Sustainable Forest Management
Indicators

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Sustainable Forest Management Indicators[1]

Executive Summary

Sustainable forest management (SFM) includes significantly reducing the potential for regret induced by the occurrence of catastrophic events such as those caused in large landscapes by wildfire and bark beetles, or a sudden collapse of industrial and/or social systems of dependencies. These kinds of events can accrue as a result of the cumulative effects of management practices applied over long periods of time. Focussing on forests, we require knowledge of the dominant ecosystem-level processes that interact with forest and stand conditions to produce such results. SFM indicators can be developed to encapsulate our knowledge in a way that will help forest managers to avoid significant intermediate and long-term negative impacts of forest practices while reaping benefits from their application in the short-term.

The number of indicators of whether we are, or are not practicing SFM tends to expand indefinitely because forests are complex. Almost any element can be defended as being important to the functioning of the whole. Fortunately this complexity can be reduced to a much more stable list of attributes through the use of systems of classification; ideally these systems should be developed so as to apply to the inventory and ground conditions alike. Three primary features of the inventory are identified for classification: stand structure, tree species composition, and site. Two secondary features are: non-tree vegetation and life forms. Features are described as being secondary because their occurrence is to be described as a function of the occurrence of primary features. The establishment and re-measurement of plots representative of the forest as a whole is needed to infer a much larger number of attributes relative to the occurrence of specific classes or combinations thereof. The systems of classification and plots constitute a viable system for forest monitoring and management.

Lignum Limited, located in the Williams Lake, B.C., has made progress in the development of a monitoring and management system as described above through implementation of their Innovative Forest Practices Agreement (IFPA) with the Government of B.C. They have established plots based on a sample of sites and stands in their phase I Vegetation Resources Inventory (VRI) that was completed by means of aerial photo-interpretation. A quantitative system of stand structure classification has been developed using some of the plot data; this system of classification lends consistency amongst interpreters and ground surveyors to the process of distinguishing between stands with different numbers of trees per hectare by diameter class. The stand structure classification has been used to characterize all of the polygons in their 600,000 (+) hectare inventory.

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Lignum has also developed a prototype growth model (RING: Radial Increment – Net Growth) to forecast the changes in stand structures with time; the model uses data from the classification as inputs for initializing such forecasts. The connections of stand structure classification to the inventory and to the forecasting of reasonably possible future forest conditions is a central component to any dynamic indicator management process as described above. The ability to do this with attention to tree-level detail is central to the protection of biodiversity in accordance with the natural disturbance philosophy or habitat systems of management, and so too, central to the resolution of many other forest management issues.

The use of the Lignum stand structure and inventory information is discussed with respect to the development and application of "old growth" indicators. Inventory and on the ground, stand-level descriptions of "old growth" must be consistent if strategic forest-level plans are to remain properly aligned. Without proper alignment strategic plans will be directed toward producing one kind of outcome, but inevitably produce another; consistency ensures that what is done in reality is properly aligned with what should be done according to "best" estimates. Stand structure classification provides a vehicle for achieving this consistency along with proper inventory update procedures and periodic establishment and re-measurement of monitoring plots that have been established to represent the inventory as a whole (using proper sampling procedures).

A comparison is made of age-based definitions of "old" with stand structure – based definitions using the Lignum inventory. This provides an example of how inconsistencies can result in a failure to meet forest management objectives. At one scale an age-based definition is used – at another a structure-based definition is used.

It is argued that a simple definition of "old" is preferred over complex and highly localized definitions of "old" that often require a high degree of subjective interpretation. This does not preclude consideration of a broader suite of "old" stand attributes when developing and carrying out prescriptions. It does preclude extensive monitoring for these attributes to make landscape-level inferences, unless such information can be affordably gathered in the course of establishing and re-measuring plots that form the backbone of the routine monitoring system referred to above. It is proposed that it may be worthwhile recording where certain kinds of prescriptions have been implemented, but this should not be carried to the extreme of trying to account for every single detail. The development of a well-defined set of treatment regimen would be useful in this context.

This report is aimed at reversing the trend toward development of a complex set of indicators, many of which can be justified on some basis or other, but few of which present any compelling reason for managers to change their practices. In such situations more research and perhaps education is needed to clarify the link between these indicators and the kinds of catastrophic outcomes referred to at the beginning of this summary.

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Introduction

The production of indicators for Sustainable Forest Management has taken on a life of its own. The list of indicators tends to grow large because it is drawn to our attention that yet another component of the ecosystem has a vital role to play in maintaining its integrity. In most cases there is good evidence to justify the indicator as being important to ecosystem function. The proliferation of indicators is driven by the fact that forests are complex systems. Aldo Leopold resonates as we are, reminded that if we insist on tinkering with the pieces, it would be prudent to save all of the parts. Perhaps his comments were an elaboration of what we learned at a younger age:

> Humpty Dumpty sat on the wall.
> Humpty Dumpty had a great fall.
> All the King’s horses
> And all the King’s men
> Couldn’t put Humpty back together again.

There are no ends to the depths of forest complexities that must be plumbed. It is advocated by some that we complete enumeration of the parts and crosscheck these with the plans to ensure we haven’t missed anything before we even begin to pull the system apart. Unfortunately we are limited in our ability to do this without making substantial sacrifices in human welfare – this being one of the central themes of sustainability. Fortunately, the system is not so delicate that it will immediately collapse upon impact. What is important then, is that our knowledge of social, economic and ecological systems can advance in the process of managing them; it is up to us to capitalize on this opportunity so as to increase the potential for reward and reduce the potential for regret.

Choosing good indicators is much like paddling down a river for the first time without having even looked at a map to see what lies ahead. As we go around the first curve there is a huge logjam. In order to avoid it we paddle hard toward the inside of the stream to avoid getting swept underneath it. Suddenly there are rapids ahead. For a moment we pull into the shore and walk along the river to see what is causing them. The river is shallow with many boulders. We decide to line our canoe along the shore rather than risk breaking it by paddling through the middle of them. New things lie ahead – perhaps a waterfall - and we must be prepared to respond to them and to do so early enough to avoid tragedy. The next time we go down the same river we recall the logjam. It is no longer there – still it useful to know that logjams may lye ahead.

In the early years as a canoeist we had to learn to identify what the *key features* were that we must respond to. Key features affect the *process* by which we reach our goal; in this case the process by which we navigate the river, paddle hard or lightly and use a variety of strokes. The features are defined by the fact that if we do not respond to them there is a good chance that we may suffer considerably and/or fail to reap the substantial benefits upon reaching our ultimate objective. No doubt there were some things that we considered important initially but later turned out not to be. Eventually it becomes apparent that with just a few features or *indicators* it is possible to produce satisfactory results. It is important to pay attention to these indicators at all times, while keeping more general watch for new ones that we have not encountered before.

There are some indicators that are too specific to be depended upon, such as the fact that there is a not a log jam just around the second bend of the river. There are many more indicators, such as the fact that the rocks are volcanic in the middle stretch of the river, that are of little or no use in helping us reach the intended destination. If we forget about them or perhaps just “put them in the back of our minds” it will not have any significant effect on the final outcome.

There are always a few indicators that were never considered before, that in fact would have been helpful when dealing with similar situations in the past and that upon second thought, are of vital importance to the functioning of our (canoeing) team. These are usually discovered at first by trial and error, informally through experience – perhaps the experience of others, formally through monitoring and/or designed experiment, or some combination thereof. Lastly, depending on our skill levels and specific knowledge of a particular situation some indicators will emerge as being more important than others. It is to be expected when dealing with dynamic systems that as one problem is seemingly solved, others will emerge as being more important.

As forest managers we need to start with a few simple indicators that are most critical to the goal of managing for sustainability in large landscapes. We are looking for forest-level indicators that will effectively guide stand-level decisions. We are looking for stand-level indicators that can be used to determine whether or not forest-level objectives have been met. If there is not enough detail encompassed within the forest-level indicators then we will not be able to reliably apply this information to ground level decisions. If there is too much detail encompassed within the stand-level indicators then we will not be able to reconcile them with the forest-level indicators. There is an *appropriate level of detail* that enables us to make effective and efficient *forest and stand* management decisions. In evaluating the level of detail that is required, it is useful to remember that the idea of indicators seems to draw our attention to the various parts of the ecosystems when what we are really most concerned about is the whole or more specifically how our interpretation of the whole emerges from the interaction of the parts. Since we are dealing with complex systems the concern is with dominant features of the whole that can be mostly accounted for with reference to only a few parts. We are primarily concerned about impacts that are global in effect, then national, provincial, regional and so on and about our own collective impacts that accrue in the reverse direction, i.e. from the bottom up. While damage on a very small scale may be significant, it is only when that damage occurs repeatedly that we begin to become concerned about broader scale cumulative impacts – think of a progressive increase in siltation of streams as an example. The focus is on understanding the cumulative effects of management practices within the context of large areas of land, water and air.

We have much to learn about how ecosystems function and how ecosystem processes interact with our activities to produce the patterns we see today and expect to see in the future. We need to better understand how these affect our economies and societies so as to better anticipate alternative reasonably possible future forest conditions (scenarios). We need to have a sense of what parts in our lack of understanding pose the greatest risks to achieving sustainability. We need to learn how to better integrate this information into systems of planning, management and monitoring that are easy to understand, follow and execute.

Dealing with uncertainty is part of forest management insofar as the questions that we have around how ecosystems function arises from various stakeholders and as a result of implementation of various activities. However, attempts to answer such questions can be implemented through research in a way that for the most part can be conducted independent of operations, notwithstanding periodic communication. For many issues we don’t have enough information to make informed management decisions and would be better off undertaking research in these areas rather than setting up elaborate indicator (monitoring and management) systems to contain the problem. Monitoring is aimed at providing the feedback necessary to keep the system moving toward the desired outcome. Research is needed to design more sophisticated controllers that if successful will prove more reliable in terms of enabling us to reach the intended destinations. There is no point adding dummy controls that have no influence on the system other than to misdirect the pilot, perhaps for a substantial period of time while he comes to this realization. Such controls could be very damaging to the entire operation. It is important to maintain a separation between research (that can be conducted largely independently of the organization) and extension (that involves transfer of information for the purpose of practical application) and management (that involves integration of the same information to achieve a desired set of outcomes). Management processes must be relatively simple to implement and follow on a routine basis and must be critical to the continuing success of any organization.

What is Sustainable Forest Management?

What is sustainable forest management? How can we determine whether or not we are doing it? What should we do if we are not currently fulfilling such mandate? A sceptic would answer these questions in reverse order as follows:

- Nothing
- We can’t
- Don’t really know

The interpretation of what exactly is “sustainability” was deliberately left vague in the Bruntland Commission so that it was easier to agree to it in principle (Constanza et al., 1997). However such vagueness has not resulted in the issue being abandoned altogether.

Various people and agencies have picked up the term and developed their own definitions for the purpose of making progress on the general concerns that were raised in the Bruntland Commission report (World Commission on Environment and Development, 1987). These concerns focussed on the positive correlations amongst the following trends: increased environmental degradation, the occurrence of poverty, increased levels of population, and increased per capita consumption of resources with increasing wealth. Sustainable development was offered up as a solution to these problems with a focus on protecting the right of future generations to have access, at minimum, to the same levels of resources as were made available to those of use here today (see Goodstein, 2002, for a more complete interpretation of this concept).

Costanza et al. (1997) distinguish between development and growth; the former means increased efficiency of the use of existing resources without increasing the total throughput or consumption of resources. Increases in throughput or consumption are equated to growth. Development by definition is sustainable whereas growth is not. Ecological economics is designed to recognize that there are finite resources available to us. The common assumption by some economists (e.g. Simon, J., 1996) that there are (will be) a large (seemingly infinite) supply of substitutes for natural products and services (that can be) developed as a result of human ingenuity has some validity when considering the long-term decline in real commodity prices, but it must be acknowledged that there are limits to how far we can go with this assumption. What is needed is a more balanced approach (Lomborg, 2001)[2]. There is compelling evidence that nature provides

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[2] Lomborg (2001) expresses considerable frustration with tendency of the environmental movement to focus on a pessimistic view of our environmental management record, and goes to great lengths to show where the record has been skewed. His frustrations parallel those of Julian Simon (1996), both of whom relate back to Ehrlich as an extreme case in harbouring this tendency. Here is what Lomborg (2001, Pp 350-352) has to say:

> If we do not make considered, rational decisions but base our resolution on the Litany, that typical feeling that the world is in decline, we will make poor and counterproductive choices. In Peru, the authorities refrained from chlorinating the drinking water because they were afraid of the risk of cancer. Today, it is considered to have been one of the main reasons for the cholera epidemic that broke out again with such vehemence in 1991. Had they known how low the risk of using chlorine actually was, the epidemic would have never occurred.
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> In 1967 Paul Ehrlich predicted that the world was headed for massive starvation. In order to limit the extent of this, he believed – reasonably enough given his point of view – that aid should only be given to those countries that would have a chance to make it through. According to Ehrlich, India was not among them. We must “announce that we will no longer send emergency aid to countries such as India where sober analysis shows a hopeless imbalance between food production and population … Our inadequate aid ought to be reversed for those who can survive.” Ehrlich was basically saying that India should be left to paddle its own canoe. India, however, has today lived through a green revolution. In 1967, when Ehrlich wrote those words, the average Indian consumed 1875 calories a day. Even though the population more than doubled, in 1998 the average Indian got 2,466 calories a day. Had we paid more notice to Ehrlich and less to Borlaug and the incredible willpower and inspiration that surrounded the green revolution, things might have looked quite worse.

The point of this discussion is to highlight the fact that there is a need for balanced perspective. The works of Costanza et al. (1997), Goodstein (2002) and from a different perspective Gunderson and Holling (2002) a large number of "non-market" goods and services that "complement" economic progress, for which there are no substitutes (Costanza et al. 1997; for a historical perspective see Thirgood, 1981). Economic growth through over-exploitation of natural resources can ultimately lead to poor health, poverty and even fighting wars over the little that remains (Klare, 2001).

Costanza et al. (1997) also point out that many economists have ignored issues related to the distribution of wealth. In particular the efficiencies of resource use are best assessed on a per capita basis. Maximum efficiency is thereby affected by the distribution of resources amongst the various members of a population because the marginal benefit (utility) associated with a marginal increase in the availability of resources diminishes with increasing personal consumption of resources (wealth). Notwithstanding that there may be social advantages in having a skewed distribution in wealth, the concern remains as a matter of degree. The adequate distribution of resources is to be determined with consideration of private (individual) versus public (collective) rights and trade-offs realized through global versus local concerns. One example of these kinds of issues relates to the use of pesticides, where private interests struggle to maximize their gains from investments on a global scale, and public interests seek to avoid long-term, uncertain consequences that could drastically reduce their welfare at a local scale. Sustainable development involves finding a solution to the problem of unequal distribution of the potentials for gains versus losses in such transactions.

The foregoing is by no means the only interpretation of what is intended by sustainable development[3]. Sustainability is focussed on the intersection of social, economic and environmental policies without giving primacy to any one of them. The recent development of the field of ecological economics is one attempt to fill the void between domains of expertise that in the past have had very little to do with one another. There are also people working to do the same thing from a general systems theory perspective (e.g. Holling et al., 2002b). In their view, "Sustainability is the *capacity* to create, test, and maintain adaptive capability. Development is the process of creating, testing and maintaining opportunity." Impediments to the building and realization of such a capacity, perhaps in an effort to maintain a status quo, tend to have the reverse effect by causing large-scale collapses with significant consequences. This applies to the management of social, economic, and ecological systems alike.

All of this points to the first step in the process of developing indicators of Sustainable Forest Management (SFM) – we must define what SFM means – what it is we are trying to achieve by practicing SFM.

The Canadian Council of Forest Ministers has defined sustainability as "forest management to maintain and enhance the long-term health of forest ecosystems, while

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provide a good start in the right direction. van Kooten et. al. (2000) provides a more detailed look at some of the issues as they relate to British Columbia. In all of these discussions the choice of discount rates looms large. I have available an unpublished paper that provides a more detailed discussion of these issues with respect to the practice of silviculture (ForesTree Dynamics Ltd. 2002).

[3] For another good discussion see Goodstein's (2002) book on Economics and the Environment.

providing ecological, economic, social, and cultural opportunities for the benefit of present and future generations" (CCFM, 1992)[4]. This definition gives primacy to the notion of maintaining healthy forests, consistent with the idea of forests providing complimentary goods and services in support of a healthy economy and society. The CCFM (2000)[2] also developed criteria and indicators of sustainable forest management (SFM; Table 1). The list appears to be comprehensive, but it begs the question – what do we do with it? Lets assume that we observed a certain level of species diversity within a landscape – is that a good thing or a bad thing? Is there such a thing as too much diversity? Pritchard and Sanderson (2002) describe the following scenario:

> *The archetypal story about cross-scale dynamics is about contagious processes in forests (fire or pest outbreak for example): fragmented forests with small scale patches may be relatively immune to disastrous fire or disease outbreak; however as they age, they may converge in flammability because of accumulating litter loads. As the characteristic spatial scale of the system increases, so does the potential for catastrophic fire.*

In short indicators are only useful if we know something about the system we are trying to manage; what we are trying to avoid is causing the system to collapse due to the cumulative impacts of our management practices, as can occur with wildfire after years of fire suppression or with bark beetles perhaps in response to warmer weather and/or loss of a bird species critical to maintaining small insect populations (Holling, 1992b) or similar kinds of outcomes perhaps induced by conducting the traditional practice of maximum sustained yield resource management without due regard for prevailing natural processes (Holling et al., 2002a; Ludwig and Carpenter, 2002; Montgomery, 2003). Indicators by themselves do not provide assurances that we will manage sustainability. In fact, it might be argued that the problem of unsustainable resource management practices is much more dependent on the context in which we use the information to make decisions. It is about making predictions of the probable consequences of our management actions, with a search for and focus on consequences that have a large potential for reward or regret. Evidence, of whether we are practicing SFM or not, is in the decisions we make and in the reasons for why we took one course of action instead of another. Evidence is also provided on the basis of whether or not we learned enough from our management experience to avoid making the same mistakes over-and-over again (causing regret or opportunistically reaping rewards regardless of the consequences)[5].

Criteria For Successful Sustainable Forest Management

In addition to defining Sustainable Forest Management in a way that gives us a good sense of direction, the next challenge to be addressed is the design of a management process that pulls and pushes us in the right direction. It must be a simple, flexible, defensible, accountable, affordable, scalable (time and space), and integrated system of

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[4] Derived from Kijazi and Kant. 2003.

[5] See Montgomery, 2003 for an account of our repeated failure to act appropriately when it comes to the maintenance of Atlantic and Pacific Coast salmon fisheries. Montgomery also discusses the failure of maximum sustained yield as an effective means of conservation.

tree-, stand- and forest-level monitoring and management. These criteria for a well-designed process of management are further described below:

- A *simple* system of monitoring and management implies that the forest management objectives are clear, attainable and verifiable within the broad forest management landscape - that employees, shareholders and the public can easily understand what the objectives are, why they are in place and to what degree they are being met. Systems of management and monitoring that do not meet these criteria have a low chance of success because they lack focus, purpose and the sense that they can be fulfilled with any reasonable chance of success.

- A system is *flexible* if it can be used to easily produce indicators of success or failure that were not anticipated to begin with but have arisen as a result of new knowledge or concern. A flexible system means that data already collected can be easily accessed and compiled to obtain the new information required. This is a matter of design of both the system itself and the software used to implement it. If the data has not been collected, then the next best option is to enable its collection as part of a routine monitoring system without having to develop a whole new survey and assessment procedure for that particular attribute. This is a matter of designing an efficient and effective system for monitoring and management.

- A system is *defensible* if we can rationally and reliably gauge the consequences of obtaining success or failure, and such consequences are important in terms choosing between alternative forest management strategies and practices.

- It is critical that people be made *accountable* for their roles in achieving the monitoring and management objectives while conducting routine operations. Accountability involves learning from doing, learning to do it better the next time, and following through with the application of that new knowledge. Organizations as a whole are accountable for ensuring that they practice structured learning to avoid the occurrence of catastrophic events while continuing to reap substantial rewards.

- A system is *affordable* if the costs of obtaining the information necessary to make informed management decisions and the costs of carrying out subsequent management activities are compensated by the potential for reward or regret. In many situations it may be preferable to develop a better scientific understanding of costs and benefits associated with particular attributes (e.g. coarse woody debris) rather than implementing costly and unreliable systems for monitoring their levels of occurrence; this does not preclude the development of stand-level prescriptions to ensure that some minimum level of the attribute, say coarse woody debris, is left behind upon completion of forest management interventions. It does preclude the use of intensive surveys to obtain (highly variable) estimates of such attributes, particularly where there are no obvious thresholds to suggest that a change in forest practices would be required.

- A system of monitoring and management is *scalable* if very detailed local-level information can reasonably be extrapolated to make reliable broad-level inferences across entire landscapes, and vice-versa. In addition it is scalable if a range of reasonably possible future forest conditions can be predicted over relatively long periods of time. If the system is not scalable with respect to time or space then strategic direction will be out of alignment with reality and there will be no reliable means for reconciling the two.

- A system is *integrated* if trade-offs in achieving one or more objectives can be consistently weighed against the attainment of opposing sets of objectives. A common currency is required for weighing the relative importance of satisfying one objective to some degree versus another. In the first instance this is achieved by having the indicator integrated into a description of how the system functions so that its impact on how the system evolves with time can be used to determine thresholds that may cause the system to become very unstable. In the second instance it is recognition that when faced with a difficult choice, for example saving a life versus not doing so because it is potentially too expensive to do so, there is an implicit value placed on certain kinds of outcomes even if we do not like to talk about them in those terms. Finally the weighing of outcomes with respect to one set of indicators versus another may be encompassed within a social decision-making process, but this is not a substitute for more comprehensive understanding of system dynamics, nor for recognition of the implicit trade-offs that are made in protecting one set of values versus another.

What follows is an example of how an awareness of these criteria can be used in the process of developing indicators of "Old Growth" within any given landscape, and how that information might be used to make better management decisions.

Old Growth Indicators

Building on the work of others, Oliver (1981) derived the following stages of stand development (Oliver and Larson, 1990):

- *Stand initiation* – after disturbance, new individuals and species continue to appear for several years.

- *Stem exclusion* – after several years new individuals do not appear and some existing ones die. The surviving ones grow larger and express differences in height and diameter; first one species and then another may dominate the stand.

- *Understory reinitiation* – later forest floor herbs and shrubs and advanced regeneration again appear and survive in the understory, although they grow very little.

- *Old growth* – much later, overstory trees die in an irregular fashion, and some understory trees begin growing to the overstory.

This kind of a classification implies an orderly progression, but Oliver and Larson (1990) are quick to address this issue:

> *The term "old growth" has also been used to describe stands of specific structural characteristics, regardless of autogenic*[6] *or allogenic processes*[7] *which led to these structures. Structural features include large, living old trees; large, dead standing trees; relatively open canopy with foliage in many layers; and diverse overstories. Such structures are achieved by a variety of major and/or minor disturbance patterns in single- or mixed-species stands; therefore they do not represent a unique stage of forest development. In addition, stands of species which do not grow large or old or which decompose rapidly would never achieve the structural definition of old growth attributed to Douglas-firs (Franklin et al. 1981). The "structural" definition is more useful in describing stands inhabited by certain rare plants and animals, regardless of how these structures were attained. Through stand management, old growth structures can be created more quickly than through natural processes (Newton and Cole, 1987).*

Therefore "old growth" may be defined directly in relation to the occurrence of rare species or indirectly in terms of a constellation of structural features that maximize likelihood of occurrence of rare species. We may be prepared to increase the presence of such structural features in the landscape in an effort to increase the rare species' populations. If through knowledge of their natural histories we can develop causal relationships with the occurrence of certain structural features (i.e. integrate the knowledge into our descriptions of ecosystem processes), then we can be more certain that such a strategy will be effective. However if no such relationships can be found we might take a more passive approach to maintaining "old growth" by ensuring that there is adequate representation of a wide range of stand structures and associated attributes reasonably dispersed throughout the landscape. Under either of these scenarios monitoring the levels of "old growth" from a forest manager's perspective will not help to decide what changes in action are needed, unless clearly defined thresholds can be identified with clearly defined consequences should management direction remain unchanged (when crossing the thresholds). More research (information / knowledge) is needed before such a monitoring system could be designed to be effective in that role.

Kremsater et al. (2003) identify three dominant mechanisms for the protection of biodiversity:

- Ensure *representation of habitat types in a relatively unmanaged state* to ensure that little-known species are retained (some aspects of natural disturbances can be mimicked in managed stands, others cannot).

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[6] Changes in growing space caused by plant interactions.
[7] Changes caused by events external to the site.

- Identify the structure of stands and landscapes to ensure that the *key elements* are present through time (intermediate filter: Diverse structures lead to diverse habitats).

- Identify *indicator organisms* to track whether retaining structures and patterns, while addressing representation, will maintain species and populations whose life needs are well understood (fine-filter: This aims at species that are not accommodated in 1 and 2).

The focus of this discussion is on the identification of the structure of stands and landscapes to ensure that the *key elements* are present through time. Kremsater et al. (2003) go on to identify the following kinds of structural elements:

- *Standard elements*: These are separate elements. Their relations with organisms are most likely expressed through a critical single resource (e.g. large hollow snags for swifts) or in a habitat model combined with other elements (e.g. multiple regression models that integrate a set of habitat element into a single indicator).

- *Integrative habitat variables*: These structures may be less directly related to the needs of particular species, but help to maintain broader communities, or a greater richness of species (e.g. patchiness).

- *Landscape structures*: The problem with choosing landscape variables to monitor as a medium to coarse filter for biological diversity is that most variables are:

    - organism specific (e.g. "percent interior", or "connectivity").
    - not related to any organism in empirical studies.
    - lacking intuitive natural history basis (e.g. "fractal dimension").
    - unsupported by either empirical studies or intuitive natural history (e.g. "contagion").

- *Process variables*: Process variables are critical to any habitat projection model. Most of these variables also influence the amount of wood harvestable from trees (economic values) and nutrient cycling or long-term site productivity[8].

- *Indicator organisms* (idealized): To interpret landscape structure, we need to know species' responses to stand-level practices, time to "recovery" of suitable habitat in managed stands, organisms' ability to move through non-suitable habitat, and their movement distances. To identify these kinds of organisms we may use real landscape or idealized indicator organisms that represent a range of responses (linked to our understanding of natural history). These include:

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[8] I would highlight large landscape level processes such as fire and bark beetles as being most important for many interior forest conditions in British Columbia.

- effectiveness of VR (variable retention) in maintaining habitat quality (habitat defined for an idealized species),
- "recovery time" of disturbed habitat,
- effectiveness of VR and stand age on dispersal distances.
- utility of different types of unmanaged, non-harvestable stands for habitat or dispersal.

The first three kinds of variables described above are described in further detail in Table 2. "Old growth" seems to fit best with Kremsater et al's (2003) notion of *integrative variables*, albeit at a higher level of abstraction when compared with the variables in Table 2.

O'Hara et al. (1996) summarized ecological definitions of structure as follows:

> *Structure is an ecologically significant attribute of vegetation considered to have three major components (Kershaw 1964): (a) vertical structure; (b) horizontal structure; and (c) quantitative structure. Quantitative structure may be further specified according to life forms, floristics, or size class distributions (Mueller-Dombois and Ellenberg 1974). The distribution of life forms has been suggested as a fundamental axis to the co-existence of species and the organization of ecosystems (Cody 1986). Mueller-Dombois and Ellenberg (1974) state that structural similarities between communities provide a basis for the comparison of functions.*
>
> *We believe a structural vegetation classification based on stand development processes reflects fine- and coarse-grained processes that operate across stands and landscapes. At small scales such as the stand or patch level, a structural classification would be useful for creation of vegetation structures which meet specific resource management objectives. At larger spatial scales, a structural classification can serve as the basis for predicting and planning for vegetation change over time. Further, a simple classification with a small number of classes can reduce the complexity of landscape-scale modeling and planning …*

Kremsater et al's (2003) descriptions of standard elements and integrative habitat variables may be further aggregated for operational use by means of developing appropriate systems of classification. That is the main characteristics identified under the first two headings in Table 2 can be more broadly characterized within the following three primary systems of classification (there are two secondary systems of classification that are required to complete this framework)[9]:

- Stand structure
- Tree species group

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[9] The term secondary is used here to imply that the expected distribution in the occurrence of secondary classes of information can be modelled as a function of the primary classes of information.

- Site (productivity)

Each of these classifications can be used to characterize a wide variety of structural attributes (standard elements and integrative habitat variables) encompassing the range of variation in forested types. These classifications and associated attributes also provide the foundation for more detailed descriptions of ecosystem processes, that are, in turn, the basis for forecasting future forest conditions. To begin with it will help to introduce some operational definitions of classes so that this concept might be better understood.

The stand structure classification embodies similarities in the cumulative distributions of the live numbers of trees (and basal areas per hectare) with respect to decreases in diameter starting from the maximum diameter (Moss, 2003; Figure 1)[10]. The concept of tree species groups embodies the proportion of area occupied by a given species[11] (Moss, 2003b). Site classification embodies differences in biophysical features and provides the foundation for establishing boundaries between units of different productivity[12]. Differences in productivity are important for gauging the expected rate of change in stand structure and tree species characteristics. Patch[13] sizes and shapes can be identified using combinations of structure, site and tree species classes (at various levels of aggregation).

While many variables we may be interested in are not used directly in the development of the primary classifications, they will tend to exhibit distinct patterns of distribution with respect to different classes or combinations thereof either by accident or causation, including by design of management practices. Therefore, large, dead trees are more likely to occur where there are large live trees, either now (correlation in space) or in the future (correlation in time). As a result we may develop secondary systems of classification, say for characterization of different vegetation communities, and expect that the occurrence of these different communities can be explained to considerable extent when placed within the grid defined by intersection of the primary classes. For any given site, stand structure and tree species class only a small number of plant communities are expected to dominate. The final challenge is to anticipate how the

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[10] i.e. Cumulative distributions are built by starting with plot-level tree diameters and aggregating the number of trees per hectare (and basal area per hectare) within each plot as the diameter approaches zero. Stand structure classes are developed by minimizing within group variability in the cumulative distribution patterns, and maximizing the between group variability.

[11] This may be further refined to represent differences in the distribution of species with respect to decreases in diameter, thereby denoting further subdivisions of groups at the lower levels of stand structure classification.

[12] Note that the actual estimates of productivity, say site index, may be localized through the process of data collection.

[13] Vandermeer and Goldberg (2003) define *metapopulations* as follows: A population distributed in patches in which each of the patches is incapable of indefinitely maintaining a viable population alone (i.e. extinction probability > 0) but where the population is maintained over the whole collection of patches because migrants from occupied patches continually reoccupy patches in which populations have gone extinct. In this context the definition of a *patch* is organism specific. For trees a *gap* is equivalent to a *patch* in the context of gap (patch) dynamics that drive individual species mortality, regeneration, and growth dynamics.

primary classes are likely to change with time due to natural processes, with and without human interventions (this is discussed later).

The notion of idealized indicator organisms[14] is more explicitly a notion of classification – it reduces the overwhelming complexity of a large number of organisms to account for the occurrences or requirements of the complete set. The purpose of life form classification (Lignum Ltd. 2000) is to:

- Provide a means to measure and evaluate the potential impacts of forest management on biodiversity be measuring habitat requirements for vertebrate species groups.

- Promote greater understanding of species habitat requirements, and the interactions between habitat, biodiversity and timber production objectives.

- Provide information to model life form responses to management and project attributes through time to better reflect future forest conditions.

Gillingham (2003) defines “life forms” as follows:

> *Life forms are assemblages of wildlife species grouped together by similarities in breeding and feeding habitats and requirements. They are based on two commonly accepted wildlife analysis techniques, species priorization and guilding, and build on the work of Thomas (1979) and Brown (1985) as modified in the Plum Creek Habitat Conservation Plan (1995).*

The *association* of any species with various kinds and combinations of specific attributes can be reduced to a more general association with various combinations of stand structure, tree species, site and vegetation classes. The *requirement* of any species for various kinds and combinations of attributes can be reduced to a set of probabilities or expected frequencies of occurrence relative to the occurrences of stand structure, tree species, site and vegetation characteristics.

In summary we can reduce the whole system of interpretation down to a few categories of information that can then be used to characterize current and future landscape

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[14] This is identified under Kremsater et al’s 2nd mechanism for biodiversity protection and then arises again as the 3rd mechanism for protection. Under the 3rd heading they list six broad groups of forest dwelling organisms: 1) *vascular plants*, 2) *bryophytes*, 3) *lichens*, 4) *macro-fungi*, 5) *terrestrial vertebrates*, and 6) *invertebrates*. These are used for: 1) indicating presence or absence with time, 2) trends in populations with time, perhaps focussing on association of various species with structural characteristics, and 3) perhaps to indicate need for further investigation into natural history. There are a substantial number of organisms identified under these broad headings. The difference here is that in the first instance described above the organisms are idealized to address habitat requirements. In the second instance specific organisms are selected for observation in part on the basis that they can be reasonably easily identified, essentially as a broader based check to ensure that major pieces are not being put in jeopardy as a result of management practices. To begin with there are no particular thresholds assigned for the purpose of indicating the need for a change in management direction.

conditions. When constructing and using a system of this kind, care must be taken to avoid the common illusion of validity (Tversky and Kahneman, 1982):

> *… people often predict by selecting the outcome (for example, an occupation) that is most representative of the input (for example, the description of a person). The confidence they have in their prediction depends primarily on the degree of representativeness (that is on the quality of the match between the selected outcome and the input) with little or no regard for the factors that limit predictive accuracy. Thus, people express great confidence in the prediction that a person is a librarian when given a description of his personality, which matches the stereotype of librarians, even if the description is scanty, unreliable, or outdated. The unwarranted confidence which is produced by a good fit between the predicted outcome and the input information may be called the illusion of validity.*

The critical step is to maintain a system of monitoring plots so that we can update the occurrences of various attributes in association with various predefined classes alone and in combination. This is necessary to better understand the nature of evolving systems. With time and experience our predictions about how ecosystems are likely to change should become more reliable. However, we must always remain vigilant that we do not succumb to the “illusion of validity”.

As part of ongoing research it is necessary to maintain various wildlife species transects so that we can monitor the association of various wildlife species with various attributes and in the process learn more about their habitat uses and requirements. What is not required is that we assess every attribute, all the time, on every hectare of land we visit. What may be required is that we develop prescription guidelines around the kinds of attributes we would like to leave behind or create through management intervention. These guidelines would be best formulated in association with various combinations of stand structure, tree species, and site classification so as to meet a broader set of forest management objectives.

To sum it all up, complex series of attributes associated with ecosystem characteristics can be reduced substantially through the use of classification. For forested ecosystems these classifications are organized around the following kinds of information:

- Stand structure
- Tree species
- Site
- Non-tree vegetation
- Life forms

The class definitions may remain relatively stable over a long period of time, but the large number of attributes associated with various combinations of classes will change in an evolving system. To some extent the changes will be predictable and to some extent they will not. To accommodate the latter it is preferred that there is a monitoring system with a sufficient number of observations that we can adjust from time-to-time for biases in our predictions, and so that we can improve our ability to make forecasts of future forest conditions. While structural features are important to the evaluation of landscape conditions, they are of little use unless we can integrate them into our understanding of how ecosystem processes drive changes in forest characteristics. Some processes are more important than others in terms of their potential for impact. Our understanding of how ecosystems change with time should begin by focussing on those that we consider most important. As we become more efficient at mitigating the extreme effects of designated ecosystem processes, it is inevitable that new processes will emerge as being important and will be deserving of our attention in the effort to obtain desired future forest conditions.

We can be more effective in forest management if we start by reducing the overwhelming complexity of ecosystems down to a much smaller number of class variables. At the stand level we can act on more specific attributes to alter the distributions of forest-level attributes relative to the intersection of pre-defined classes. With an effective monitoring program we can assess the impacts of these decisions on forest-level characteristics, by observing the change in the complex set of attributes on the ground and through aerial surveillance. To the extent possible the class definitions should remain consistent with time, even though attributes associated with such classes may be changing.

The remainder of this discussion attempts to lend further clarity to these generalities by focussing on a specific issue: stand structure classification and it’s use in answering the question, how much “old growth” do we need?

Characterizing Stands, Sites and Tree Species in the Cariboo

In British Columbia the definitions of “old growth” vary in accordance with the scale of observation, which is not consistent with the need for a scalable monitoring and management system as outlined above. At the landscape scale, “old” is usually defined relative to stand age, but at a finer level of detail, attempts have been made to define “old” relative to a list of structural attributes that in many cases parallel those outlined in Table 2. The end result of this process is that the estimated amount of “old” stands at the landscape level is a poor reflection of what actually exists on the ground based on structural definitions.

A simple way of reconciling the structural definitions with age definitions would involve undertaking a random sample of a sub-population of stands to determine what proportion of each age class is indeed old. However there are some challenges in doing this effectively. To begin with, “old growth” assessment procedures are often complex and introduce a high degree of subjectivity, with the result that such exercises can be costly and somewhat unreliable without a large number of samples, and without two or more independent assessors to develop reliable estimates. Secondly, “old growth” is only one of many features that forest managers are charged with trying to maintain at certain levels or create anew. If for each and every issue we were to develop a separate sampling procedure, the costs of sample establishment and monitoring would become far too expensive. A simpler approach is recommended and available through stand structure, site and tree species classifications along with some consideration for ecosystem dynamics.

Stand Structure Classification

A quantitative system of stand structure classification was developed recently for application to the Lignum Innovative Forest Management Agreement Area (IFPA) in the vicinity of Williams Lake in central British Columbia (Moss, 2003; Farnden et al., 2003). The classification is implemented with respect to the observed numbers of live trees per hectare by diameter class relative to a set of distinct individual class distributions. Once a classification has been assigned it can be used to infer conditions related to a much larger number of related attributes (e.g. clumpiness[15] with respect to horizontal arrangement of trees, numbers of dead trees by diameter class, etc.). Unlike most other attempts at stand structure classification, no effort was made to link structure with the process of development; this is consistent with the notion that development pathways are not as orderly as we once thought them to be.

The Lignum Limited classification is based on the identification of 17 groups. This number was selected to increase the precision of inferences with respect to characterizing stand structure similarities, while at the same time not making them so precise that stand structures would be difficult to distinguish from one another in the field without establishing plots (which are expensive, but this does not preclude establishment of plots to gain further precision in estimating the numbers of trees per hectare by diameter). The quantitative aspect of this classification means that tree diameters can be measured within new plots and the cumulative distributions of the basal area per hectare and trees per hectare can then be compared with the original set of plots used to build the classification (Figure 1) to determine which class the new plots belong to. This procedure may be extended to classifying the average stand condition derived from a collection of plots, as well as characterizing the within stand variation, once again with reference to each of the individual plots therein. As a result, there is a certain level of objectivity added to the process of classification, because of the quantitative procedures used to minimize within group variability and the fact that these procedures can be extended to correctly classify new plots or stands. Of course subjectivity enters into the procedure in terms of the number of groups that were defined (17 in this instance), and when applying the procedures starting with delineation of different stands. Other tools are available to assist in the process of classification, including a dichotomous key, and references to ground and aerial photo's representing archetypal examples of each structure, perhaps in combination with differences in tree species composition.

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[15] A reliable estimate of clumpiness within a stand can be calculated using plot level statistics (basal area per hectare and numbers of trees per hectare) expressed in terms of the coefficient of variation. The higher the coefficient of variation, the more clumpy the distribution.

In terms of potential for future improvement, it would be useful to extend the classification to account for differences in the crown positions of various tree species. The initial decision to deal with differences in the distributions of numbers of trees with respect to tree size and independent of tree species was to ensure that structural classes could be inferred easily across a wide variety of species compositions. If species were allowed to enter into the determination of stand structure at the top end of the classification hierarchy, the classification would have been cumbersome to use and more limited in its domain of application.

Stand structure classification is useful at a variety of scales and for a variety of purposes as described by O'Hara et al. (1996). It provides the vehicle for scaling up observations from individual tree levels of detail to patch and stand levels of observation; these can in turn be aggregated to represent entire landscapes. After developing the initial classification, Moss (2003c) developed a method for rescaling plot-level stand structure classification to the characterization of roughly 600,000 hectares in the Lignum IFPA inventory. In the process of doing this work, allowance had to be made for the fact that variation in stand structure classification at the polygon-level of detail would increase relative to the original classification. By providing for this increase in variability the link from tree-to-stand-to-landscape-to-forest level statistics can be made more reliable and consistent (Moss, 2003c). This includes the ability to make inferences about a large number of attributes beyond just those used in defining the classification itself, because underlying both the original (plot level) and inventory level classifications are plots that are uniquely assigned to one class or another and that describe a large number of other tree characteristics (e.g. pathological remarks, live crown, spatial distributions by means of stem mapping, etc.) as well as associated site and non-tree vegetation characteristics.

Tree Species Group Classification

Tree species obtain a special status in forested landscapes as being distinct from other kinds of biota. This occurs because trees are dominant features in most forested landscapes, and humans have considerable control over how many trees of what kind are or will be present in the landscape. Insofar as tree species and sizes change with time, there is interest in understanding how these are likely to affect changes in the rest of the ecosystem. This is not to deny the influence of other species on tree development patterns; it is simply to state that the dominant first order impacts of forestry, beyond building and maintaining roads and landings, is the decision as to which trees and stands are cut and which trees and stands are planted, and how. These decisions affect what other kinds of vegetation will occupy the site through time as a result, and they affect wildlife species habitat availability. Once again, a classification with respect to tree species composition is useful for reducing the complexity of species occurrences down to manageable proportions so that we have a general procedure for characterizing stand conditions.

Site Classification

In British Columbia the methods most commonly used in forest site classification were derived from the work of Krajina (1969). It is based on the notion that vegetation progresses toward a relatively stable climax in the absence of large-scale high intensity disturbances. Climax stands can be recognized where overstory species are regenerated in the understory so that the stand has seemingly become self-replacing with time (it has been found on some instances that understory trees are the same age as overstory trees with the end result that notion of "climax stands" has been discredited according to current thinking on the topic). Differences in plant associations along a transect can be ascribed to differences in soil moisture and nutrient regimes. Differences between transects across broader geographic regions, can be characterized by climax plant associations occurring in mid-slope positions that are moderately well-drained; difference between such "average" conditions are used to delineate larger scale differences in broad climatic conditions. These latter differences reflect differences in Biogeoclimatic zones, subzones and variants. The factors that influence these differences are the same factors that drive differences in site productivity.

This system of classification has served forestry professionals well, in spite of the many conceptual and practical deficiencies that have come to be recognized with time[16]. The idea that dynamics are driven by an interaction of plant, soil, terrain, topography, and climatic factors is reasonable enough. The primary role of site classification is to account for differences in soil, terrain and topographic features. Site classification is primarily for the purpose of reducing the complexity of site characteristics down to a manageable number while enabling inferences with respect to the occurrence of a much larger suite of attributes. Site classification is a fundamental component of the inventory, in the same ways that tree species and stand structure classification are.

Stand Dynamics

It is important to be able to forecast future stand conditions – stand structures change with time. Stand dynamics can be reasonably portrayed using standard growth and yield modelling techniques. For stands that consist of a variety of tree species and diameters, individual tree models are useful for estimating changes in stand structure starting with a particular set of initial conditions. In the inventory framework described above, the inputs to such models come from plots that are characterized in terms of the inventory-level stand structures as well as the species groups that they belong to. Each individual plot can be projected forward through time to estimate increases in various tree dimensions, mortality due to competition and perhaps senescence, as well as the numbers of trees that become newly established through the process of regeneration. Changes in the expected stand development pattern caused by stand-level interventions due to treatment or natural disturbances can also be modelled.

The ability to forecast future forest conditions with enough detail to characterize changes in stand structure and species composition, is critical to the development of any strategic plan. The decisions that we make today have a ripple effect on what the forest will look like tomorrow and beyond. In other words we will be living with the results for a long time; just what those are likely to be encourages us to making some kind of a forecast of probable outcomes. For example, in the case of protecting "old growth" we are constrained by the fact that it will disappear if we simply try to protect what is left

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[16] For some of these concerns see O'Hara (1996).

without recruiting new stands to fit with our definitions. We must have a compatible set of tools for forecasting how much old growth there is likely to be in the future and where it is likely to occur, meeting the second half of the requirement for *scalability* described above. The stand structure classification provides the basic information necessary for making such forecasts, along with additional information on tree species composition and site productivity (e.g. site index).

Any system of forest and stand management and monitoring that cannot be adequately scaled to represent broader spatial and temporal aspects of forests and landscapes will produce less reliable representations of reality. In such situations we generally use different kinds of information to represent different scales of observation. As a result the chances of making misdirected management decisions are increased.

Landscape Dynamics

Our pictures of forest and stand dynamics can be refined by incorporating more realistic descriptions of dominant ecosystem processes such as fire and bark beetles, these being processes that we can influence through management practice. The goal is to reduce the cumulative impacts of our practices with respect to the potential for occurrence of catastrophic or significant events over relatively long periods of time. Making better estimates of stand structure attributes can increase the detail used to describe those impacts. It is often the case that landscape level processes leave behind at least some structures from the “old” forest. These form the basis for the establishment of “new” stands with or without management intervention. Stand structures interact with both natural and human induced ecosystem processes to manifest future forest conditions. Our goal is to guide the processes toward more favourable outcomes - to steer them away from those that are less desirable.

How Much Old Is In The Cariboo

Given that there are 17 stand structure classes in the Lignum system of classification, let us assume that stand structure classes 11 to 17 can be used to represent “old growth” conditions in both the inventory and on the ground. The prototype stand structure guide (Farnden et al. 2003.) describes class 11 as follows:

> *Description*
>
> *Stand structure class 11 stands are predominantly even-aged, with most of their basal areas in trees in the 25 to 60+ dbh range. Basal areas generally exceed 40 m^2/ha, but lower values may be possible.*
>
> *Top heights for pine are greater than 22 m, for spruce greater than 23 m and for Douglas-fir greater than 25 m. Stands in this class will have full canopies, although some gaps may be starting to form. Pine stands in this class will be quite old, but spruce and Douglas-fir stands may still be quite vigorous, particularly on good sites.*
>
> *Development Patterns*

> *This class encompasses all of the oldest even-aged stands. Stands grow into structure class 11 from class 10. Stands in class 11 may still be self-thinning, particularly vigorous Douglas-fir stands on good sites, but more typically the primary cause of tree mortality will have shifted to stochastic insect and disease losses. Without further large scale disturbance stands will start to progress into 12, 13, 14, 15 and 16 as the canopy breaks up and growing space is re-occupied by trees growing up from below. With major losses of large trees, such as a major bark beetle disturbance, trees will move into the lower number classes (12, 13 and 14). With more gradual break-up of the canopy, stands will move into classes 15 and 16.*
>
> *Predominant crown ratios may be highly varied, ranging from 30 to 70%.*

Other classes are described in a similar format. For the purpose of describing "old" the plots underlying this classification could be further investigated to determine the presence or absence of a larger number of characteristics. Estimates could be made of the proportion of area in each class that are likely to meet more stringent criteria for defining old growth. It must be recognized there are diminishing returns from such an exercise that applies an increasing number of constraints to the classification of "old growth"; as the number of constraints and severity of constraints increase it will become increasing difficult to find stands that meet such criteria under any event – pre-European or otherwise. What is much more important than adding and tightening constraints is how we manage within a stand structure class so that with time stands and landscapes will develop the frequencies and co-occurrences of characteristics we would like to see.

Figure 2 describes the distribution of stand structures by age and stand structure class for leading lodgepole pine and Douglas-fir stands[17] in the Lignum inventory. The x-axis represents the age class in multiples of 10 so that "1" indicates an age ranging from 10 to 19. The y-axis represents the area in inventory associated with age and structure class combinations. According to the structural definition of old described above, inventory polygon age assignments do not provide a good indicator, albeit the proportions of old do increase with increasing age (Figure 3). For Douglas-fir leading stands a total of 52.2% of the area satisfies the criteria of old, whereas for lodgepole pine stands only 17.7% satisfies this criteria. This may be caused by two factors:

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[17] For the purposes of discussion herein we are assuming that the stand structure descriptions in the field guide (based on plot level classification) are identical with the description of the stand structures in the inventory (based on polygon level information) which as mentioned above is approximately correct but not true using strict definitions. A broader interpretation applies to the inventory due to the within stand or polygon variability. Part of the reason for this discrepancy is that the polygons were not delineated with respect to the classification to begin with. Another reason is that if they were delineated with the classification in mind there would have been a large number of polygons. The cost of redoing a photo-based inventory is directly proportional to the number of polygons and the kilometres of line used to distinguish between polygons (Moss and Reimer, 1999). Therefore, it is preferred that some within polygon variability be accepted to avoid diminishing returns from producing an ever smaller size and larger number of polygons.

- Lodgepole pine stands may be less likely to meet the requirements for the structural based definition of "old" because of the high proportion of poor sites and/or repressed stands (due to dense, uniform regeneration that occurs after wildfire and perhaps to a lesser extent due to logging), and because the species tends to be shorter lived due to the impacts of bark beetles and fire.

- Selection logging has been used in Douglas-fir stands, whereas clearcutting is the dominant practice in lodgepole pine, as indicated by the much greater proportion of stands in inventory structure class 1 (Figure 4).

This discussion clearly demonstrates the advantage of using structural definitions rather than age-based definitions for defining "old growth". Firstly stand age is an ill-defined concept when we consider the variety of stand structures that exist in the landscape. It is difficult to manage for stand age if treatment regimes involve anything other than clearcutting and even-aged management, whereas we have a much larger number of options when it comes to managing for structure.

The stand structure classification provides just enough information to provide: a) a reliable (necessary and sufficient) description of what can be said to constitute "old", b) an estimate of the amount of "old" in the inventory, c) a means of verifying whether if the indicated "old" stands actually occur where the inventory says it should, and c) a basis for upgrading the inventory based on ground observations, thereby forming the foundation for adaptive forest management. In this process operational activities can be conducted in such a way that it can be verified whether or not strategic level objectives are being met and to what degree; the results can be reflected through inventory updates and these in turn can be incorporated into further consideration of the preferred strategic directions.

Changes in stand structure can be forecast using individual tree growth projection models, so that forest management activities can be directed today for the purpose of producing desired outcomes tomorrow. The chances of succeeding in this endeavour are improved when compared with the situation where this dos not hold true.

A more complex set of old growth assessment procedures would increase the amount of detail required to reconcile inventory with ground conditions with diminishing returns to forest managers. Provided that old trees are allowed to die and rot without being harvested, and that other components such as lichens can be maintained with appropriate harvesting prescriptions, there is no need to account for these activities at the forest-level beyond recording a condensed version of the prescription (treatment regimen) and where and when it was applied. The development of management regimen is useful in this case to capture the dominant prescriptions or guidelines that are being applied. If every exception is to be recorded, given that no two prescriptions are alike, or at the very least, no two applications of the same prescription are alike (see Gadow and Hui. 1999. Pp 121 to 128), forest managers will once again find themselves not being able to see the forest for the trees when it comes time to interpreting the cumulative impacts of their practices.

The impacts of forest practices should be monitored on a broad scale rather than focussing on gathering detailed information from individual harvest units and subdivisions thereof. It is the cumulative impacts of forest management practices that we are most concerned about, not the effects of each specific decision[18]. Hence many desired characteristics of "old growth" can be taken care of at the stand level of management, provided that the dominant characteristics required for "old growth" are handled at the landscape level of management. The stand structure classification provides a framework for doing both of this.

How Much Old Growth Is Enough?

There are two dominant ways to determine how much old growth is needed:

- Determine the apparent range of natural variation and manage landscapes within that range accordingly.
- Use knowledge of species' natural history to estimate how much area is required to maintain viable populations, perhaps filtered through a process of life form classification.

In both cases the stand structure classification provides a useful basis for patch definition. Patches have certain features such as size, shape, distribution, interior qualities, etc. A patch may be defined as any continuous feature belonging to the same stand structure class, and may be further modified by other restrictions such as, "of the same tree species group". In our picture of forest dynamics patches will be created, coalesce, be broken apart through random effects, and so on. The factors driving these changes are many, but to begin with the focus might be on stand dynamic factors (growth, mortality, competition, regeneration), impacts of landscape level factors (wild fire, bark beetles)[19] with consideration of random events to account for remaining factors. Figure 5 provides a more detailed description of how stand structure classification can be utilized to determine the apparent range of natural variability. The same kind of logic can be extended to evaluate species habitat availability based on knowledge of species' requirements.

Conclusion

This paper began with an over-view of sustainability. Sustainability means different things to different people. It is important to clarify that meaning if the concept is to become the basis for good forest management. Fundamentally it is about finding social, economic and environmental boundaries that if breached in the short-term have a reasonable likelihood of significant negative impacts in the future. It is then about

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[18] Of course there are exceptions to this, for example where we are trying to maintain or enhance a small fragment of last remaining habitat, but what we are trying to avoid by managing cumulative effects is the need to resort to this kind of "last ditch" effort.

[19] There are a wide variety of factors. Since it is difficult to focus on all of them at the same time, a choice has to be made to begin with as to those that are most important.

designing forest management practices so that we maintain forests in such a way that avoids such thresholds, perhaps with some margin of safety[20].

In the next section we discussed the production of indicators of sustainability. There is a propensity of the list to grow to unmanageable size because ecosystems are complex and therefore the potential numbers of boundaries that might cause adverse impacts looms large. Very quickly the number of indicators that must be managed becomes unmanageable. The concerns represented by each one of them might well be justified but the thresholds for obtaining sustainability and the cumulative effects of violating such thresholds are usually not understood well enough to motivate managers to do anything differently. For these items we need more research to better appreciate their role in ecosystem processes. Where we need to focus more of our attention is on processes and outcomes that dramatically alter the landscapes we are trying to manage and that have significant repercussions as a result. This section concluded with a list of criteria for meaningful indicators as follows:

- Simple
- Flexible
- Defensible
- Accountable
- Affordable
- Integrated

The topic of "old growth" was raised to provide a more detailed discussion about indicators and their role in forest management. Concepts about what "old growth" is and what indicators are needed to manage it were introduced as a matter of legitimate concern with regard to managing for sustainability. This topic was also used to illustrate the propensity toward producing large numbers of specific attributes that are deemed as necessary determinants of whether or not a give condition truly represents "old growth". In many cases the indicators are further promoted as a means for discerning trends, but there is limited understanding of what we should do with such information once we have it. Again, and without wanting to discredit such concerns, it was argued that these complex measures could be avoided by organizing the inventory around 5 systems of classification as follows:

- Stand structure
- Tree species

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[20] This concept can be carried too far. While margins of safety seem prudent, they can also result in lost opportunities to realize certain benefits or create other problems that have not yet been anticipated.

- Site
- Non-tree vegetation
- Life forms

Taking this one step further we then focussed on stand structure classification. The Lignum Limited system of stand structure classification was introduced. The classification is quantitative, meaning that the classification was built from actual plot data rather than by means of drawing pictures and providing verbal descriptions that lead to classification that are open to wide-interpretation and therefore lacking in consistency of application. When combined with the remaining systems of classification a basis is established for making reasonably reliable inferences about the occurrence of a much more detailed list of attributes in the inventory. The assertion that it is possible to do so is based in part on the methods and results of using known plot-level stand structures to make inferences about polygon-level stand structure characteristics. Similar kinds of extrapolations have made using predictive ecosystem mapping (PEM; Resources Inventory Committee, 1999) in British Columbia. The assertion is also based on the knowledge that individual tree growth models can project the plot-level data used to underwrite development of the stand structure classification, thereby enabling the forecasting of future forest conditions.

The projections of stand structure across space can be easily verified through field visits, and corrected in the inventory as required without the need for establishing additional plots (which are expensive), but with the ability to do so if added precision is required. The projections of stand structures and the inventory as whole through time can also be checked, with a plot-level monitoring system wherein the plots are established based on statistical sample of a well- defined population of stands, and where such plots are re-measured periodically. It was argued that to have an effective monitoring and management system it is critical that the description of any class remains consistent with respect to what is interpreted in the inventory and what is interpreted on the ground, otherwise it is quite likely that strategic plans will establish management directions that either can’t be implemented in reality or can be, but with little chance of success in producing the desired forest-level outcomes.

This discussion was followed by a comparison of “old growth” in the Lignum inventory using age based versus stand structure definitions. While it was observed that as the inventory age class increases, the proportion of old according to structural definitions also increases, it was pointed out that they are two very different things. It was argued that age provides a poor means for assessing “old”; it is a questionable statistic for representing anything other than very even-aged stands and it can’t be used to reflect the benefits of management practices that result in stands that have more “old” characteristics. The discrepancy in the amount of old based on the two different definitions provides an indication of how plans formulated according to one definition (i.e. age) can be misdirected when compared with another (i.e. structure). A shortage of old may be deemed when in fact none exists.

The question was raised as to, “How much “old” do we need?” While no specific answer was given to this question, two methods were described as to how this could be estimated based on natural disturbance philosophy or the use of life form classification. It is important that such questions be addressed if the indicator is to be of any use in management decision-making. These methods could be used alone or in combination. The approach using natural disturbance is interesting because it places the problem in a dynamic context. The same process can be used to develop management strategies in an effort to mitigate catastrophic effects of landscape-level processes in combination with the application of alternative sets of management regimes. In taking this approach managers are advised to continue to gain a better understanding of ecosystem patterns and processes. Over long periods of time, it is clear that by solving one set of problems (e.g. the occurrence of fire using fire suppression) others can be created (e.g. less frequent fires tend to be larger and/or more favourable conditions are created for a catastrophic outbreak of bark beetles). There is a need to have one eye on the road to continue in the right direction we are headed and one eye on the ditch to make sure we don’t drive into it.

What makes this whole process worth considering is that the principles of classification, inventory monitoring and management, and strategic planning and implementation described herein have a general application that goes well beyond the discussion of “old growth” or habitat assessment. The same system applies to better scheduling of harvests, for example to ensure that each stand cut produces the maximum return on capital invested and that harvest scheduling is done to deliver the best products possible based on market demand (e.g. in low pulp markets, stands are selected with a higher sawlog component). It applies to making reasonably reliable estimates of standing stocks of carbon and the rate at which incremental carbon is accrued, perhaps for the purpose of selling carbon credits. It applies to forecasting watershed dynamics and developing pictures of the visual quality impacts of harvesting. As already mentioned it applies to the development of better estimates for assessing the risks and hazards associated with fire, bark beetles, windthrow, root rots, etc.

As world population continues to grow the demands on earths resources will increase, not withstanding that the impacts of those demands will be mitigated somewhat through product substitution and technological development. Unfortunately there are no substitutes for much of what nature has to offer, nor should we count on them in the future. No matter how hard we try to preserve nature, change will occur - some for the better and some for the worse. We should continue to engage with nature by making use of her resources, but we should make every effort to learn more about the consequences. We must come to terms with the cumulative impacts of our practices over large areas and long periods of time if we are to avoid large scale and sometimes, irreversible impacts on our own ability to maintain a reasonable sense of wellbeing. The question that we have tried to address is not about whether we should address these kinds of issues; rather it is about how should we go about it? This paper is intended to point in a direction that will improve our chances of success and that is within our means to implement. The social, economic and environmental systems that we are trying to manage are complex. We must not be too complacent about how far we have come or about how far we have to go, and at the same time we must learn to walk before we can run.

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Table 1. Criteria and general description of indicators for SFM (CCFM, 2000)[1].

Criteria	Element	Description
Conservation and Biological Diversity	Ecosystem diversity	Representation of forest types in protected areas.
	Species diversity	Indicators of species diversity
	Genetic diversity	In/ex situ conservation strategy for commercial and endangered species
Ecosystem Condition and Productivity	Disturbance and stress	Anthropogenic disturbance and stress
	Ecosystem resilience	Indicators of ecosystem resilience
	Extant biomass	Indicator species, MAI
Soil and Water Conservation	Physical environmental factors	Water quality, dynamics of aquatic fauna
	Policy and protection factors	Best practice guidelines, policy statements
Global Ecological Cycles	Global carbon budget	Local estimates, budgets
	Forest land conversion	
	Carbon dioxide conservation	Energy conservation, forest industry emissions
	Policy factors	Forest inventories, policy statements
	Hydrological cycles	The impact of forest practices
Multiple Benefits	Productive capacity	Sustainability trends/depletion of non-timber resources
	Competitiveness	Profitability, markets, R&D, innovation
	Contribution to economy	Contribution of non-timber products/values
	Non-timber values	Optimal utilization/sustainability

Table 1. continued.

Criteria	Element	Description
Society’s Responsibility	Aboriginal and treaty rights	
	Participation by Aboriginal communities	Guidelines, terms of reference & policy statements to aid and ensure commitment, define roles and reduce risk
	Sustainability of forest communities	“
	Fair and effective decision-making	“
	Informed decision making	Public involvement in the design of the decision making process Mutual learning, public education, R&D; multi-resource inventories.

Table 2. Habitat and landscape structures (derived from Kremsater et al. 2003).

Standard elements	**Integrative habitat variables (habitat structures)**	**Landscape Structures**
Live trees: species, dbh, height, height of live crown (used to define vertical structure), trunk breaks, and visible disease or pathogens.	Vertical structural diversity: forbs, shrubs and trees.	Tracking variables: distribution of patch age and size classes, edge-contrast length and interior, road densities and distribution.
Snags(standing dead trees): dbh, height, decay class and top breakage.	Horizontal patchiness of other elements: biological richness = f(heterogeneity). Canopy gaps, dense patches of trees and internal soft edges.	Dynamic Aspects:
Coarse woody debris: species, size, decay class (need for projection models).	Special ecosystem types within stands: Particular site types enhance diversity of surrounding stand – small wetlands, headwater streams, seepage areas, small landslide areas, etc.	
Canopy: cover, depth, and composition.	Representation of site series within stands: (BC specific – species occurrence = f(site series).	
Shrubs: cover and composition.		
Ground cover layers: cover, height/depth and composition of forb, moss/lichen, litter/duff and inorganic layers.		

Figures

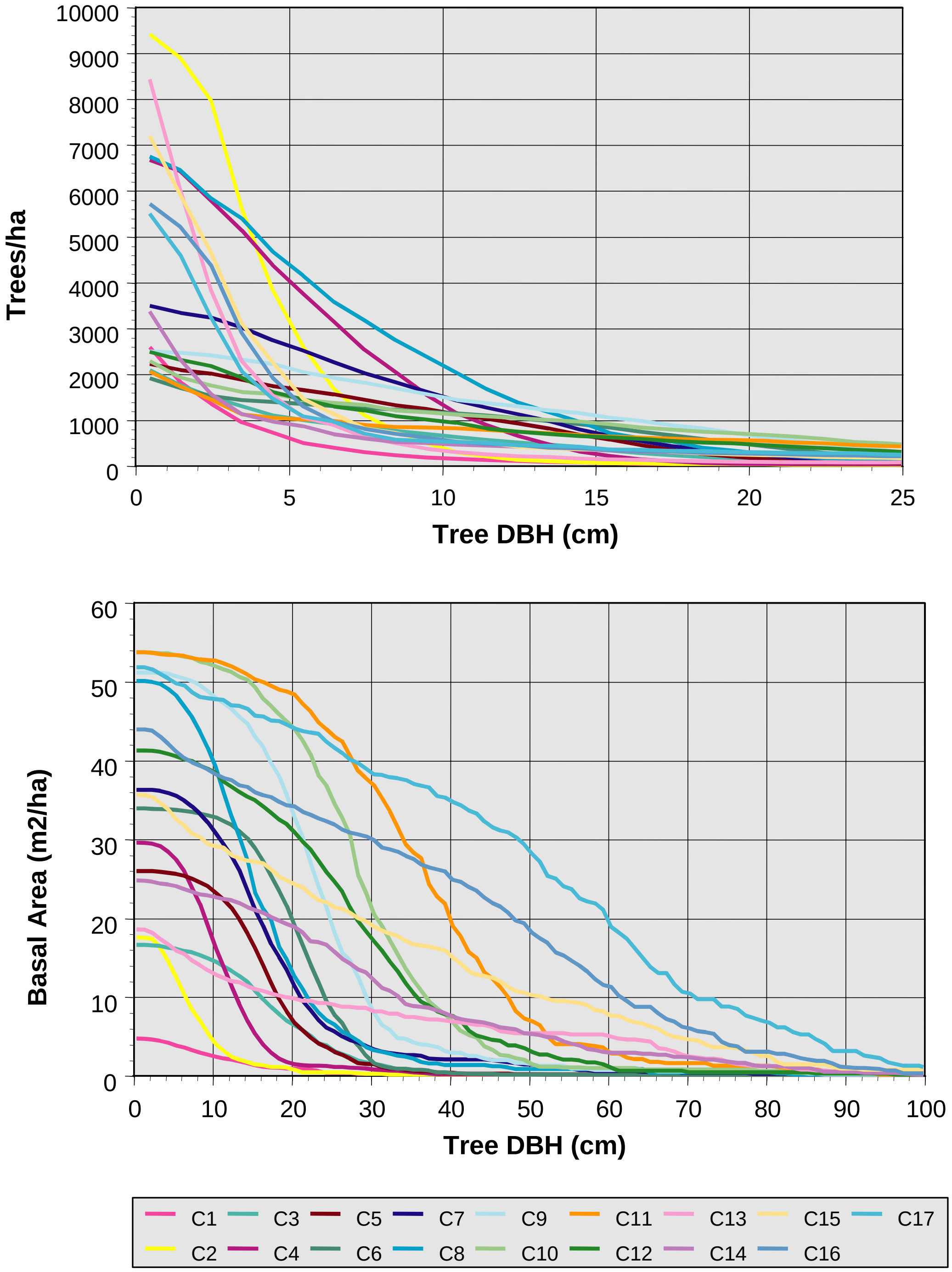

Figure 1. Average cumulative distributions of trees per hectare and basal area per hectare for 17 stand structure classes. Derived from 422 plots representing a wide variety of stands dominated by Douglas-fir and lodgepole pine. Classes 1 to 11 conform with stands that have a relatively narrow diameter distribution (with respect to the mean), conventionally referred to as “even aged”. Classes 13 to 17 correspond with stands conventionally referred to as “uneven-aged”. Class 12 is intermediate between the two.

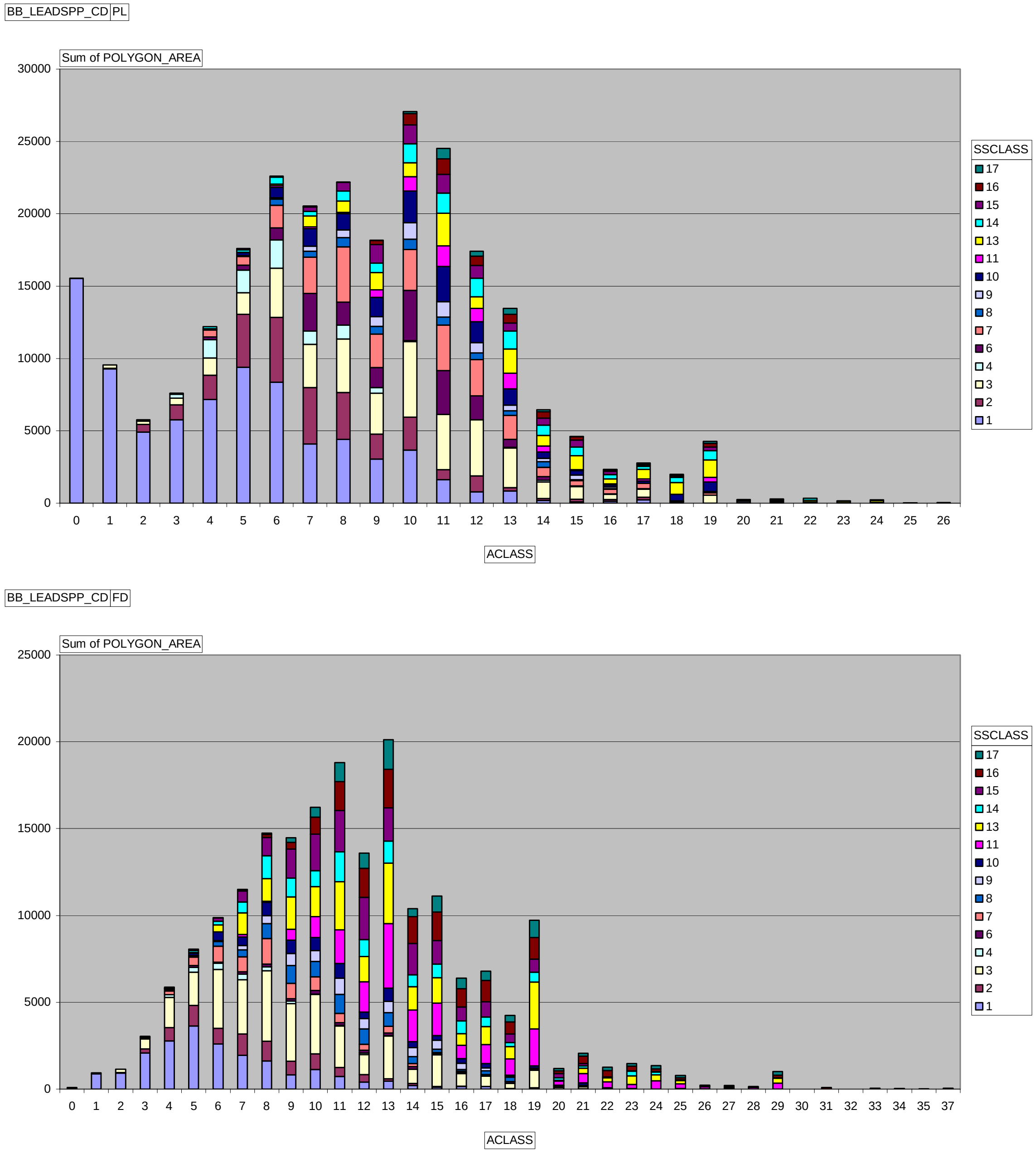

Figure 2. A comparison of the area (hectares) in each age class (x-axis, e.g. "1" includes ages 10 to 19) and stand structure (legend) class for leading species lodgepole pine (top graph; 258,107 ha.) and Douglas-fir (bottom graph; 197,159 ha.) stands in the Lignum inventory (530,998 forested hectares including lands that are adjacent to, but outside of the IFPA).

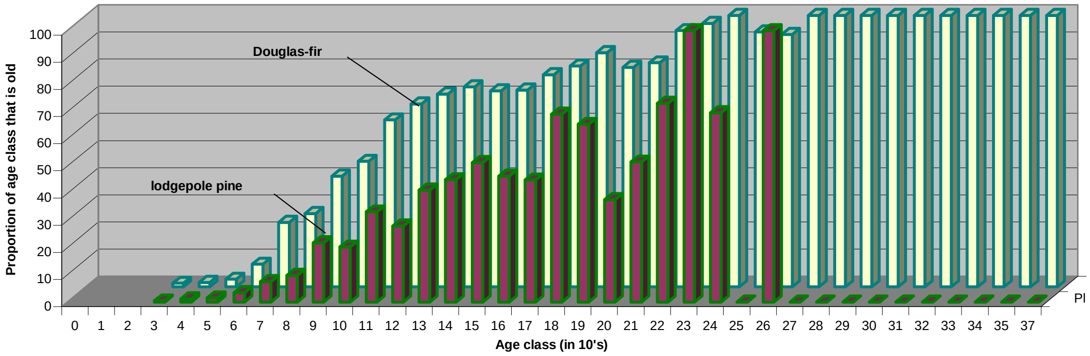

Figure 3. The proportion of each age class satisfying the criteria for “old growth” for leading species lodgepole pine and Douglas-fir stands in the Lignum inventory based on the requirement to be in stand structure classes 11 to 17, inclusive.

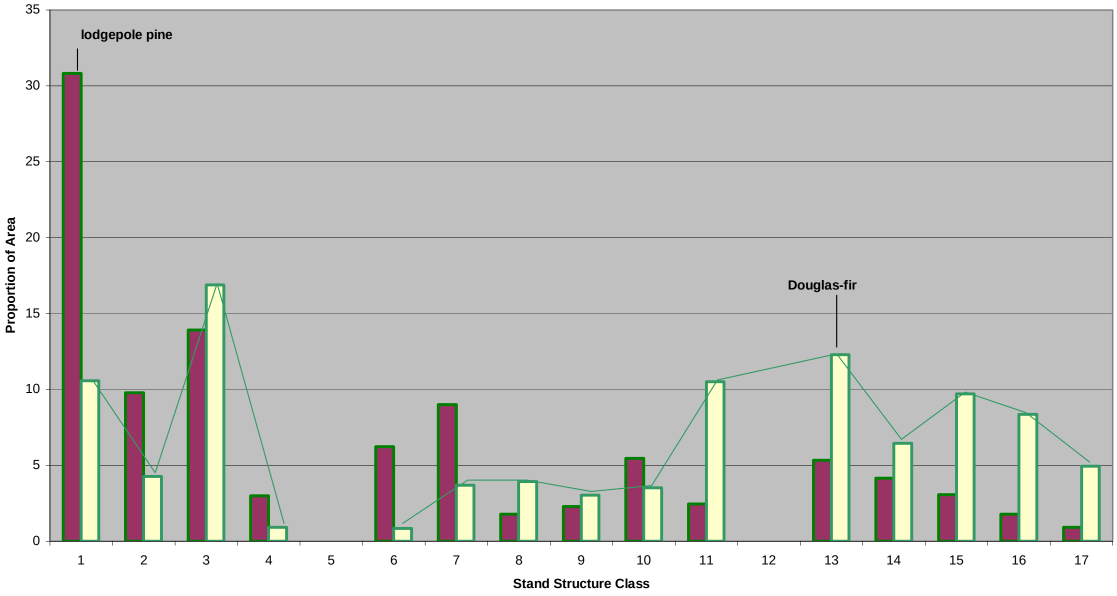

Figure 4. The total area in each stand structure class expressed as a proportion of the total occupied by each of the leading species in the Lignum inventory. Douglas-fir has a greater proportion in stand structures 11 to 17, while lodgepole pine has greater proportions in classes 1, 2, 4, 6, 7 and 10. Classes 5 and 12 in the original classification are empty in the inventory stand structure assignments as a result of the process used to scale up from plot- to polygon-level detail. Inventory assignments represent a complex of plot-level assignments, but are labelled with a single number keep it simple. In proportion to the total area of leading species lodgepole pine stands, “old growth” occupies 17.7% of the area. For Douglas-fir the figure is 52.2% of the area.

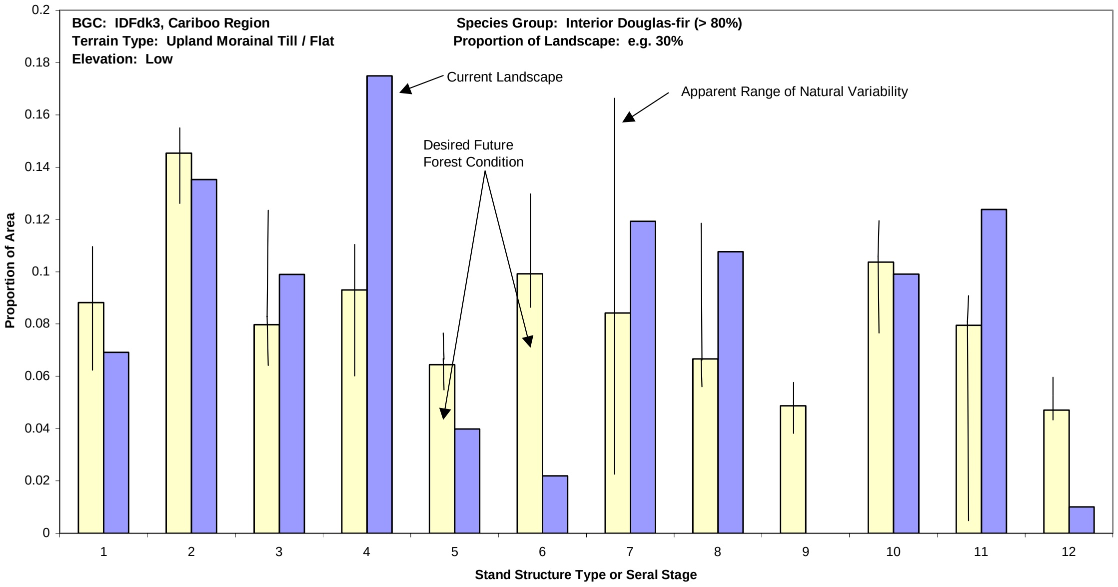

Figure 5. Managing within the apparent range of natural variability – a schematic diagram. The landscape unit is portrayed as a low elevation, upland morainal till portion of the IDFdk3 of the Cariboo Region currently dominated by Douglas-fir. The blue bars represent the condition of the current landscape, providing the same kind of information provided in Figure 4 (that is based on real data). The yellow bars portray something different. Landscape dynamics are simulated with consideration for stand dynamics and fire (for example) in a stochastic simulator. Fire regimes models are calibrated at first to reflect estimates of the frequency (average fire return intervals), intensity and severity of fires observed historically (see Cumming and Wong, 2002). After running perhaps a 100 simulations without consideration for human intervention and for periods extending until a dynamic equilibrium becomes apparent, the average distribution of stand structures is described by the height of the yellow bars and the range of variation in those distributions is characterized by the thin lines passing through the centre of each yellow bar. The interaction of ecosystem processes with tree, stand and landscape level features and the characterization of the reasonably probable outcomes derived from these interactions is much enriched by the use of stand structure classification. In the process other information such as the amount of dead wood, the speed with which it decays, falls to the ground, and continues to rot, the establishment of non-tree vegetation can ultimately be integrated into the process to provide more detail. Other information about patch size, shape and distribution, complexity of landscapes, etc., can also be incorporated into this description. The process can be drawn closer to reality by starting with an actual inventory with this kind of information – such as the Lignum inventory. This diagram makes it clear that "old growth" represents just one part of the ecosystem, with the remaining parts being equally important. The schematic diagram is probably incorrect insofar as over very long periods of time a large-scale event will occur of sufficient magnitude to destroy the entire system.