

Characteristics of Resilient Ecosystems and Strategies for Ecosystem Adaptation to Climate Change

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To adapt British Columbia's forest management to climate change requires a collaborative effort between managers and scientists. Appropriate guidelines and policies will be needed to operationally respond to the opportunities and challenges presented by a changing climate. Presented here is an overview of adaptation strategies, their characteristics and some specific examples in an effort to further the conversation on the extent to which current forest and range management policies foster these strategies and characteristics, and to identify whether any current policies limit future adaptation options.

Climate change adaptation is contingent on three fundamental issues:

1. **Complexity**, forests are a complex system with inherent features that must be addressed in adapting to climate change.
2. **Uncertainty**, ecological and management interactions, shifts in disturbance regimes and ecological community reorganization prompted by climate change will further challenge forest management planning, and
3. **Accelerated Rate of Change**, the climate has always changed, however the current rate of change exceeds historic climatic trends and is likely to overwhelm the capacity for some species to adapt both temporally and spatially.

Over the past decade, forested ecosystems have become recognized as **complex systems**. Relevant to forested ecosystems, complex systems and the way they function have these features (from Campbell et al. 2009):

- they are made up of many parts (trees, small mammals, birds, insects, soils, etc.) and processes (mortality, succession, disturbance cycles, nutrient cycling, species migration, etc.) that interact with one another and their environment over multiple scales of time and space;
- these interactions, which give rise to heterogeneous forest structures, may range from strong and direct to weak and diffuse and can be modified by negative or positive feedback loops with the environment to stabilize or destabilize ecosystems;
- feedback loops may be non-linear, which means that small differences in starting conditions following disturbance could cause large, unexpected, and unpredictable changes in ecosystem structure and development;
- forest ecosystem boundaries are difficult to determine and are open to influences outside the system;
- forest ecosystems have "memory," which means that biological legacies of previous states influence present and future states; and

- forest ecosystems are made up of smaller units of biological organization (i.e., individuals, populations, species, communities) that are also complex systems.

Forest management can be adapted to foster resilient ecosystems. How any specific resource value or location may be managed is dependent on local conditions and socially desired ecosystem services. Managing for adaptation entails minimizing the risk of adverse climate change impacts, such as minimizing vulnerability to disturbance, managing to cope with uncertainty, and managing to minimize the rate of ecological change. Climate change adaptation strategies can be separated into three categories:

1. **Resilience:** management practices that maintain or enhance the ability of ecosystem to cope with change;
2. **Resistance:** management strategies designed to resist the influence of climate change; and
3. **Transformation:** management that facilitates the shift of ecosystems from their historic condition to one that is more appropriate for an emerging climate (Millar et al. 2007).

Resilience

A goal of managing for resilience is to “implement forest management practices that minimize the risk of rapid, unexpected ecosystem changes that could generate negative socio-economic pressures” (Campbell et al. 2009). The capacity for ecosystems to recover from disturbances and the risk of unexpected change can be increased by managing for structural and functional diversity of ecosystems across all scales - micro, stand, watershed, and landscape. This can be achieved by diversifying management practices, such as variations in timber harvesting and reforestation patterns. No single predictable forest condition can be reliably predicted or planned for; instead planning must be done at a hierarchy of scales to establish cross-scale management objectives that identify ecosystem services and aim to maintain ecological functions. This could improve the chances of increasing response diversity to future disturbances and environmental change while maintaining ecosystem services.

Potential management strategies that could promote ecosystem resilience include the following (adapted from Campbell et al. 2009):

- introducing fire into ecosystems where historical fire cycles have been disrupted by past fire exclusion and made these ecosystems more vulnerable to severe future fires.
- developing forest harvest and regeneration patterns that generate a diversity of stand ages and compositions over landscapes to reduce forest vulnerability to future insect and disease outbreaks (Woods et al. 2005; Carroll et al. 2006; Campbell et al. 2008).
- varying the shape and size of clearcuts, and leaving patches or stream buffers to reduce vulnerability to potential for increased windthrow disturbance (e.g., Kimmins 2004).
- using alternative harvest systems—for example, alternative partial harvest systems and various silviculture techniques could be used to generate microenvironment changes (e.g., changes in snowmelt patterns, exposure) to

facilitate the re-establishment of species that would otherwise be ill-adapted to regenerate in a new climate.

- planting species mixes that occur following natural disturbance—avoiding practices that generate uniform post-disturbance stands that may be highly vulnerable to future disturbance (British Columbia Ministry of Forests and Range 2007).
- reducing the effects of invasive species—warmer climates are apt to increase the spread and establishment of invasive plants, which may be tenacious competitors with planted seedlings or other early seral vegetation that provides valuable animal habitat (Floyd et al. 2006; Vila et al. 2007).
- planting resistant genotypes—breeding and using resistant planting stock may help protect against the anticipated expansion of certain insect and disease outbreaks.

Resistance

Management strategies that resist climate change may be necessary to protect high value resources or urgent situations to minimize loss of services. This approach may be more short term and be costly. Potential management strategies that may resist the effects of climate change include the following (adapted from Campbell et al. 2009):

- removal of invasive species,
- establishing refugia by identifying areas that could be buffered from the direct effects of climate change and provide a source of propagules for new forest ecosystems.

Transformation

The effect of climate change may be unavoidable in some areas and a management approach centred on ecological transformation may be appropriate. This would include facilitating the migration of species and genotypes (range shifts), resetting ecological successional trajectories through alternative planting, and promoting landscape connectivity. Potential management strategies that may help ecosystems shift to a more climate-appropriate state may include the following (adapted from Campbell et al. 2009):

- planting seedlings from a range of seed sources, particularly from more southern or lower-elevation populations—this could help maintain productive forests of the same species while the climate changes and local seed sources become less well adapted to new environments (Wang et al. 2006; O'Neill et al. 2008a, 2008b).
- planting logged sites with species expected to be adapted to the new climate (Rehfeldt et al. 2006; Millar et al. 2007; O'Neill et al. 2007). This could include planting species that have historically occurred south of the British Columbia border.
- banking surplus seed: broader use of non-local seed sources may require the procurement and banking of many different seedlots (Ledig and Kitzmiller 1992).
- Planting broader and new mixes of tree species over landscapes. This could help maintain forest productivity and resilience when the climate is rapidly

changing (O'Neill et al. 2008a, b). For example, for a particular BEC site association, planting on logged sites may have currently preferred stocking prescription of 40% spruce and 50% pine, but in anticipation of climate change, this might be continued on only half of the site, and the other half could be planted with varying ratios of more pine, up to 100% pine. Species that did not occur previously in historical climates may also be introduced into the mixes.

- Planting species over a broader range of environments. We currently know little about how climate change will affect the ability of species to re-establish in different locations, or how varying responses to change in different locations will affect species interactions. Redundant plantings of species (and populations) over a range of climatic and edaphic conditions, including those outside the boundaries of historical geographic ranges and preferred/optimal habitats will not only hedge against the risk of losing management investments, but monitoring at these sites will likely provide valuable information about future patterns of survival, growth, and forest productivity (e.g., Millar et al. 2007; O'Neill et al. 2008b).
- Facilitate the migration of species and range shifts by developing landscape structures that have a minimum of physical and biotic impediments to species migration.

Summary

Adapting to climate change implies implementing more diverse practices where management focuses on maintaining ecological function and ecosystem services rather than specific forest structure and composition. Further, it is assumed that there will be a variety of outcomes, some of which will be unexpected, but all can be learned from and potentially adapted to. The management framework needs to be flexible to allow for diversity, promote experimentation, learning and adjustment.

In summary, because forest and range ecosystems are complex adaptive systems it is difficult to identify a specific set of rules for their management. The specific characteristics that need to be managed will vary by location, current activities, past disturbances and the nature of the specific ecosystems being managed. Adapting to climate change requires three overarching questions to be considered by managers:

1. Does management address the complex nature of the ecosystem and the interaction with human activities?
2. Does management incorporate the uncertainty associated with ecological response and the uncertainty with respect to future ecological reorganization?
3. Will management accelerate the climate change increase in rate of spatial and temporal ecological change?

Table 1 lists four climate change adaptation management issues and the associated adaptation characteristics that should be considered.

Table 1. Adaptation management issue and generic characteristics that should be considered.

Adaptation Characteristic	Adaptation Management Issue			
	Manage as Complex System	Cope with Uncertainty	Cope with spatial change	Cope with temporal change
Complex at multiple scales - micro, tree, stand, watershed, landscape	✓	✓		
Diverse ecological interactions across time and space	✓	✓	✓	✓
Structurally and functionally diverse	✓	✓		
Biological legacies - ecological memory	✓			✓
Diverse responses to disturbance	✓	✓		✓
Diverse species, ages and patterns		✓		
Redundant representation of values - old growth, ungulate winter range, rare sites, etc		✓		
Connectivity across scales		✓	✓	
Supportive of propagule dispersion		✓	✓	
Reduced exposure and sensitivity to large scale disturbance - fire, insects, disease				✓

In conclusion, adapting successfully to climate change on BC forests and range lands will mean encouraging practices that recognize the complexity of forested and rangeland ecosystems and foster the characteristics of resilient ecosystems and

facilitate appropriate transformation, while allowing for resistance strategies on high value areas in the short term.

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