must be wary of the consequences of prediction and learn to adjust and adapt as contingencies interpose on our predictive models.

In certain areas of science, molecular biology for example, the positivist paradigms of reductionism and determinism have proven extremely successful. But any general model of science has to account for phenomena at the macroscopic level as well. Prediction is a fundamental part of the scientific process and a critical aspect of society's mandate to science. But the ideal of predictive certainty, to the extent that it informs public policy, has been the source of many damaging illusions. A better ideal for science, in my view, is that it constantly and energetically seek to broaden, deepen and re-evaluate our understanding of reality, a reality written in causal processes, propagated and interacting through space and time.

2.5 Is Science a Method?

The claim has been made that the positive benefit of science and the source of its demarcation from other knowledge-seeking activities are defined by its method:

> ...those who wish to defend some privileged status for scientific knowledge...attempt to define some universal, ahistorical methodology of science which specifies the standards against which putative sciences are to be judged. (Chalmers 1990, p.11)

The scientific positivist who argues that a meaningful statement is one that can be empirically verified, and that scientific method is the way to gain empirical verification, might claim that scientific method is the only way to gain correct knowledge of reality.

On a standard textbook definition of scientific method (e.g. Dellow 1970 or Wilson 1952), scientific knowledge begins with the collection of data, via observation and controlled, replicated experiments. The data are then systematized or ordered until such point as an hypothesis can be posited, through inductive inference, that might explain the apparent order. The test of an hypothesis is a comparison of its consequences or predictions with empirical evidence. Predictions are made by deductive inference.

> If...repeated experiments show that the predictions are consistently verified, the hypothesis is elevated to the dignity of a *law*, and it can be used as a foundation for further work. (Dellow 1970, p.22, author's italics)

The process of hypothesis formation is the process of discovery in science. One method by which hypotheses are generated is by inductive inference. This involves reasoning from specific information to more general concepts or principles. This may involve passive observation of instances of similarity, difference and co-variance, it may involve comparison, it may involve the Baconian method of intervening in a system and observing the effects or it may involve the use of controlled, replicated experiments. In the latter case the aim is to limit the influence of extraneous factors in order to more clearly see the relations of interest. Hypotheses may also be developed on the basis of analogy or metaphor. The mechanical philosophy of Descartes is a large-scale metaphor or heuristic that has generated countless scientific hypotheses.

Hempel (1966) argues that the process of hypothesis formation requires creative imagination and is not necessarily rational. As an example he offers Kekule's discovery of the structure of the benzene ring in a dream about snakes. Similarly, Kepler's study of planetary motion is said to have been inspired by his interest in mystical doctrines and his desire to demonstrate the *music of the spheres* (Hempel 1966).

An examination of the process of hypothesis formation invites skepticism about a universal scientific method. One way to remove this skepticism is to place the rationality and universality of science elsewhere in the process of scientific activity.

> ...scientific objectivity is safeguarded by the principle that while hypotheses and theories may be freely invented and *proposed* in science, they can be *accepted* into the body of scientific knowledge only if they pass critical scrutiny, which includes in particular the checking of suitable test implications by careful observation or experiment. (Hempel 1966, p.16, author's italics)

Popper (1963), who was centrally concerned about the logical problem of induction, takes a similar position. Hypotheses are to be seen as myths and the rationality of science consists only in its unflaggingly critical attitude toward such myths. A theory is never considered to be true, it can only be falsified by flinging it against the world in a systematic way. To be scientific, an hypothesis must have deductive consequences that can be tested against empirical evidence. Popper solved the problem of induction by removing it as a part of rational science. On his view hypotheses could not be confirmed, as this involves inductive inference, but only falsified given the success or failure of testing its deductive consequences against empirical evidence.

But what is a valid test of an hypothesis? When do we decide that a theory or hypothesis has been falsified and by what criteria do we decide to discard it? Chalmers argues that Popper's criteria, indeed all attempts to provide such criteria, fail to account for the history of science.

Chalmers offers Newton's astronomy as an example of a theory faced by observations incompatible with it but which persevered and had a "dramatically successful career". Similarly, Maxwell recognized that his kinetic theory of gases "could not possibly satisfy the known relation between the two specific heats of all gases"[13]. However, Chalmers (1990, p.18) points out that

> All of the considerable successes of the kinetic theory occurred *after* the difficulty for the theory was appreciated. (author's italics)

MacIntyre's example from economics, offered in the last section, provides evidence of a hypothesis that has high explanatory power even though its test consequences fail to match reality. In ecology, deductive inferences frequently fail to match up with empirical evidence because of transient or contingent conditions. In practice the model is not discarded until it can be determined that the failure is due to the model and not to unforeseeable contingencies in the ecological system to which the model does not apply. The model or hypothesis may still provide means of understanding the unexpected results. In 1990 record low harvests of coho salmon in British Columbia were not predicted by population ecologists. However, it is believed that the salmon changed their migratory route in a previously unobserved way, perhaps due to an *El Nino*[14] event, such that they were captured in American waters[15]. The unexpected result may be used to improve the model by inductive inference.

That the deductive model of science is the only model is disputed by Kaplan:

> ...we know the reason for something either when we can fit it into a known pattern, or else when we can deduce it from other known truths. (Kaplan 1963, p.332)

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[13] As quoted by Chalmers (1990, p.18) from Maxwell's first paper on the subject in 1859.
[14] *El Nino* events involve a periodic warming of ocean currents in the Pacific Ocean and associated changes in characteristic weather.
[15] From personal communication with Gordon Haas and Dana Atagi of the Fisheries Institute, University of British Columbia, Vancouver, B.C.

Kaplan provides examples of the pattern method in behavioral psychology. This method involves explaining an event by identifying it as part of an organized whole. Consider the extinction of Irish elk on a pattern model. We cannot predict the extinction as a deductive consequence of evolutionary theory. But if we think of evolution as a pattern operating in nature we can *explain* the extinction by saying how it fits into the pattern of evolution. Moreover, the successful explanation of the extinction lends inductive support to the general theory of evolution. The argument has been made that evolution is not a scientific theory because it does not fit the deductive model (Peters 1976). Sober (1987) provides compelling evidence to the contrary, but even if evolutionary theory does not fit the deductive model, its success as a scientific theory is evident in its explanatory power.

Arguably, the extinction of Irish elk can be considered as a deductive consequence, by retrodiction, of evolutionary theory. To do so we are required to construe the rules of deductive inference in a way rather different from the rules for deductive inference science has traditionally followed. On Hempel's (1966) view, for example, a deductive inference is a necessary consequence of law-like generalizations and initial conditions. In ecology or sociology where no law-like generalizations have appeared, deductive inference would appear to follow a different model. As a result of contingency model predictions never ideally match reality. The theory or model must be continually adjusted by inductive inference as a result of test consequences. Nelson Goodman suggests that this may not be a problem:

> Principles of deductive inference are justified by their conformity with accepted deductive practice. Their validity depends upon accordance with the particular deductive inferences we actually sanction and make. If a rule yields inacceptable inferences, we drop it as invalid. (Goodman 1965, p. 63-64)

Goodman's remark sounds curiously to me like justifying the rules of deductive inference by induction. In fact, inductive and deductive logic both play important roles in the process of science:

> ...if we were to reject induction, there would be no way in which any scientific generalization could be established on the basis of empirical evidence. (Salmon 1984, p.249)

Inductive inference plays an important role in the creation of hypotheses and in the process of developing theory. As the deductive consequences of a theory are compared with evidence there is a process of induction by enumeration that contributes to the overall acceptability of the theory. Deductive inference and inductive inference are both necessary tools that interplay in the process of scientific inquiry.

Dellow indicated that the standard of science was to discover law-like generalizations. That this standard may be unachievable by many sciences without compromising their ability to broaden our understanding of nature is indicative of the way scientific standards have changed through time. As our understanding of the world has grown, our expectations of knowledge about it has had to keep pace. Following Hume, science sought to discover constant conjunction between cause and effect but, as we have seen, Newton's gravitational theory made it fashionable to be agnostic regarding causes and seek correlations. I have argued that contemporary science and philosophy have solved, at least at the macroscopic level, the Newtonian problem of action-at-a-distance and the Humean problem of causal connection. The aim of science, as I see it, is to discover the network of causal processes that can provide an understanding or explanation of natural phenomena. Events at the sub-atomic level suggest that our *a priori* view of the world may change yet. Action-at-a-distance in quantum physics may ultimately be explained by the discovery of some mechanism currently unknown to us or, on the view of the distinguished physicist Steven Weinberg, it may be accounted for by a geometric description of nature of an unfamiliar variety:

> ...I strongly suspect that ultimately we will find that the four-dimensional nature of space-time is another one of the illusory concepts that have their origin in the nature of human evolution, but that must be relinquished as our knowledge increases.[16]

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[16] As quoted in Salmon (1984, pp.258-259).

The various methods and the changing standards of science support the argument that no universal, ahistorical method of science is to be found. No regimented definition of scientific method seems able to account for the complexity of the scientific process:

> Science has not one aim but many, and its development has passed through many contrasted stages. It is therefore fruitless to look for a single, all-purpose 'scientific method': the growth and evolution of scientific ideas depends on no one method and will always call for a broad range of different enquiries. Science as a whole - the activity, its aims, its methods and ideas - evolves by variation and selection. (Toulmin 1961, p.17)

Chalmers argues that the methods of science are relative to historically contingent standards. Methods and standards can be evaluated by the extent to which they serve the aim of science:

> How the aim of science is to be evaluated is certainly relative to other aims and interests, but once that aim is adopted, then the extent to which various methods and standards serve it is not a matter of subjective opinion, but a matter of objective fact to be practically established. (Chalmers 1990, p.8)

Nagel (1961) sees the difference between science and common sense as lying in its critical attitude. There is no special set of techniques or rules of discovery that can guarantee the success of the scientific enterprise; there is only

> ..the deliberate policy of science to expose its cognitive claims to the repeated challenge of critically probative observational data. (Nagel 1961, p.12)

Nagel argues that no set of rules can guarantee satisfactory explanations nor eliminate every personal bias or source of error.

> ...no antecedently fixed set of rules can serve as automatic safeguards against unsuspected prejudices and other causes of error that might adversely affect the course of the investigation. (Nagel 1961, p.13)

We might reasonably conclude that

> ...the scientist has no other method than doing his damnedest.[17]

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[17] This quote is attributed to P.W. Bridgman by Kaplan (1963, p.27).

How can science be characterized, if not by its method? The aim of science is to explain the events that occur in the world around us, by developing general knowledge that can be interpreted in specific cases. As Chalmers argues, the methods of science can be objectively evaluated on their practical merits in contributing to this aim. Bad or trivial science is to be distinguished not on the basis of its failure to adhere to appropriate methods but for its failure to contribute to acceptable causal explanations of the phenomena we experience. The objectivity of science cannot be guaranteed by method but only supported by an open and critical mind.

2.6 The Objectivity of Science

What is the nature of scientific knowledge? On one hand science is viewed as pure rationality and objectivity, seeking to describe the world as it is. If we accept that our sensual experience of the world is real and that it corresponds to an objective reality, science is no more than the attempt to describe and explain that reality. At this level there is subjectivity in science because there is no possibility for scientists of sensing the world in a way that is not conditioned by their experience as an individual in a society. At another level science is seen as being subjective because it is grounded in particular, historical situations where it has served the prevailing ideology. An environmentalist might argue that science has been mandated to develop means of exploiting and dominating nature and our knowledge of nature is skewed by this emphasis.

Marcello Cini (1991) writes that

> ...scientific knowledge is neither pure objectivity nor pure subjectivity. It simply reflects, in its forms and in the means it utilizes for representing nature, the influence and conditioning of the surrounding social context. Expressed in different terms, science provides us with an image of the world that has been constructed and is continually remodeled through a selection of those aspects of the surrounding reality which, in determinate social and historical conditions, appear problematic to the community of those who are involved in this enterprise. There is no doubt that this image incorporates objective properties of what lies outside - if it were not so, our species already

> would have been extinct for some time - but it remains an image constructed by and for us. (Cini 1991, p.40)

Science and scientists do not just try to understand the world, they also live in it. The objectivity of science is compromised, in a sense, because science is a social enterprise. Science is sanctioned and funded by the society of which it is a part. Scientists are human beings with individual social and moral points of view. The choice of phenomena to study and the approach to that study may reflect the values of the scientist, of a society in a particular historical context and/or the concerns of a funding agency. While scientists may strive to be objective and value-free the historical context within which they operate influences the kinds of questions they may ask.

The science of eugenics was a legitimate scientific enterprise in its time that contributed to our current understanding of human genetics. But the motivation for a science of eugenics came from elements in a fading empire that blamed its decline on the inherent moral laxity of the inferior *races* who nonetheless bred at a disproportionately high rate. Science mandated to discover a means of breeding drunkenness out of the British people is unlikely to discover the full range of causes having a propensity to result in drunkenness.

There are many examples of how scientific research can be mandated by funding sources and other social institutions. Simberloff noted that the Ecosystem Studies Program of the American National Science Foundation had twice the budget but only half the proposals of the General Ecology Program. He argued

> ...that the ecosystem paradigm is seductive on economic grounds alone, independent of either philosophical or biological considerations. (Simberloff 1980, p.29)

A clearer example is provided by the agricultural mechanization suit brought against the University of California in the 1980s[18]. The suit, which was decided in favour of the claimant, argued that research conducted at the University of California was skewed towards

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[18] This information was presented in a lecture by David Noble of Drexel University, Philadelphia, Pennsylvania at the Robson Square Media Center, Vancouver, B.C., November 27, 1987.

the agro-corporations and could not be used by small farmers. The university was ordered to prepare a plan for research designed to help the whole spectrum of the public.

As an example of scientific innovation that had negative benefits for the rural agriculture community consider the mechanical tomato harvester. It reduced the unit cost of harvesting tomatoes but its prohibitive capital cost made it compatible only with a highly concentrated and extensive style of growing. The number of tomato growers in California declined from roughly four thousand in the early 1960s to some six hundred in the 1970s with a reduction of an estimated 32000 jobs[19]. The artifactual consequence was a profound alteration of the social fabric of rural California.

The manner by which scientific research is mandated can skew our perception of reality. Forest research has focussed on developing growth and yield models of commercial tree species, on breeding programs to improve the genetic make-up of these species and on silvicultural techniques for improving their growth and yield. The mandate for science was to find ways to increase the yield of merchantable wood fibre. What has resulted is an image of the forest as a simplified tree farm. In recent years research in the remaining primary forest has begun to reveal how little this image captures of the complexities of forest ecosystems. This research has been motivated in part by the environmental movement but also by concerns that the current state of scientific knowledge about the forest and the current level of practice are inadequate to sustain forests capable of producing the wide range of amenities that we currently enjoy.

Scientists are largely motivated by a compelling desire to attempt to understand the phenomena of the world around them. To a certain extent the kinds of questions that science asks and the state of scientific knowledge will reflect the mandate provided by funding agencies and ultimately, in a democratic society, the public. The desire to extract more wealth from forests produced the image of the simplified conifer plantation where energy is

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[19] this example is from Winner (1980).

not expended on other species. Public and scientific concerns over this agenda have helped to create a new mandate to research forests in a more holistic fashion.

The history of science provides examples of science conducted in spite of its social and historical context and in spite of the opposition of the prevailing ideology. Galileo, Newton, Darwin and Einstein conducted their researches on mechanics, planetary motion and natural evolution not to topple the prevailing views but rather, with grave misgivings regarding the consequences of their findings. Galileo was censured by the Inquisition for his work supporting the heliocentric cosmology. Darwin originally planned not to publish his work because of fears it would upset his wife's Christian sensibilities. Their efforts are the result of attempting to see the world "without superstition or imposture". Being open to the phenomena and being critical of my preconceptions, biases and personal ideology are the only sense I have of what it means to be objective. The forms of science are designed to help me see objectively but make no guarantee of the objectivity of my findings.

I have presented science as an activity that attempts to develop general knowledge that can be used to interpret specific instances. For integrated sciences, at least, there is always variation between generalization and reality. Science is both a theoretical and an interpretive discipline. The signature of science is a critical attitude towards its current state of knowledge.

Science is a cultural activity and is largely mandated by the society within which it exists. A growing awareness of the impacts of human activity on the global environment has focussed attention on the science of ecology as the means to ameliorate environmental degradation. I will turn next to the issue of ecology as science and issues of special significance to the scientific study of the environment.

3. ECOLOGY AS SCIENCE

The study of nature and the search for pattern and harmony within it go back, no doubt, as long as people have had occasion to wonder. The term ecology comes from the Greek word *oikos* meaning house. The beginnings of ecology as a science are rooted in the Darwinian revolution in biology which promoted a slow shift in perception of the world as fixed, orderly and immutable to a perception of the world as orderly, in a sense, but at the same time contingent, and thus dynamic. The German biologist Ernst Haeckel's early definition of ecology in 1870 still contains the essence of modern scientific ecology:

> [Ecology involves]...the investigation of the total relations of the animal both to its inorganic environment and to its organic environment - in a word, ecology is the study of all the complex interrelations referred to by Darwin as the conditions of the struggle for existence.[1]

Ecology is a science of the relationships between living beings and other living beings and with their environment. As a consequence, it is a polymorphic discipline, encompassing pure and applied science involved in the study of plants and animals living in marine and terrestrial environments.

A growing body of evidence, coupled with public recognition of the impact of humanity on its environment, have raised the profile of scientific ecology as a means of understanding the global environment and mitigating biotic impoverishment and ecological degradation. As the 21st century approaches we are faced with the effects of large-scale industrial pollution, natural resource depletion and species extinctions due to habitat destruction. The limits of the environment impose on our growth as a species and as a culture.

The expectations placed on ecology have been tempered by its perceived inability to make substantial contributions to the resolution of the environmental problems confronting

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[1] As quoted in Kormondy (1976, p.x).

us. Some writers have suggested that this state of affairs is due to the juvenile nature of ecology as science[2]. On this view, ecology either has not yet developed a comprehensive theoretical framework from which predictive tools can be constructed; or wastes too much effort developing theory without enough attention to empirical generalization. In spite of these methodological debates, G. M. Woodwell, for example, argues that

> ...there is a difference of several orders of magnitude between what we know about nature and what we do about managing our wastes. (Woodwell 1989, p.15)

If we know more about natural systems than we put to use, what are the barriers to the implementation of ecological knowledge? One is our basic human aversion to change. Ecological knowledge often suggests that we must alter or limit what may be culturally ingrained and/or lucrative activities. It is difficult to tell fishers they cannot fish or loggers they cannot log. It is difficult to impose costs on or shut down an industry that contributes employment and tax dollars to the national economy.

The fact that ecological knowledge is easy to question provides a second, more tangible obstacle to its application. Ecological systems are extremely complex, contingent and historical in nature. Each new problem must be treated as a unique experiment without exact controls or replicates. The complexity and contingency of ecological phenomena preclude a reductionist approach. Knowledge about a system must be accumulated by formalized trial and error methods and adjusted constantly as new contingencies arise.

Ecological knowledge comes not in the form of tight causal proofs, of constant facts, but in the form of a story about the present, based on the present and recent past, that suggests how the story may proceed into the future. A good story is based on empirical data, on causal relations, on both theoretical and empirical generalizations and on experience. The project of ecological science is to build up a kit of conceptual tools, both theoretical and empirical, that facilitate the telling of a useful and plausible story. A good story of any kind

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[2] See, for example, Peters (1991) and MacFadyen (1975).

correctly interprets the available facts but the totality of facts regarding ecological phenomena may be beyond our reach for fundamental and practical reasons. The nature of the subject, in this case ecological phenomena, may not permit the kind of certain knowledge acclaimed by positivist philosophy as the goal of science.

The integrity of ecological science has also been questioned because of its confusion with various *ecologisms*. Elements in the environmental movement have, sometimes justifiably, sometimes questionably, appropriated ecological knowledge to ground moral and political positions. The concept of ecology has been broadened to include not just the science of ecology but an unsecured belief that any change or disturbance to the natural world is wrong. This normative use of the word ecology clearly transcends the scientific quest to understand nature and clouds the issue of ecology as science. The emphasis of this chapter will be on ecology as science.

The chapter begins by characterizing the nature of ecological phenomena and will illustrate how ecological knowledge is constrained by the nature of its subject matter. The brief history of ecology has been dominated by two debates that will be discussed in the remainder of the chapter. The first debate centers around the assumption that there is an appropriate object of study for ecological science. Should ecologists study organisms, populations, communities or ecosystems? The second debate revolves around the question of how to study ecological phenomena. Is ecology inductive science or deductive science, empirical science or theoretical science?

Both of these debates are based, in my view, on a misguided adherence to the positivist ideology that dominated ecological thought until around the middle of this century and is still prevalent. In the first half of this century ecology was concerned with developing universal theory that would provide predictive certainty. Emphasis was on finding the appropriate methods and spatiotemporal scale by which universal pattern could be identified. By recognizing that universal pattern and, thus, predictive certainty are beyond the sights of scientific ecology we can move beyond these debates and re-assess the kind of knowledge that ecology can provide. This will lead to a more productive role for ecology in the social debate on human agency in the environment.

Ecology provides conceptual tools in the form of conditional generalizations that can be used to interpret specific contexts. The nature of the phenomena precludes the attainment of universal, certain knowledge by ecological science. The extreme environmental movement and the extreme industrial movement make the same mistake in assuming that some kind of complete scientific knowledge dictates what our future course must be. Environmentalists use science to support an agenda of preservation while industrialists use the same science to support an agenda of exploitation. The kind of knowledge that ecology can produce is rather different and suggests a more subservient and supportive role for ecology in the social process of public policy-making.

3.1 The Nature of Ecological Phenomena

Ecology covers a field so wide that a reductionist approach is tempting. But no one fundamental unit of study can account for the complexity of ecological phenomena. In physics, chemistry and many aspects of biology the unit of study is relatively discrete. The ecologist, however, must cope with a much larger range of observation classes. In order to develop an understanding of ecological phenomena, the ecologist must have a thorough grounding in physics, chemistry and biology, and then address the interaction between individual and environment, the dynamics of populations of individuals, and of interacting populations, and the flow of energy and nutrients in the environment in relation to interacting populations.

That ecology cannot agree on a single unit of study is a consequence of the hierarchy of complexity and not just a symptom of ill-health or immaturity in ecological science. The population, the community and the ecosystem are levels of abstraction that have produced useful concepts for understanding ecological phenomena. But no one type of observation class can be expected to unify ecological science. The ecologist must retain a broad perspective even while focussing on specific aspects of the more complex system.

In addition to being complex, ecological phenomena are, in G.G. Simpson's term, *configurational*:

> The unchanging properties of matter and energy... are *immanent* in the material universe. The actual state of the universe or of any part of it at a given time, its configuration, is not immanent and is constantly changing. (Simpson 1963, p. 24, author's italics)

The interactions within and between populations and communities of organisms and the environment result in new causal processes that cannot be foreseen from an understanding of the *immanent* properties of the system. Ecological phenomena are historical phenomena and ecological science is not just the quest for immanent properties but also the interpretation of history. The trajectories of populations, communities and ecosystems are not linear. It is possible, for example, to know the mechanisms of seed dispersal in a plant community but not be able to predict the arrangement of the plant community. Seeds may be dispersed by wind but then be subject to secondary dispersal by animals. Contingency lends a creative dimension to ecological phenomena that, by itself, places them beyond the scope of deterministic science.

While the configuration of ecological phenomena is dynamic in response to contingencies, the components of ecological phenomena are themselves in a constant process of change in response to contingencies. Change occurs through organic evolution which involves random genetic mutation and natural selection in response to environmental contingencies. Change also occurs through the capacity of living things to propagate causal influence in response to contingent information via sensory processes. Many species of organisms have the ability to learn new behaviors and to teach these behaviors to their offspring. Behavioral adaptations by individuals will in turn affect the structure of populations and communities.

Ecological phenomena are subject to the unpredictability of various environmental agents. Global and local weather patterns may be deterministic but in a chaotic way. They may be statistically predictable over very large spatiotemporal scales although there appears to be sporadic randomness even at this scale. At local, particular levels of scales the chaotic behavior of weather may be intractable to prediction. We may be able to predict that lightning storms will occur but not where lightning will strike and wildfires will start. Weather and weather-related events such as storms, wildfires and insect epidemics are critical forces operating on ecological phenomena. While the larger forces at work in the ecosphere, wind and ocean currents, continental drift and mountain building, may be persistent over relatively short times, their consequences for local, particular ecological phenomena may be far less predictable.

The study of ecological phenomena, thus, entails the search for immanent properties governing ecosystem behavior but also the historical determinants of configurational sequences. Ecology, like geology, sociology and economics, differs from physics or chemistry in that it is a historical science. Ecologists study specific aspects of ecological phenomena in order to construct theory, principles, concepts, and laws that can be used to explain or understand why ecological phenomena are structured in the way they are and how they might proceed into the future.

Ultimately nature is historically-bound; it is an unreplicable experiment. It is necessary to bound nature in space and time to develop an understanding of concrete aspects of it. The issue of spatiotemporal scale is critical to an assessment of the predictability of ecological phenomena:

> ...ecology cannot set up a single spatiotemporal scale that will be adequate for all investigations. As a result, ecologists must be careful not to extrapolate from any single type of observation to the nature of the underlying system. (O'Neill et al. 1986, p.19)

At small spatiotemporal scales, where the phenomena can be abstracted to a small number of components, ecological systems appear to be essentially deterministic (Pimm 1991, O'Neill et al. 1986). Population dynaimcs of single species and two-species interactions, for example, have been successfully modelled in the short-term at least (Kingsland 1985). Similarly, very large number systems, where there is a large number of components that are independent and essentially identical, appear to be statistically predictable. The behavior of gases follows this model.

Ecological phenomena fall into the category of middle number systems (O'Neill et al. 1986). As scale is expanded the interactions between components of the system become increasingly critical to understanding the dynamics of the system (Pimm 1991).

> There are too many components to describe each by a single equation; there are not enough to simply average properties. (O'Neill et al. 1986, p.44)

Structured interrelationships produce contingencies and local, particular phenomena are also subject to contingencies as a result of chaotic weather-related effects. These contingencies encourage evolutionary and behavioral changes in organisms that are in part random. Taken all together, the implication is that a certain degree of stochasticity or uncertainty is an essential feature of ecological phenomena.

Certainty is beyond the grasp of ecology and ecologists must continually re-assess and adjust their interpretation of ecological phenomena. Like the Bhuddist novice the ecologist must learn to live with the question rather than hoping for an ultimate answer.

3.2 What Do Ecologists Study?

In his classic treatise on humanity and nature, Glacken (1967, p.423) wrote:

> I am convinced that modern ecological theory, so important in our attitudes toward nature and man's interference with it, owes its origin to the design argument: The wisdom of the creator is self-evident, everything in the creation is interrelated, no living thing is useless, and all are related one to the other.

Perhaps the oldest ecological theory is the idea of a *balance-of-nature.* The birth of ecology as a science corresponds to the transformation of this idea "from a divinely ordered nature to an order generated by nature itself via evolution" (McIntosh 1980, p.204). The debate surrounding the idea of harmony or balance in nature and about how to study the natural world began, in earnest, with Gleason's (1926) individualistic concept of the plant formation and the challenge it posed for Clements' (1916) supraorganismic model of plant formation.

The formation, community, association, coenose or society were concepts applied in the search for fundamental units of recurring groups of species (McIntosh 1985). The process of change in ecological formations had been recognized in the late 19th century, notably by Thoreau, who provided the term succession, and by Warming in 1895, in his *Oecology of Plants*, an early classic in the ecological literature (McIntosh 1980). Cowles, who studied the forests of the eastern United States around the turn of the 20th century, was the first person to systematically study the succession of plant *communities*, endeavoring to discover *laws* that would govern the processes of change. McIntosh sums up Cowles' contribution by noting that he

> ...established the phenomena of plant succession as fundamental to ecological thought, but the laws and theory he sought remain elusive to this day. (McIntosh 1980, p.208)

Inspired by Cowles, Clements formulated what he considered to be a deductive universal system to describe ecological succession. Clements believed the plant community to be integrated like an individual organism. He postulated an orderly succession in which *pioneer* species are established on a disturbed site and subsequently change the environment, facilitating the establishment of *seral* species. As a group of species replaces another, the habitat is increasingly controlled by the organisms, leading to a stable, self-reproducing, *climax* community.

Clements was influenced, by his own admission, by the positivism and organismic philosophy of Herbert Spencer. The idea that ecological units were organismic wholes, the properties and succession of which could be described by deterministic laws and theory, was seductive to ecologists at a time "when Comtian Spencerian positivism was almost a religion to scientists" (Worster 1977, p.212). In viewing the plant community as an organismic whole and as the fundamental unit of ecological inquiry, Clements' holism was a kind of naive reductionism. The complexities of ecological phenomena were reduced to a single spatiotemporal scale from which predictive models could be developed.

Clements' positivist view of plant communities and the promise of deterministic models of plant succession were also of interest to the growing community of people interested in forestry (Rodgers 1951). They fitted well with the ideas of 19th century German forestry which were attracting interest in the United States at the turn of the 20th century. The Clementsian view of supraorganismic communities as evolving integrated entities with homeostatic properties formed the dominant view in American ecology prior to 1950 (McIntosh 1985).

The challenge to Clements' holistic determinism came from Gleason, who believed

> ...that the association was a product of largely chance arrival of organisms selected by a continuously varying environment and held that the results of succession need not follow in any orderly, predictable way. (McIntosh 1980, p.211)

Gleason's questioning of the objective reality of the plant association was published three times between 1917 and 1939 but was largely ignored until ca. 1950 when it began to be used by a new generation of ecologists to attack the Clementsian *paradigm* (Simberloff 1980, p.17).

The supraorganism was attacked as a *fortuitous abstraction* and the assumption that the community causes its own development and persistence was criticized as an *a priori* explanation, rather than an empirically derived mechanism. Raup (1981, p.1), for example, described his disaffection with the succession theory of Clements and Cowles:

> ...I began to be suspicious of Clements' emphasis on biological succession as a system for interpreting the history of the vegetation in any given spot... I began to wonder whether any "dynamic" interpretation of present vegetation could be projected backward or forward through the changes in landform, climates and soils that we know have occurred since the ice disappeared, many of which are still going on.

Clements' idea of the plant community as a supraorganism held out the hope of a description of the vast complexity of natural systems. The resurrection of Gleason's ideas was, in effect, an acceptance that what order was apparent in nature could best be accounted for by studying the populations that made up an assemblage. The new population ecology was reductionist in a different sense than Clements' idealistic holism. Populations were thought to represent an integration of the forces of natural selection and thus, no *a priori* essential forces needed to be posited to account for ecosystem behavior. An ecosystem could be viewed as the sum of its populations and their interactions.

Simberloff (1980) saw the demise of Clementsian ecology as a victory for materialism over essentialism. There are two ways to interpret this claim of victory. It could be seen as supporting a reductionist view; a plant and/or animal community is an assemblage of populations, not a supraorganism. A second way to understand the succession of the Gleasonian paradigm is that while ecologists accepted that ecosystems or communities or assemblages displayed *emergent* properties, they believed that the best way to produce theory and predictive models and develop an understanding of the whole was through a reductionist approach.

The work of Lotka, Volterra, G.F. Gause and Pearl earlier in the century had produced a body of mathematical theory to describe populations and two-species interactions. The success of Raymond Pearl's work on human demography, Chapman, Nicholson, and Andrewartha and Birch on insect populations, and Graham's modelling of fish populations provided powerful tools for managing natural populations that were socio-economically important (Kingsland 1985). Thus, there were practical concerns that gave impetus to the new theoretical population ecology as well as the desire of ecologists to develop a predictive science along the lines of physics and chemistry. Pearl, who had been profoundly influenced by Pearson's **The Grammar of Science** and later studied with Pearson in London, took the positivist view that the logistic curve was a law of nature (Kingsland 1985).

Hutchinson and MacArthur expanded the use of mathematical theory to the study of communities. MacArthur acknowledged the complexity of ecological systems and the role of history and contingency but believed that for ecology to become a science it must search for pattern:

> We use our naturalist's judgment to pick groups large enough for history to have played a minimal role but small enough so that patterns remain clear. (MacArthur 1972, p.177)

MacArthur's approach remained reductionist, in a sense, in searching for a level of scale where invariant pattern will emerge.

The dichotomy between Clements and Gleason begins to dissolve when the effects of spatiotemporal scale are introduced. Clements addressed temporal dynamics while ignoring spatial variability. Gleason took the opposite approach, emphasizing spatial pattern with less attention to temporal concerns (O'Neill et al. 1986). In effect they were addressing different aspects of the same problem.

The difficulty of addressing ecological phenomena at appropriate spatiotemporal scales encouraged the development of the ecosystem concept and the introduction of systems theory to ecology. Tansley introduced the term *ecosystem* in a 1935 paper in the journal *Ecology*:

> But the more fundamental conception is, as it seems to me, the whole *system* (in the sense of physics), including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment of the biome - the habitat factors in the widest sense.
>
> It is the systems so formed which, from the point of view of the ecologist, are the basic units of nature on the face of the earth.
>
> These *ecosystems*, as we may call them, are of the most various kinds and sizes. They form one category of the multitudinous physical systems of the universe, which range from the universe as a whole down to the atom.[3]

Lindemann, and later E.P. and H.T. Odum elaborated the trophic-dynamic aspects of ecosystems, focussing on trophic organization and the movement of energy and nutrients in

[3] As quoted in Golley (1993, p.8).

the system (McIntosh 1985). Emphasis was placed on the ecosystem as the fundamental unit of study for ecology:

> Ecosystems are real... they have in them certain general structural and functional attributes that are recognizable, analyzable and predictable. (Kormondy 1976, p.1)

E.P. Odum, rather like Clements, described the ecosystem as orderly, directional and predictable, being controlled by organisms. The ecosystem consists of biotic and abiotic elements that form a unit of co-evolution. The study of ecosystems introduced thermodynamics, general systems theory and information theory to ecology. Various writers argued that "systems analysis is the scientific method itself" (McIntosh 1980, p.228). Odum's idealistic holism, like Clements' organismic holism is a kind of naive reductionism. The positivist ideal is still present in the search for invariant pattern. In a recent decades there has been a shift in ecology from idealistic holism to what Levins and Lewontin (1985) call dialectical holism and Norton (1991) calls contextual holism.

A system consists of two or more interacting components surrounded by an environment with which it may or may not interact (O'Neill et al. 1986). Systems are everyday components of human existence, not just in ecology, but in the world of machines and social institutions. Ecosystems display organized complexity although components do not have a common aim and the idea that the ecosystem can be conceptualized as a system does not imply any *a priori* commitment to the ecosystem as a supraorganism. An ecosystem may preserve an internal configuration with slow gradual alterations in that configuration:

> The ecosystem is still a system even if it is conceptualized as having a quite different organization than the organism. (O'Neill et al. 1986, p.39)

The ecosystem is a level of abstraction at which pattern in biotic organization and abiotic processes, and historical contingencies can be recognized. Ecosystems such as lakes and watersheds are relatively discrete in space and are functionally integrated. They are, however, not necessarily orderly or predictable. They are still part of the whole biosphere where new contingencies arise.

An ecosystem is not a functional whole that determines the behavior of its components nor is it simply the sum of its components. It is a level of organization that shows structural uniformity while integrating basic physical, chemical and biological processes in a historical context. The ecosystem integrates lower levels of organization such as atom, cell, organism and biotic assemblage. New systems properties emerge at each level of organization in response to interacting causal processes. An ecosystem is best understood as a dialectical whole (Levins and Lewontin 1985) where the parts influence the whole as the whole influences the parts. Norton (1991) calls this contextual holism. The parts must be understood in the context of larger systems and no whole is "reified" as absolute.

In a substantial review, O'Neill et al. (1986) noted that much of contemporary ecology can be divided into population/community ecology and process/functional or ecosystem ecology:

> Population-community ecologists tend to view ecosystems as networks of interacting populations. The biota are the ecosystem and abiotic components such as soil or sediments are external influences. (O'Neill et al. 1986, p.8)
>
> In an extreme form, the functional approach implies that energy flow and nutrient cycling are somehow more important or more fundamental than the biotic entities performing the function. (O'Neill et al. 1986, p.10)

They emphasized that few ecologists fall into either extreme of the spectrum, but the specific problems that interest them draw them in one direction or the other.

Both approaches, however, have limitations such that neither can provide an adequate conceptualization of the ecosystem. To understand the structure and function of an ecosystem it is necessary to understand the dynamics of the biota and the flow of energy and information amongst them. To manage a forest, for example, we need to know the growth patterns of tree species, their community dynamics, and the mechanics of energy and nutrient flow that make growth possible. Ecologically sound management of resources requires knowledge from both approaches.

Population ecology, community ecology and functional ecology all produce useful information in the context of different spatiotemporal scales and different questions we ask of nature. The species, the population, the community, and the ecosystem are all levels of abstraction that are useful in different contexts of enquiry. Each level of spatiotemporal scale, in the context of higher levels of scale within which it operates, tells part of the story.

The ecosystem provides a useful level of integration for managing environmental intervention. It allows us to consider the impacts of harvesting populations, for example, within a broader physical perspective. The ecosystem level also provides a level of abstraction at which we can consider other values that humans derive from nature. As an example, one of the most useful tools for managing forests in British Columbia is biogeoclimatic classification, a system that successfully integrates population/community ideas with functional ecology while recognizing the ecosystem as the fundamental unit of forest management (Klinka 1979). Public debates on wildlife, water quality, aesthetics, wilderness conservation, old-growth preservation and timber extraction can all be conducted within an ecosystem perspective (e.g., Commission on Resources and Environment 1993).

Ecologists generally maintain an ecosystem perspective regardless of whether they do behavioral, population, community, or functional ecology. It is important to understand the ecotypic variation within species, how populations are regulated and how they interact, and how energy and nutrition flow within the system. While focussing on smaller details ecologists and managers must be aware of the larger context within which they operate.

3.3 What Kind of Science is Ecology?

The positivist quest for predictive certainty has fostered a lengthy debate on what kind of science ecology is; theoretical or empirical science, inductive or deductive science. Some ecologists have argued that the progress of ecology has been limited by the lack of a strong theoretical basis by which to organize and relate the glut of data, simple principles and diverse mathematical models it has produced, and that

> ...ecology will not come of age as a science until it has a sound theoretical basis... (Maynard Smith 1974, p.6)

Similarly, Rosenzweig argues that

> As sciences mature, they develop a hypothetico-deductive philosophy. They progress by generating hypotheses and disproving them in controlled experiments. (Rosenzweig 1976, p.779)

Tempering the enthusiasm for general theory in ecology has been the recognition that the complexity and contingency evident in ecological phenomena may limit the kind of theory possible.

> ...the natural desire for general theory by ecologists may be frustrated by the absence of a master plan and the great diversity of relationships. (McIntosh 1980, p.199)

Sagoff (1984) has argued that theoretical models are abused and over-used in ecology and have not been particularly useful in explaining natural systems. Ecology might not be able to provide universal theory capable of explaining and predicting the order of natural events and it might indeed "be more useful if it were construed as a more political, historical, intuitive, and interpretive discipline" (Sagoff 1982).

Another school of thought within ecology holds that there are two kinds of theory:

> The first type, for which I retain the term empirical theory, is the type of theory that merely predicts the future states of a system. Often it is no more than the expression of the correlation between two state variables of a system. The second type of theory also predicts, but it goes beyond mere prediction. It purports to explain to us why the system behaves as it does. (Rigler 1982, p.1324)

Rigler (1982) argues that ecology needs to develop a strong base of empirical *theory* in order to become a predictive science. This view echoes the positivist ideal by implying that prediction is the main concern of science.

Rigler (1982), however, misuses the term theory by applying it to statistical regularity. Theory is the means by which statistical regularities are explained:

> Theories are usually introduced when previous study of a class of phenomena has revealed a system of uniformities that can be expressed in the form of

> empirical laws. Theories then seek to explain those regularities and, generally, to afford a deeper and more accurate understanding of the phenomenon in question. (Hempel 1966, p.70)

The kinetic theory of gases, for example, explains a wide variety of empirically established regularities "...as macroscopic manifestations of statistical regularities in the underlying molecular and atomic phenomena" (Hempel 1966, p.71). Succession theory attempts to explain observed regularities in different aged plant communities on similar sites. The identification of empirical regularities and the construction of theory to explain them are two aspects of the process of science.

At the heart of these arguments are two problems that have faced ecology throughout the century. First, ecological theory is always underdetermined with respect to reality. Ecological phenomena are fundamentally historical phenomena. New phenomena occur that vary in significant ways from those which preceded them. It is difficult to produce unequivocal empirical evidence for theoretical constructs through hypothesis testing.

On the other hand, endless streams of data and correlations are meaningless without the organizational framework that theory provides:

> Scientists are perennially aware that it is best not to trust theory until it is confirmed by evidence. It is equally true, as Eddington pointed out, that it is best not to put too much faith in facts until they have been confirmed by theory. This is why scientists are reluctant to believe in ESP in spite of indisputable facts. Only when a reasonable theory can account for these facts will scientists believe them. (MacArthur 1972, p.253-254)

Theory is the means by which we seek to explain the phenomena that we experience, to ask why things happen the way they do. The idea of a purely empirical science comes from a skeptical position about causes. From this position, as I have described in chapter 2, the project of science is to make predictive generalizations. But it now seems possible to subscribe to a causal view of the world and look for the set of causal processes and interactions that result in a phenomenon, in other words, ask why the phenomenon of interest occurred.

Theory in ecology takes a different form than that of a universal deductive framework. Theory, for ecology, is the nexus of principles, concepts, models, and empirical generalizations that ecologists use to interpret specific contingent phenomena. Science, for the ecologist, must be theoretical, empirical and interpretive all in the same breath.

To strengthen the point let me turn to the question of inductive and deductive science. I have argued in Chapter 2 that induction and deduction are modes of logic that are both necessary to the scientific enterprise. What does it mean when ecology is referred to as inductive science or deductive science? In one sense the question seems to hinge on whether there is a mechanical order or Cartesian-style rationality in nature such that we can develop theoretical constructs and deduce their necessary consequences as testable hypotheses. This exercise might be described as theoretical deductive science. If order in the natural world is absent, or is apparent only in restricted spatiotemporal scales, we are reduced to describing natural history, the characteristics of different species and short-term trends in their relations. This project might be described as inductive, empirical science.

Platt (1964) and Sagoff (1984) have championed the methods of inductive inference as the gateway to success for science and scientific ecology, respectively. Paine's (1980) research on intertidal communities is offered by Sagoff (1984) as an example of the successful application of inductive inference to an ecological phenomenon. But Paine's use of inductive inference in exploring multispecies interactions was undertaken as part of his contribution to the development of food web theory:

> The central significance of webs is derived from the fact that the links between species are often easily identified and the resultant trophic scaffolding provides a tempting descriptor of community structure. If this structure is in any fashion related to the persistence of natural communities or their stability, however defined, then we are dealing with issues of vital ecological significance. (Paine 1980, p.667)

The empirical, inductive aspect of Paine's research is an important part of his attempt to develop theory that might provide "...a realistic framework for understanding complex, highly interactive, multispecies relationships" (Paine 1980, p.682).

Inductive, empirical, natural history-type investigations are the means by which a food web is constructed. The objective is to develop concepts that describe the processes of species interactions and community regulation that can be used to explore other systems or communities. Ecological theory comes in the form of conditional generalizations that can be used to interpret the behavior of specific systems. The theoretical construct, in this case, the food web, provides a means of organizing data collection and generating hypotheses regarding the organization and linkages in the system. Food web theory provides ideas about the kinds of relationships that are possible in a system but the structure of any given system requires empirical investigation which may expose new kinds of relationships. The utility of food web and other ecological theory depends on an ongoing dialectic between theory and data.

Another example of the dialectic between data and theory is the use of non-linear or dynamic population modelling in what has been called adaptive resource management (Walters 1986). The use of non-linear models makes explicit that growth or recruitment in a resource population is always a function of its current condition. At each time step the model updates the condition of the stock based on its prior state. The complexity of the underlying biological and physical systems that causes high levels of natural variability and the paucity of data may make the model initially predictively weak, but each new year's data is used to improve the model by fine-tuning parameters or replacing it with a more appropriate model. This approach accepts that the biological reality will gradually slip away from the mathematical abstraction and adapts accordingly by comparing deductive consequences to empirical data and re-approximating model parameters or the model itself by inductive inference. Adaptive modelling provides an alternative to the difficulties of monitoring management experiments with controls or replicates. Systematic trial and error probing to determine optimum levels of resource use can be conducted with dynamic models as a monitoring tool.

Order is present, in nature, as a result of natural selection and co-evolution encouraging well-defined types of behavior in individual organisms and in relationships within and between organisms in response to each other and to the environment. In addition, ecosystems conform to the immanent laws of physics and chemistry. Disorder is also present as a consequence of the plasticity of individual organisms that allows opportunistic behavior in response to environmental variables and interactions with other organisms. In addition, the processes of evolution and co-evolution are ongoing. As no two pieces of the landscape are alike, it is not surprising that no two assemblages of plants and animals are alike. Ecosystems display difference and similarity in their structure, function and temporal process.

By inductive inference and speculation theories can be constructed that attempt to explain how the system operates. The occurrence of unforeseeable contingencies limits the predictive power of ecological theory. The model or theory must be adjusted inductively in an iterative fashion and calibrated to specific contexts. Deductive models in ecology do not take the form of a mathematical or logical syllogism. Their predictions are not mathematical or logical necessities. What they do is allow the generation of hypotheses that provide opportunities to expand our understanding by fostering a dialectic between deductively inferred generality and inductively inferred particulars.

Raup argued, in 1950, that we needed to know much more about the natural history of species in order to manage our exploitation of them. It has proven equally necessary to develop an understanding of the relations between species and the physical qualities of the systems in which they reside. A variety of approaches and levels of investigation are appropriate to a science that covers as enormous a range of phenomena as ecology. Robert MacArthur warned ecologists not to become obsessed with methods or intellectual approaches but to encourage a variety of different ways of research. Recognizing the complexity and variability of the natural world, he was also concerned about the search for generality in theory:

> A well-known ecologist remarked that any pattern visible in my birds but not in his *Paramecium* would not be interesting, because, I presume, he felt it would not be general... the structure of the environment, the morphology of the species, the economics of species behavior, and the dynamics of population changes are the four essential ingredients of all interesting biogeographic patterns. Any good generalization will be likely to build in all these ingredients, and a bird pattern would only be expected to look like that of *Paramecium* if birds and *Paramecium* had the same morphology, economics, dynamics, and found themselves in environments of the same structure. (MacArthur 1972, p.1)

3.4 Ecology and Society

The natural world is a complex and contingent phenomenon that is irrevocably bound in history. Ecological science has developed a body of knowledge regarding many different aspects of nature that is useful in interpreting the behavior of specific contexts within the natural world. Population models, for example, are useful for determining harvest rates but the population is part of a larger system that interacts causally with the population such that models will hold, without adjustment, only in the short-term. The study of the community provides valuable insight into the relations between populations but is subject to the same constraints. Population and community ecology, in the context of the ecosystem, provide important parts of the story in the attempt to successfully explain ecological phenomena.

It has been useful to view ecological complexity from a systems perspective. Ecosystems are systems, but are open, and are evolving in a non-linear fashion. The complexity of ecosystems makes it difficult to predict their future states with certainty. The ecosystem, nevertheless, is the best level of integration for evaluating the diverse values that people hold with respect to nature. People are part of ecosystems; their actions are a necessary part of contingent explanations within ecology. The ecosystem is, for this reason, the level at which environmental management is most effectively conceptualized.

The uniqueness of ecosystems and their inherent uncertainty make it difficult to learn by using an experimental approach involving controls and replication. One response to this dilemma is the concept of adaptive environmental management[4]. This approach employs dynamic systems models as monitoring tools for trial and error probing in management experiments. The benefit to science is that ecological simulation models can be tested in the real world where they can be made more rigorous by comparison with actual results. Management can be improved by using an experimental protocol that makes management a learning experience.

Science, and scientific ecology, capture many aspects of the way the world is. The natural world is subject to contingency and its configuration is constantly changing. There is much that science can say about specific aspects of nature but there is much about nature of which science can say little. Science cannot, for example, ascribe value to nature. People ascribe values to nature and the aspects of nature that science explores are influenced by the values society imposes on nature at a given time in history. In this way society provides the mandate for science.

Ecology, for example, cannot say that beauty is more valuable than lumber. Ecology cannot prove that there is a balance or harmony in nature. Ecology as science cannot provide a grounding for the argument that man is sinning against nature by destroying her ideal organizing forces. Science can say much about the consequences of different actions. Arguments about what it is right or wrong to do are arguments that transcend science.

Science, and scientific ecology, can describe and explain the processes resulting in desertification, lake eutrophication or atmospheric pollution. Scientific ecology can make us aware of the extent to which we are changing the natural capital on which we depend to make our human economy and human culture function. Ecology can help us address these issues when and if we decide to address them. Ecology cannot tell us it is a sin not to do so.

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[4] See, for example, Holling (1978), Walters (1986), and Hilborn and Walters (1992).

The development of scientific forestry has been strongly influenced by the positivist ideal of certainty. The limitations of ecology as a predictive science have thus limited its contributions to the management of forests. In recent years a growing recognition of ecological uncertainty, and a realization of its importance in the management of forests, has brought changes to the practice of forestry. These shifting perceptions of forests and forestry echo changes in our perception of science and its capacity to characterize the physical world, and changes in the values that society sees evident in nature. An abridged history of scientific forestry and its current state of flux in British Columbia will be the subject of the next two chapters.

4. THE RISE OF SCIENTIFIC FORESTRY

The application of science to forests and the idea of scientific forest management were encouraged by two developments in post-Renaissance Europe. One was the recognition of the economic value of forests. With the rise of liberal capitalism, forests became valued as a rich source of commodity goods. The second idea came from the evolving positivist ideology. Science was the means to ensure the efficient organization of society and the management of resources.

The development of a *scientific* forestry took place primarily in the 19th century at the height of European culture's faith in Cartesian "rationality" and scientific positivism. One of the forefathers of North American forestry, Bernhard Fernow, described forestry as

> ...the application of scientific methods in the production and reproduction of wood crops.[1]

The science he described, at the turn of the century, was a science of predictable order, the ahistorical science of the positivist philosophy.

The cornerstone of scientific forest management has been the concept of sustained yield forestry. As defined by the Society of American Foresters:

> [Sustained yield] as applied to a policy, method, or plan of forest management, implies continuous production with the aim of achieving, at the earliest practical time, an appropriate balance between growth and harvest, either by annual or somewhat longer periods.

The history of scientific forestry is essentially the history of sustained yield forestry. The development of rules and models for achieving sustained yield forestry mirrors, in many ways, the development of science and scientific ecology over the last two centuries. The concept of sustained yield forestry reached North America when the main interest in forests was as a source of economic wealth but the need for regulation of their exploitation was being recognized. What follows is a brief history of the development of scientific forest

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[1] As quoted in Rodgers (1951, p.53).

management and its introduction to North America with particular focus on British Columbia. The main purpose will be to illustrate the positivist influence on the development of scientific forestry at a time when ecological science was in its infancy.

4.1 An Art of Necessity

> Forestry is an art born of necessity, as opposed to arts of convenience and of pleasure. Only when a reduction in the natural supplies of forest products, under the demands of civilization, necessitates the application of art or skill or knowledge in securing a reproduction, or when unfavourable conditions of soil or climate induced by forest destruction make themselves felt does the art of forestry make its appearance. (Fernow 1913, pp 1-2)

Throughout human history, wood has been a primary source of fuel for cooking, heating and smelting, and of building materials for houses and boats. Both Plato and Lucretius wrote that wood was the prerequisite for civilization. The destruction of forests due to over-use was the main factor in the decline of the Mesopotamia of Gilgamesh, Mycenaean Greece and bronze age Crete[2]. The defeat of Athens in the Peloponnesian Wars was largely due to its inability to procure ship timber and

> ...the rise and decline of fuel supplies in Rome closely paralleled the fortunes of the Empire itself. (Perlin 1991, p.128).

Records from the ancient world describe attempts to regulate the cutting of forests but these appear to have been short-lived, typically being interrupted by war and changing political associations. Timber shortages were faced by looking elsewhere for new timber supplies through conquest or negotiation.

In medieval Europe, there are examples of towns and villages that managed coppice stands on a sustained yield basis[3]. But the general concept of a regulated sustained yield management of forests did not appear until the end of the Thirty Years War (1618-48),

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[2] The history of forest use in the Mediterranean is discussed in Thirgood (1981) and Perlin (1991).
[3] See, for example, Heske (1938) and Perlin (1991).

which historians conventionally take to signal the end of feudalism and the emergence of the nation-state, and the beginning of the Age of Enlightenment.

The bloody trail of destruction left by the Thirty Years War left Europe confused and discouraged, and her forests depleted. With no resolution to the religious conflicts that precipitated the war and the Peace of Westphalia mainly the result of the exhaustion of the resources of the combatants, the citizens of Europe were hungry for stability and a sense of certainty. The rationalism expounded by Descartes, and its success, later in the century, in the mechanistic world-view provided by Newton, offered the means of re-grounding the political world in a more stable fashion (Toulmin 1990). The nation-state was viewed as a natural part of the cosmos with the monarch as God's representative on earth and loyal subjects beneath in a *natural* hierarchy of social structure:

> ...abstract, context-free...modern science - *as it actually came into existence* - won public support around 1700 for the legitimacy it apparently gave to the political system of nation-states as much as for its power to explain the motions of planets, or the rise and fall of the tides. (Toulmin 1990, p.128, author's italics)

The Age of Enlightenment brought about the application of science and mathematics to the problems of economics, administration and social practice.

The depletion of timber supplies in the 17th century led to the first *modern* writings on forestry. Thirgood (1983) suggests that the first written description of sustained yield forestry appeared in John Evelyn's *Sylva* of 1664. Evelyn's principles were applied sporadically with some success but had little lasting impact (Thirgood 1983).

For the roots of scientific forestry we must turn to Germany in the 18th and 19th centuries. German-speaking Central Europe in the 18th century was a loose federation of duchies, kingdoms and free cities. Timber shortages and the breakdown of feudalism following the Thirty Years War encouraged the development of an institutional device to bring order to the use of forests (Lee, 1982). With the move to a mercantilistic state-controlled economy, the control of forests by the feudal estate was gradually replaced by state control. The economic philosophy of mercantilism regarded the state as an individual merchant. The mercantilistic state was a closed economy in which the state might grow rich by exporting more than it imported. Accordingly, high import tariffs were imposed and efforts were taken to create self-sufficiency in natural resources[4]. The bureaucratization of the state financial apparatus required a science of state finances for the management of fiscal administration and resource management. The new science of state administration became known, in Germany, as the *cameral sciences* (*Kameralwissenschaften*). From the cameral sciences came the beginnings of scientific forestry (*forstwissenschaft*).

Forstwissenschaft, as it developed, was decidedly mathematically-based and theoretically-oriented:

> At the Cameral College in Kaiserslautern, for example, mathematics was one of the subjects required of every student, and "empiricists" wishing to proceed straight to practical studies without this preparation were not welcome. (Lowood 1990, p.321)

The earliest methods for regulating forests were area-based. On an area-based system, foresters estimated the growth cycle, what we now call the rotation, and then partitioned the forest into divisions equal to the number of years in the growth cycle. This method was adequate for relatively short growth periods typical of coppice farming and periodic clearing of underwood. But the areal division of the forest ignored the difference between sites and the increasing variation in volume yield in older stands. Other problems included the inflexibility of the system to adjustments of the cut and, perhaps most seriously, annual yields could not be predicted over the growing cycle. For the fiscal planning and management required by the new bureaucracy, it was necessary to know the amount of lumber and fuelwood to be harvested.

Recognition of these problems motivated interest in developing techniques for measuring tree volume and developing volume-based forest regulation. By the end of the

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[4] My discussion of mercantilism and its relation to forestry is based on Haley (1966) and Lee (1982).

18th century, German foresters, led by Heinrich Cotta and Georg Hartig, had worked out steps for determining, predicting, and controlling forest production. Cotta developed experience tables which gave empirically-derived volume estimates for standard-sized trees:

> From summary investigations based entirely on verified judgment, we go through various stages to more exact investigations, first of individual trees, then of the supply, growth, and yield-determination of individual stands, and finally of whole forests.[5]

By the turn of the 19th century, forest science was well established, both academically and practically, in the German states. The main tenets of this rational synthesis of "calculation and cameralism" were the twin concepts of the regulated or *normal forest* and *sustained yield*:

> ...the ideal of the "regulated forest" proclaimed the preservation of the forest's maximum yield under a sound system of forest economy. (Lowood 1990, p.333)

The rationalism of the modern world and its off-shoot, the nation-state, required certainty and stability and the Grail of scientific forestry, as it entered the 19th century, became sustained yield. The goal of forest management, for Hartig, Cotta and their followers, was to "deliver the greatest possible constant volume of wood"[6].

To achieve the greatest possible constant volume of wood, or the *maximum sustained yield*, the practice developed of harvesting stands at the point where the mean annual increment was maximized (Figure 4-1). As a tree reaches maturity, wood increment begins to gradually decrease because of the energy the tree must expend on maintenance. Therefore the rotation was set at the point in time when the current annual increment declines to meet the mean annual increment, at which point the marginal rate of return equals zero. The management problem is then how to regulate the forest in such a way that equal annual volumes of wood are reaching the rotation age. The solution was to re-structure the abnormal

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[5] Cotta, as quoted in Lowood (1990, p.331).

[6] Hartig, as quoted in Lowood (1990, p.338).

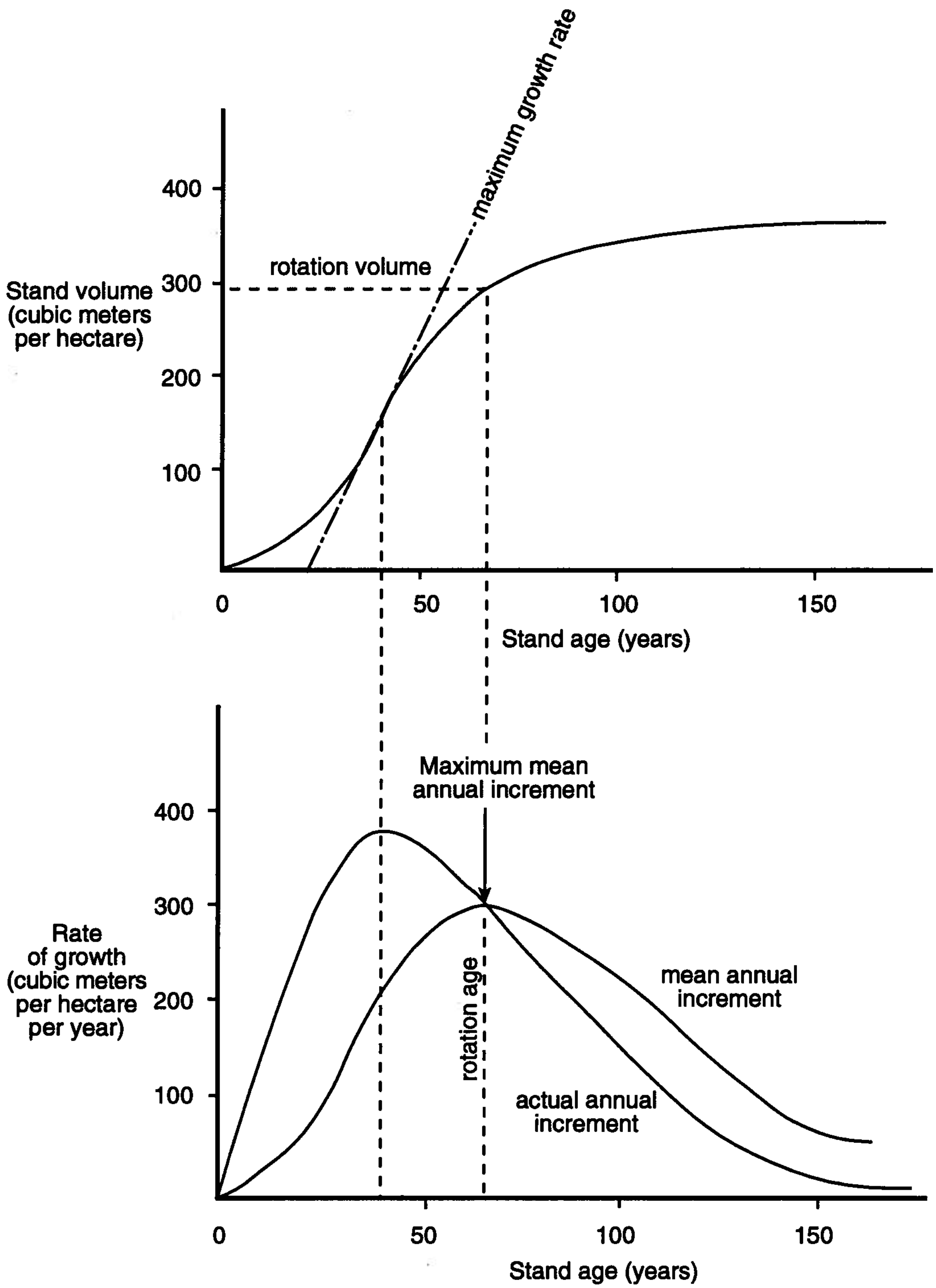

Figure 4-1. The rotation age that maximizes forest growth

forest into a *normal forest*, a forest having a number of annual harvest blocks equal to the rotation.

A standard definition of a normal forest is offered by Brasnett (1953):

> A normal forest is an ideally constituted forest with such volume of trees of various ages so distributed and growing in such a way that they produce equal annual volumes of produce which can be removed continuously without detriment to future production. (see Figure 4-2)

The conceptualization of the normal forest was originally a consequence of the problems of forest measurement. By abstracting the forest into standard classes of trees and ignoring the vast diversity of the forest, measurement could be facilitated. Experience tables were developed that gave volumes, derived stereometrically, geometrically or by sampling, for the *standard tree*, by size and age class. From a few samples it was supposed that the whole forest could be characterized (Lowood 1990).

In the 19th century two events had important effects on German forestry. Cameralism gradually gave way to economic liberalism, and coal began to replace wood as the primary fuel for heating and smelting. With decreased pressure on the forests for fuel, there was a move to replace mixed-wood, multi-aged forests with monocultural, even-aged forests of spruce and pine that had better form and physical qualities, and consequently higher value, for timber. With the simplification of the forest, the normal forest was transformed from useful abstraction to reality:

> The German forest became an archetype for imposing on disorderly nature the neatly arranged constructs of science. ...In the hands of a suitably trained forester, mathematical order and practical utility became one enterprise. (Lowood 1990, p.340-41)

The goal of most forest managers, to this day, is to regulate the yield of the forest in a fashion so designed as to achieve a *normal* forest.

Before the end of the 19th century, two quite different challenges were offered to the German ideal of sustained yield forestry, both of which influence the current debate in North America. The first, by an economist, was an argument that forests should be managed not by

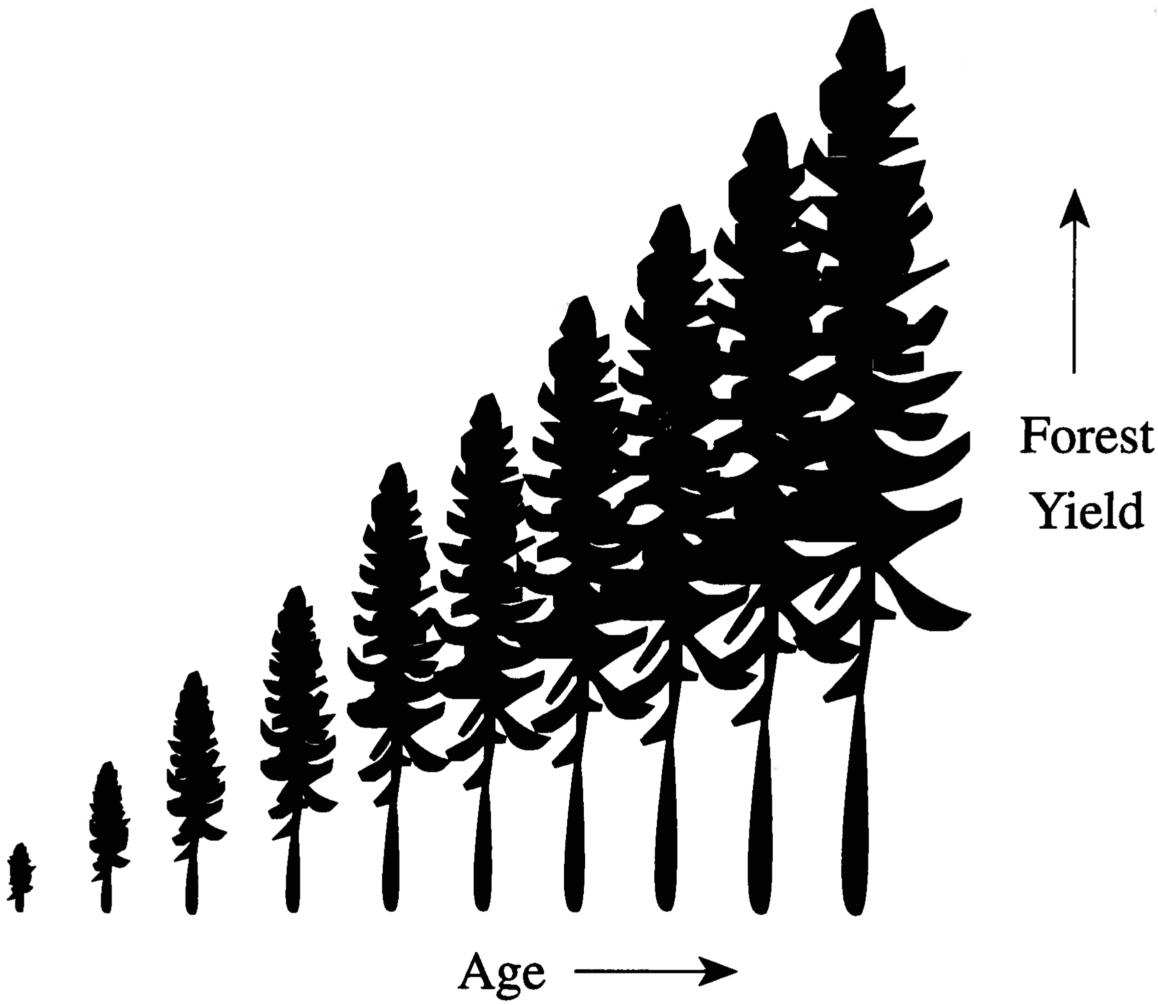

Figure 4-2. The Normal Forest. Each schematic tree represents the volume of trees at various ages distributed in such a way that they produce equal annual volumes for harvest.

their capacity for growth but on the criterion of financial return. The second challenge, from a very different position, expressed the concern that the quest for normality and financial return were compromising the biological integrity of the forests.

As transportation and communication improved, and coal became the primary fuel for cooking and heating, local communities were no longer as dependent on the timber supplies in their immediate vicinity. In the spirit of liberal capitalism,

> Wood had changed from a carefully rationed essential material to an ordinary commodity, the production of which should be governed largely by financial considerations. (Heske 1938, p.37)

The new school of economic thought, led by Pressler, argued that the practice of harvesting stands to maximize yield was economically inefficient. Each forest stand should be considered as a separate financial undertaking and cutting should take place when the value of the increment ceases to represent a satisfactory return on the capital value of timber and land. Pressler advocated the conversion of mixed high forest to pure spruce for the production of pitwood and pulpwood on short rotations (Brasnett 1953). According to Heske (1938) these arguments were largely ignored by German foresters except to the point of recognizing the importance of evaluating the profitability of forest management. The debate surrounding economic rotation versus physical rotation remains contentious to this day.

Pressler's arguments did lend impetus to the practice of converting mixed high forest to spruce or pine monocultures. This practice was applied in Bavaria, Bohemia, Austria, and the German-speaking cantons of Switzerland, and in this century in Scandinavia and the United Kingdom. Towards the end of his life Cotta expressed concern about planting pure spruce stands outside their natural habitat where they became susceptible to wind, drought, and insect attack (Brasnett 1953). In Heske's (1938) words:

> Unquestionably, there was at first an increase in the money income. But the even-aged plantations of a single species ("monocultures") were contrary to nature. Sooner or later, they showed serious defects, such as soil deterioration and decreased rate of growth, lessened resistance to animal and plant parasites, and increased liability to injuries from snow, hoarfrost, and wind.

> As foresters gained better knowledge of the natural sciences, however, they realized that forestry which is to be truly profitable in the long run can never contravene natural laws but must be based upon them. (Heske 1938, p.39)

Spruce is generally a nutrient-demanding species and may depend on the nutrient-rich leaf litter of beech and other hardwoods to maintain the nutrient status of the soil. Insects, diseases, and animal damage are typically more damaging in uniform stands because of the continuous availability of the host and possibly because of stress induced by nutrient deficiency (Stoszek 1988). In mixed stands the effects may be dispersed and mitigated by increased predator diversity (Schowalter 1989). Wind damage is typically more severe in even-aged pure stands of spruce because of its characteristically shallow rooting habit and root connections in the upper soil layers (Fowells 1965). If one tree falls it may pull several others down by the roots. In multi-aged stands with a layered canopy the intensity and effects of wind may be mitigated.

In the last quarter of the 19th century, Karl Gayer argued that foresters had to recognize the biological factors that control the life of the forest. Gayer's emphasis on practical common sense and holistic, natural forestry was opposed to the

> ...one sided striving for normality and the mathematical calculations of profit. This school demanded that the forest be treated in accordance with biological laws, i.e.; mixed forest instead of the schematic culture of pure stands; retention of the soil-improving broadleaf species, especially beech; natural regeneration instead of clear-cutting with artificial seeding or planting; and uneven-aged form of forest in place of the forest composed of schematically arranged even-aged stands. (Heske 1938, p.40)

Gayer's *Back to Nature* movement had a profound influence on German forestry. His ideas were adopted throughout southern Germany and in the German speaking cantons of Switzerland, and in France led to Biolley's Methode du Controle (Haley 1966).

Closely connected to Gayer's ideas was the *Dauerwald* (continuous forest) movement that appeared after the turn of the 20th century. The continuous forest model was based on

> ...recognition of the fact that the forest is not merely an aggregation of individual trees, but is an integrated, organic entity... Health of the forest and

> lasting maximum production of timber are possible only if all parts of the forest entity function without hindrance. (Heske 1938, p.42)

To Dauerwald advocates schematic monocultures lacked "harmonious" structure and internal resistance to external dangers. Accordingly, the continuous forest movement believed that clear-cutting, which brought about the destruction of countless members of the cooperative whole, should be replaced by single-tree selection methods that retained the intact forest (Heske 1938).

At the time of Heske's writing in 1938, there was a vigorous debate in German forestry about the problems of monoculture and how to cultivate healthy forests. Land tenure patterns in Germany allowed the development of a variety of styles of forestry and a debate, based on actual experience, of the merits of each. The Prussian Government advocated the idea of the continuous forest and the abandonment of clear-cut systems (Schindler and Godbe 1993) These reforms were, of course, interrupted by World War II and the forests suffered severely, during the conflict, from over-use. In the 1950s the cause of nature-minded forestry was taken up by a group of foresters and forest owners who practiced continuous forestry on state experimental and private forests. The debate between even-aged, clear-cut system forests and continuous forests is again current in Germany following heavy storms in 1990 that reportedly caused proportionately greater damage in even-aged stands (Schindler and Godbe 1993).

German scientific forestry appears to have developed as a kind of scientific positivism. The emphasis on mathematical precision and the program of simplification to allow effective prediction echo the explicitly positivist statements of the French Comte and the English Pearson. The debate between the forest as an aggregation of trees and the forest as an integrated, organic entity provides a preface, of sorts, to the debate between Clements and Gleason in the 1920s and the current debates about forest practice worldwide.

4.2 Scientific Forestry Reaches North America

American forests had been exploited since colonial times for local fuel consumption, homebuilding and land clearing for farming, and also to supply the shipbuilding industries of western Europe. Exploitation accelerated with the growth of the American population and the development of industry. Pinchot remarked that in the last half of the 19th century

> Public opinion held the forests in particular to be inexhaustible and in the way. (Pinchot 1947, p.1)

But by this time, concern was beginning to be expressed about the devastation of American forests. In 1850, 25% of the land area of the United States was forested; by 1870 this figure is estimated to have been reduced to 15% (Perlin 1991). Forests in the Eastern and Lake states were largely depleted. Recognition of the importance of forests to American prosperity came roughly at the same time. Writing on the destruction of the forests of Wisconsin, Increase Lapham noted, in 1867, that

> Few persons...realize...the amount we owe to the native forests of our country for the capital and wealth our people are now enjoying...without the fuel, the buildings, the fences, furniture and [a] thousand utensils, and machines of every kind, the principal materials for which are taken directly from the forests we should be reduced to a condition of destitution.[7]

The time was ripe for the introduction of ideas about managing forests for continuous production.

Germanic scientific forestry and the idea of sustained yield forestry were introduced to North America around 1900 by Bernhard Fernow and Gifford Pinchot[8]. Fernow was a German forester who came to America, in 1876, to marry an American woman he had met while studying forestry at Muenden in the state of Hannover. Fernow was the first professional forester in North America and was influential in introducing the idea of a profession of forestry and promoting forestry education in both the United States and

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[7] As quoted in Perlin (1991, p.354).
[8] The roles of Pinchot and Fernow in introducing German forestry to North America are discussed in Lee (1982), Twight (1988) and Miller (1989).

Canada. He worked at various times as a private consultant, as Chief of the Forestry Division of the United States Department of Agriculture and as the first Director of the New York College of Forestry at Cornell University and of the Forestry School at Pennsylvania State College. In 1907, Fernow was appointed dean of the first forestry school in Canada at the University of Toronto (Rodgers 1951).

In 1902, Fernow produced the first American textbook on forest economics, *Economics of Forestry*. He declared the "ideal of the forester" as

> [A] forest so arranged that annually, forever, the same amount of wood product, namely, that which grows annually...may be harvested.[9]

Fernow's restatement of the sustained yield principle has become part of the orthodoxy of professional forestry in North America.

Although the science of ecology was in its infancy at the turn of the 20th century Fernow referred to forestry as "applied ecology". Cowles, Clements and others were developing a rudimentary knowledge of the ecological characteristics of forest trees in the northeastern United States. Fernow is reported to have welcomed the appearance of Clements' *Research Methods in Ecology* in 1905 and recommended it to foresters (Rodgers 1951).

While Fernow was the first to introduce the ideas of scientific forestry to North America, Gifford Pinchot was the prime mover in putting them into practice. Pinchot decided to become a forester at a time when timber was something to be got rid of:

> "How would you like to be a forester?" asked my foresighted Father one fortunate morning in the summer of 1885, just before I went to college. It was an amazing question for that day and generation - how amazing I didn't begin to understand at the time. When it was asked, not a single American had made Forestry his profession. Not an acre of timberland was being handled under the principles of Forestry anywhere in America. (Pinchot 1947, p.1)

Pinchot went to Yale and took courses he believed would be relevant to forestry and then spent several years in France and Germany studying the most advanced forest

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[9] As quoted in Behan (1978).

practices[10]. Upon his return in 1892 he took charge of timber management on the Biltmore estate in North Carolina. In 1898 Pinchot followed Fernow as Chief of the Division of Forestry, later the Bureau of Forestry in the Department of Agriculture. Under his leadership the Bureau moved from an agency that merely dispensed information to one that actively promoted sustained-yield practices.

Pinchot's goal was to educate the public and the private forest industry about scientific forest management. He offered the services of federal foresters to draw up management plans and by 1905 owners of some three million acres had applied for assistance. Pinchot undertook inquiries into forest fire destruction in order to convince lumbermen that fire protection would pay. He studied tree planting and advised forest owners about reforestation problems. He also initiated management on federal forest lands.

The ideals of scientific forest management championed by Pinchot were well suited to the *progressive conservation* movement which reached its zenith during the presidency of Teddy Roosevelt. At the turn of the 20th century the United States were undergoing turbulent times economically and socially as the frontier disappeared. The conservationists preached the *gospel of efficiency*, a rational, scientific approach to management which would eliminate waste by regulating the application of harvesting effort and making the system produce to its highest potential (Hays, 1959). For some the progressive conservation movement was merely the attempt to bring sound businesss principles to managing the nations' resources but it was also a kind of moral crusade. Lee (1982) argues that part of the appeal of sustained yield forestry was as a symbol of biological continuity during a time of social upheaval.

The principles of the conservation movement were consistent with some of the dominant intellectual ideas of the day, notably scientific positivism. The conservation

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[10] My discussion of Gifford Pinchot comes from Pinchot (1947), Pinkett (1970) and Hays (1959).

movement reflected the positivist ideal that the democratic process couldn't guarantee rational and scientific decisions. Science was the means to determine right action:

> People took comfort in the idea that the world ran like precision clockwork - and not only could be fully understood through the pursuit of science, but could also be fine-tuned by human beings for optimal performance. (Shideler and Hendricks 1991, p.22)

Like the German cameralists, the conservationists envisioned centralized control of resources and their management by a technical bureaucracy.

Pinchot and Roosevelt expanded the national forest reserves and promoted rational, scientific forest management as part of the conservationist philosophy. A National Conservation Commission was appointed in 1908 with the mandate of inventorying all the natural resources of the nation. But after the defeat of Roosevelt in the 1909 election interest in progressive conservation and sustained yield forestry flagged.

By the early 1900s the forests of the Eastern States, Lake States and Southern States had largely been depleted and speculators began to look to the west for new sources of virgin timber. The shift of focus to timber speculation in the Northwestern states carried with it the debate about sustained yield forestry. The new champion of sustained yield was David T. Mason who had graduated in 1907 from the new Yale School of Forestry that Pinchot had helped to establish at his *alma mater*. In the 1920s Mason established himself as a consulting forester in the Northwestern United States where he helped to develop private land sustained yield programs for the Crown Willamette Paper Company (later Crown Zellerbach) and the Weyerhauser Timber Company among others (Richardson 1983).

As a lobbyist Mason argued that sustained yield forest management was the way to promote stabilization of the national timber supply, the forest industry, and the local communities that depended on forest jobs. He believed that sustained yield management would promote the conservation of water, soil, climate and recreation opportunities (Mason and Bruce 1931). Mason's position was a continuation of the progressive conservation philosophy of Pinchot and Teddy Roosevelt:

> ...a sound plan of forest conservation...[and]... the national timber supply can be provided *most efficiently* through sustained yield forest management. (Mason and Bruce 1931, p.5, author's italics)

The Great Depression helped to re-stimulate interest in conservation and sustained yield forestry. Franklin Roosevelt's support for a national reforestation program was a contributing factor in his 1933 presidential election victory (Patton 1994). The new government instituted the Civilian Conservation Corps which put people to work in the forest, building roads and trails, fighting fires, and planting trees.

The long debate over sustained yield management on the National Forests had become focussed on the idea of cooperative management. Mason acted as a lobbyist for the lumber companies in trying to implement this idea (Richardson 1983). Public lands would be added to company lands to create a sustained yield unit that would be managed by agreement between the Forest Service and the lumber company. This plan was enshrined as the Sustained Yield Forest Management Act of 1944. Industry proposals to develop cooperative sustained yield units were successfully opposed by small local contractors and labor groups and only one such unit was established (Lee 1982). The concept of cooperative forest management had considerably more success in British Columbia later in the 1940s in the form of Resource Management Agreements (later, Tree Farm Licences).

Sustained yield forestry re-appeared as a public issue in the United States in the 1960s with the emergence of the modern environmental movement and its opposition to unregulated harvesting on public lands (Lee 1982). Despite its extended history, the legal requirement of sustained yield forestry on public lands was not enacted until The Multiple Use and Sustained Yield Act of 1964. Since that time sustained yield policy has been under constant challenge, particularly from forest economists following on the ideas of economic efficiency put forward by Pressler. Consequently the Forest Management Act of 1976 authorizes departures from nondeclining even-flow policy (Lee 1982).

4.3 Introduction of Sustained Yield Forestry to British Columbia

The history of forestry in British Columbia is fairly typical for North America. Land clearing for homesteading followed by unregulated exploitation for profit were based on the perception that the forests were effectively limitless. Around the turn of the 20th century the North American timber industry discovered the rich timber resources of the Pacific Northwest setting off a kind of timber boom. The rapid expansion in the cutting of timber in British Columbia exposed the need to assess the ability of the province to regulate the exploitation of timber.

In 1909 the first Royal Commission on forestry in British Columbia (known as the Fulton Commission, after the Chief Commissioner, F.J. Fulton) was convened to address how best to dispose of crown timber in a fashion that would provide maximum benefit to the province. The commission addressed concerns about the wastage of wood due to low utilization standards, the destruction of forests by fire, and particularly the problem of licensing and dispensation of timber rights. The report recognized the economic value of the resource and the need to regulate its exploitation. The forests of British Columbia were still so vast at this time that in the report of the Commission, prepared by M.A. Grainger, the Commissioners commented thus:

> Two things are therefore plain; one, that the value of standing timber in British Columbia is destined to rise to heights that general opinion would consider incredible today; the other, that under careful management heavy taxation need never fall upon the population of the province. (British Columbia 1910, p.20)

At this time the American Conservation Movement was in full bloom and affected the public attitude toward forestry in Canada (Haley 1966). The Canadian Forestry Association was formed in 1900 with a platform of promoting forest conservation. Around the turn of the century, the Dominion government created almost 10 million acres of Dominion timber reserves following the lead of the United States Department of Agriculture. In 1906 a forestry conference was convened in Ottawa that included addresses by many of the leading North American foresters including Fernow and Pinchot. Among its recommendations were the development of a national forest policy, the establishment of provincial Forest Services and the promotion of the aim of sustained production (Haley 1966).

The ideals of the conservation movement are echoed in the report of the Fulton Commission:

> The natural advantages of our country must remain unimpaired, the public revenue and the lumbering industry must both be protected, in other words, a sound policy of forest conservation must be established. (British Columbia, 1910, p.67)

In preparing their report the commissioners had met with Fernow and Pinchot and employed Overton Price as a consultant to help Grainger draft the legislation that became British Columbia's Forest Act (Orchard 1964). Price had worked with Pinchot at the U.S. Forest Service and had also served on Roosevelt's National Conservation Commission.

The passing of the Forest Act in 1912 made no explicit provision for sustained yield management but in Section 12(1) included provision for the establishment of provincial forests for "the perpetual growing of timber" (British Columbia 1912). The Forest Act also provided for the establishment of a Forest Branch within the Department of Lands. The first chief forester was H.R. MacMillan who had been a classmate of Mason's at Yale (Richardson 1983). MacMillan, with the assistance of Price, organized the new Forest Branch on the model of the United States Forest Service (Orchard 1964) which Fernow and Pinchot had built on the model of the Prussian Forest Service (Twight 1990). The responsibilities of the Forest Branch included overseeing the disposition of timber and managing the new provincial forest reserves.

MacMillan requested that the federal government conduct a survey of the forest resources in British Columbia. In 1918, the Canadian Commission of Conservation released the publication *Forests of British Columbia* by Whitford and Craig. Whitford was an American ecologist who had been recommended for a position with the Commission of

Conservation by Fernow. *Forests of British Columbia* provides a detailed estimate of the extent of the forest resources of the province, a review of the current state of management, and a description of the characteristic features and range of the main timber species. The report also offers an interesting re-statement of the conservationist ideal:

> All the efforts of the Dominion must be devoted to production and economy. The vast resources of Canada, to which the term 'illimitable' has been so frequently applied, because of lack of knowledge, must be turned to some useful purpose. Untilled fields, buried minerals or standing forests are of no value except for the wealth which, through industry, can be produced therefrom. (Whitford and Craig 1918, p.1)

After the Forest Act was passed in 1912 the rate of cutting of forest land increased while forest practices, including regeneration of the new forest, remained generally poor (Haley 1966). The Forest Branch, in its annual reports, began to express concern over the condition of the forests and *overcutting* on the coast:

> ...the object of creating Provincial Forests is to keep the areas permanently productive. Not only must we leave the area in a condition for regeneration but we must also guard against too rapid cutting, or we will have not permanent but periodic production with long lapses of time between one crop and the next. (British Columbia Forest Branch 1925, p.81)

MacMillan had staffed the Forest Branch, to a large extent, with students of Fernow's from the University of Toronto. Trained in the principles of German scientific forestry, they became the main advocates of a sustained yield policy. Sustained yield management plans for many of the Provincial Forests were prepared although it was not possible to regulate timber sales in a fashion that would conform to these plans (Haley 1966).

In 1937 the Forest Service released a comprehensive report, *The Forest Resources of British Columbia* authored by F.D. Mulholland. The purpose of this report was to bring up to date the 1918 work of Whitford and Craig. Mulholland's report presented results of a new provincial forest inventory and offered commentary on British Columbia's forest policy. Mulholland was an Englishman educated in forestry at the University of Edinburgh and was a staunch proponent of sustained yield forestry (Bishop and Bishop 1988). In his analysis of

British Columbia's forests Mulholland argued that unchecked exploitation of the forest must end:

> Management for a sustained yield is essential for the permanent prosperity of *British Columbia's greatest industry* and it demands immediate attention. If it is not introduced before the present large forest revenues have disappeared, it is doubtful if capital will be available for the extensive rebuilding of denuded forests which will then be necessary. (Mulholland 1937, p.12, my italics)

The changes in forest policy suggested by Mulholland and his superior, the chief forester C.D. Orchard, prompted Premier John Hart to appoint a one-man commission, in 1943, to investigate the state of British Columbia's forests. Sustained yield forestry was formally adopted as the basis of British Columbia forestry as a result of the report of the commissioner, Mr. Justice G.M. Sloan. Establishment of the Royal Commission was motivated by several factors. The Forest Service had advocated the adoption of sustained yield forestry for some time. The larger timber firms, faced with competition from the Baltic and Scandinavian nations, were demanding greater security of tenure to justify investment in utilization facilities (Pearse 1976). In addition, the CCF provincial party, which had been kept out of power in 1941 by a Liberal-Conservative coalition, was demanding nationalization of the forest industry. Marchak (1983) argues that sustained yield was adopted because

> The CCF could be "tamed" by a forest policy of "sustained yield" conservation, and the same policy, advocated by the large companies, would undermine both the competition from small loggers and the appeal of small companies to the public, since the small loggers could not advocate or survive on more restrictive legislation. The B.C. Forest Service supported the large companies in their presentations to the first Sloan Commission, assuming, as the companies argued, that larger timber holdings and longer-term harvesting rights would allow them to plan and therefore implement sustained yield principles. (Marchak 1983, p.37)

The Forest Service was faced with the problem of trying to correct the errors of the past. Large areas of land were held in temporary tenures from around the turn of the century. These tenures which included timber leases, timber licences and timber berths gave the holder the right to cut timber and no responsibility to ensure regeneration, the land reverting to the crown after cutting. Large portions of the mainland coast and Vancouver Island were held in temporary tenures providing an obstacle to the implementation of sustained yield management. The new proposal was to combine crown land with land under temporary tenure and land owned outright by forest companies into coherent management units held in long-term, renewable tenure by the forest companies. The restriction on companies that entered into these new agreements was that they practice sustained yield forestry on the whole unit (Pearse 1976).

Larger companies were favored because they could provide the capital necessary to construct large-scale processing facilities and create lasting employment for the growing population. The contribution of private industry to the development of forest management in British Columbia was deemed essential as the province did not have the resources to undertake the enterprise and to do so would contravene "...the democratic and free-enterprise principles of the country" (Orchard 1952, p.21).

On the evidence presented to him, Sloan argued for the adoption of sustained yield forestry and emphasized the idea of yield maximization:

> ...the sands are running out and the time is now upon us when the present policy of unmanaged liquidation of our forest wealth must give way to the imperative concept of a planned forest policy designed to maintain our forests upon the principle of sustained yield production. (Sloan 1945, p.10)

> That then must be our objective: To so manage our forests that all our forest land is sustaining a perpetual yield of timber to the fullest extent of its productive capacity. (Sloan 1945, p.127)

The way to achieve sustained yield was to liquidate the existing *decadent* forest and transform it into a managed or *normal* forest:

> ...it is the object of sustained-yield management to bring irregularities [in wood flow] into balance over relatively short periods, so as to minimize interference with the establishment of a regular series of age-classes in the next rotation. (Sloan 1956, p.223)

> ...sustained-yield...can not be reached until our mature timber on the Coast is cut and the area now covered by that old growth - which might just as well be in piles in a lumber-yard as in the forest, so far as increment is concerned - is growing a new forest. (Sloan 1945, p.129)

The prevailing mentality at the time was that old-growth forests were *rotting on the stump*. They were producing no appreciable growth and were at risk to infestation by insects and disease, and to wild-fire. Sloan argued that sustained yield management was not only desirable for timber yield regulation but would also enhance other social and biophysical amenities from the forest:

> ...sustained yield policy, perpetuating our forest stands, will not only provide a continuity of wood supply essential to maintain our forest industries, primary and secondary, with consequent regional stability of employment, but will ensure a continual forest cover adequate to perform the invaluable functions of watershed protection, streamflow and run-off control, and the prevention of soil erosion. (Sloan 1945, p.128)

In order to implement the new policy Sloan recommended radical changes to the forest tenure system. Rather than having land revert to the crown after logging, he advocated the allocation of Crown timber to private industry in long term tenures. Secure tenure would allow the implementation of sustained yield forestry and motivate capital expenditure to develop processing facilities for the long-term. The Forest Management Agreements between government and industry that resulted have had a lasting impact on forestry in B.C. They were the fore-runners of today's Tree Farm Licences.

Sloan also recommended that unalienated Crown land be organized into "public working circles", which came to be known as Public Sustained Yield Units, to be managed by the government on a sustained yield basis. These would provide timber for smaller companies and independent loggers "...with neither the means nor the inclination to manage forest areas" (Haley 1966, p.210).

Sloan had recommended that another Royal Commission be appointed 10 years hence and in 1956 the second Sloan Commission was published. It was essentially a re-statement of the sustained yield philosophy, dealing with problems in administrating the changes brought about by the 1945 Commission. One of the recommendations by Sloan in 1956 was the expansion of artificial regeneration programs and silviculture in general. This led to the development of a more extensive nursery program and research on provenance, genetic improvement and site preparation in the late 1950s and 1960s (Knight 1990). The standard textbook on silviculture for that time offers a positivist approximation of the purpose of silviculture:

> The forester should work for the good of the forest as an entity, not for the sake of the forest itself, but to ensure that it will remain a permanently productive source of goods and benefits to the owner and to society.
>
> The reasons [for practicing silviculture] are economic and mainly involve attempts to produce more useful forests than nature can and to do so in far less time. (Smith 1962, pp.2-3)

The 1950s and 1960s were also the time of the pioneering work of the forest ecologist Vladimir Krajina. His research was a major contribution to an understanding of the ecological characteristics of forest trees that could facilitate silviculture practice (Weetman 1982). Moreover, Krajina was largely responsible for bringing an ecosystem perspective on forests to British Columbia (Klinka 1979).

In the 1960s and 1970s new concerns about the state of forest management began to appear. Licensees were concerned about over-regulation in terms of harvesting practices, forestry practices and resource use. The public, led by the modern environmentalist movement, began to express concern about the impacts of timber management on non-timber values and the protection of the natural environment.

Moreover, questions arose concerning the ability of sustained yield forestry to provide the fullest long-term economic and social benefits from the forest resource and to enhance their productive capacity. These concerns led to the Royal Commission on Forestry of 1976 headed by Peter H. Pearse, an economist at the University of British Columbia. One of the main results was a restructuring of the tenure systems for forest licensing that clarified to some extent the roles of government and industry. Changes brought about by the Pearse

Commission form the basis of forest management in British Columbia today and will be discussed in more detail in the concluding section.

4.4 Forest Yield Regulation in British Columbia

In order to achieve sustained yield forest management as formulated by Sloan (1945, 1956) the forest would have to be *normalized* with an even gradation of age-classes. The provincial forests were predominantly old-growth timber and the objective became to draw down the inventory of old-growth timber in a fashion that would ensure near-equal annual or periodic harvests during the transition to normality, and ensure that the old-growth timber would last until second growth timber was ready for harvest.

From 1945 until 1977 annual allowable cuts on the Public Sustained Yield Units and most Tree Farm Licenses were calculated using the Hanzlik formula. The formula was developed by E.J. Hanzlik of the United States Forest Service for determining the annual allowable cut in forests such as those of the Pacific Northwest that contained a preponderance of mature age classes. While the Hanzlik formula is no longer used for yield forecasting in British Columbia I will describe it in some detail for two reasons. First, it provides a simple means of illustrating the basic assumptions that go into forest regulation. Second, the rate of cut has changed very little since new techniques were adopted in 1977 and the new techniques are little more than elaborations of the Hanzlik concept. Thus, the Hanzlik formula represents an important part of how we got where we are today. I will then describe the changes in yield regulation brought about by the Pearse Commission.

The Hanzlik formula[1] calculates the annual allowable cut as:

$$AAC = Vm/R + I$$

where:

	Vm	=	the volume of mature and over-mature timber of age R or greater
	R	=	rotation, or period of years required to establish and grow timber crops to a specified condition of maturity.
	I	=	mean annual increment, or average annual rate of growth throughout the rotation of timber less than the rotation age R.

In order to maximize increment the rotation age is established for each stand type as the time when the average annual rate of growth achieves its highest rate or *culmination point*. Trees, as a rule, produce proportionately less wood as they age and allocate more of their energy to maintaining foliage and root systems. In terms of merchantable wood volume, forest stands can be modelled by the logistic growth curve (Figure 4-1). The traditional forestry idea is that trees *mature* at the culmination point before *decadence* sets in. The volume of mature stands is then the volume of stands of an age past the culmination point. Average increment on immature stands is calculated as the culmination volume or volume at rotation age divided by the rotation age. Culmination volume is predicted from growth and yield models.

The first growth models for the province, developed by the B.C. Forest Service (now the Ministry of Forests), were empirical, hand-drawn volume over age curves. The next development was the construction of Chapman-Richards non-linear growth models based on the logistic growth models developed by the school of population ecology:

$$V = b_1\left(1 - e^{b_2 A}\right)^{b_3}$$

where V = volume

A = stand age

b1,b2,b3 = regression coefficients.

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[1] The original reference for the Hanzlik formula is Hanzlik (1922). See also Chambers and McLeod (1980) and British Columbia Forest Service (1971).

The Province was stratified into 12 Forest Inventory Zones, 17 Growth Type Groups and four site classes (good, medium, poor, low). Using plot data from variously aged natural stands, equations were constructed that predict merchantable volume as a function of stand age for each stratum.

More detailed, variable density yield equations have now been developed for each commercial species by including site index, average basal area (m^2) per ha and average stand diameter as additional variables in the basic Chapman-Richards equation. Basal area and diameter provide a measure of stocking and density. Site index is a relative measure of growth potential that provides an indicator of site quality. Site index is determined by estimating the average height of trees at a certain reference age on a given site. In British Columbia the reference age is 50 years as indicated at breast height (1.3m).

Variable density yield models are constructed using sample plot data and refined using permanent sample plots and stem analysis. Permanent sample plots are re-measured at periodic intervals to determine the pattern of growth. Stem analysis involves dissecting individual trees and counting the growth rings at intervals up the stem to determine the age at which the tree reached a certain height. Tree height shows a strong correlation with volume.

The yield models are for stands that are composed of predominantly one species. For mixed species stands volume is estimated using proportions of the predictions for each species assuming that there is no interaction between species that affects their pattern of growth. For example, if the stand is 60% Douglas-fir and 40% Hemlock the estimate of volume would be 60% of the estimate for a pure Douglas-fir stand and 40% of the estimate for a hemlock stand.

In addition to the estimate of allowable annual cut given by the Hanzlik formula, an area volume allotment check was used. This procedure involved an algorithm which runs through one rotation at the indicated AAC to see if it is sustainable throughout the projected rotation age and if a sufficient volume of second growth was ready at the end of the rotation. The AAC could then be adjusted upwards or downwards to ensure sustainability.

The AAC could also be adjusted for *non-recoverable losses* or lands that may be lost from production during the rotation. Losses may be due to land alienation for other purposes, logging roads, regeneration delays, stand treatment losses, breakage, insects, disease, and fires.

Calculation using the Hanzlik formula or the more current simulation techniques provides the *indicated* AAC. The *actual* AAC is then determined by the chief forester based on additional considerations which include the economic and social conditions in the province.

Since the Royal Commission of 1976 and the subsequent new Forest Act of 1977, the methods for regulating the yield and for calculating the annual cut have changed in British Columbia. Pearse (1976) argued for changes to the system of yield regulation by noting that at the time of his writing allowable cuts in most of the Public Sustained Yield Units in the province contained numerous conservative biases. He suggested that utilization standards would improve in the more uniform managed forests and that growth rates tended to be underestimated for several reasons. Growth was estimated from existing stands while managed stands were expected to add volume considerably faster. The productivity of land occupied by mature timber may fall short of its potential for new crops. Improved utilization standards and growth might also shorten rotation ages.

In addition to biases in the physical assumptions surrounding sustained yield, Pearse noted some economic limitations of the policy. Consideration of the interest on capital and other economic considerations would shorten rotations increasing timber supply in the short-term at least. Delaying the harvest of old-growth stands was thought to impose costs on the citizens of British Columbia because it delayed the economic benefits and postponed "new growth on lands now occupied by stagnant timber". The equal annual yields also limited the flexibility to respond to changing markets and economic climates. In general, Pearse argued that the yield regulation policy in place at the time implied that the future would be like the past:

> While prognostications about future trends in silviculture, industrial technology, and other variables unavoidably involve some speculation, few would argue that the best assumption is that they will remain unchanged; yet this is implied in the present allowable cut policy. (Pearse 1976, p.232)

> I recommend that the sustained yield policy be directed more systematically toward enhancing industrial and environmental values. This calls for a shift in emphasis, from the traditional effort to achieve maximum equal annual harvests from all the province's timberland, to attainment of the fullest long-run economic and social benefits from available forest resources and to enhancement of their productive capacity. (Pearse 1976, p.373)

The new procedure for regulating the rate of cut that resulted involved the use of forest estate models designed to optimize timber flow. Since the late 1970s there has been a shift to more flexible simulation models that allow for a consideration of non-timber values. This innovation has allowed policy makers to consider alternative rates of cut, different land-use options, different intensities of management on different parts of the land base and other factors in the determination of cut. The next step, currently underway, is the development of spatially-based simulation models that will give foresters more flexibility to actually manage the landscape. A spatial data base in the form of a Geographic Information System (GIS) is in preparation and groundwork for a new provincial forest inventory is underway.

One of the recommendations of the Pearse Commission was that Public Sustained Yield Units be re-organized into larger Timber Supply Areas (TSAs). The rationale was that the new system of TSAs would make more sense administratively by organizing the forest estate around processing facilities and forest tenures. Yield regulation by TSA would also improve flexibility by scheduling harvest and management activities over a larger area:

> Imbalance in certain characteristics such as age and species distribution can create supply problems if the harvest rate is calculated for small areas.[12]

Re-organizing the Provincial forest into larger administrative units provided the added benefit of allowing an increase in AAC at a time when "...shortfalls in AAC within

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[12] B.C. Ministry of Forests. 1978. "Yield regulation within timber supply areas." Victoria: The Ministry. As quoted in Chambers and McLeod (1980).

Public Sustained Yield Units (PSYUs) [were] surfacing" (Chambers and McLeod 1980). Dowdle (1976) provides an explanation of how increases to the AAC were possible:

> Suppose, to take a simplified example, we start with two areas: A and B... assume area A contains only over-mature timber stands with a zero net growth rate and B contains thrifty, immature stands growing rapidly.
>
> The initial harvest rate on A would be the total inventory volume divided by the rotation age. Area B would not have any harvest since all its timber is less than rotation age. By the simple act of combining A and B into a single planning unit, harvest can be increased. Growth rates on area B would make it possible to liquidate the old growth inventory on area A at a faster rate.

Section 7 of The Forest Act of 1977 (Consolidated November 10, 1992) describes the relevant considerations in the calculation of allowable annual cut:

7. (3) In determining an allowable annual cut under this section the chief forester, despite anything to the contrary in an agreement listed in section 10, shall consider

(a) the rate of timber production that may be sustained on the area, taking into account

  (i) the composition of the forest and its expected rate of growth on the area;

  (ii) the expected time that it will take the forest to become re-established on the area following denudation;

  (iii) silvicultural treatments to be applied to the area;

  (iv) the standard of timber utilization and the allowance for decay, waste and breakage expected to be applied with respect to timber harvesting on the area;

  (v) the constraints on the amount of timber produced from the area that reasonably can be expected by use of the area for purposes other than timber production; and

  (vi) any other information that, in his opinion, relates to the capacity of the area to produce timber;

(b) the short and long term implications to the Province of alternative rates of timber harvesting from the area;

(c) the nature, productive capabilities and timber requirements of established and proposed timber processing facilities;

(d) the economic and social objectives of the Crown, as expressed by the minister, for the area, for the general region and for the Province; and

(e) abnormal infestations in and devastations of, and major salvage programs planned for, timber on the area.

The above factors are taken into account in a timber supply analysis undertaken for each TSA. Timber supply analysis is undertaken by the Ministry of Forests with input from the timber industry and other relevant resource agencies. The goal is to plan a sustainable level of harvest while ensuring that other resource values are incorporated into timber management planning.

A number of management options for each TSA are defined. For each option a long term sustained yield analysis is undertaken. The Multiple Use Yield Calculator (MUSYC)[13] has been used although the Ministry of Forests is currently switching to an in-house simulation model. With sustained yield as a constraint, the model has five categories of information as inputs:

1. the timber harvesting land base, defined by a land base analysis,
2. growth and yield assumptions,
3. management assumptions,
4. funding restrictions and costs of management, and
5. timber harvesting assumptions.

The outputs from the model are:

1. schedules of harvest,
2. reports on silviculture regimes,
3. the long run sustained yield,
4. schedules of management costs, and
5. a description of the changing structure of the inventory.

Timber supply analysis is an iterative process. Options are developed until they meet the goals of the Ministry of Forests and other concerned resource agencies. After reviewing a report on resource options, the Chief Forester, with advice from Regional and District staff, selects an option and establishes a provisional AAC for the TSA.

The Pearse report recognized the potential for a "falldown" in the rate of harvest. While old-growth stands have a lower rate of increment than younger forests they have accumulated wood for a much longer period of time. For example, a coastal old-growth forest might have a standing volume of $500m^3$/ha and a culmination volume at 100 years of

[13] MUSYC was developed by the U.S. Forest Service for management planning on the National Forests.

$300m^3$/ha (Forestry Undergraduate Society 1983). To transform 100ha of old growth to a balanced age distribution with maximum age 100 requires cutting $500m^3$ per year until year 100 when the annual cut will fall to $300m^3$. The Hanzlik formula forecasts a smooth reduction in cut over one and a half rotations although he suggested that the rate of cut could be accelerated if the surplus at the end of one rotation would be too great (Hanzlik 1922). The British Columbia policy has been to accelerate the cut in order to liquidate old-growth timber in one rotation. This results in a more abrupt falldown at the end of the first rotation.

While improved yields and utilization standards in managed stands may off-set the potential falldown effect, there are significant uncertainties about the sustainability of the current rate of cut. The recommendations of the Pearse commission encouraged increases to the rate of cut (Figure 4-3) that have continued to the present. The aim of maximizing the yield is still the single most important factor driving forest management in British Columbia.

The indicated annual allowable cut has been between 70 and 80 million m^3 for the last decade while the Ministry of Forests suggests that the long run sustainable yield, under current management practices, will fall well below the current level (British Columbia Ministry of Forests 1984). Reductions to the AAC in several Timber Supply Areas around the province in the last several years, and the public controversies surrounding these reductions and other forestry-related issues, suggest that we are reaching the point of *necessity* that Fernow, quoted at the beginning of this chapter, called the birthstone of forestry.

Forestry in British Columbia is possibly the largest scale application of the German cameralist forest program in the world. Almost the entire forested land base of the province is organized into a small number of large management units for the purpose of maximum sustained yield management and are under the ultimate control of a single technical bureaucracy. In the next chapter I will discuss how changes in the values of the human constituents of British Columbia's forests and changes in scientific understanding of forests are forcing changes in British Columbia's forest policy.

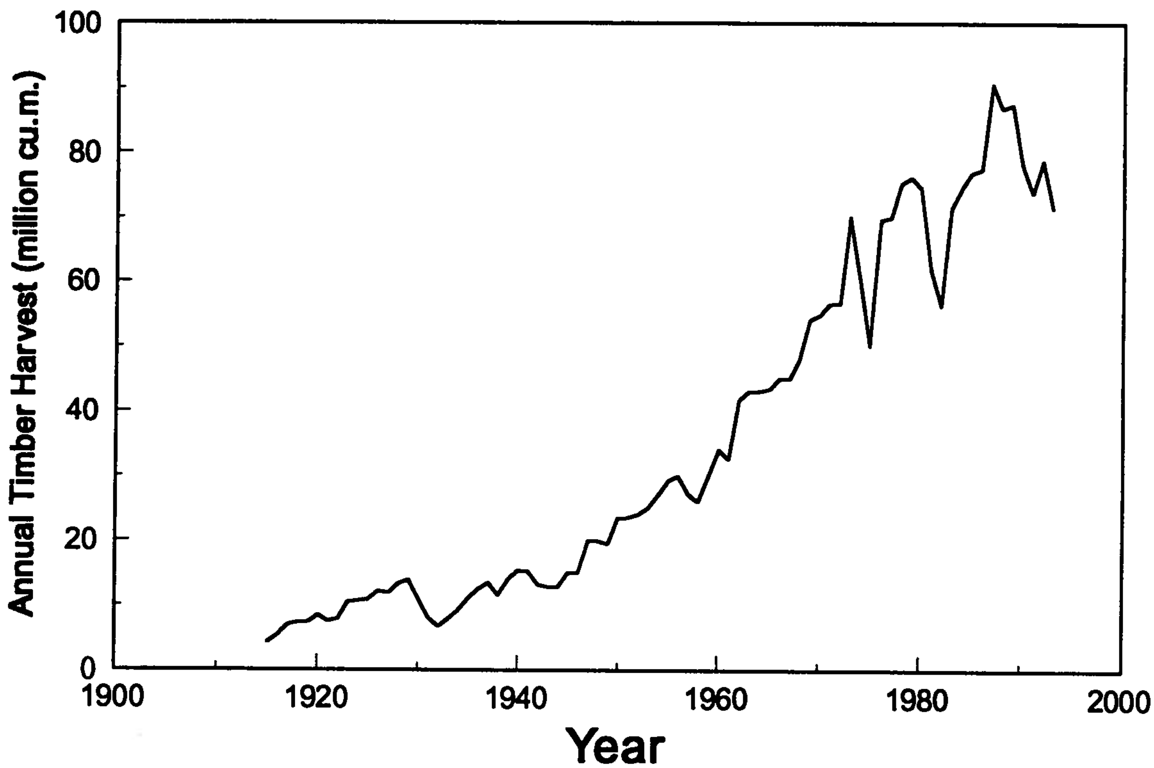

Figure 4-3. British Columbia Annual Forest Harvest (1915-1993).

Sources:	1915-1944	Sloan (1945), using conversion of 240 bd. ft. = 1 cu. m. (Larry Sluggett, Timber Harvesting Branch, B.C. Ministry of Forests, pers. comm.).
	1945-1992	Harvest Data, Timber Harvesting Branch, B.C. Ministry of Forests and B.C. Ministry of Forests Annual Reports.
	1993	Compendium of Forestry Statistics, 1993, Canadian Council of Forest Ministers, Ottawa, 1994.

5. THE TROUBLE WITH NORMAL

Approximately half of the land base of British Columbia, an area covering 47.9 million ha, is forested. Roughly 94% of the total forested land base in British Columbia is publicly owned. Currently about 22.7 million ha of crown land is managed for commercial forestry on the principle of maximum sustained yield. Some 2.7 million ha are held in private ownership and the remainder is considered economically inoperable (Travers 1993).

The mandate of British Columbia forestry has been to maximize the economic benefits to the province and to encourage industrial development and job creation. The intentions and effects of the Sloan Commissions and the Pearse Commission were to promote large-scale industrial forestry. This agenda has come under increasing scrutiny in recent decades for two reasons.

The first was the growing public awareness of unpleasant side effects to the program of maximum sustained yield forestry. People became concerned with the disappearance of forests and the appearance of what they considered to be large, unsightly clearcuts. This spawned an environmental movement within British Columbia devoted entirely to forestry issues.

The second reason for scrutiny of British Columbia's forest policy was the appearance of a new body of scientific knowledge generated from an ecological perspective. While this may have predated public environmental awareness it was given a strong impetus by the growing public and consequent political concern. Ecologists began to talk about forests as complex, dynamic, interconnected, adaptive ecosystems as opposed to aggregations of trees. Research appeared on *old-growth* forests that portrayed them as dynamic and self-renewing rather than as unproductive and decadent. Fisheries biologists began to characterize the effects of logging practice on stream habitat of anadromous fishes and wildlife biologists expressed concern over the loss and fragmentation of habitat for forest-dwelling animals. On a more technical level concern arose over whether in fact we could meet the stated agenda of sustaining the yield. The net effect has been to place pressure on government, industry, and the profession of forestry to develop new initiatives.

The concept of *sustained yield* could have a very general meaning, but in its development in forestry it has taken on a very specific meaning. In general sustained yield could mean managing a system such that some quality(ies) of the system can be sustained while maintaining the system in some desired state. A forest could be managed to produce a sustained yield of quality drinking water, to maintain a certain quality of wildlife habitat, or simply to sustain the integrity of the ecosystem.

Sustained yield forestry, as it has evolved over the last two hundred years, makes its goal the production of the maximum, sustainable volume of merchantable wood fibre. The objectives of this enterprise are the restructuring of the forest into the idealized *normal* forest and the development of growth models of commercial species. The focus of research has been on the silvics of commercial tree species, their growth rates, site requirements and the means required for their regeneration.

The concept of sustained yield forestry and its companion, the normal forest, contain assumptions that mirror, in a sense, the assumptions of positivist science:

1. The reductionist assumption that growth models of commercial timber species, designed to facilitate prediction of yield, somehow characterize the performance of the whole system.
2. The assumption that we can improve on nature; that, for example, old growth forests are *decadent* and require replacement with healthy younger stands.
3. The assumption that future forests will be like those used to generate predictive models, or *the myth of certainty*.

Ecology, at the present time, with its emphasis on dialectical or contextual holism and the recognition of uncertainty offers some alternative ways of thinking about forests that challenge the received view of traditional forestry. In this chapter I will present some of the challenges posed by ecologists and ecologically-minded foresters. Many of these ideas are speculative and not well documented but I have tried to present ideas that are, in my opinion, at least plausible. My purpose is not to advocate any one view of forests or forestry but to consider the manner in which the appearance of a new body of scientific insight has influenced the public debate on forestry.

The challenges posed by scientific knowledge and public environmental awareness have resulted in a series of new policy initiatives that put constraints on the central goal of timber management. These include strategies for protected areas and for old-growth preservation, and the development of a forest practices code. The current political rhetoric on forestry is focussed on the idea of sustainable forestry as part of a program of sustainable development. Some aspects of these recent developments will be discussed in the conclusion to this chapter.

5.1 The Forest or the Trees

What level of understanding of forest ecosystems do single species growth models provide? A forest is much more than a population of trees. Heske (1938, p.41) tells us that by the early part of this century German foresters had learned by experience that

> ...the forest is not merely an aggregation of individual trees, but is an integrated, organic entity, comprising all the innumerable living organisms that exist from the roots deep in the ground to the crowns that sway high in the sunlight, from the smallest soil microbe to age-old tree veteran.

Ecological systems are integrated, and contingent, such that disturbance of one part of the system will affect other parts. As contingencies themselves cannot be predicted with certainty, the predictability of the development of forest ecosystems will diminish with time from the point of prediction.

The problem of extrapolating from the growth model of a single species to a general model of the performance of the underlying system lies at the heart of the polemic between functional or ecosystem ecology and population or community ecology[1]. Ecosystem ecology has focused on energy flow, nutrient cycling and other ecosystem processes, essentially ignoring species dynamics. Population and community ecology, on the other hand, focus on the diversity, distribution and interactions of species.

From the time of Clements and Gleason (see Chapter 3), the debate has raged over how to develop an understanding of complex ecological phenomena. Population or community ecologists would argue that an understanding of species and species dynamics are pre-requisite to any understanding of the larger system. The functional ecologist argued that as ecosystems are integrated systems, properties of the whole such as energy and nutrient flow are critical.

The design of interventions in ecological systems, such as forests, requires integration of knowledge from both approaches. Knowledge of species and species dynamics is critical to understanding their role in nutrient and energy dynamics. Knowledge of energy and nutrient dynamics is critical to understanding the structure and function of the system and the significance of each species. Ecosystem understanding comes from knowledge of the dynamics of species *and* the flow of energy and nutrients within and between species, and of the pattern of ecosystems on the landscape. Much of the recent advance in ecological theory comes from recognizing the necessity of integrating the two approaches (Paine 1980, Pimm 1991, O'Neill et al. 1986).

In British Columbia forestry, the standard practice has been to use single-species growth models to predict rotation ages or disturbance cycles for whole ecosystems. However, knowledge of energy and nutrient cycling from ecosystem ecology suggests that the processes essential to maintaining productivity may not, in all cases, be sustained on the cycle of disturbance projected by the reductionist single-species model (Kimmins 1974).

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[1] My discussion of the population/community and ecosystem ecology distinction and the need for integration of the two approaches is based on Carney (1989), O'Neill et al. (1986), MacFadyen (1975) and McIntosh (1985).

Following a disturbance such as clear-cut logging, nutrient capital is lost through log removal and through leaching of nutrients from the soil by drainage waters while the site is not fully occupied. The amount of time required for the site to recoup these nutrient losses may affect its capacity to produce trees at the same rate as prior to disturbance.

The mechanisms by which a site conserves or adds nutrient capital are provided, in many cases, by what have been considered economically uninteresting components of the system. For example, nitrogen and other nutrients needed by trees are typically accumulated by seral *weed* species that invade new clearings and prevent the loss of these nutrients via leeching. In forestry, the singular focus on tree growth and the desire to condense the time required to produce commercial wood products makes this re-establishment phase after forest harvesting an inconvenience. While seral species may contribute to the maintenance of long-term site productivity they also compete with young crop trees. Left to nature the establishment of the new forest and the stocking of the new stand may not meet the standards of current management practice. Herbicides, slash burning and mechanical site preparation have been employed to slow the establishment of brush, promote the growth of crop tree seedlings, and shorten the regeneration period. These treatments, however, may accelerate the loss of mineral nutrients by removing nutrient-retaining seral species and by reducing the humus layer where mineral nutrients are stored. Traditional forestry practice has considered only the negative impacts of seral *weed* species in trying to reduce the *regeneration delay* portion of the rotation age. Sustainable forestry, on my view, requires more careful consideration of the positive ecosystem functions that seral weed species perform.

Many forests include in their composition tree species that are considered undesirable from an economical point of view. One strategy for improving the yield of the forest has been to attempt to improve the stocking of commercially more desirable tree species through artificial regeneration and post-planting spacing treatments. The potential importance of economically less valuable tree species in the process of nutrient cycling has been ignored. In Germany, for example, removal of the soil improving Beech and the establishment of even-aged plantations of a single species reportedly resulted in soil deterioration, decreased growth and lessened resistance to insects and diseases (Heske 1938).

In northern Ontario, white spruce (*Picea glauca* (Moench) Voss) commonly grows in association with trembling aspen (*Populus tremuloides* Michx.). White spruce is a relatively nutrient-demanding species (Fowells 1965) and the nutrient-rich aspen leaf litter may play an important role in maintaining the productivity of the site. Attempting to grow white spruce as a monoculture may have negative impacts on the productivity of such sites.

In southwestern B.C., Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) commonly grows on lower elevation seepage sites in association with red alder (*Alnus rubra* Bong.). Since the alder competes for growing space, a great deal of effort has gone into developing techniques for removing it with herbicides and manual brushing techniques. Red alder, however, is a nitrogen-fixing species that contributes to the nutrient-richness of the site (Binkley 1983). What effect its removal may have, over one or more commercial crops is difficult to measure, but it should be a considered in assessing the projected productivity of Douglas-fir stands. Moreover, alternative treatments could be considered. A short rotation of alder with thinning and underplanting is one possibility. Underplanting of more shade tolerant species such as grand fir (*Abies grandis* (Dougl. *ex* D. Don) Lindl.) and western redcedar (*Thuja plicata* Donn *ex* D. Don *in* Lamb.) has been attempted operationally on such sites.

On the north coast of British Columbia red alder and black cottonwood (*Populus trichocarpa* Torr. & Gray) grow on river floodplains in association with Sitka spruce (*Picea sitchensis* (Bong.) Carr.). Sitka spruce typically grows in the understory of the faster growing hardwoods for the first 30 to 50 years until the shorter lived species begin to die out. One of the benefits to the spruce trees is that the shade provided by the hardwood overstory apparently protects it from attack by the spruce weevil (*Pissodes strobi* Pk.), an insect that feeds in the terminal leader and causes dieback of at least two years' growth (Wood and McMullen 1983). In the Kitimat Valley, south of Terrace, B.C., herbicide removal of the hardwood overstory appears to be related to an epidemic infestation of spruce weevil that has resulted in a decades long regeneration problem. In 1993 and 1994 I was involved in establishing operational trials designed to grow Sitka spruce under a managed hardwood overstory.

The growth models currently in use were constructed using data from forest stands dominated by one species. In fact, most stands are mixtures of two or more species. Mixed species stands exhibit different patterns of stand structure than do pure stands and the assumption that single-species models can be used proportionately is questionable. Mixed species models have been developed for the Queen Charlotte Islands and southeastern British Columbia and more research in this area is likely.

The growth models used in British Columbia include a site variable (site index) that attempts to account for variability in site quality. Site index is a measure of the height of site trees at an index age. For example, the potential for height growth at age fifty might be 40m on a good site while only 15m on a poor site. Typically site indices for specific stands are unknown and must be estimated from generalized site index curves prepared from sample data. The curves provide mean data for good, medium and poor sites by forest type. Tree growth potential is likely to be far more variable than this simple site classification can account for (Monserud 1988).

Biogeoclimatic site classification, as being developed in British Columbia, can reduce the unexplained variance in site productivity (Green et al. 1989). By developing indices of site productivity by site association[2], variation due to soil, topographic position, elevation and aspect may be accounted for. Variation in growth rates, as a consequence of genotypic variation, may also be explained to a greater degree by such an approach (Monserud 1988).

In spite of their limitations, relatively simple volume as a function of age models are still the most useful predictive tools available for forecasting productivity. Process models

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[2] Site association is one of the basic units of the biogeoclimatic classification system. See the last section of this chapter for a more detailed description.

while critical to developing an understanding of ecosystem function, have generally proven to be too complicated, containing too many assumptions and too many parameters that can't be reliably estimated, to provide useful forecasting tools for planning.

The fundamental limitation of growth models is that they are merely descriptions of how forest stands have grown in the past but not *why* forest growth is possible. Both kinds of models may be relevant in the process of planning forest management if considered as hypotheses and there is continual interplay between prediction and monitoring of the predictions in the real world. An adaptive framework would allow for the adjustment of models as new information accrues.

5.2 What is a Normal Forest?

The agenda of British Columbia forestry, since the Sloan Commission of 1945, has been to liquidate the residual old-growth forest. This includes very old forests (perhaps 300 to 1000 years old) on the coast and *overmature* forests (generally between 150 and 250 years old) in the interior. Fernow introduced German forestry to North America in this way:

> The object of forest regulation, then, is to prepare for the change of an abnormal forest into a normal forest.[3]

The idea behind the *normal forest* was to organize the forest in such a way as to allow for regular cutting cycles. After removing the old forest it could be replaced with a more orderly, efficient plantation forest.

The relevant definition for the word normal offered by Webster's dictionary is "conforming to a type, standard, or regular pattern". Modern ecological understanding of the forest as an integrated system has generated new ideas that question whether the current conception of the normal forest will produce results that satisfy the desires of society.

One of the key assumptions in forest management is the determination of rotation age. At what age should a stand be harvested? In British Columbia the policy choice has

[3] From Fernow's *Economics of Forestry* published in 1902, as quoted in Haley (1966).

been to harvest at the *physical* rotation (Figure 4-1) where maximum sustained yield (MSY) might be realized.

Three other considerations that might go into a policy decision about rotation age are discussed in most standard texts on forest management[4]:

1. The *technical* rotation refers to the age most economically suitable for producing certain wood products. Veneer logs might require a lengthened rotation while if the stand is to be grown for pulpwood a shorter rotation than MSY might be appropriate.

2. The *financial* rotation maximizes the net present worth of the forest land. Net present worth is determined by subtracting the discounted value of all anticipated costs of growing the forest from the discounted expected revenue. The concepts of soil rent and financial rotation were developed in 19th century Germany by Pressler and Martin Faustmann. The financial rotation is generally shorter than the physical rotation depending on the interest rate chosen.

3. The *pathological* or *natural* rotation is based on the silvical qualities of the tree species that dominate the stand. Species of *Abies*, for example, are susceptible to heart rots and rotations shorter than the physical rotation may maximize the useable wood volume. Other species may become susceptible to insect or disease infestations past a certain age.

All these considerations focus on tree growth and wood production. A changing scientific conception of the forest and an expanded awareness of the variety of amenities it offers suggest other relevant considerations in the choice of rotation age. Kimmins (1974) has suggested the *ecological* rotation as the cycle of disturbance that sustains essential ecosystem processes. Other considerations might be the maintenance of forests in a condition that optimizes quality water production, wildlife habitat, biodiversity, aesthetic beauty or some measure of ecosystem integrity. The temporal frequency and the spatial pattern of disturbance will have a significant effect on these nonconsumptive forest attributes. Any consideration of a rotation raises questions of value.

In a brief prepared for the Minister of Forests in 1963 the Greater Vancouver Water District captured the then prevalent dismissal of old growth forest:

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[4] see, for example, Davis (1966), Brasnett (1953) and the Forestry Undergraduate Society (1983).

> The decadent forests covering the water catchment areas, with a heavy cedar content and a high incidence of snags coupled with the frequency of lightning activity, constitute a continuing and increasing fire hazard. The recent infestation of the balsam woolly aphid has now spread over the entire watershed area and for which no counter measures have yet been found, is yearly adding more snags to an already unsatisfactory condition.
>
> These conditions call for the immediate start of a scientific program of management of the forests within the watersheds. By applying the principles of good forest management the watersheds can be improved. (GVWD 1963)

The word "decadent" means a state of decay or decline. If a stand is decadent it could be argued that it is reasonable to replace it with a young stand. But a growing body of evidence suggests that old-growth stands are not adequately described by the concept of decadence. Old-growth stands are dynamic and in many cases display properties of resiliency that enable them to absorb stresses and recover from disturbance. The process of *normalizing* the forest involves simplifying its structure and biodiversity, and potentially decreasing its resiliency (Franklin et al. 1987).

Old-growth forests are thought to be susceptible to *pests*, insects and disease pathogens, that cause tree mortality and wood decay. Our knowledge of forests, and subsequent understanding of forest insects and diseases, has developed from a desire to extract products from the forest. Webster's Dictionary defines a pest as "a plant or animal detrimental to man". Thus, no organism is a pest in itself, but only in the context in which it affects human life, or resources used by humans, in a significantly negative manner.

The study of insects and diseases in forestry has focussed primarily on organisms as *pests* of timber production and quality. There are abundant examples of organisms that from one point of view are pests but in another context are beneficial. Dwarf mistletoes (*Arceuthobium* spp.) are parasitic plants that may cause a significant reduction in the growth rate and utilization potential of trees (Baranyay and Smith 1970). Dwarf mistletoe brooms, however, may also provide nesting and refuge habitat for birds and small mammals (Tinnin 1984). While mistletoes may be significant pests in the context of timber production, they may contribute positively to forest ecosystem biodiversity.

Ambrosia beetles are small wood-boring insects that attack downed logs and reduce the attractiveness of sawn lumber. McLean (1985) estimated that ambrosia beetles cost the coastal B.C. lumber industry Can.$65 million in quality reduction in 1980-81. From another point of view ambrosia beetles play an important ecological role:

> They are often among the first insects to invade the dead or recently injured tissues of a tree. The ambrosia fungus that they introduce starts the slow process of breaking down the wood, and the vacated beetle galleries offer entrance courts for other saprophytic fungi. (Lindgren 1990, p.8)

Pathogens are generally considered destructive when wood production is the primary goal of management. From another point of view, the action of forest pathogens may increase both spatial and temporal diversity and are important actors in forest development. In moister climates of interior B.C., van der Kamp (1991) suggests that root disease pathogens may be major agents of diversity by breaking up uniform landscape into a variety of forest types:

> ...the combination of cover in the surrounding conifer stands and browse available in the root disease centers may provide near optimum conditions for moose and deer. Also, these root diseases create a constant supply of snags in all stages of deterioration, thus providing essential habitat for cavity nesting birds... the root diseases create special habitats that may favour plant and animal species not well adapted to living in dense, even-aged, coniferous stands. (van der Kamp 1991, p.354)

In addition, wood decay fungi, which recycle carbon,

> ...create special niches both in living trees, snags, down logs, stumps and rotting roots which may be essential for the survival of some animal and plant species. (van der Kamp 1991, p.354)

Similarly, Stoszek (1988) argues that outbreaks of defoliating insects such as the Douglas-fir tussock moth and the western spruce budworm

> ...are indicative of forest ecosystems under stress from the nutrient limitations caused by natural or management-induced factors... the main effects [of defoliation] on the host tree are the reduction of leaf area and carbohydrate synthesis. Reduction of leaf area increases penetration of light and precipitation to the forest floor, temporarily increasing available moisture,

> microbial activity, and cycling of nutrients. The non-host trees benefit most from such changes. (Stoszek 1988, p.258-259)

Although we cannot know the process of a thousand year cycle there is evidence that Coastal old-growth forests have the capacity to renew themselves from within. Insect and/or disease mortality creates gaps in the canopy that allow young trees to enter the stand. The structure and composition of the stand may change over time but through this process of *gap replacement* a shifting mosaic of structural units persists that increases the range of habitats and promotes high, stable biodiversity (Franklin et al. 1987)

In spite of the supposed decadence of old growth forests, insect and disease infestations can be more problematic in the more uniform, structurally simpler second growth forests. Disease fungi, for example, may reach persistently high levels following logging or stand spacing, causing high mortality in seedling and sapling stage trees (Finck *et al.* 1992, Baker 1988). The German experience, discussed in Chapter 4, was that managed forests were less resilient to insects and diseases than natural stands (Heske 1938). Douglas-fir tussock moth and western spruce budworm infestations in eastern British Columbia, Washington and Oregon appear to be more damaging on sites where high-grading[5] has left dense pure stands of Douglas-fir (Schowalter 1986). The spruce weevil and the black army cutworm are examples of insects that were of little significance in natural forests but have become important pests of managed stands (Finck et al. 1992).

The impacts of old-growth dependent pests such as the hemlock looper and the balsam woolly adelgid may be mitigated by the resiliency of old-growth forests. These were the insects that motivated the introduction of *scientific forest management* in the Vancouver watersheds. The hemlock looper attacks and causes high mortality in old-growth hemlock stands but infestations are infrequent and short in duration (Turnquist 1991).

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[5] High-grading is a forestry practice that involves selective cutting of the largest, economically most desirable stems.

The balsam woolly adelgid is an introduced pest that caused high levels of mortality of Amabalis fir when first introduced to the watersheds in the late 1950s. It has since subsided to endemic levels and does not appear to pose a threat to forest health[6].

The resiliency of natural forests to insects and diseases may be due to the prevalence of predators and parasites of insect pests, bacterial and viral diseases, and birds that regulate the populations of destructive insects. Studies from western Oregon and North Carolina indicate that predator and parasite populations are significantly reduced following clear-cut logging. Herbivore biomass (primarily aphids), which was relatively insignificant in mature, structurally complex ecosystems, was increased dramatically in young stands (Schowalter 1989).

> A structurally and functionally diverse ecosystem, such as these old-growth forests, maintains predator diversity and impedes herbivore success in discovering suitable hosts and completing development. These studies suggest that widespread forest simplification will have serious consequences for pest management. (Schowalter 1989, p.321)

Although it is apparent that many species of birds eat insects it has been difficult to illustrate what their effect on population size might be. A recent study conducted in a young Missouri Ozark deciduous forest provides empirical evidence that birds can significantly reduce insect populations contributing to a significant increase in tree growth (Marquis and Whelan 1994).

Another important feature of natural forests are mycorrhizae. The term mycorrhiza refers to the symbiotic relationship between certain fungi and plant roots (Maser 1988).

> Mycorrhizal fungi absorb nutrients and water from the soil and translocate them to a host plant. In turn, the host provides sugars from its own photosynthesis to the mycorrizhal fungi. (Maser 1988, p.26)

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[6] These observations are based on surveys, in 1993, for the balsam woolly adelgid in the Seymour Watershed conducted by the author and Phero Tech Inc. on contract to the Greater Vancouver Regional District.

Most of the forest trees common to British Columbia depend on mycorrhiza-forming fungi for nutrient uptake. Fungi represent a large amount of biological diversity in forest ecosystems. Different fungi may benefit different hosts in different ways:

> Some mycorrhizae may be important for phosphorus uptake. Some may be important for lengthening root life, protecting against pathogens, enhancing water uptake; some may be important in certain pH's. (Amaranthus 1990, p.59)

Seedling survival and subsequent growth appears to be strongly affected by the retention of native populations of soil organisms (Amaranthus 1990). Management activities such as clearcutting and prescribed burning may reduce the diversity and abundance of these beneficial soil organisms. Brush species that invade the site after forest clearing may sustain soil microflora such as mycorrhizae. By eliminating the brush phase mycorrhizal diversity may be reduced (Amaranthus 1990).

The forests of the Pacific Northwest are home to a diverse concentration of wildlife, a significant portion of which requires mature or old-growth forests (Bunnell 1990). Habitat loss and fragmentation has raised concern about the health of a variety of animal populations. These include the Vancouver Island marmot, caribou, grizzly bears, and a number of species of small mammals, reptiles, amphibians and birds (Harding and McCullum 1994).

A program of liquidating old-growth forests and replacing them with younger, structurally simpler forests would appear to institutionalize the reduction of biodiversity. The B.C. Ministry of Forests is beginning to address these issues with research on biodiversity and through its proposed Old-growth Strategy and other initiatives. The importance of preserving old-growth forests, not just for recreational and aesthetic reasons, but for ecological reasons, is slowly being recognized. Sustaining long-term site productivity may require the maintenance of ecosystem resiliency, its ability to absorb stress or change without significant loss of function. This capacity may be related to biodiversity (Franklin et al. 1987).

The argument for conserving ecosystem diversity was best made by Aldo Leopold in his classic, *A Sand County Almanac*:

> If the biota in the course of aeons has built something we like but do not understand, then who but a fool would discard seemingly useless parts? To keep every cog and wheel is the first rule of intelligent tinkering. (Leopold 1949)

Kimmins (1992), in responding to the oft-quoted Leopold, argues that forest ecosystems contain a certain degree of redundancy:

> The idea that the loss of a single species of bird or small mammal will result in a dramatic alteration, or even the eventual destruction, of a forest ecosystem is simply not supported by the available evidence. (Kimmins 1992, p. 164)

The point, however, is that it might be foolish to discard parts that we *do not understand.* A growing body of evidence suggests that some relatively obscure parts of forest ecosystems may perform valuable functions in sustaining ecosystem resiliency. Their contributions are not yet well understood. The positivist argument might be that we can compensate for the activities of these components with technologies such as fertilizers, herbicides and nursery practice. The uncertainty surrounding the effects of such treatments on ecosystem resiliency, the relative costs (financial and other) and the public desire for such solutions requires more careful consideration.

What is a normal forest? To what pattern should a forest conform to provide a sustainable flow of the many and various amenities that forests offer? The concept of the normal forest assumes that there is some universal model of the pattern to which a forest must conform. The traditional idea is that a normal forest is one simplified, spatially and structurally, so as to facilitate an optimum, even and predictable flow of wood. This positivist view is at odds with our current level of ecological understanding of forests. The interconnectedness, contingency and uncertainty in ecological systems suggest that the word "normal" has little meaning at all in this context.

Forests are extremely diverse just within British Columbia. Coastal forests, for example, may have a high degree of structural complexity due to the infrequency of large-scale disturbance and the small openings created by windthrow, insects and diseases. In the boreal forest, where large-scale wildfires are far more frequent, forests are far less structurally complex. The diversity of forests might suggest a diversity of management strategies as opposed to the uniform model in place. A variety of styles of forestry may be necessary to produce a healthy forested landscape that satisfies the broad range of needs and values of its human constituents.

5.3 The Myth of Certainty

The scientific positivist believed in a world that could be described mechanistically. Because the world was constructed in a classical machine-like fashion, its trajectories could be foreseen with deterministic certainty. While agnosticism about causes made it impossible to understand why things happen the way they do, it was possible to describe nature and create descriptive formulae that would enable us to predict its future states.

Sustained yield forestry, as it has evolved in British Columbia, is the product of a positivist philosophy that viewed natural phenomena as essentially universal and ahistorical. The policy of equal annual yields forever has created an illusion of certainty in the face of a growing awareness of large-scale uncertainty. Maximum sustained yield forestry contains the tacit assumption that the future will be like the past.

Forest management, as practical ecology, is subject to uncertainty as a consequence of ecological contingency and as a consequence of shifting social perceptions of the values inherent in forests. Ecological systems are complex, contingent and evolutionary such that they keep "slipping away and changing under us":

> Rarely is it possible to predict even the short-term effects of major interventions. Given complete biological understanding, we would still be faced with the unpredictability of various environmental agents. (Walters and Hilborn 1978, p.157).

The contingency of ecological systems and high natural variability make it difficult to know where the MSY actually is (Larkin 1977, Sissenwine 1978) or if it remains consistent over time. Science may be largely incapable of predicting safe levels of resource exploitation and optimum levels of exploitation may best be determined by systematic trial and error (Ludwig et al. 1993).

The forest managers of British Columbia face significant ecological uncertainties. Will clearcutting impair soil productivity by compaction, erosion and nutrient removal via wood extraction? Will forest ecosystems be simplified and diminished in terms of biodiversity in the transition to second growth forests? Will insect predator and mycorrhizae diversity be diminished and will these have long term effects on the frequency of herbivorous insect infestations and on tree growth, respectively? Will losses in soil biota and *undesirable* plant species occur and will these losses affect soil nutrition? Will global climate change stress ecosystems and will the transition to managed forests affect the ability of forest ecosystems to buffer these stresses?

There is a reasonable doubt as to whether the future will be like the past. It is possible to address these uncertainties to some extent through research but this may necessitate departures from a maximum sustained yield policy and from the ideal of objective, abstract science. The questions posed above may best be addressed by a structured *learn as we go* approach. Adaptive management of forest ecosystems requires scientists to become involved in the practice of forest management and conceive of forestry as one large management experiment.

To develop an understanding of forest ecosystems it may be necessary to preserve portions of natural forest for study and comparison. This would require a reduction in the rate of cut and more careful monitoring of the effects of management activities. The role of science would be to design management activities as experiments and facilitate our capacity to learn as we go. For example, there is currently no protocol for monitoring forest development after cutting. Yield predictions are made from stand-level reductionist models based on seedling regeneration but we have little idea if the predictions are being met. By not monitoring forest management activities a golden opportunity to expand our understanding of forests is lost.

One of the consequences of managing for a maximum sustained yield is that initial yields from the resource are much higher than the long run sustained yield (LRSY). This is typical in fisheries where the initial population size is above that which would produce the maximum sustainable yield, and in forests that are, on average, older than the age of maximum mean annual increment. The problem is compounded as governments have typically offered incentives and subsidies to new operators while the resource is being utilized below the MSY (Smith 1980). In British Columbia the short-term economic benefits to the province from timber harvesting have historically discouraged barriers to entry into the market (Woodcock 1990). Given the uncertainty about where the MSY actually is, it has proven difficult to know when incentives should be removed and expansion should be regulated. In fisheries, the consequence has typically been an over-commitment of fishing effort resulting in over-exploitation and often failure of the fishery (Clark 1973; Ludwig et al. 1993).

The long time frame of forestry makes it more difficult to determine when over-commitment of effort to the resource is occurring. Smith (1980) argues that to manage a resource for MSY is to manage on the verge of conflict. Conflict comes from the changing goals and expectations of resource users. In British Columbia forests, conflict over resource use has become the norm. It seems reasonable to suggest that the conflict is due in part to over-commitment of the harvest.

As we reach the transition to second growth forests, resource options in the old-growth forest have become more tightly constrained. Because of the much smaller volumes being logged in past times (Figure 4-3) there will be insufficient second growth available to sustain the current logging rates. Allowable cuts are currently being reduced by the provincial government in the transition to the long run sustained yield. Efforts to preserve old-growth forests for scientific, aesthetic or cultural reasons are usually directed at areas scheduled to be logged within the next ten years. The areas proposed for preservation are small in terms of the whole forested land base but in the short term they are critical to the forest industry. The introduction of constraints on logging practice to conserve wildlife habitat has further tightened the noose. The failure to account for uncertainty in the social domain, the changing goals and aspirations of people, has become a significant problem for the policy of maximum sustained yield forestry.

As outlined in the preceding discussion, there are three fundamental problems with a policy of maximum sustained yield forestry:

1. The problem of extrapolating from the growth model of a small number of species to a general model of the performance of the underlying system.
2. The effects of maximizing the production of one system component on other system components.
3. The assumption that the future will be like the past.

In a complex, interrelated system, it is unlikely that the dynamics of any one component can provide an understanding of the dynamics of the whole. In an interrelated system maximizing the productivity of one component will have significant effects on other systems components. In a system subject to contingency the future will not be like the past.

Sustained yield forestry has been concerned with a flow of products and not with the state of the resource. The rate of cut was designed to regulate the forest such that it might achieve the highest rate of growth. Thus, sustained yield forestry was concerned with the *actual* productivity of wood products and not directly with the *inherent* productivity, or with the state of the forest at any given time (Greber and Johnson 1991). It has been assumed that managing the forest to achieve the highest rate of actual productivity would sustain the inherent rate of productivity, and the state of the forest that results would satisfy non-timber values. There are significant uncertainties underlying this assumption.

5.4 Sustainable Forestry

The art and science of forestry has been undergoing profound changes in recent years that will continue into the foreseeable future. An ecosystem perspective is tacit in the move from sustained yields to *sustainable forests*:

> There is...an emerging consensus that forests should be viewed as ecosystems and that human activity in the forests should be managed within that context. (Griss 1993, p. 535)

The Canadian Council of Forest Ministers, representing the Federal and Provincial governments, has recently announced the Canadian commitment to sustainable forests:

> We have strengthened our foundations for conserving the natural diversity of our forests... We have refined our planning and management practices to incorporate a broader range of forest uses and interests... We have refined our ability to ensure the continued productivity of the forest. (CCFM 1992)

The emerging paradigm of forestry is based on an increasing awareness of the interconnectedness of forest ecosystems, on the view of forests as an interactive system of plants, animals, soil, water, topography and climate:

> If you cut a tree you influence wildlife habitat, water yield, fuel loading, scenic beauty, forage production, energy flow, and nutrient cycling. (Behan 1990, p.15)

The systems view of ecological phenomena has had a significant impact on the rhetoric of forestry. A systems view is implicit in the idea of integrated resource management (IRM) which considers non-timber values as at least constraints on timber management. IRM recognizes that the forest is a "unified ecosystem, consisting of a complex of interdependent processes and organisms" (Carrow 1994, p.19).

Ecologically-based forestry and integrated resource management are key elements of several recent initiatives in British Columbia forestry. These include provincial strategies for old-growth and protected areas, and the new Forest Practices Code[7]. The Forest Practices

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[7] At the time of writing the Forest Practices Code had been passed in the legislature but was in a two month appeal period prior to its expected enactment in June, 1995. My discussion of

Code incorporates much of the work that went into the development of the Interior Fish Forestry Wildlife Guidelines and Coastal Fisheries Forestry Guidelines. These guidelines outline forest practices that are designed to conserve fish and wildlife habitat while allowing for commercial harvesting. Their basic philosophy is that the forest is a network of connected ecosystems on the landscape. Harvesting must be designed in a way that maintains the quality of wildlife habitat and overall biodiversity by minimizing fragmentation, and providing habitat reserves and dispersal corridors. The guidelines incorporate the idea that managing forests to most closely resemble natural forests is the best way to maintain biodiversity (Seip 1994) and other values.

The guidelines also include aspects of what has been called *New Forestry* (Hopwood 1991). New Forestry has been described by Lertzman (1990) as

> ...an attempt to define forest management with timber production as a by-product of its primary function: sustaining biological diversity and maintaining long-term ecosystem health. (Lertzman 1990, p.5)

The practices of New Forestry are designed to enhance the diversity of managed stands and promote development of old-growth characteristics. Practices that have been proposed include logging methods that retain living trees, standing dead trees (snags) and fallen logs, and the establishment of mixed species stands (Hopwood 1991).

A prerequisite for landscape-based ecosystem forestry is a means of ecologically classifying forest land. This has been provided in British Columbia by the development of biogeoclimatic ecosystem classification (BEC) (Meidinger and Pojar 1991) based on studies carried out by V.J. Krajina and his students from 1949 to 1975. In the 1970s, the B.C. Forest Service began a program of ecosystem studies that continued on Krajina's work in developing a classification and description of ecosystem units (Pojar et al. 1987).

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the code is based on discussion papers and proposed versions of the standards and regulations.

The system is based on Sukachev's concept of the biogeocoenose, similar to Tansley's ecosystem concept, and the floristic theory of J. Braun-Blanquet, a community approach to ecological analysis. Sukachev defined a forest biogeocoenose as

> ...that part of the forest uniform over a certain area in the composition, structure, and properties of its components, and in the interrelationships among them; that is, uniform in the plants, animals, and microorganisms inhabiting it, in the parent material, in its hydrological, microclimatic (atmosphere), and soil environments and the interactions among them; and in the kind of matter and energy exchange between these components and other natural phenomena in nature.[8]

Sukachev emphasized the dynamic character of the biogeocoenose:

> The biogeocoenose as a whole develops through the interaction of all its variable components and in accordance with special laws. The very process of interaction among components constantly disrupts the established relationships, thereby affecting the evolution of the biogeocoenose as a whole.[9]

The BEC system accounts for the dynamic character of ecosystems by accounting for vegetative succession, site disturbance, pedogenesis and geomorphology.

Classification in the BEC system is based on vegetation, climate and soil (including topography and parent material). The main units of classification are the biogeoclimatic zone, sub-zone and site unit. Classification at the zonal level is based on regional climate complemented by descriptions of prevailing pedogenic processes and characteristic plants. Zones are divided into sub-zones on the basis of more local climatic, pedogenic and vegetative features (Klinka et al. 1979).

Within sub-zones, site units are described by an edatopic grid (Figure 5-1) based on the concepts of soil moisture regime (SMR) and soil nutrient regime (SNR). SMR and SNR reflect soil properties such as parent material, texture, depth and pedogenesis, and topographic features such as slope, slope position and aspect. For example, lower slopes receive seepage water while an upper slope or crest tends to shed seepage water. As seepage

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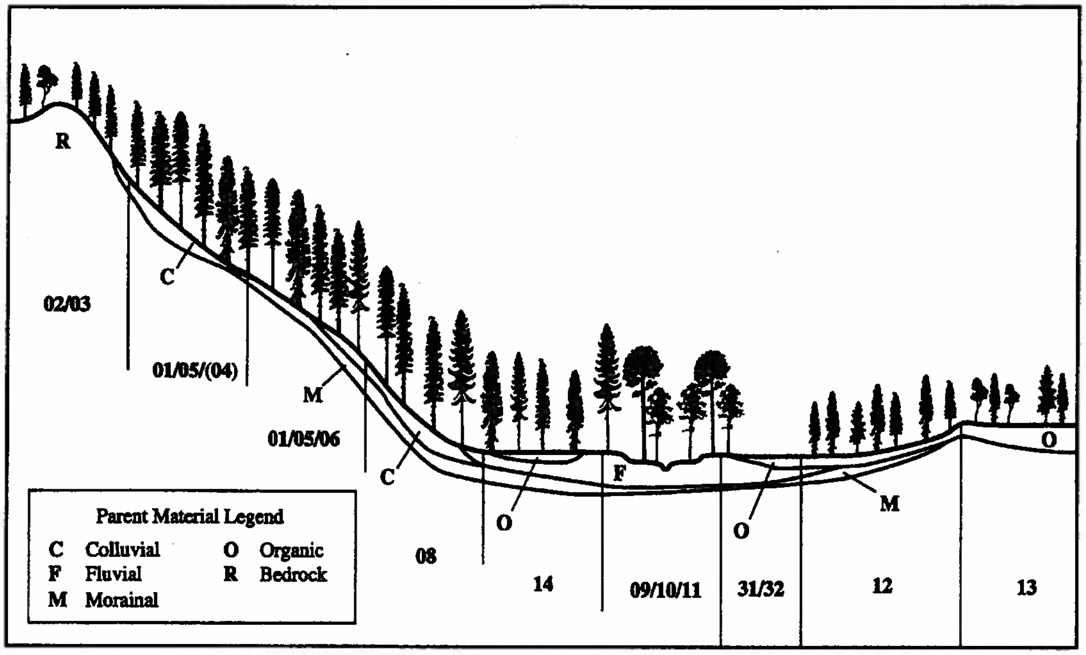
[8] Sukachev and Dylis (1964), as quoted in Klinka et al. (1979, p.2).
[9] Sukachev (1960), as quoted in Golley (1993, p.173).

CWHvm1 Landscape Profile[a]



CWHvm1 Edatopic Grid

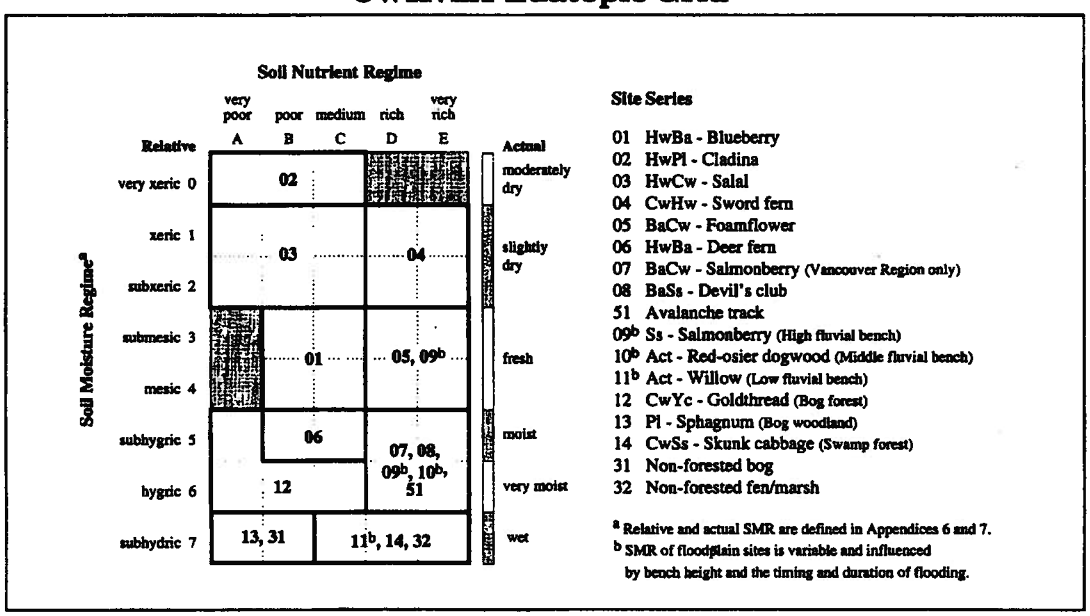


Figure 5-1. Ecosystem classification units in the Coastal Westerm Hemlock biogeoclimatic zone (CWH), very wet maritime subzone (vm), submontane variant (vm1).

Source: Banner et al. 1993

water carries mineral nutrients, lower slopes generally have a richer SNR. Soil features such as texture and parent material affect the capacity of the soil to hold water and the availability of mineral cations.

Vegetation reflects and influences the physical conditions of a site. The BEC system uses Braun-Blanquet's concept of the plant association in the diagnosis of the site unit. Species with relatively specific site requirements are used to develop a diagnostic combination of species (Pojar et al. 1987). A description of environmental factors alone leaves the difficult question of what their integrated effect on plants might be:

> Vegetation plays the key role in the evaluation of site quality because:
>
> 1. it can be easily observed and objectively described; and
> 2. it is an integrator of the ecosystem [,] the best expression of the combined influence of numerous environmental factors, the biotic community itself, and ecosystem history. (Klinka et al. 1989, p.5)

The combination of vegetation and site provides a powerful interpretive tool for describing relatively uniform units on the landscape. Experience from a certain site unit can be extrapolated to similar units at other locations. The B.C. Ministry of Forests has completed mapping of the province at the sub-zone level and characterized the major site units (ecosystems) within each sub-zone. Management interpretations are being developed for site units and growth and yield data are in the process of being correlated by site unit. With the development of spatially-based forest management planning tools, ecosystems can be used as the basic planning unit for forest management.

Biogeoclimatic ecosystem classification has been successfully used for wildlife habitat classification (Hamilton 1988) and for evaluating the incidence and hazard of disease organisms (Beale 1987) and insects[10]. Preliminary results have suggested that BEC may be useful for describing the incidence and frequency of fungi, including mycorrizhae[11].

Biogeoclimatic ecosystem classification is a deductive shell that allows us to make inferences about the characteristics of specific ecosystems. It can be continually improved through inductive inference as new information is gathered and new interpretations are made. To be effective it must be continually re-evaluated as new contingencies arise.

The BEC system is a scientific and a forest management success story. The synthesis of process/functional ecological theory and community ecology provides a meaningful framework for expanding our understanding of forested ecosystems and meeting our management objectives. Vegetation alone can be fallible in site description and diagnosis because of site disturbance and the random processes of migration. Site factors alone do not reveal their integrated effect on vegetation or the effect of vegetation on site. Biogeoclimatic ecosystem classification affords a powerful interpretive context for organizing and expanding our knowledge of forests and makes possible the practice of sustainable forestry.

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[10] Biogeoclimatic classification has been used to evaluate the potental impacts of mountain pine beetle, spruce beetle and gypsy moth by Phero Tech Inc., 7572 Progress Way, Delta, B.C.

[11] Personal communication with Sharmin Gamiet, Mycology Resources, 356 Dafoe Rd., Abbotsford, B.C.

6. TRANS-SCIENTIFIC FORESTRY

> For me, there is no way which is the way the world is; and so of course no description can capture it. But there are many ways the world is, and every true description captures one of them. (Goodman 1960)

The positivist assumption was that there was one way the world is and that science was the means to describe the one way. Science was the way to determine right action and structure the activities of human agency. If a conflict arises it has been typical to mandate more research; more science would determine the best course of action.

The current state of ecological knowledge poses questions as to whether there are not one but many appropriate ways to see the world. Complex, dynamic systems may not be described by one ideal description. The population, the community, the ecosystem and the gaia hypothesis are levels of abstraction that capture aspects of the historically contingent whole reality.

Science has developed a protocol for inquiry that limits the categories that can be addressed. Science can construct an edifice of knowledge about an objective reality at the cost of being able to say much about subjective reality. The range of human beliefs and values provides an additional range of ways the world appears. The world is a source of beauty, the world is a source of spirituality, the world is the home of creatures other than ourselves.

Although science does not pronounce on basic value questions it is mandated by society to pronounce on derivative value questions. For example, science can say to society "If you want to preserve old growth forests they must be of a certain minimum size". Or "If you want to log in this area *and* conserve scenic beauty logging could be done in this fashion".

The issues that forest science is asked to address typically involve a mix of questions of fact and questions of value. Such issues belong in the domain of what Weinberg (1972, p.209) has called *trans-science*:

> I propose the term *trans-scientific* for these questions since, though they are, epistemologically speaking, questions of fact and can be stated in the language of science, they are unanswerable by science; they transcend science.

I suggest that all the major issues of environmental management are trans-scientific for two reasons. First, ecological uncertainty makes it impossible to produce the kind of knowledge that could answer them definitively. Second, "the issues themselves involve moral and aesthetic judgements: they deal not with what is true but rather with what is valuable" (Weinberg 1972, p.213).

In this chapter I will outline three major issues that dominate the current debate on forest management in British Columbia. What is the role of science in resolving these issues? How can scientific knowledge interface with the values and aspirations of human culture in a framework that allows rational and liveable decisions to be made. To be rational they must accord with the facts as we know them and address the goals of society. To be liveable they must accord with the beliefs and values of human culture.

6.1 Is Clear-cutting "Bad" Forest Practice?

The Premier of British Columbia visited Germany in 1993 to respond to the condemnation of clear-cut logging practices in B.C. The German Greenpeace movement has been attempting to promote a boycott of B.C. forest products as a means of halting clear-cut logging.

The opposition to clear-cutting is based on a blend of matters of fact and matters of value. Large clear-cuts with no attention to slope stability have caused erosion and stream degradation. Habitat reduction and fragmentation have raised concern about species loss and reductions in biodiversity with attendant impacts on ecosystem integrity.

British Columbia's song birds are reportedly in decline and the habitats of caribou, grizzly bear and other mammals are threatened. Logging of old-growth forests is having serious impacts on lichens, insects and microbes which may be important in maintaining forest *health* (Harding and McCullum 1994). The notion of ecosystem or forest health, itself, contains values that can't be reduced to scientific analysis (Ehrenfeld 1992).

For some, clear-cutting is compromising the aesthetic quality of the British Columbia landscape. The issue of clear-cutting also raises significant moral questions about the rights of non-human species and the rights of future generations of humans. Perhaps the ultimate question of value is "do we care enough about these issues to change our economic activities in order to address them?". To some a successfully regenerating clear-cut is the next logical step in a successful human enterprise while to others it is a grievous insult to the landscape; something is lost that can't be regained.

What role can science play in the social debate surrounding the trans-scientific issue of clear-cutting. One of the mandates given to forest science has been to develop a better understanding of the effects of clear-cutting on forest ecosystem structure and function. In the past clear-cuts were often thousands of hectares in size spanning, in some cases, entire watersheds, islands and mountains. In the early 1980s, new guidelines limited clear-cut size to 250 ha. More recent concerns raised by ecological science and the environmental movement have resulted in more restrictive guidelines. The Forest Practices Code, when enacted, would limit clear-cut size to 40 hectares in the southern part of the province and 60 hectares in the north.

In the past the mandate of forest science has been to promote economic activity. When logging activity first began on the British Columbia coast in the 19th century the common practice was to high-grade high-value trees using handsaws. The trees were chosen for their accessibility to water where they could be felled and tumbled down the slope with hand jacks or winched using steam engines into the ocean for transport. As technology provided power saws, trucks, railroads and expanded markets, it became economically efficient to harvest all the timber in a large area. In the 1930s it became common practice to run a rail line up a valley and log the entire valley (Mahood and Drushka 1990). Today clear-cut logging is still considered the safest and most economically-efficient means of extracting wood from the forest.

In the transition to sustained yield forestry there also developed a quasi-ecological rationale for clear-cutting. The most desirable species for timber has been Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) which is relatively intolerant of shade and prefers a mineral soil seedbed (Krajina et al. 1982). Clear-cutting was thought to best mimic the large-scale wildfires or windthrow events following which Douglas-fir appears to most successfully regenerate in nature. The German school of sustained yield forestry provided the additional rationale that clear-cutting would provide the opportunity to plant seedlings and improve the stocking and distribution of Douglas-fir in the stand.

Douglas-fir and other species, notably pines (*Pinus* spp.) are considered to be successional or sub-climax species. They have co-evolved to occupy a site after disturbance and typically, in the absence of disturbance, their abundance is diminished over time. In many coastal and higher elevation interior forests a wetter climate makes wildfires infrequent. Over time the composition of such forests tends to more shade tolerant species, such as western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and true firs (*Abies* spp.) that can regenerate successfully in the understory. Such forests typically undergo gap replacement in which single trees or groups of trees are killed by combinations of disease and windthrow and are replaced from the understory. In these forest types single-tree or group selection logging methods[1] may, arguably, more closely mimic natural processes (Coates 1994).

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[1] Single-tree and group selection are standard forestry practices that involve maintaining a continuous forest cover by removing single trees or small groups of trees at each cutting cycle.

The forests of British Columbia have been managed under a single regime for most of this century. As a result, we have little experience with forest practices other than clear-cutting. The environmental movement tends to view selection silviculture as a panacea for what they perceive to be destructive forest practice. In 19th century Sweden, on the other hand, clear-cutting was thought to be a panacea for centuries of selective cutting that had left the forest structurally and genetically impoverished. In Ontario selective cutting of yellow birch (*Betula alleghaniensis* Britton)/ sugar maple (*Acer saccharum* L.) stands, in this century, degraded stands to the point where, in many cases, clear-cut and start over seemed the best thing to do.

Clear-cutting has been shown to be inappropriate in some ecosystems in British Columbia, notably in very hot, dry climates such as those of the southern interior; in others clear-cutting may be the best choice, short of not cutting at all. In many cold, northern forests a thick layer of acidic organic matter develops that insulates the soil and promotes permafrost or very low summer soil temperatures. Kimmins (1992) argues that partial cutting may maintain low soil temperatures while clear-cutting with some form of mechanical site preparation may reinvigorate soil processes and ecosystem productivity. However, in the presence of permafrost, clear-cutting has the potential to create serious instabilities by altering the soil thermal regime and the soil moisture regime sufficiently to create bog conditions. The problems of regeneration in boreal ecosystems have not been solved no matter what the logging system.

In my opinion, most of the ecosystems of British Columbia could be managed using any silvicultural system if applied appropriately. It has been a myth of foresters that shade intolerant species could not be managed with selection systems. There is testimonial evidence, from Vancouver Island, B.C., that Douglas-fir can be successfully managed for timber production on a selection system (Loomis 1990). Partial cutting techniques in lodgepole pine (*Pinus contorta* Douglas var. *latifolia* Engelmann), designed to reduce losses to the mountain pine beetle (*Dendroctonus ponderosae* Hopkins), have shown promising results in western Montana (McGregor et al. 1987).

Bark beetles, notably the mountain pine beetle and the spruce beetle (*Dendroctonus rufipennis* Kirby) infest vast areas of mature forest in the B.C. interior. Government policy has been to clear-cut infested areas to salvage wood, prevent spread of the insects, and mitigate the potential fire hazard. In areas such as municipal watersheds where a continuous forest cover is desirable it may be possible to mitigate the hazard to infestation by partial cutting designed to diversify the overly uniform host. Current infestations can also be managed by single tree removal of infested trees with or without semiochemically-baited trap trees.

There are many examples, throughout the province, of fully stocked conifer plantations following clear-cutting. Where timber production is the primary social goal clear-cutting may still be the best approach. Many of the problems of the past are gradually being solved by reducing the size of cuts and regulating the pattern of cutting on the landscape, and by improved guidelines for slope stability, road-building, and streamside protection.

Some of the proposed "guiding principles" for timber harvesting in the new Forest Practices Code are

> Harvest patterns and cutblock design should reflect a balance of biological, social, and economic objectives.
>
> To achieve integrated resource management objectives, the prescription of cutblock sizes, shapes, and patterns should be based on a consideration of such factors as windfirmness, edge effects, desired wildlife travel and dispersal corridors, fisheries-sensitive zones, aesthetic values, biological diversity, roles of ecosystem components in ecological processes, natural disturbance regimes, and the feasible application of harvesting and site preparation methods. (British Columbia 1995, p.101)

The problems of habitat fragmentation and losses of habitat diversity in the transition to managed forests are slowly being acknowledged. Harvest patterns are required, under the

Code, to incorporate a linked network of mature timber throughout the landscape that satisfies the requirements of wildlife habitat and "social and recreational values". The Forest Practices Code also includes guidelines for designating special management areas for the protection of old-growth forests, recreational values, wildlife habitat, streamside and riparian areas and community watersheds.

While new regulations may ameliorate problems that have existed with clear-cutting in the past they do little to address the concerns of those constituents who are opposed to clear-cutting in any form. Any scientist who would argue that clear-cutting is preferable to selection forestry argues with reductionist facts against subjective values. To argue in this way involves making the positivist assumption that matters of fact, such as the economic efficiency of clear-cutting and the growth responses of conifer plantations, carry more weight than matters of value, such as the *desire* to maintain continuous forests. This involves misconstruing the role of science in a democratic social process.

The question of whether we should be clear-cutting or practicing some kind of continuous forestry is not essentially a scientific question. There are matters of fact that may inform the debate but they do not pre-determine the outcome. Both alternatives have different social, economic and ecological consequences. Science should inform the debate by providing relevant information pertaining to these consequences and by making society aware of the limits of scientific knowledge when attempting to explain historically contingent phenomena. To be just, a resolution of the debate on cutting practice must come as a result of a democratic social process in which *values* are given equal voice with *facts*.

Science can help society to learn from the choices it makes. It is now possible to develop landscape level GIS-based simulation models that could be used for probing the effects of the new regulations and other proposals on a given landscape unit. This kind of tool allows a visualization of the landscape that could illustrate what different management regimes might look like and could also be used as an information source in evaluating how well management is meeting its objectives. Landscape level simulation provides a framework for incorporating new information and allows us to learn as we go, in a systematic fashion, and adapt accordingly.

It is difficult to argue that clear-cutting is the best alternative when no alternatives are being attempted. There is far too little information on continuous forestry techniques in British Columbia to know how well they might meet the landowners' objectives. A simple way in which the government of British Columbia could address the public protest against clear-cutting would be to designate land for continuous forest management. Some knowledge of the alternatives might provide a better context in which to consider the current practice.

6.2 Is Logging Appropriate in Municipal Watersheds?

The Greater Vancouver Water District (GVWD) comprises 57,971 ha of owned and leased land in the Capilano, Seymour and Coquitlam watersheds. The overriding objective of watershed management is to provide quality water to the 1.5 million residents of the greater Vancouver area.

The debate on logging in the watersheds goes back to the turn of the century[2]. Prior to 1900 resource use in the watersheds was generally unrestricted but in the early 1900s contrasting views on harvesting practices began to appear. In 1926 the Greater Vancouver Water District was formed with E.A. Cleveland as Chief Commissioner. Mr. Cleveland favoured a closed watershed and in spite of arguments favoring logging put forward by Professors at the University of British Columbia and commercial logging interests, all commercial logging operations were phased out by 1936.

[2] My discussion of watershed history is based on Coop (1992) and Economic and Engineering Services Inc. (1991).

The lobby to allow logging continued. The desire to log in the watersheds was motivated by the highly valuable old-growth cedar and Douglas-fir. But arguments for logging in the watersheds were based on the notion that old-growth forests were overripe or decadent, they were susceptible to insect and disease infestation, and posed a high risk for catastrophic wildfire. A managed forest would be healthier and more resistant to insects, diseases and wildfire.

After Cleveland's death in 1952, the pro-logging lobby gained in strength. The main argument behind the argument for *scientific management* of the watersheds was that the high incidence of snags in old-growth forests, coupled with the frequency of lightning, created an increasing fire hazard. Standing dead trees are more likely to ignite when struck by lightning. Tree mortality caused by the balsam wooly adelgid (*Adelges piceae* Ratz.) leant impetus to the pro-logging argument.

The balsam woolly adelgid, native to silver fir forests in central Europe, was introduced to North America around 1900 and discovered in the Vancouver watersheds in 1958 (Harris 1968). Although not a serious pest of European firs it has caused widespread mortality in North American firs. In the watersheds, amabalis fir (*Abies amabalis* (Dougl. *ex* Loud.) Forbes) makes up 4% of the inventory and rarely accounts for more than 25% of the tree cover in a given stand. In 1967, the balsam wooly adelgid was reported to have infected 25% of the amabalis fir in the watershed.

Mortality by the adelgid added new snags and strengthened the perception of high fire hazard and the generally unsatisfactory condition of the forest. In petitioning the provincial government to allow changes to the terms of tenure to allow logging, the GVWD also suggested that larger trees require more water for evapotranspiration, reducing the amount of water available for stream flow.

Since 1961 the GVWD has embarked on a program of active forest management based on the principles of sustained yield forestry. The aim of management has been to salvage damaged stands and reduce the risk of major disturbance, such as forest fire or insect infestation, by creating a more diverse age-class structure and a more stable forest landscape through the implementation of sustained yield forestry.

In recent years the anti-logging lobby has gained strength. Arguments against logging are based on the premise that logging and road-building increase the potential for erosion and surface run-off, and consequently a reduction in water quality. The argument has been made that the filtering capacities of thick humus layers and coarse woody debris, typical of old-growth forests, provide better water quality than clear-cuts and subsequent managed forests.

In 1991 the GVWD undertook a Watershed Management Evaluation and Policy Review (EES, 1991). The study, conducted by Economic and Engineering Services Inc., recommended that the requirements of sustained yield forestry, as enacted in tenure agreements with the Ministry of Forests in 1963, be removed. The requirement for growing perpetual crops of commercial timber was deemed to be an encumbrance to the central goal of providing quality water.

The watershed review also recommended that a detailed ecological inventory, including ecosystem mapping, be conducted to provide a data base for long-term management planning. A low-level, pro-active forest watershed management program was advocated, that would be based on risk management criteria with respect to slope stability and erosion potential, the incidence of insects and disease, fire hazard and long-term forest stability. This would involve small scale logging to replace forest stands that are *unhealthy* or pose a high risk of insect and disease infestation or high fire hazard.

A moratorium on logging in the watersheds has been in effect since 1993, pending completion of the ecological inventory and long-term vegetation management plans. The public outcry against logging in the watersheds has effectively halted activity for the present.

The debate, as it stands, is between those who advocate closing the watersheds to human activity and letting nature take its course and those who believe that a pro-active presence in the watershed can improve the quality of the forest and ensure the delivery of quality water into the future.

The argument for logging is based on the premise that old-growth forests are decadent or in some way *unstable*. The growing body of research on coastal old-growth forests suggests that the impacts of insects and diseases are relatively insignificant. Disease does not appear to have any major impact on coastal old-growth forests (Franklin and Waring 1979, Franklin et al. 1981).

The most significant insect pests in the watersheds have been the hemlock looper and the balsam woolly adelgid. Infestations of the hemlock looper are infrequent and short in duration and rarely kill all trees over extensive areas (Turnquist 1991). The balsam woolly adelgid, which caused significant mortality when first introduced into the watersheds in the 1950s and 1960s, has subsided to endemic levels and does not appear to pose a threat to forest health[3]. Amabalis fir is not a dominant species in the watersheds and is more frequent in the cooler and wetter parts of the watersheds where an increase in the number of snags is less likely to result in a significant fire hazard.

Fires in coastal old-growth forests are infrequent and generally small in size. Fire frequencies in such forests vary from 150 to 500 years, becoming less frequent with increasing elevation (Feller 1992). Although the most fire-proof stands are mature forests where available fuels are at a minimum, fire hazard in coastal old-growth forests is generally low[4]. Feller (1992) notes that in the period 1953-1990 almost half the fires and roughly 70% of the area burned, in the watersheds, was due to people-caused fires. It appears likely that left to themselves, the effects of insects, disease and wildfire in the watersheds might be less or no more intrusive those of logging.

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[3] As discussed in Chapter 5, page 109.
[4] Personal communication with Bruce Blackwell, Consulting Forester, B.A. Blackwell and Associates Ltd., 3087 Hoskins Rd., North Vancouver, B.C.

While there is no compelling evidence to suggest that logging is necessary to maintain the integrity of watershed forests, neither is there compelling evidence that logging in the watersheds, since the 1960s, has had any significant impact on water quality or production (EES 1991). The kind of small-scale logging on stable slopes advocated by the GVWD may diversify the landscape and reduce the risk of extensive wildfire and large-scale infestations of the hemlock looper, apparently an old-growth dependent insect. The most compelling argument for logging in the watersheds may be to simply maintain a presence to respond to natural events. Other benefits might include jobs for the local community and logging revenue to support the GVWD infrastructure and off-set the costs to water-users.

Those opposed to logging are also concerned with the preservation of old-growth ecosystems and recognize the watersheds as one of the last preserves of old-growth forest in southwestern British Columbia. Currently about 62% of the watersheds, mostly at higher elevation, is classified as watershed reserve where current vegetation will be left intact. In the 1991 review, recommendations were made to develop an old-growth strategy including the preservation of old-growth corridors from valley floors to higher elevations.

On my reading of the available information there are alternative ways of accomplishing the primary goal of supplying quality drinking water to the citizens of Greater Vancouver. Logging or not logging in the watersheds both have risks and benefits. We can't know the future and what we know is inconclusive. Closing the gates may result in a catastrophic wildfire. Logging and road-building may cause extensive erosion and/or landslides. Not logging will ensure a wilderness landscape while logging will provide jobs and revenue to offset the costs of the water delivery system.

The single dominating purpose of management in the watersheds is to produce quality water. The question, then, is what other resource values can be realized without compromising the overriding objective. Logging has the potential to affect water quality through increased sedimentation as a result of increased surface run-off and by the rapid leaching of mineral nutrients such as phosphorus and nitrogen that follows vegetation removal. Logging could be conducted in an experimental fashion that would allow long-term evaluation of the magnitude of these effects. One such experimental approach could involve paired comparisons of adjacent streams within one of the municipal watershed or within an adjacent watershed that is scheduled for logging. Different logging regimes could be compared to unlogged streams by monitoring water quality variables. Baseline data could be gathered for a period of time before treatments begin. Science, in this fashion, provides a protocol for learning as we go rather than as a source of information for creating final solutions (Holling 1978).

The debate over whether or not to log within municipal watersheds has been presented from both sides as a matter of fact. It cannot be resolved as a matter of fact because to do so requires us to make assured prognostications about historically contingent phenomena. Moreover, to attempt to do so belies the fact that this issue is essentially a question of value. Those who value a managed, uniform forest and the revenue it produces are pitted against those who value some sense of the sanctity of old-growth forests. To attempt to resolve this debate in the language of science is a subversion of the social process.

6.3 Are British Columbia Forests Being Over-cut?

The annual cut in British Columbia is currently between 75 and 80 million cubic meters (Figure 4-3) and the long run sustained yield (LRSY) is estimated to be significantly lower at the current level of practice (B.C. Ministry of Forests 1984). The Ministry of Forests has made cuts to the AAC in recent years in response to timber supply shortages in certain regions. As we begin the descent to LRSY the debate surrounding the issue of overcutting takes on a new significance.

Environmentalist groups have dubbed British Columbia the "Brazil of the North" in response to the perceived destruction of temperate rainforests. This view clearly makes the implication that British Columbia's forests are being overcut. On the other hand the Forest Planning Committee for the Science Council of British Columbia has suggested that the rate of cut in British Columbia forests could be increased to 120 million cubic meters by the year 2020 and to 160 million cubic meters in the next 60 to 80 years (Science Council of British Columbia 1989).

The Forest Planning Committee recommended that a goal be set of increasing the yield by 50% thereby increasing the annual cut to a sustainable level of 120 million cubic meters. This would be done by practicing basic silviculture (plantation establishment) on a committed land base of 27 million hectares, and intensive silviculture (thinning, pruning, fertilization) on good and medium sites which make up roughly half of the current working forest.

In a Forestry Canada-sponsored survey of professional foresters, roughly 25% of responding B.C. foresters believed that AACs were definitely too high while more than 45% felt they were likely too high. Less than 5% believed that AACs were too low and around 23% responded that they were about right (Figure 6-1). The perception by professional foresters that we are overcutting comes, I believe, from uncertainty about the extent to which the productivity of the forest can be increased and whether this is what the client desires. The client in this case is the public who own the vast majority of British Columbia's forest land. Without professing to speak for professional foresters, I believe there are a number of significant problems for an agenda of increasing the level of cut.

Intensive silviculture treatments such as brushing and weeding, juvenile spacing, thinning, pruning and fertilization are designed to improve stocking, species composition, wood quality and rate of growth. There is ample evidence that they can have positive effects throughout a rotation by encouraging competitive advantages for

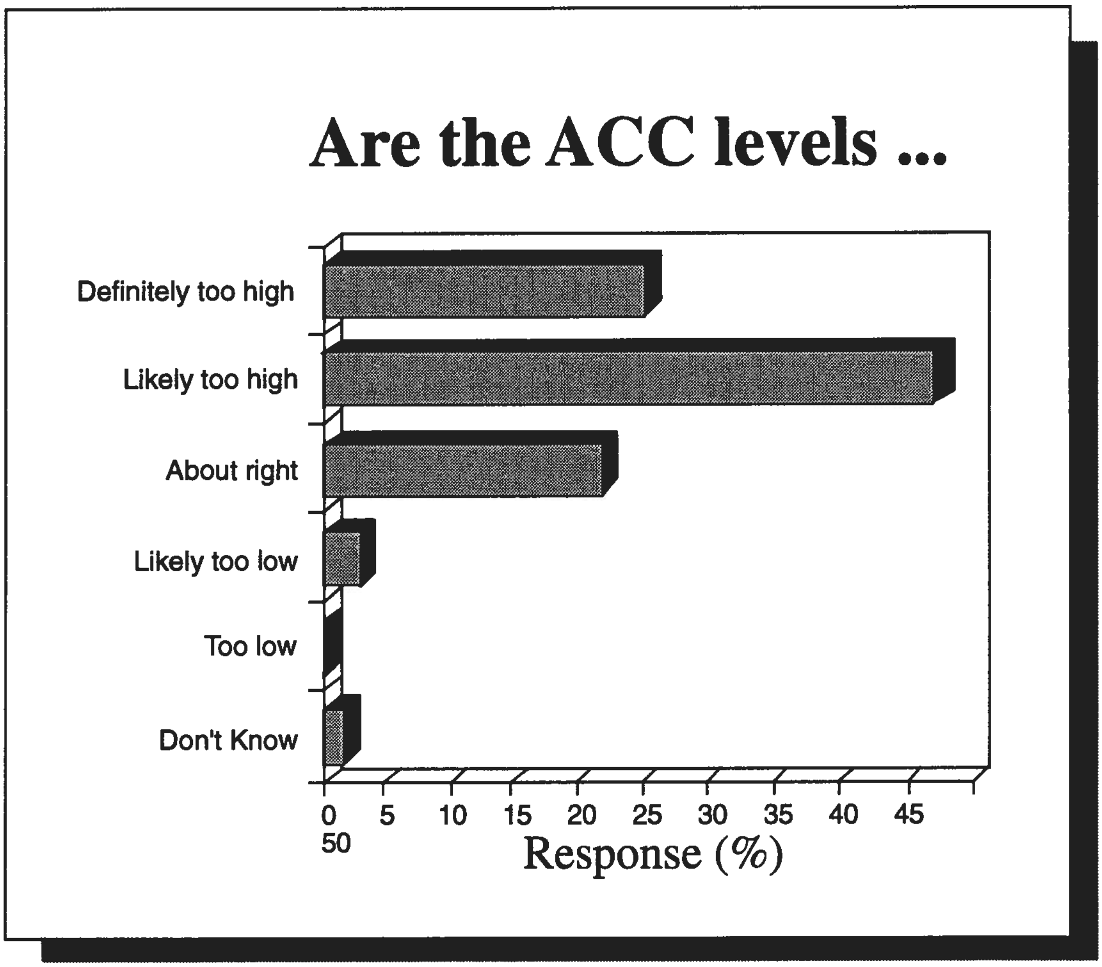

Figure 6-1. Results of a survey of British Columbia Professional Foresters conducted by Forestry Canada.

Source: Association of British Columbia Professional Foresters (1991) crop trees. The magnitude of these effects and the effects on inherent site productivity are not well known. Inputs of nitrogen fertilizer will almost certainly have negative effects on nitrogen-fixing bacteria and other soil microorganisms that are important to productivity in the long term. Fertilizers may also negatively affect mycorrizhal root associations. The controlled, replicated long-term experiments necessary to illustrate such effects have only recently begun, in part because biogeoclimatic classification has only recently provided a tool that allows sites of assuredly similar ecological properties to be compared.

The Forest Planning Committee (SCBC 1989) suggests that the productive forest land base is about 30 million hectares and that deferrals, old-growth preservation and watershed protection will reduce this to 27 million hectares. Currently the managed forest is around 24 to 25 million hectares. The difference will come, to a large extent, from moving up the hillsides into sub-alpine forests about which little is known. They appear to require much longer time periods to produce new forests (Klinka et al. 1992). Harvesting and silvicultural methods that are successful at lower elevations may produce far different results at higher elevations (B.C. Ministry of Forests 1993).

Another source of doubt about the capacity of intensive silviculture to solve our problems is the cost. Given the low rate of return on forest investments does intensive silviculture make sense economically? The natural forest offers returns at a very low cost. Will the increase in benefits offset the increased cost? How many new problems will be created by changes in forest structure that impact on the capacity of the forest to respond to ecological contingency?

Much of the research effort in British Columbia has been motivated by the perceived need to produce more wood. Will more wood benefit the owners of the forest enough to offset the loss of the native forest or do we need to look for ways to get more social and economic benefit from a reduced cut?

If we could increase the yield by 50%, where would it get us? While the level of annual cut has been in the neighborhood of 80 million cubic meters for the last decade the actual long run sustained yield may be closer to 60 million cubic meters. This would suggest that if we committed almost the entire accessible, productive forest in British Columbia, for the primary goal of timber production, a 50% increase in yield would indicate an annual yield of 90 million cubic meters.

The idea that British Columbians should commit the vast majority of their productive forest to a single cameralist agenda is not a scientific issue as much as a question of value. Modern science cannot justify long-term fixed solutions to problems of environmental management. The argument for committing our resources to increasing the yield of forests is based on the belief that wood production should be the primary goal of land-use and that more wood will provide increased social benefits. The issue is not nearly so simple.

Opinions about overcutting are likely as diverse as the forests themselves. Greber and Johnson (1991) describe eight perspectives from which an opinion on overcutting could be formulated. Different perspectives arise from different ways of appreciating the forest and/or from focussing on different forest components or different amenities the forest offers. The values we hold most dear will influence our point of view concerning the available facts. For example, if I value efficiency above all else it may bother me to see old forests left standing that are producing no appreciable increment or to see cutovers left to brush in as a means of providing wildlife browse. From this perspective, overcutting will occur when, regardless of the level of investment, the growth rate of the resource cannot match the level of exploitation. From another perspective, overcutting may occur when it impairs my ability to appreciate some other aspect of the forest that I value. Although arguments about overcutting are often made in the language of science they are essentially judgments of value.

The rhetoric of the last several years suggests that a significant constituency within British Columbia sees preservation of primary forests and biodiversity as important goals. Others are concerned about loss of jobs in the forest. The mandate of sustainable forestry puts maintaining the inherent productivity of forest ecosystems as a primary goal. Preserving old-growth forests and constraining forest practices to conserve wildlife habitat almost certainly will necessitate reductions to the rate of cut. Maintaining long-term site productivity may also encourage old-growth preservation and lengthened rotations. Can these goals be met without significant social costs in terms of lost jobs and tax revenue? What is the of role of science in helping society to resolve this fundamentally social issue?

6.4 Bridging Two Cultures

As understanding of complex, changing ecological systems has expanded, it has become less clear that science can provide the kind of knowledge necessary to show that there is a *right* way to manage forest ecosystems. This lack of certainty or ability to choose between alternatives like those described in the preceding sections of this chapter has provided the greatest obstacle to an acceptance of ecological science as the appropriate basis for forest management.

Ecosystem classification and simulation models are caricatures of reality. They are snapshots in time. Scientific understanding of ecological phenomena is like a causal map. It attempts to describe the network of causes that result in ecological phenomena. Like a map, ecological scientific understanding attempts to show how to get from A to B. It may show several alternative ways to get from A to B. Being a snapshot in time it cannot capture contingencies or configurational changes that have occurred since the map was prepared. The map shows a road but not the bridge wash-out or the tree fallen across the road. Like a map, ecological knowledge cannot guarantee that we will get there at all.

Given the best understanding possible, a recognition of contingency means we must expect the unexpected, build flexibility into our plans, be prepared to adapt to new contingencies, new knowledge and new cultural values. Science cannot provide universal generalizations that dictate how the future will unfold with predictive certainty but it does provide conditional generalizations that allow us to interpret the unfolding of the world in specific contexts. This kind of general knowledge can be used as a protocol for learning from the activities we choose to undertake.

The search for universal, timeless order in nature is foiled by the historical nature of ecosystems. The application of scientific results cannot guarantee timeless solutions to human problems because of the changing values of people. Toulmin sees this realization as part of a substantive change in our intellectual agenda:

> The model of "theoretical grasp" as the formal ability to master a deductive system that describes a permanent and ubiquitous "order" in nature, is giving way to a substantive ability to discover the local, temporary relations embodied in one specific aspect of nature, here and now, in contrast to another, elsewhere, a million years ago. (Toulmin 1990, p.204)

The way to learn about a specific aspect of nature is to become involved with it, in a sense to live with it. Science provides the means of maximizing the ability to gain a certain kind of knowledge from the experience. Forest management must become an adaptive experiment; a lived experience.

Biogeoclimatic classification provides a means of identifying ecosystems with similar structural and functional properties. Simulation modelling is a formal procedure that can be used to project and compare the effects of different management regimes on biodiversity, scenic beauty, recreation and long-term ecosystem resiliency insofar as our understanding allows. Ultimately the only way to determine if intensive silviculture is effective in a specific context is to try it. Similarly the only way to determine if selection silviculture or continuous forestry can meet the goals of society is to attempt it in an adaptive, scientific framework.

There are obstacles to such a strategy. The forested land base of British Columbia has been committed to a single style of management and is controlled by a small number of large corporations (Marchak 1983). Large-scale single agenda forestry provides few opportunities for learning about alternatives. An adaptive, experimental approach to forestry suggests a smaller scale, more diversified strategy that focuses on specific contexts and a variety of approaches that maximize the opportunities for learning. A good first step would be more adequate monitoring of what is currently being done in the forest. Opportunities to learn from past practice have been lost by the failure to employ an experimental management protocol.

Science as a protocol for learning provides a means for clarifying many aspects of the issues society faces. There remain the differences in opinion resulting from varying beliefs and values. Loggers believe that the right to log is part of their cultural heritage. Environmentalists believe in the rights of wilderness landscapes. Foresters believe they can generate healthy, productive forests. All may be right from their own point of view.

> Tolerating the resulting plurality, ambiguity or the lack of certainty is no error, let alone a sin. Honest reflection shows that it is part of the price that we inevitably pay for being human beings, and not gods. (Toulmin 1990, p.30)

One way to explicitly address the ambiguity and uncertainty regarding forest management is to involve the public in the decision-making process. This is the strategy behind the establishment in British Columbia of the Commission on Resources and Environment (CORE):

> The government has asked the Commission to develop and implement a world-leading strategy for land use planning and management as a part of a larger commitment to sustainability (CORE 1993).

The CORE process is based on the politics of participation because

> ...the public is demanding a more participatory role in the development of public policy [and] they ensure results that better fulfill the broad public interest than decisions that are shaped by the lobbying of powerful and vocal interests. (CORE 1993)

The Commission on Resources and Environment has sponsored public participation processes for land use planning in several regions of British Columbia and public hearings for a comprehensive provincial land use plan are in progress.

A second approach to involving the public in forest policy development is to "bring more people to the places where trees grow" (Carrow 1994, p.21). One such approach is the concept of the community forest which gives the community responsibility for forest management decision-making. The responsibility of decision-making will deepen the sense of relationship to the land and help people to better understand its importance in their day to day lives. Another model that has been suggested is the co-management model, in which industry, government and private citizens work together as partners to develop means of managing forests to satisfy all concerns with the aim of fostering

> ...the awareness and practice of long-term responsible stewardship of public resources at the local level (Pinkerton 1993, p.34).

The value of public participation is in developing *cultural capital* (Folke and Berkes 1992). Cultural capital refers to our means of relating to nature, of understanding our place in it and the means and adaptations by which we act in and modify the natural environment. The development of sustainable forestry is not just a scientific enterprise but requires society to develop an ethic of sustainability and cultural values that promote the development of a less destructive relationship with the ecosphere.

Adaptive management, contextual as opposed to universal science, and public participation all suggest that changes to the scale and agenda of British Columbia forest management are required. The monopoly on timber rights held by the large timber companies and the large-scale administration of maximum sustained yield forestry impose barriers to the implementation of alternative strategies and to a more direct involvement of the public in their own forests. A smaller scale of management in a diversity of styles might better promote the capacity to learn scientifically and the involvement of British Columbians in the everyday practice of forestry. Adaptive management in response to public participation provides one potential way of integrating science and human values. Science and society can work together to probe how the goals of society can be met.

A second way that science has contributed to the integration of science and human values, perhaps unintentionally and often unwillingly, is through the development of what David Ehrenfeld has called *bridging concepts*. One example of a bridging concept is biodiversity. While ecological science has expended great effort in attempting to operationalize this concept it has, at the same time, intuitive appeal to the larger culture. Biodiversity provides a concept by which the variety of life and the effects of human activity on other species can be grasped.

A second example of a bridging concept is the notion of systems or more specifically ecosystems. One of the definitions for a system offered by Webster is "a group of interacting bodies under the influence of related forces". Humans can recognize themselves as one component and a critical source of contingency in a complex, dynamic, interrelated system.

Ehrenfeld (1992) describes the idea of *ecosystem health* as a bridging concept:

> Health is an idea that transcends scientific definition... it contains values that are not amenable to scientific methods of exploration... Health is a bridging concept connecting two worlds: it is not operational in science if you try to pin it down, yet it can be helpful in communicating with nonscientists. Equally important, if used with care in ecology, it can enrich scientific thought with the values and judgements that make science a valid human endeavor. (Ehrenfeld 1992)

There is a movement in ecology to use health as metaphor for cataloging the kinds of stresses that ecosystems are subjected to and the impacts on ecosystem structure and function. An identification of common symptoms of ecosystem distress and the processes of ecosystem response might lead to a set of diagnostic principles for assessing ecosystem health (Rapport 1989, Schaeffer et al. 1988).

There are problems with this strategy. It is difficult to define a normal state for ecosystems that are in a constant state of flux as a result of contingency, environmental fluctuations and natural disturbance. Undisturbed ecosystems may show non-equilibrium dynamics or several quite different equilibrium states. In a complex system with many functions and processes an assessment of health could be a function of which aspects of the system are considered. While science can describe changes to a system in response to stress the question of whether or not a system is *unhealthy* may be largely a question of values and interpretation.

Attempting to operationalize health as a scientific tool ignores the fact that it is a very simple intuitive notion. The main value of the idea of health may be as an intuitive, general notion that bridges science and human life. Consider some examples from the area of human health. If a child reads about the destruction of the tropical rainforest and begins to display psychosomatic symptoms of illness a medical doctor, using the diagnostic principles of modern science, might determine that she is healthy. Similarly,

> ...a five-year remission from cancer, following strenuous treatment of the disease, may be equated with health by medical statisticians, but not necessarily by the patients whose definition of health embraces a far larger universe of experience. (Ehrenfeld 1992)

It may be possible to identify symptoms of distress in specific ecosystems and their effects on ecosystem resiliency but the notion of health includes human values and interpretations that transcend scientific definition. Its value is as a line of communication between two worlds, a bridge between science and society.

Bridging concepts can help promote a stronger dialogue between science and society and facilitate the public process of determining what our social goals should be. Bridging concepts such as ecosystem and health can foster an understanding of the world as a complex, interconnected system, while informing scientists about the beliefs and values of human culture and helping us all to develop an ecological consciousness.

7. CONTEXT TO A CONVERSATION

Social living requires common goals or beliefs or, failing those, a set of constraints that each member of the community agrees to abide by. If each member of a society believes in the same god or subscribes to the same mythology conflict may be minimal. In western culture, conflict arising from a plurality of beliefs, moral codes and mythologies has made social harmony by cultural sanction a problematic ideal.

For the last several centuries western society has looked to science as an important means of promoting social harmony. Positivist science promised the ability to predict the future and control nature, and to construct a rational social order. When social disharmony arises we have looked to science to provide a resolution.

Science has failed in this role for several reasons. First, the natural world is an historically-bound, contingent system. The complexity and interrelatedness of natural systems make it impossible to predict and control the future states of nature with certainty. The scientific positivist looked to develop timeless, universal law-like generalizations that could be used to make assured predictions about the future states of nature. In the last half century, science has begun to recognize the importance of historical contingency and has shifted its focus to attempting to understand and explain local, timely aspects of nature. The emphasis, in science, is shifting to the development of conditional generalizations, based on the causal structure of the phenomena, that can be used to interpret particular cases of natural phenomena.

A second problem for science is that it can say very little about basic questions of value. Social issues, like those of environmental management, cannot simply be reduced to the language of science without extra-scientific assumptions being made. For example, the debate on clear-cutting versus continuous forestry cannot be resolved without assumptions about what values the forest is being asked to provide.

Sustained yield forestry was an attempt at a scientific solution to a social issue. Proponents of sustained yield argued that its implementation would stabilize local communities by providing constant employment, stabilize the national timber supply and protect the environment from degradation (Mason and Bruce 1931). Sustained yield forestry is not *bad* science; it was the science available at a particular time, adapted to suit a particular historical context. In the current historical context, sustained yield forestry has some significant limitations. Based on a limited understanding of forest ecosystems it could not account for the variety, complexity and dynamic nature of forests. Maximizing the production of a single system component has had contingent effects on other system components with the potential for effects on long-term system resiliency. There are outstanding questions as to whether maximum sustained yield forestry can sustain the forest in a state that conforms with the goals of society or even, perhaps, sustain the yield.

As a technocratic solution, sustained yield could not account for the changing goals and aspirations of society. As we move away from the frontier stage of social development, society has expressed desires to preserve old-growth forests, wildlife populations, biodiversity in general, and scenic beauty. It has proven difficult for the government to respond because the land base has been fully committed to the over-riding goal of maximum wood fibre production. Sustained yield as a fixed solution has failed to account for the constant process of change.

There are outstanding questions as to whether large-scale industrial forestry, resulting from the policy choices made in 1945, is providing long-term benefits or stability to local communities. Travers (1993) points out that the number of jobs in the forest industry has remained virtually the same since the early 1960s while the rate of cut has doubled. Others might argue that indirect employment in, for example, the service industry has increased significantly. Are the benefits of maximizing the yield being equitably distributed? Rather than asking how can we produce the maximum continuous volume of wood fibre for the market, with the maximum profit margin, should we be asking how we can provide, on this piece of land, work and sustenance to the greatest possible number of people while maintaining the means of production and the array of other values the forest provides?

The positivist ideal of scientific forest management has occluded extra-scientific assumptions about value and social benefit. To make these assumptions clear it is necessary to address social issues in a social context. To some this suggests that we should discard science. But the root of science is the simple human desire to question why. The attempt to understand the intricacies of the natural world, in a structured, rational way, has been part of human consciousness throughout recorded history. We could not form questions of value about sustainability, conservation or preservation without the image of the world that science provides and continually attempts to improve. Accepting and communicating that the future state of the physical world is, to some extent, uncertain due to ecological contingency and that there are many areas of human experience about which science can say little are necessary steps if science is to regain the trust of the public and play a constructive role in human affairs.

The present-day concept of sustainable development and its corollary, sustainable forestry, have the potential to provide a bridge between science and human values. The World Commission on Environment and Development has stated that

> Humanity has the ability to make development sustainable - to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. (WCED 1987, p.8)

The goals of sustainable development are very similar to the goals that sustained yield forestry has failed to meet. They include maintaining the stock of ecological capital, improving the distribution of income, and reducing the degree of vulnerability to economic crises. These goals contain social, moral, political and ecological considerations that preclude sustainable development from being a purely scientific concept. In fact science had very little to do with the inception of the notion of sustainable development and the claim that characterizing the issues of fact, the context in which disagreements about beliefs and values take place. Science can sustain the conversation by acknowledging the meaning that other aspects of human culture bring to "bridging concepts" such as sustainable forestry, ecosystem health and biodiversity. Science can sustain the conversation by providing a protocol for expanding our understanding of the effects of specific interventions in specific contexts.

If neither religion nor science can provide a grounding for determining our actions, what are the alternatives? The only answer that I can offer is the simple art of conversation. We must cultivate institutions that make people the agents of determining their own public policies. Only through contact and through conversation can we learn to be tolerant of, and co-exist with, beliefs and values contrary to our own. While this process may be slow and frustrating it is, to me, the only fair and just possibility.

Science can work for society to help clarify its goals and aspirations and think more clearly about ways to achieve them. Science cannot predict past the immediate future with any degree of certainty and it cannot tell people what the correct choice may be. The role of science is not to provide answers but to help society choose the questions with which it prefers to live.

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