2009

British Columbian Forest Policy and Management in a Changing Climate

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4/14/2009

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Introduction

Climate change poses major challenges for British Columbia's forested ecosystems, natural resource managers, and the communities that depend on them. BC's temperate and boreal forests provide a host of values, ecologically, economically, and socially, to those locally and globally. Sustainable forest management as a management framework and philosophy has been identified as the overarching goal of Canadian forest public policy, in order to sustain the values created by the forests into the future (Haley and Nelson 2007). The purpose of this paper is: first to discuss the ecological implications of climate change on BCs forested ecosystems and secondly, to explore the options, risks, and opportunities that are available to BCs forestry policy makers, strategic planners, and managers in order to incorporate climate change elements into their decision-making process and work towards sustainable forest management.

The future of BC forests in light of climate change

Evidence for global climate warming is mounting. The Intergovernmental Panel on Climate Change (IPCC) reports that 11 of the 12 warmest years on record occurred from 1995 – 2006 and that the linear trend of warming is exceeding predictions made in their previous Third Assessment Report (IPCC 2007). The major cause for the change in global climate is attributed to anthropogenic emissions and the consequent accumulation of greenhouse gases in the atmosphere, starting with the industrial revolution and increasing sharply during the 1970s through the present (IPCC 2007). Globally, sea levels are rising, average air temperatures are increasing, and days and nights are hotter and drier than historically (IPCC 2007). Although warming is spread across the globe, it is affecting land masses at higher latitudes in the northern hemisphere more than their counterparts and winter temperatures more than summer (IPCC 2007).

The IPCC predictions of future conditions and climates were made using global circulation models (GCMs) and four emissions scenarios (IPCC 2000).The different scenarios explore the possible range of greenhouse gas output depending on future socio-economic states: world trade, social and cultural values, and technological advancements. The "A" storylines are based on a future world with very little emphasis on alternative energy technology and increasing greenhouse gas emissions; whereas the "B" storylines are more optimistic and based on considerable efforts and advancements in this area.

Climate change in British Columbia

For British Columbia (BC), all current GCMs predict a general increase in mean annual temperature (MAT), as well as warming in both summer and winter. Of particular note are anticipated increases in minimum winter temperatures and maximum summer temperatures, accompanied by less precipitation during the growing season (Table 1) (Wang et al. 2006). Northern BC is predicted to experience more warming than southern BC, while warming along coastal BC will be partially mitigated by its proximity to the ocean. Precipitation is predicted to generally increase in the winter, but summers are predicted to become warmer and drier. Return intervals for extreme weather events are predicted to decrease (Spittlehouse 2007). Although trends are fairly obvious, future conditions are difficult to define as a great deal of uncertainty exists within and between the models (Table 1).

Table 1: Temperature and degree days predictions for three British Columbia cities using two different global circulation models and two different emissions scenarios. MAT (mean annual temperature), Tminwinter (mean minimum winter temperature), Tmaxsummer (mean maximum summer temperature), MSP (mean summer precipitation from May to September), DD>5 (degree days greater than 5), DD<0 (degree days less than 0) (Wang et al. 2006).

Fort Nelson		**58°50'**	**122°35'**	
		CGCM		HAD
	2000/Current	A2 2080	B2 2080	A2 2080
MAT (°C)	-0.4	3.7	2.3	3.2
Tminwinter (°C)	-25.5	-17.7	-20.1	-22
Tmaxsummer (°C)	24.2	28.1	27	29.5
MSP (mm)	304	333	484	311
DD>5	1626	2300	2058	2377
DD<0	2605	1895	2128	2152
Penticton		**49°28'**	**119°36'**	
		CGCM		HAD
	2000/Current	A2 2080	B2 2080	A2 2080
MAT (°C)	7.5	11.1	10	14.1
Tminwinter (°C)	-6.5	-3.2	-3.8	-1.5
Tmaxsummer (°C)	25.3	29.1	28.1	36.9
MSP (mm)	143	124	127	89
DD>5	1982	2900	2604	3923
DD<0	397	204	250	139
Vancouver		**49°11'**	**123°10'**	
		CGCM		HAD
	2000/Current	A2 2080	B2 2080	A2 2080
MAT (°C)	10.1	13.3	12.4	13.9
Tminwinter (°C)	1.1	4.1	3.4	4
Tmaxsummer (°C)	21.1	24.7	23.7	27.4
MSP (mm)	278	249	250	190
DD>5	2127	3294	2918	3537
DD<0	21	0	0	0

Climate change throws into question the future health of BC's forested ecosystems. BC's forests are likely to be presented with many ecological challenges including: species composition changes; adaptation and migration abilities; productivity; potential shifts in species range; shifts in interspecific competition; and altered natural disturbance regimes. Natural disturbance regimes include both biotic, such as insects and diseases, and abiotic, such as fire and windthrow. Many factors determine a species' ability to occupy a certain area in time: climate, migration and adaptation abilities, soil and its associated microfauna and fungi, disturbance regimes, and interactions among all these factors. Interactions among the above factors and human activities may introduce further uncertainty into the mix.

Distribution shifts

Climate envelopes (CEs) and climate envelope modeling are useful tools to establish potential future tree and other plant species' ranges. Although CEs only take into account climatic factors in determining potential species ranges, they have predicted species ranges that have mirrored the observed ranges on the ground, evidence that climate is the major controlling factor to species distribution (Hamann and Wang 2006). Hamann and Wang created what are known colloquially as the flying BEC (Biogeoclimatic Ecosystem Classification) zones to predict potential species ranges in BC (2006). GCMs were used to predict future conditions by mapping current climate niches associated with current common BEC assemblages on maps of predicted future climates. The models represented only the potential range of the species, not their ability to migrate into the area (Hamann and Wang 2006).

In British Columbia, studies show that temperate tree species may have shifting potential ranges due to climate change. Range contraction is likely to occur on the south edge, while ranges are predicted to expand to the north and to higher elevations (Hamann and Wang 2006). Expansion to the north is predicted to occur at the rate of 100 km per decade (Hamann and Wang 2006). Hardwood species distributions are predicted to be less affected by climate change than conifers, on average (Hamann and Wang 2006). Subalpine and other mountainous ecosystems could be greatly affected, as their range may shift completely out of their current distribution in fifty years (Hamann and Wang 2006).

Migration and adaptation

The ability for a species to migrate into a new, climatically suitable area depends on its migration rate. Historical post-glacial retreat tree migration rates have been studied from fossil pollen records. Migration rates were originally found to be close to 1000m per year, but further studies have shown that migration rates were likely much slower and could be less than 100m per year (Aitken et al. 2008, Pearson 2006). These recent studies bring into question the ability of species to keep up with the rapidly moving climatic niches, which are predicted to shift much faster than the post-glacial warming (Malcolm et al. 2002).

Migration rates depend on fecundity, dispersal mechanism and distance, seed and seedling survival, number of outlier populations, and barriers to dispersal, as well as biotic interactions, genetic adaptation and abiotic factors (McKenney et al. 2007). Species with infrequent masting events and large, heavy seeds that are likely to disperse short distances are at a disadvantage. Pioneer species, which reach reproductive maturity earlier and often have light seed, far-reaching and isolated populations from previous pioneering colonization, and seeds transported by vagile animals, such as birds, are more likely able to migrate at a much quicker rate. Malcolm et al. (2002) predict that climate change will decrease biodiversity by giving an edge to opportunistic pioneer species. Barriers to dispersal, such as large water bodies, agriculture, urban development, or lack of nearby suitable habitat in which to disperse, may have significant effects on migration rates (Malcolm et al. 2002, Pearson 2006). Discounting human facilitation or rare dispersal events and accepting only historical migration rates of 100m per year, it would take 1000 years for the average species to move an equal distance to the shift expected from climate change over a decade.

Species adaptation to a new climate is possible as well. Some tree species have a larger suitable climatic range than they currently occupy. These species are likely to be much more adaptable to new climates than those with a very narrow range. Western larch (*Larix occidentalis*), for example, is likely to be able to expand its range into new areas, as they have been found to be well adapted to environments outside their distribution. Chewter (2008) found that western larch was a suitable species for planting in three different subzones of the Sub-Boreal Spruce (SBS) BEC zone, well outside and north of its current range of distribution.

Although tree species may show acceptable growth outside their ranges, there is no guarantee that fecundity will be as high as in their provenance. For example, lodgepole pine (*Pinus contorta var*. *latifolia*) populations planted 5 – 10 latitude south of their provenance produced 50% fewer strobili than their counterparts from further south planted in their home range (Hannerz et al. 2001). It is possible that stresses caused by adaptation to a new environment results in reallocation of resources into growth, but reproduction is neglected.

Soil and soil microfauna

Soil is another factor that determines vegetative composition of an area. Soil moisture and nutrient holding capacity is not likely to change dramatically or quickly with climate change (Simard, pers. comm. 2008). Position on the slope, aspect, texture, and structure remain constant regardless of climatic variation. Alteration of soil characteristics is likely to be gradual as the inputs from vegetation change the composition of nutrient additions to the soil. Lack of mycorrhizal associations, however, can limit establishment and productivity, and even alter species composition on a site. Loss of a species from an area, especially repeated loss, can reduce or eliminate inoculum of the mycorrhizal species on which it depends for establishment and productivity. Moreover, Simard's studies (2008) show that a diversity of mycorrhizal fungi are important in all types of vascular plant establishment, as well as ecosystem resilience in the face of ecosystem stress from climate change, and loss of diversity of ectomycorrhizal fungi can drastically alter ecosystem composition.

Natural disturbance regimes

The timing, frequency, duration, scale, and intensity of natural disturbance regimes are predicted to be altered by changes in global temperatures and precipitation (Dale et al. 2001). In the BC interior, recent massive wildfires have been partially due to uncharacteristically hot and dry weather attributed to climate change. Extensive wildfires in western North America are no longer being solely attributed to mismanagement such as fuel build-up and overactive fire suppression. Earlier springs, thus early freshets, coupled with warmer summer temperatures and a longer fire season are now being linked to an increase in the scale of fire disturbances (Bachelet et al. 2007). If large-scale fires happen at decreased return intervals, species composition may change permanently to those species that are better adapted to rapid re-colonization of burned areas. Warmer temperatures leading to decreased moisture content in foliage may increase fuel flammability, but this factor may be offset partially or completely by increased precipitation (Bergeron et al. 2004). This will depend on the timing and distribution of the precipitation (Lynch et al. 2004). Wetter winters may decrease the initial fire risk in the spring, most notably when spring freshets from heavier snow pack occur, but summer precipitation is more likely to be a deciding factor for fire risk and fuel moisture than average annual precipitation. Increased storm frequency may lead to higher likelihood of lightning strikes as ignition sources (Lynch et al. 2004). Effects of climate change on forest fire disturbances is likely to differ regionally, depending on how, and to what extent, the seasonal variation of the climate changes in the future (Bachelet et al. 2005).

Shifts in temperature and precipitation are altering insect and pathogenic disturbances. The recent outbreak of Mountain Pine Beetle (*Dendroctonus ponderosae*) in BC is record-setting and climate change may be partially to blame. Higher minimum winter temperatures are allowing over-wintering larvae and adults to survive the winter. Warmer temperatures throughout the year allow for one or more generations per year, as the insects are no longer required to enter diapause and are thus able to develop to reproductive maturity more quickly. Warmer air temperatures are less limiting for pine beetle activity further north (Dale et al. 2001). Quick life cycles and rapid migrations may allow insects to migrate with the climate faster than associated tree species, exposing temperate tree species to exotic species (Dale et al. 2001).

Warmer, moister climates give many fungi an advantage when infecting their hosts. Dothistroma needle blight (*Dothistroma septosorum*), normally a minor defoliator pathogen native to BC, is beginning to cause more extensive damage to lodgepole pine and has even caused mortality among mature lodgepole in Northern BC (Woods et al. 2005). The most likely cause for the elevated incidence and severity is a marked recent increase in mean summer precipitation and temperatures, which allows the pathogen to continually produce and disperse asexual spores throughout the growing season (Woods et al. 2005). Although broad predictions show summer precipitation decreasing, global circulation models, regardless of emissions scenarios, predict a regional mean summer precipitation increase of up to 10% by 2080 in northern BC (Table 1). Native pathogens and their hosts co-evolve to limit competitive advantage for either, but weather conducive to pathogen reproduction, dispersal, and infection may disrupt the balance and cause wide-spread damage or mortality.

Policy, Planning, and Forest Management

Climate change accelerated by anthropogenic activity is widely accepted by the scientific community. Inherent uncertainty in the models (GCMs) and carbon dioxide emission scenarios raises many questions as to the extent climate is predicted to change and its associated effects on forested ecosystems. The current and future actions of the global society will play a large role in the magnitude and speed of climate change. The future of forests depends on the degree to which climate change impacts soil properties and processes, abiotic and biotic natural disturbances, and each species' ability to either adapt to the new environment in which it is established or to migrate to more suitable environments.

Although uncertainties abound regarding the extent and magnitude of effects on British Columbia's forests, the painful reality is that policy makers, strategic level planners, and operational forest managers will need to take climate change and its impacts into account during forest management. The historical challenges introduced by managing a dynamic entity, such as forested ecosystems, are only magnified by the increasingly more dynamic climate change. The important lessons taken from past experiences are no longer sufficient for basing daily forest management decisions in policy, planning, and management (Millar et al. 2007).

Under the assumption that BC's overarching objective is to achieve sustainable forest management (SFM), the Montreal Process is one measure of progress towards this objective. The Montreal Process, specific to global temperate and boreal forests, lists seven criteria, all of which are critical in meeting SFM standards. The criteria are based upon biodiversity, productive capacity, ecosystem health and vitality, soil and water resources, global carbon cycles, socio-economic benefits, and institutional frameworks (Figure 1) (The Montreal Process 2007). For the purpose of this paper, the scope will be limited to policy, and strategic and operational planning for maintenance and conservation of biodiversity and productive capacity of ecosystems.

Figure 1: The seven criteria for the conservation and sustainable management of temperate and boreal forests, as laid out in the Montreal Process (2007).

The Montreal Process criteria for sustainable forest management	
Criteria 1:	**Conservation of biological diversity**
Criteria 2:	**Maintenance of the productive capacity of forest ecosystems**
Criteria 3:	Maintenance of forest ecosystem health and vitality
Criteria 4:	Conservation and maintenance of soil and water resources
Criteria 5:	Maintenance of forest contribution to global carbon cycles
Criteria 6:	Maintenance and enhancement of long-term multiple socio-economic benefits to meet the needs of society
Criteria 7:	**Legal, policy, and institutional framework**

Policy Implications

There are many BC forestry policies that must be re-considered in light of climate change. Some of them include: the rules governing species selection, seed transfer limits, the crown tenure system, and creation of a system that encourages market diversification from forest resource values. Although this is not the forum to do in-depth policy analyses, the following suggestions are meant to open discussion about how policy can be one avenue to facilitate planners and managers in their quest towards achieving BCs forests objectives and managing for a multitude of values.

Seed Transfer Limits

Seed transfer limits are the rules that govern the geographic transfer of seed for reforestation. The Chief Forester was given the authority to set rules around the transfer of seed for reforestation by sections 43 and 32 of the Forest Planning and Practices Regulation (FPPR) and Woodlot License Planning and Practices regulation, respectively (Ministry of Forests and Range Tree Improvement Branch 2009). The main purpose behind seed transfer limits is to maximize forest productivity and decrease the risk of maladaptation. The transfer limits outline the geographic range within which seeds can be transferred. The ranges are defined by latitude, longitude, and elevation, which are used to match the seeds to those environments in which the seeds are environmentally adapted and are able to reach their full genetic potential (Ying and Yanchuk 2006). This range becomes increasingly hard to predict when environments are changing rapidly due to climate change.

With the development of GCMs and climate envelope modeling, there is concern about the ability of species and specific seedlots to continue to perform optimally under the various predicted climate scenarios. Use of seed in reforestation activities that may be optimally productive under predicted future climatic conditions is one way to alleviate some of the concern (Ying and Yanchuk 2006). Therefore, flexibility around seed transfer and timely incorporation of climate change research into seed transfer regulation will give forest planners and managers more flexibility when making critical decisions (Ying and Yanchuk 2006). Ogden and Innes (2007) recommend the rules for governing seed transfer be relaxed in order to: assist species distribution changes by introducing them to new areas, address the problem of when species are no longer suited to an area, and encourage the flexible forest policies required to respond the ever-dynamic climate change.

There are tools available to assist bureaucrats in determining seed transfer zones. The flying BEC zones provide a good initial indication of where seeds may be able to reach their full genetic potential (Hamann and Wang 2006). Computer tools, such as Seedwhere, are developed to assist in seed and seedling transfer decisions. Seedwhere is a Geographic Information System that maps out the climatic similarity of a selected area of interest to a larger region (McKenney et al. 1999). Seedwhere can be used with historical climate data, as well as models of future climates (McKenney pers. comm. 2009). Tools such as these are useful for an initial jumping off point, but should certainly not be the only consulted resource when making policy decisions . Policy makers must depend on personal experience and sound judgement to make decisions based on sound ecological scientific evidence. Moreover, increasing flexibility in the transfer of seed will allow managers to use local knowledge, an invaluable element in forest management, to practice the art and science of forest management.

Crown Tenure System

The Crown tenure system in BC plays a chief role in how licensees and forest industry firms make decisions, conduct operations, and ultimately how well they meet and serve social objectives. In short, the Crown tenure system underpins every aspect of the current forest industry. To that end, a full discussion of the Crown tenure system is not attempted here.

The Crown tenure system plays an integral role in the success or failure the ability of the BC forest industry, as a whole, to attain sustainable forest management (Haley and Nelson, 2007). The vast majority of BC's tenures are relatively short term. Other than the 99 year leases offered to community forests, the vast majority of tenures held in BC are far shorter than the average rotation length (Ministry of Forest and Range 2006). In short, there is no incentive to think long-term when considering management options, especially in short term decisions (Ogden and Innes 2007). If the Crown tenure system offered longer tenures to licensees, there would be social and economic incentive to consider short-term decisions as playing into long-term goals towards the general health, productivity, and vitality of the forests as an integral piece of profits and economic sustainability. Natural resource management is unlikely to ever reach economic or ecological sustainability if all goals, decisions, and targets are based solely on short-term factors.

Furthermore, the majority of tenures granted in BC are volume-based Forest License tenures. These tenures are not only short, 20 – 25 years, but also do not legally require any long-term strategic planning by the tenure holder. Short-term decisions, on the scale of operational planning, are the only legal planning obligations (Ministry of Forests and Range 2006). The licensee does not have any incentive to undertake longer term strategic planning, which further undermines the purpose of reaching sustainable forest management.

Another aspect of the current Crown tenure system to consider is that currently Crown forest tenures only encompass the rights to timber and do not include the rights to non-timber forest products, recreational rights, or carbon rights. This creates an environment where timber becomes the main economic good for management, while the other values are secondary. The carbon markets, while still in relative infancy, could provide an alternative source of economic prosperity for those with tenures. The option of managing for carbon sequestration to be sold as carbon credits on the market should be a viable economic option for forest managers. Without carbon rights for tenure holders, this alternative is ruled out.

Market Diversification

BCs forests not only offer a multitude of ecological values, such as water quality, biodiversity, wildlife, fish, carbon sequestration, but also provides socio-economic opportunity. The biophysical changes in the forests from climate change will likely spur socio-economic consequences (Ogden and Innes 2007). Legislative policy can be used to pursue socio-economic policy and to increase its resilience.

Currently, policies now are set up for one economic value for BCs forests: softwood lumber. This is perpetuated by the tenure system, the current policy framework, and the economic reality of the times. Forest managers would be better armed to manage for climate change if they had more alternatives available to them. Moreover, if there was a more diversified economy, both from the forest resources, and in the surrounding communities, maintaining and enhancing long-term socio-economic benefits may be better facilitated (Ogden and Innes 2007). As of 2008, there are over 17,000 persons directly employed in the forest sector (BC Stats 2008). The futures of all 17,000 directly employed persons, their families, and the majority of their communities are currently sunk into one economic alternative: timber. If climate change has negative biophysical impacts on forest productivity, in turn forestry-dependent communities will feel the full force of those impacts. Diversifying the economy would likely introduce more socio-economic resilience.

Global carbon markets, initiated in response to global climate change concerns, have seen skyrocketing growth since their inception. In 2007, the global carbon market, led by the European Union Emissions Trading Scheme (EU ETS), was valued at US $30 billion. Reductions by individuals and corporations were traded on the voluntary market valued at US$100 million (Capoor & Ambrosi 2007). The majority of carbon credits due in the forest industry would arise from carbon sequestration and reforestation efforts. They would likely be traded as an allowance-based transaction by those operating in carbon- and energy-expensive sectors. The carbon market is fairly well established in Europe, with the EU ETS. In North America there is still a great deal of risk associated with it, as the policy framework for carbon systems and overseas credits has not been finalized (Capoor and Ambrosi 2007). Although the market is still in an emerging state, and there is much speculation around framework and methodology, carbon sequestration and the trading of resultant credits could be one lucrative option for BCs forest managers.

Forestry-dependent communities are common across rural British Columbia. Policy to help these communities diversify their economy would help to bring economic stability and resilience for the future. Currently, as the forest industry is struggling financially, these communities are experiencing economic contraction. Climate change's effects on the forest industry throw into question the survival of such communities. By diversifying the economy, the chance of socio-economic sustainability is increased, as they will have other industries to support them if the forest sector continues to see negative growth or the forest's capability to provide the goods and services is impacted from climate change.

There is opportunity for forest policy to improve the socio-economic benefits that the forest industry provides to society. Increased resources and funding towards innovative, value-added wood products may help to increase recovery and to find suitable uses for beetle-killed pine and other lower value species, such as hemlock and fir. At a time when the forest industry does not have the resources to commit to research and development, there is room for government to take an active role in making the forest industry more efficient and effective.

Strategic and Operational Planning

There are an overwhelming number of recommendations proposed by various experts regarding the current and future management of temperate forests in times of climate change. This paper will discuss some of the many recommendations that may be appropriate to implement. The scope of this paper will limit the discussion to those operational and strategic recommendations relevant to criteria one and two of the Montreal Process: conservation of biodiversity and maintenance of productive capacity.

In order to achieve sustainable forest management, there must be clear values and objectives. It is likely that values, expectations, and society's desired use of BC's forests will need to be re-examined and adapted in order to best manage BC's forests with climate change (Spittlehouse 2005). Forest planners and managers may be overwhelmed with alternative management options. It is the forest professionals' job to incorporate those elements that are suited to their situation, site, and objectives. There is no substitute for experience, good judgment, and local knowledge. Considering experience, good judgment, and local knowledge in combination with innovative ideas and results of recent research will allow the forest professional to manage effectively.

Biological Diversity

There is little debate about the importance of biodiversity in BCs forested ecosystems. Among the values attributed to ecosystem biodiversity is the idea that ecosystems are more resistant and resilient to environmental changes with greater species richness (Noss 2001). Biodiversity helps to keep a healthy, functioning, resistant and resilient ecosystem that is better suited to adapt to new environmental conditions (Ogden and Innes 2007, Noss 2001). Although there is agreement over the importance of biodiversity protection in the face of climate change, there is a broad array of recommended actions in forest management. In a comprehensive literature review by Heller and Zavaleta (2008), 524 separate recommendations were found regarding biodiversity management in a changing climate.

The ability of species to migrate and adapt to the new climate will be a determinant factor to their ultimate success or failure. In order to facilitate species migration, forest connectivity should be maintained, as well as avoiding forest fragmentation (Noss 2001, Spittlehouse and Stewart 2003). Change in land-use and lack of near-by suitable habitat to migrate create barriers to the dispersal for tree species (Malcolm et al. 2002, Pearson 2006). This becomes especially evident for those species with heavy seeds and infrequent masting events that are not able to disperse over long distances. Maintaining connectivity may help to decrease the chance of a barrier for such species.

Adaptation to new climates is an important trait for species survival under changing climatic conditions. Those species with a greater diversity of genes may be able to better adapt to changing conditions (Noss 2001). Because genetic diversity increases the potential for adaptation, Ledig and Kitzmiller (1992) recommend that federal governments commit to conserving gene pools in seed banks. During reforestation activities, Noss (2001) recommends using individuals from a wide range of localities. Not only may this strategy provide an "insurance policy" for the future of the forests, it may also help reduce the legal risk for forest managers. If one locality turns out to be mal-adapted, another may flourish. On the other hand, over-diversification of stands may pose a risk if the stand is so diverse that there are not a sufficient number of adapted trees to create a fully stocked stand. In all cases, forest managers should employ common sense and local knowledge when implementing management recommendations. On the positive side, if legal risk for the forest managers is reduced, they may feel more comfortable experimenting with adaptive management.

As noted previously, fire regime change due to climate change is a complex issue and resulting fire activity is likely to differ regionally. There are many species assemblages that either flourish after or depend on fire for their persistence. Complete fire suppression will shift competitive advantage away from those species that depend on natural fire occurrences. On the other hand, if fire disturbance regimes shift to a higher frequency of events, those species that depend upon intact fire-free ecosystems will likely decline. Therefore, a strategy that mixes protection, suppression, and prescribed burning, depending on location may be the optimal approach (Noss 2001).

Operationally, there are few biodiversity-protecting recommendations available to forest managers that are above and beyond what is considered current-day responsible forest management. Examples include allowing natural generation where feasible, planting a diversity of well-adapted species on site during reforestation, and controlling invasive species (Noss 2001). Hardwoods have often been treated similar to invasive species during forest management because they compete strongly with softwoods, especially during establishment. Because hardwoods are likely to be less affected by climate change than softwoods, it may be beneficial to encourage hardwood productivity, rather than hampering it. Moreover, maintaining a diverse matrix of stand structures, ages, and species mixture will provide a range of habitats to which a variety of species are well-suited.

Productive capacity of forest ecosystems

Inherent in the idea of SFM is the tenet that productive capacity of the forests is maintained to allow ecological functions and processes to perpetuate for the long term. Productive ecosystems signal healthy, functioning ecosystems; conservation of soils and water; and the capacity of those ecosystems to provide the goods and services on which humans depend (The Montreal Process Working Group 2000). Forest productivity is generally measured by the increase of biomass of an ecosystem or the Net Primary Productivity of an ecosystem over a determined interval in time (DeLucia et al. 1999, Clark et al. 2001). Reductions in productive capacity in a forested ecosystem may indicate unsound forest practices or impacts from environmental agents, such as climate change (The Montreal Process Working Group 2000).

The question on the forefront for forest managers is how existing and future forests will respond to climate change, in terms of forest productivity. Furthermore, there is still a great deal of uncertainty regarding the magnitude to which the forests' response will impact future goods and services, foremost timber supply (Spittlehouse 2005). Moreover, the magnitude and intensity of productivity change from climate change will likely vary from region to region. For example, research by Jones et al. (1995) shows that elevated carbon dioxide levels will likely decrease forest productivity in the south-east and south-central regions of the United States, meanwhile productivity in the Pacific Northwest is modeled to increase. There is likelihood, though, that limited levels of nutrients in the soil will offset some or all productivity gains from increased levels of carbon dioxide (Spittlehouse and Stewart 2003). Furthermore, the models upon which these studies are based introduce further uncertainty.

Silvicultural management may facilitate migration to suitable climates faster than would be possible naturally. With increased flexibility in seed transfer limits, managers can use seed and seedlings sourced from those provenances that will be best suited for the future climate of an area. Unfortunately, there still remains a major managerial hurdle when choosing provenances for reforestation. If seedlings are planted to be well adapted to future predicted climates, the chance of successful initial establishment is reduced, due to current climatic conditions for which the species may not be well suited. Moreover, soil conditions may not be suitable for some northward movement, for example, mycorrhizae beneficial for seedling establishment may not be available (Spittlehouse and Stewart 2003). A compromise may be to underplant natural regeneration with other species or genotypes where the natural regeneration is predicted to be an inappropriate source for the future forest or predicted climatic conditions (Spittlehouse and Stewart 2003). In addition, it may be advised to plant species and provenances that are productive under a wide range of climatic and environmental conditions, plant intimate species mixtures, or to plant seedlings sourced from several provenances on the same site to hedge against the uncertain future (Ledig and Kitzmiller 1992). The harsh reality of this scenario is that only commercially valuable species likely will be assisted by forest managers, as commercially valuable species are the ones that will provide economic incentive and consideration. Non-commercial species will be forced to migrate without manager intervention (Spittlehouse and Stewart 2003), unless they are a conservation priority. This may hasten the change in species assemblages that is already predicted, for better or worse.

Shifts in natural disturbance regimes may have a large impact on ecosystem productivity, as well as an immediate and direct impact on the goods and services provided by forest ecosystems. Managers may choose to proactively take action before a disturbance, to reduce vulnerability and mitigate resulting damages. For example, managers could alter stand structure by thinning from below, changing tree spacing and density, and reducing fuel on the forest floor to reduce the forests' vulnerability to fire disturbance (Dale et al. 2001). There is also the option of managing the disturbances as they occur. This would include rapid responses to pest, pathogen, and fire disturbances (Dale et al. 2001). Although disturbance management for singular disturbance events is fairly well studied, forest response to multiple disturbances, as well as how forest disturbances interact with each other, is not well researched and will continue to add to uncertainties in times of climate change (Dale et al. 2001).

Adaptive Management

The uncertainties of climate change as it impacts forested ecosystems in BC lend well to the model of adaptive management. Large-scale ecosystem management is full of complex interactions among the environmental, social, and economic realms. The uncertainty that results from such complex interactions, functions, and processes limits the utility of the conventional hypothesis testing normally advocated by other scientific communities and approaches (McLain and Lee 1996). Adaptive management recognizes the existing uncertainties and establishing methodologies in order to test hypotheses surrounding the uncertainties (Holling 1978, as cited in Ogden and Innes 2007). Adaptive management uses management as a method to learn about the way in which a system works. It requires continual monitoring and evaluation of outcomes to modify and improve management strategies (Ogden and Innes 2007). Although there has been harsh criticism surrounding previous implementation of adaptive management (McLain and Lee 1996), the complexities and temporal constraints in climate change do not offer many alternatives.

Adaptive management in BC's forested ecosystems should take a science-based approach, rather than the "trial by error" approach whereby initial choices are made haphazardly and later alternatives chosen from those choices that produce better results (Walters and Holling 1990). Moreover, it should allow forest managers more flexibility to depart from the "one-size-fits-all" approach that has resulted in similar silvicultural prescriptions over a vast geographical area. A structured decision-making approach, as outlined by Ohlson et al. (2005), may help forest managers to make optimal decisions regarding adaptive climate change forest management, according to the specific ecological, economic, social, and cultural circumstances and constraints in the specific geographical area and ecosystem that is in question. To that end, forest managers must first define the problem, recognizing constraints, risks, and uncertainties in order to pro-actively manage for climate change in BC's forests.

Conclusion

Forests are complex ecosystems in which the full scope of interactions among ecological, economic, societal, and cultural factors is not fully understood. The uncertainty is further confounded by the uncertainty which exists around the future of the global and regional climate and its biophysical impacts on forested ecosystems. Further uncertainties abound surrounding the future forests' ability to provide the ecological, social, economic and cultural values desired by society.

Forest policy can be used as a tool to facilitate successful forest management, ecologically speaking, and to pursue socio-economic goals. Forest policy should permit a flexible and adaptable range of management options. Climate change will impact many policies and their successful implementation, not solely one. For this reason, monitoring of intended and unintended consequences of forest policy, and adaptation of policy accordingly, will be an important aspect moving into the future.

Strategically and operationally, forest management should be centered on creating resilient, resistant forests that can adapt to the changing climate. Maintaining and protecting biodiversity and managing to best maintain forest productivity will hopefully allow a future of healthy, productive, functioning forested ecosystems with the ability to provide all the values important to the global and local society. There are a multitude of recommended methods and strategies in order to best achieve sustainable forest management. Forest managers and planners need to be aware of, and consider, a multitude of management options to introduce adaptive forest management for climate change. Continual education of forest managers on the options available to them will be important as more research leads to improved understanding of climate change's impacts on forests in BC. Perhaps most importantly, forest managers should incorporate new recommendations with their own experience, local knowledge and common sense. The same forest management strategies do not work in all regions and areas. The optimal solution will be to introduce those new recommendations that make sense given the region of interest. Moreover, avoiding using the same set of strategies throughout the province likely will give BC's forests an insurance policy against future impacts of climate change.

Lastly, the relationship between society and BC's forests may change with the new environmental future. It is important, not only for society, but for BC's forest managers and policy makers, to re-establish societal views, objectives, values, and expectations from the forest, in light of climate change. In the same vein, it will be important for society to be educated on climate change, its impacts on the forests, and the physical limitations that it may place on their ecological functions and productivity.

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