branch lines

UBC Forestry University of British Columbia

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Our Changing Climate

Our changing climate

OUR CHANGING CLIMATE WILL HAVE huge effects on the forests of BC, Canada, and the world. Understanding these impacts is the goal behind a range of innovative research programs at the Faculty of Forestry. Our faculty members are evaluating the potential changes we might expect within our forest ecosystems, including changes to water resources, stream flow and fish populations. Changes to forest management and the ability of tree species such as poplar to meet climate adaptation goals while supporting our forest industry are being analyzed, as is the role of our forests in sequestering carbon. Finally, visions of how our communities might adapt to reduce their carbon footprint help inform us about the contribution that we can all make towards a greener and more sustainable future.

My own research focuses on bioenergy and biomass wood-based liquid biofuels in particular, which have the potential to reduce the ecological impact of the transport sector over the long term. Liquid biofuels are one way in which bioenergy (or energy derived from biomass) may be delivered to the consumer, and are one of the only renewable and sustainable options that are compatible with the existing transportation sector. In Canada, most biofuels today are derived from agricultural products including sugar, corn starch and vegetable oil (as well as waste oil products). As many of you will be aware, there is currently a 'food-vs.-fuel' debate which questions the use of these products for ethanol or biodiesel production. We know that increased food prices will have an impact on food security and human well-being in some nations, particularly where food is scarce owing to poor growing conditions or other environmental factors. We believe that increasing the proportion of biomass-based biofuels will help minimize the expected rise in food prices.

A number of new technologies are being pursued, including our own bio-based process, which will allow the production of wood-based liquid biofuels for transport. It is likely that a number of these technologies will be commercialized over the next three to ten years; indeed, several pilot-scale plants have already been in operation for several years (in Canada as well as Sweden, Japan, Spain, the United States and other countries). Most dramatically, six industrial-scale demonstration plants have been approved for construction in the United States, with others being constructed in other countries.

The development of an expanded bioenergy industry, and in particular the creation of a cellulosic liquid biofuel sector, has significant implications for forestry. Canada has the largest reserves of commercial forest growing stock in the OECD, followed by the United States, Australia, Sweden, France and Finland. Our reserves of forest biomass will become increasingly important as policies designed to expand the use of bioenergy come into effect.

By 2017, we anticipate that policy-dictated increases in wood-based liquid biofuels will result in a huge increase in demand for biomass. This increase will have

impacts on all forest companies, and BC – with its large forest resource – will have a significant role to play. We estimate that additional demand for wood could be as high as 150 million m^3 across Europe and North America by 2017; this is almost ten times BC's current annual allowable cut. Only Canada has the potential to be able to supply this amount of biomass. At this point, the lack of a clear policy position in Canada means that, by default, we may continue to play a role as the provider of feedstocks to other developed nations – rather than reaping the benefits of wood-based bioenergy and biofuels for ourselves. The current export of BC based wood pellets to Europe is a good example of this phenomenon.

Research at the Faculty of Forestry will be invaluable in helping us understand the impacts of climate change on forests. Equally important is the ability of this research to identify positive ways in which we can adapt to – and thrive in – a changed climate, environmentally, economically and socially. This special, expanded issue of Branch Lines will hopefully give you an idea of some of the exciting possibilities that exist for our forests and our forest-based industries. We look forward, as always, to your suggestions and comments and hope that you find inspiration in this review!

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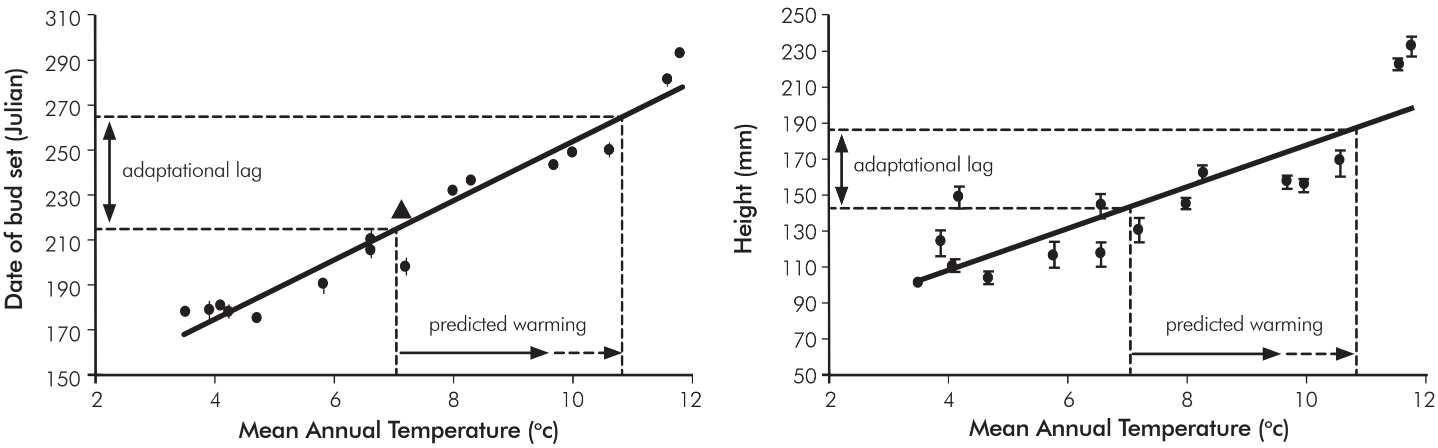
Dean

The fate of tree populations in a changing climate

FOREST TREES HAVE WITHSTOOD CHANGES in environmental conditions on time scales from daily to millennial and beyond; however, the rates of change predicted for the next century are much higher than those ever experienced in the past. In the face of rapid and substantial climatic change, trees have three possible evolutionary fates: they can migrate as conditions change and track the climatic conditions they are adapted to across the landscape; they can stay in one place and adapt to the new conditions through the process of natural selection over generations; or they can become extirpated. It is highly unlikely that they can migrate quickly enough to keep up with the rate of current climate change. Fossil pollen records and genetic studies suggest that the fastest species migrated following the last ice age was 100 m per year, yet rates more on the order of 1000 m per year would be necessary to keep up with predicted levels of global warming. It is likely that many common species will adapt over several generations, but not without an adaptational lag. For example, climate warming may provide a favourable extension to the growing season at the northern limits of a species range but individuals are "programmed" to cease growth in response to day length rather than temperature and thus would be maladapted to the new conditions, i.e., suffer an 'adaptational lag' (see Figure on page 13 from an invited review article by Aitken *et al*. to be published this month in Evolutionary Applications). However, over multiple generations of natural selection driven by higher survival rates of those trees growing longer and larger under a milder climate, the population would become more closely adapted to new conditions. The quicker climate changes the larger adaptational lags will be, and the longer populations will take to adapt. An upset in the synchronization of trees with their climates may lead to losses in productivity, increases in mortality, and changes in the severity of insect and disease outbreaks.

Many tools have been developed in recent years that aid in the prediction of future forests. These include sophisticated regional climate models that accurately predict current temperature and precipitation variables; global circulation models that predict changes in global and regional climates due to increased levels of carbon dioxide; species distribution models that predict the future locations of populations, species, and ecosystems based on the climates that organisms currently inhabit; and genetic and genomic tools to better understand levels and geographic distributions of genetic variation for genes involved in the local adaptation of populations to climate.



An illustration of the adaptational lag that may occur with climate change for Sitka spruce. Seed collected from 17 populations from across the species range of Sitka spruce (northern California to Kodiak Island, Alaska) were grown together in an outdoor experiment at UBC. Date of bud set and height growth vary with mean annual temperature (MAT) of the location of seed collection, indicating local adaptation and the synchronization of growth of individuals with local climate. The range in increase in predicted mean annual temperature for Prince Rupert, BC (current MAT=7.1^{0}C) by the 2080's is illustrated by horizontal arrows, while the vertical arrow illustrates the extent of adaptational lag that will occur if global warming achieves the maximum predicted. (Figure data from PhD thesis of Makiko Mimura).

Group members in the Centre for Forest Conservation Genetics (CFCG) are using these tools to predict the locations of future habitat for our native tree species; to test the validity of such predictions by establishing field and growth chamber experiments; and to understand the genetics, genomics, and physiology of adaptation to climate. This information will be used by forest managers, policy makers, and conservation planners to select appropriate seed sources for reforestation for future climates, to predict the health of future forests, to predict the persistence of species in parks and protected areas for conservation purposes, and to determine when human intervention is needed to actively move species to new appropriate habitat.

CFCG Associate Director Dr. Tongli Wang is using different types of species distribution models including Random Forests in conjunction with his ClimateBC model to predict future habitat and to select seed sources for reforestation. Research Associate Dr. Pia Smets is evaluating the physiological and growth response of populations of lodgepole pine and interior spruce to temperature and drought, and comparing short-term responses to those observed in long-term provenance trials to determine if we can draw meaningful conclusions about climate change. Former PhD candidate Dr. Andrew Bower developed seed transfer recommendations for restoration in a changing climate for the rapidly declining species whitebark pine. PhD student Sierra Curtis-McLane is testing predictions of current and future distributions of whitebark pine by planting seeds in field experiments in locations predicted to currently have climates that will support this species but that are outside of the species range as a test of facilitated migration strategies. PhD candidate Jason Holliday is investigating the genomics of local adaptation to climate in Sitka spruce, and to date has identified a few hundred genes that appear to be involved. MSc student Colin Huebert is evaluating local adaptation in Garry oak and developing seed transfer recommendations for current and future climates by studying population differences in seedlings grown from acorns originating from California, Oregon, Washington and BC. Scientist Christine Chourmouzis is using predictions of future habitat to evaluate whether the genetic resources of native tree species are adequately conserved in parks and protected areas in BC.

For more information on these projects contact Dr. Sally Aitken (sally.aitken@ubc.ca), Christine Chourmouzis (chourmou@interchange.ubc.ca) or Dr. Tongli Wang (tongli.wang@ubc.ca) at UBC's Centre for Forest Conservation Genetics. The Centre's website www.genetics.forestry.ubc.ca/cfcg provides highlights of additional projects as well as recent publications from the Centre's research staff.

Fueling the future – poplar is popular at UBC

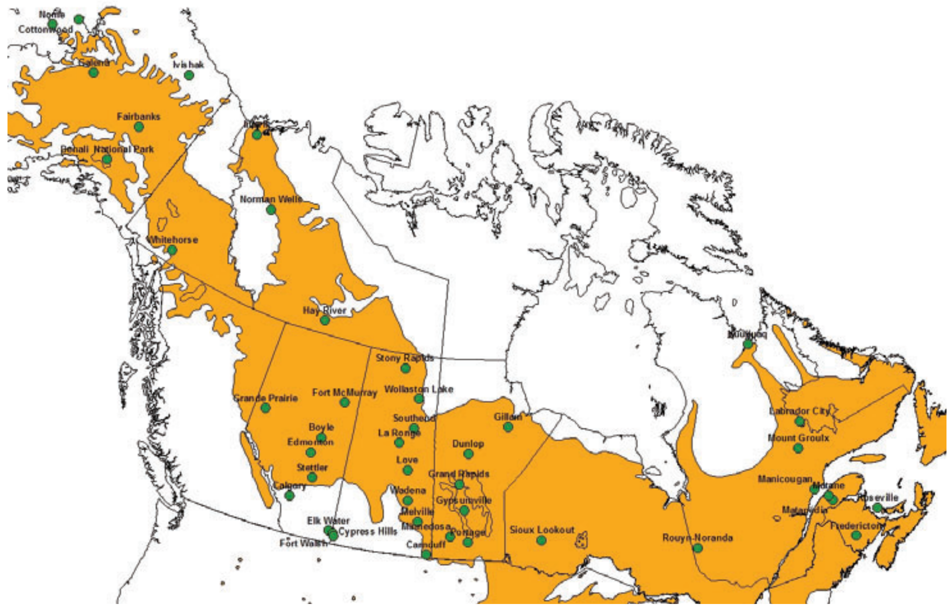
THERE IS MUCH INTEREST in afforestation as a strategy to help mitigate climate change by sequestering carbon and, ultimately, providing feedstock for renewable biofuels. These opportunities are likely to be greatest in intensively managed stands of rapidly growing trees. In Canada, there are several million hectares of marginal agricultural lands potentially available, mostly in the prairie provinces. But what's actually available to plant? Not much it seems. Most of the available hybrid poplars currently planted in Canada are derived from species or populations adapted to relatively mild climates. While some of these "mild climate" clones are suitable to southern Ontario and southwestern British Columbia, few can survive on the prairies. There is, however, within our native forests, a tremendous untapped genetic resource, pre-adapted to the Canadian climate.

Ignoring aspens, Canada supports four of five North American poplar species. For example, balsam poplar is found in every province, from the US border to Inuvik, while black cottonwood occurs throughout British Columbia and adjacent areas of Yukon and Alberta. Appropriate selections and new hybrids could greatly increase the potential area that can be successfully planted to poplar.

Several researchers at UBC are studying genotypic variation in adaptive traits in poplar. To this end, some 750+ genotypes of balsam poplar (*Populus balamifera*) and black cottonwood (*P. trichocarpa*), plus a wide selection of hybrids (including crosses with eastern cottonwood) are now springing up, in somewhat patchy fashion, at UBC's Totem field. This "forest" might not last long, given the rate of campus development, but many of these genotypes grow so rapidly that if left uncontrolled there would be a continuous canopy within just a few years. Most of the clones come from two range-wide provenance collections – the BC MoF black cottonwood collection originally put together by Dr. C.C. Ying, and the new AgCanBaP balsam poplar collection compiled by scientists at the Prairie Farm Rehabilitation Administration (PFRA) Shelterbelt Centre, at Indian Head, SK. The AgCanBaP collection consists of some 15 individual clones from each of 43 populations.

So what are we doing with them at UBC? Several projects are underway or have been completed. In collaboration with Richard Pharis at the University of Calgary, Rob Guy and Shawn Mansfield (Faculty of Forestry) are investigating plant hormone profiles, fiber properties, carbon isotope composition, photosynthesis, and several other physiological parameters in black cottonwood, balsam poplar and various hybrids. This work forms the basis of thesis projects for Virginie Pointeau and Faride Unda. In addition, Raju Soolanayakanahally (Guy lab) has been working closely with Dr. Salim Silim at the PFRA, both in Saskatchewan and

at UBC, to characterize growth potential, photosynthetic rates, resource-use efficiencies and single-nucleotide polymorphism (SNP) variation in the complete AgCanBap collection. Using a subset of clones from the BCMoF collection, Hannah Buschhaus (Guy lab) recently completed her MSc thesis on variation in nitrogen isotope discrimination. Activity is not restricted to just the Faculty of Forestry. Quentin Cronk (Faculty of Land & Food Systems) and colleagues in Botany, for example, have been studying morphological variation, phenology and SNPs in the black cottonwood collection.



Populations of balsam poplar constituting the AgCanBaP provenance collection.

Physiology and other fancy stuff aside, the single most important attribute dictating the rate of biomass accretion is the length of the active growing season (i.e. the period from bud break to leaf drop). Timing of bud break in the spring is largely controlled by temperature. There is genetic variation in this trait but, in the main, when trees from different locations are planted in a common garden they generally flush out within a few days of each other. The same is generally true of cottonwoods, but a notable exception we've noticed at the UBC common garden is that trees from very high latitude can break bud in what we locally consider to be the depth of winter. They also set bud several months too early (during our spring) because they are sensitive to the relatively short photoperiods encountered in Vancouver. Unlike bud break, bud set and (later) leaf drop are under tight photoperiodic control, and for these traits there are very strong latitudinal clines. In a common garden, genotypes from lower latitudes are in better synchrony with local conditions and remain active over a much greater portion of the available season, and they consequently accumulate far more biomass.

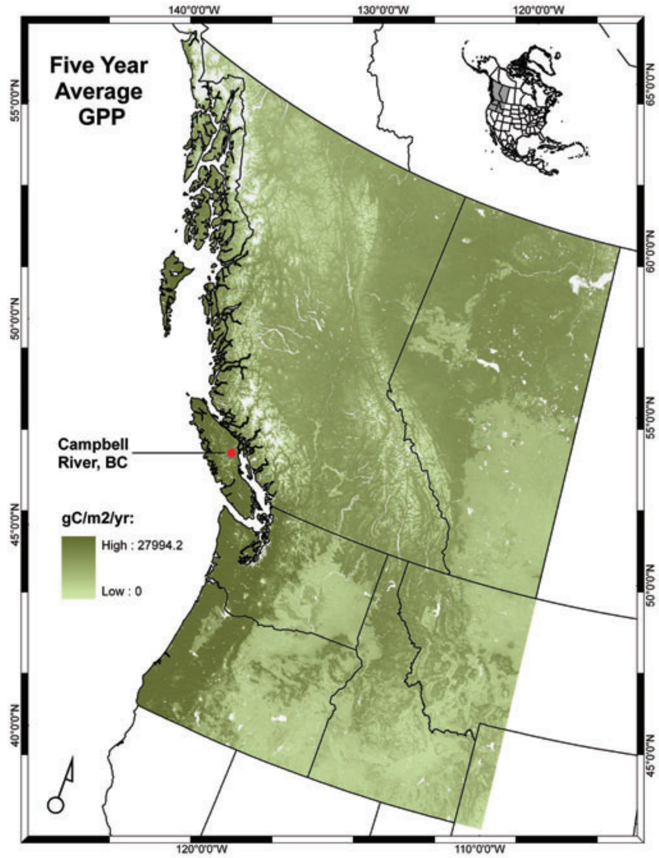
Although trees representative of northern populations generally do not grow as much as those from the south over any given summer, they can in fact possess higher photosynthetic rates. Indeed, they may also show the more rapid growth if measured over just a few weeks at the height of summer. We recently reported that light-saturated photosynthetic rates increased with latitude of origin in provenances of black cottonwood. This variation was well correlated with foliar nitrogen, stomatal conductance, and stomatal density.

The cline towards increased photosynthesis with latitude may be a generalised phenomenon among deciduous trees in North America. A similar trend is found in paper birch and Sitka alder and we see the same pattern in the AgCanBaP poplar collection. We speculate that northern provenances may have inherently high photosynthetic rates to compensate for the reduced leaf longevity associated with shorter growing seasons. Indeed, under an extended photoperiod in the greenhouse, where free growth is maintained, the fastest growing balsam poplar clones are from the far north. Clearly, the intrinsic growth rate must be assessed separately from the realized growth that occurs in a common garden. In other words, the largest individuals do not necessarily have the greatest growth potential if photoperiodic adaptation is unaccounted for. This raises the intriguing prospect of breeding trees from high latitude with trees of the same species from low latitude to combine high photosynthetic rates with a longer growing season. Using balsam poplar, such crosses have now been performed by collaborators at the PFRA and the "hybrid" progeny are undergoing assessment at Indian Head.

For further information contact Rob Guy, Department of Forest Sciences at 604-822-6023, rob.guy@ubc.ca or Shawn Mansfield, Department of Wood Science at 604-822-0196, shawn.mansfield@ubc.ca

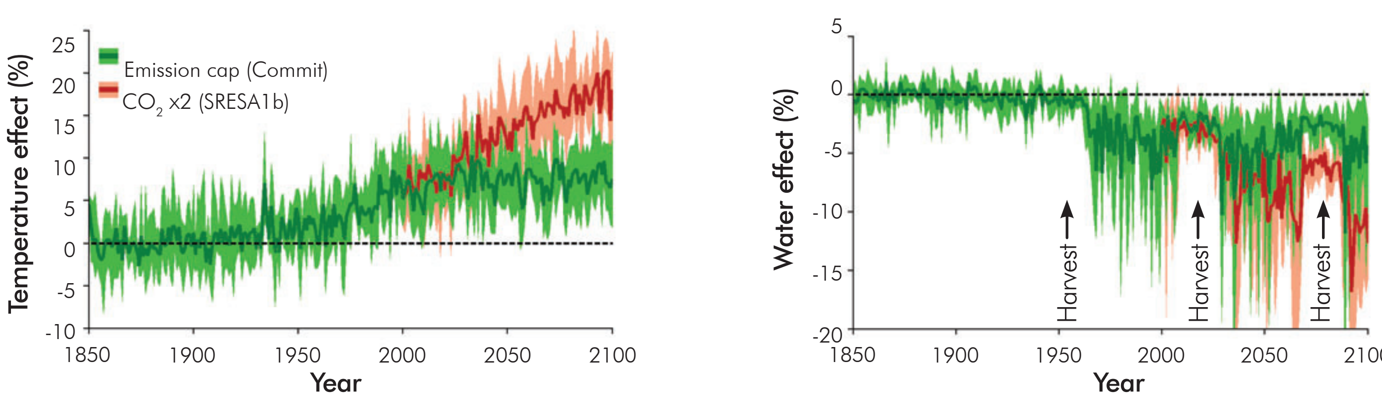
Climate-induced variability in forest growth capacity

RECENT ADVANCES IN THE FIELD OF palaeoclimatology have led to a better understanding of climate patterns, such as the El Niño-Southern Oscillation and Pacific Decadal Oscillation. As these patterns have a strong influence on physical and ecological processes throughout large areas of North America, it is important to understand the extent to which human-induced global climate change may be manifested through such patterns and their societal implications. Having already experienced a 0.7°C increase in average temperature, continued warming in BC may have a strong influence on the forest sector through changes in forest growth rate and the frequency and intensity of disturbance and drought, ultimately changing the composition, structure and function of forest ecosystems in the region. By estimating current and future forest growth, we can anticipate changes that will affect management of timber resources, conservation, and land-use planning.

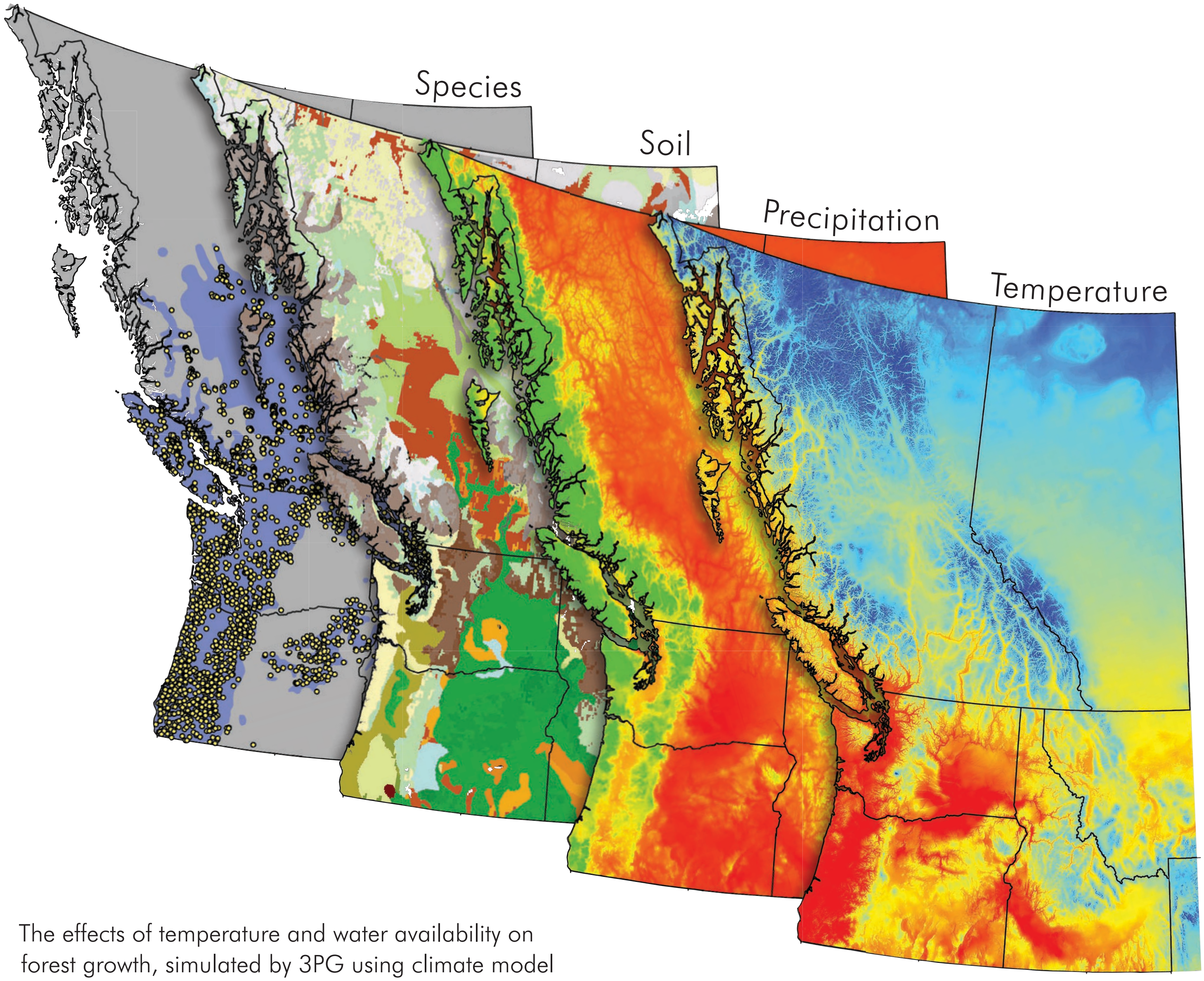


Annual Gross Primary Production of the Pacific Northwest as predicted by NASA, MODIS satellite observations.

Researchers in the Faculty of Forestry's Integrated Remote Sensing Studio (IRSS) are using this Pacific Northwest region to develop and test a stand-level physiological growth model (3PG), which accounts for climate variability through a set of constraints on potential growth imposed by solar irradiance, temperature, frost, humidity, and soil water availability. Measurement campaigns, undertaken by the Canadian Carbon Program (CCP) near Campbell River, have made it possible to calibrate the model and assess how accurately the model represents these climatic effects.



Model simulations near Campbell River, BC showing percent changes in forest growth associated with the effects of temperature (left) and water availability (right) according to two climate change scenarios using Environment Canada's coupled global climate model, CGCM3.1/T47 and hypothetical harvesting events. Shading reflects the variability produced by multiple runs of the climate model.



The effects of temperature and water availability on forest growth, simulated by 3PG using climate model and hypothetical disturbance scenarios, suggest that growth enhancement due to increased temperature may be partially (or entirely) counteracted by drought stress due to changes in water supply and demand. The net growth response associated with these contrasting effects remains a topic of open scientific debate. Although the net effect may seem small at the local scale, widespread and sustained changes may have significant socio-economic consequences.

Requirements for the forest growth model include monthly climate variables, soil fertility and water holding capacity, species ranges, and optional forest canopy properties such as leaf area index. Thus many spatial data layers (centre spread) are needed to extrapolate the predictions across the entire region. As the study area encompasses a diverse range of surface types and vast expanses of mountainous terrain, spanning parts of both the United States and Canada, assembling the necessary spatial data layers has been a substantial challenge.

This project will produce, for the first time, high-resolution (250 m) regional surfaces of potential and actual forest growth, intended to provide forest managers with consistent estimates of potential and actual timber harvest baselines and future forest yields. The project also contributes to an ongoing effort within the scientific community to understand and incorporate knowledge of climate-induced variability in forest growth into national estimates of carbon accumulation.

This research is jointly funded by NSERC, Biocap Canada and the Canadian Carbon Program (CCP) with support by the Canadian Forest Service and Interfor. For more information contact IRSS research team members Nicholas Coops, Todd Schroeder or Robbie Hember at 604-822-6452 or nicholas.coops@ubc.ca

Climate variability, climate change and streamflow

STREAMFLOW IS AN important source of water for human uses such as domestic water supply, hydro-electric power generation, irrigation and recreation. It is also an important component of aquatic habitat. Late-summer flows are particularly important as that season is often a period of high demand for water and coincides with the timing of salmon migration and spawning for many runs. Except for glacier-fed streams, late summer is typically dominated by low flows, which are sustained by release of catchment storage primarily in the form of groundwater. Extreme low flows can result in water shortages, reduced dilution of pollutants, impeded ability of salmon to migrate to their spawning grounds, and can result in high water temperatures, with potentially deleterious effects on cold-water species such as bull trout.

There is increasing concern that low flows may become more severe under future climatic conditions. Even in glacier-fed catchments, continued glacier retreat may diminish the buffering effect of glacier melt during drought conditions. To address these concerns, research led by Dan Moore, Diana Allen (SFU) and Paul Whitfield (Environment Canada) has examined the effects of past climatic variability and potential future climatic change on low flows in British Columbia. This project, titled "Climate Change and Low Flows: Influences of Groundwater and Glaciers," was funded by the Climate Change Impacts and Adaptations Research Program (CCIARP) of Natural Resources Canada. In addition, ongoing work on the hydrologic implications of future climate change in glacier-fed catchments is being conducted as a component of the Western Canadian Cryospheric Network (WC2N), funded by the Canadian Foundation for Climate and Atmospheric Science (CFCAS). WC2N is a five-year project that involves scientists and resource managers from UBC, University of Northern British Columbia, University of Victoria, University of Alberta, University of Calgary, Western Washington University, the University of Washington and Portland State University, as well as Natural Resources Canada, Environment Canada and BC Hydro.

Bridge Glacier, southern Coast Mountains, British Columbia. September 2006.

Statistical analysis of past data has shown that unglacierized catchments are generally exhibiting declining trends in September streamflow through most of British Columbia, but not in August. Glacierized catchments, on the other hand, show the opposite pattern, with dominantly negative trends in August but not September. There is also clear evidence for the effect of multi-year storage change only for the glacierized catchments.

For streams fed by rainfall and snowmelt, late-summer flows depended in part on conditions in the preceding winter and spring. For example, winters with low snow accumulation, especially when followed by an early spring snowmelt, resulted in reduced late-summer flows. Many climate

Bull trout.

change scenarios suggest that snowmelt in British Columbia may occur earlier than at present, potentially resulting in more extreme late-summer low flows. However, summer weather, especially the amount of rainfall, appears to have a stronger influence on late-summer flows than conditions during the preceding winter and spring. Except in northwestern British Columbia, August streamflow has been declining in glacier-fed catchments since the 1970s, consistent with the documented glacier retreat over the same period.

Overall, summer groundwater levels seem to have lowered across the province, despite an increase in winter precipitation and recharge during the same time period. Due to the limited availability of long-term well records near gauged streams, the attribution of whether and how these changes have affected low flows proves difficult due to differences in aquifer properties and influences of pumping of water from wells tapping the aquifer.

A computer model of glacier dynamics and catchment hydrology was applied to the Bridge River, a major source of flow for BC Hydro's Bridge-Seton hydro-electric facility, located west of Lillooet. Bridge Glacier is out of equilibrium with the current climate and has been retreating. Even assuming no further climatic change, the model predicts that the glacier will continue to shrink for the next 50 to 100 years before coming into climatic equilibrium. The associated reduction in glacier area will result in reduced glacier runoff and lower streamflow, particularly in August. Climate warming scenarios based on the A2 and B1 scenarios developed by the International Panel for Climate Change result in more rapid retreat.

Ongoing work by collaborators in WC2N is focusing on documenting past changes in glacier area and volume over the province, and developing models for predicting glacier response to future climate change, as well as the implications for water supply and aquatic habitat. In particular, ongoing studies are documenting the past, present and potential future magnitude of glacier runoff in the Columbia River system.

For further information on this research, contact Dan Moore, Department of Forest Resources Management, at 604-822-3538 or rdmoore@geog.ubc.ca

Meltwater stream.

Climate warming and salmon fisheries – a game of double jeopardy

PACIFIC SALMON (*Oncorhynchus spp.*) support the most valuable commercial and recreational fisheries in western Canada generating over $1 billion of revenue annually. They are also an important component of aquatic food chains, are integral to mythology, spiritual integrity, and local economies of Pacific coast First Nations, and are icons for the general public, with abundant salmon confirming healthy and pristine environments.

For the past 10 years, research lead by Dr. Scott Hinch (Department of Forest Sciences, and, Institute for Resources, Environment and Sustainability) and his graduate students, post doctoral fellows and colleagues has assessed the impacts of climate change on sockeye salmon (*O. nerka*) in the Fraser River, Canada's most productive salmon system. Most stocks of Pacific salmon now encounter warmer rivers during their spawning migration than in any time since records were kept. The Fraser River (as well as several other BC salmon systems) have experienced a >1.5°C average increase in peak summer water temperature over the past 40 yrs. Eight of the past 10 summers have been the warmest on record and climate models predict even warmer peak temperatures in the near future. Because of climate warming and a change in migration river-entry timing by several of the large stocks, segments of all Fraser sockeye stocks are now encountering river temperatures >19°C during a portion of upstream migration. This temperature encounter has profound evolutionary significance because no sockeye stock any where in the world is known to have initiated river migration at 20°C.

Since 2002, Hinch's group along with management agencies and private partners, have used biotelemetry to study the success of river migration to spawning grounds for 1000s of sockeye from several Fraser stocks

Photo courtesy Pete Rand, Wild Salmon Center.

Mature male sockeye salmon on spawning grounds.

and have provided clear evidence linking migration mortality and extreme temperatures. Extensive evaluation on one stock revealed that when river temperatures were 2-4°C higher than average, segments of the run exhibited extraordinarily high mortality (70-100%), but survival improved for individuals which utilized cold water refugia available in deep portions of lakes. Nevertheless, migration mortality seems to vary among stocks at a given temperature, suggesting either stock-specific differences in high temperature susceptibility or variable ability to utilize cold-water refugia. Field respirometry studies have provided evidence for the former as temperature optima is correlated to historical migratory temperatures. Thus, thermal tolerance and survival is likely stock-specific. Gene arrays of one Fraser sockeye stock which survived poorly during a high temperature migration suggested that some fish are entering the river with physiologies not conducive to high temperature stress.

The costs to the fishery of thermal-related sockeye mortality has already been substantial. In two recent extreme temperature years, 1998 and 2004, ~ 5 million fish disappeared during migration (wholesale value $50 million); in-season 'precautionary' reductions in harvest to help escapement was estimated at $16 million in forgone revenue. Future costs are equally alarming. For example in 2004, mortality was so cataclysmic that there may not be enough sockeye migrants to support commercial, recreational or Aboriginal fishing on the Fraser in 2008. Climate warming and the recent examples of exceptionally high sockeye mortality constitute a severe conservation risk and put the sustainability of Fraser sockeye and fisheries in doubt. Moreover, biological extirpation is an imminent possibility for several small stocks (i.e. the endangered Cultus Lake sockeye stock), threatening biodiversity for Pacific salmon.

New policies are shifting sockeye salmon harvesting from cool ocean to warm river locations. Historically, commercial harvesting generally took place in coastal marine environments. But with recent changes in federal fisheries policy and management strategies (i.e. Aboriginal Fisheries Strategy, Selective Fishing Policy, Treaties and Transition Strategy), harvest opportunities for First Nations and recreational fisheries, both of which primarily occur for sockeye in freshwater, either have increased or will increase. In fact, First Nations have priority access over all other user groups to harvest

Scott Hinch taking a blood sample from a sockeye salmon.

sockeye (in 2006, >1 million fish) and the previously non-existent recreational fishery for Fraser sockeye a decade ago has grown to be the largest of its kind in the Fraser (~200,000 fish in 2006). At issue is not necessarily the number of sockeye harvested, but the number of fish incidentally harmed and killed by the harvesting methods in warm freshwater. Many freshwater harvest methods (e.g. gill nets, angling) can result in escapees and released fish whose chance of survival is reduced by their exposure to warm temperature. That stress of capture can cause delayed mortality in salmon has been well recognized for over 50 years and many studies over several fish taxa have shown that strenuous exercise under high temperatures causes post-exercise mortality. Equivalent research for Pacific salmon is simply lacking. Without this information, especially in an era of warming climates, it is impossible for fisheries managers to ensure sustainability of fisheries and conservation of stocks. Hinch's group and colleagues have recently been funded through the NSERC Strategic program to conduct research to investigate the effects of temperature and handling stressors on the physiology, behaviour and survival of adult salmon and to assess effects of adult migratory thermal experience on eggs and offspring. Their findings will provide important information that will be used to help the fisheries management agencies with their task of predicting migration mortality, predicting future stock sizes, and managing habitat to conserve the resource.

For further information contact Scott Hinch, Department of Forest Sciences, at 604-822-9377 or scott.hinch@ubc.ca. A fully referenced version of this article can be found on our Faculty web site at www.forestry.ubc.ca/Research/ResearchHighlights/tabid/108/Default.aspx

Sequestering carbon through soil fertilization

BOREAL, TROPICAL AND temperate forests store vast amounts of carbon, two-thirds of which is in the soil. Altered C fluxes to and from forest soils could profoundly influence atmospheric CO_2 levels, and the implications of forest management practices on C storage and fluxes need to be factored into forest management decisions. Forest fertilization, particularly with nitrogen, may be one means of increasing the C-sink potential of forest soils, by causing more atmospheric CO_2 to be fixed by trees and also increasing the amount of organic matter that becomes humified rather than being released as CO_2. There is mounting evidence that greater N availability in soil and litter interferes with the decomposition of litter, causing more C to become humified and enter into long-term storage as soil organic matter.

Assessing the potential of forest fertilization to sequester carbon requires quantification of the additional C sequestration in biomass and soil, and we also need to ensure that the potential benefits of increased C sequestration are not accompanied by increased greenhouse gas emissions. In addition to CO_2, methane (CH_4) and nitrous oxide (N_2O) are important greenhouse gases. The greenhouse warming potential of CH_4 is 23 times and N_2O 296 times greater than CO_2 over 100 years. However, almost nothing is known about the effects of forest fertilization on greenhouse gas fluxes.

These are the questions currently being addressed in a collaborative research project, involving Drs. Sue Grayston, Cindy Prescott, Gordon Weetman, Brad Seely (Forest Sciences), Gary Bull (Forest Resources Management), Bill Mohn (Microbiology), Real Roy (University of Victoria), BC Ministry of Forests and Range and Western Forest Products Inc.

Grayston and colleagues have compared C storage in trees and soil and greenhouse gas fluxes in three 25-year-old forests (lodgepole pine in the interior of BC; Douglas-fir and western hemlock on the coast on Vancouver Island) following fertilization with urea (200Kg N) or fertilizer mix (N, P and micronutrients) and unfertilized controls. Stand volume and C content and soil C content were assessed 12-18 years after the initial fertilization. Nitrogen fertilization increased individual tree biomass and increased soil C sequestration in the lodgepole pine and western hemlock stands. Modeling of C storage data indicated that N fertilization increased total ecosystem C storage at rotation (80 years) by 12-16% in western hemlock and 24-25% in lodgepole pine. Fertilization resulted in an initial increase in CO_2 efflux as the fertilizer urea was mineralized, but rates returned to control levels within 14 days in all forest types. Fertilization led to a brief inhibition of soil CH_4 uptake in lodgepole pine stands and N_2O efflux in Douglas-fir stand. Our initial conclusions are that fertilization of these forest types has the potential to increase C sequestration, and that the initial impacts of fertilization on soil greenhouse gas dynamics are short-lived and minor.

Taking gas flux measurements (Amer Khan graduate student).

The final stage of the project will be an assessment of the economic viability of forest fertilization as a strategy to maximize C sequestration and reduce biosphere greenhouse gas emissions. Forest fertilization has the potential to increase timber revenue from faster growth of the forest, and additional revenue through carbon/emissions trading. The information gathered in these case studies in BC forest types will assist in the development of cost-effective strategies for enhancing biosphere C stocks.

For further information visit: http://faculty.forestry.ubc.ca/beg/ or contact Sue Grayston in the Department of Forest Sciences at sue.grayston@ubc.ca or 604-822-5928. This work is supported by an NSERC strategic grant and the BIOCAP Canada Foundation.

Will the water be there?

An exploration of climate change and the future of water resources in the Okanagan region

WATER RESOURCES, their management and use, are sensitive to variations in climate, and will be influenced by climatic change. Hydrologic studies of various watersheds throughout the world suggest that climate change will affect total annual flows, seasonal water supply and demand, and will have implications for ecosystem balance. Challenges can be expected for water managers as they seek to meet multiple objectives (energy, irrigation, domestic uses, navigation, flood control, etc.).

Researchers working on a collaborative project led by Environment Canada and UBC are using hydrological modelling to look at the long-term implications of climate change on water resources in the Okanagan region. This project is an important component of an overall effort to describe future changes in water supply and demand for several scenarios of climate change and population growth in the southern interior of British Columbia.

The UBC Watershed Model, developed by Professor Michael Quick of the Department of Engineering, was chosen to model precipitation-runoff processes in a number of gauged watersheds in the basin and tributaries entering Okanagan River and the main-stem lakes. This model has been used extensively in British Columbia, has been shown to adequately reproduce the hydrologic response of watersheds, and has previously been used in climate change studies in the Fraser River Basin.

Snowmelt is an important feature of annual streamflow patterns, and a warmer climate is expected to lead to earlier snowmelt. In the Okanagan, and many other watersheds which are also characterized by seasonal snowmelt, a warmer future would

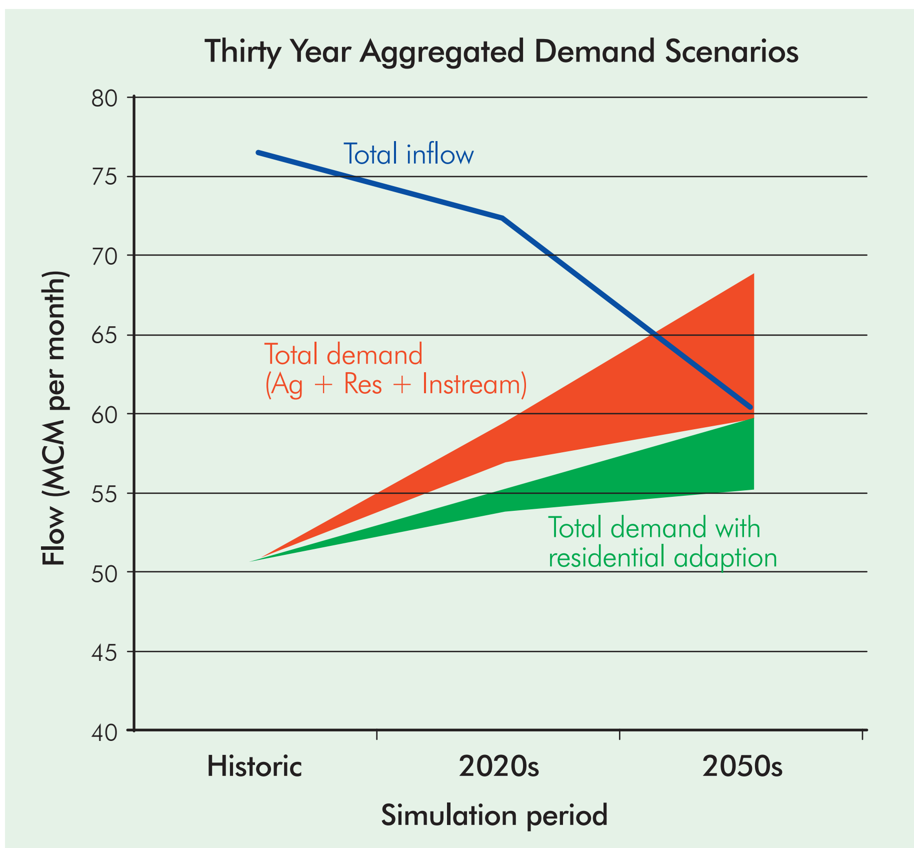


Figure by Stacy Langsdale from the 2006 final report.

Projected changes in Okanagan water balance for historic and projected average years. Potential water savings from residential users would partially offset the reduction in surplus between inflow and demand. (From the 2006 final report.)

result in an earlier seasonal peak in streamflow, followed by a longer period of minimum flows during the growing season.

For each of the scenarios used in this study, we projected that annual runoff volume would decline, while at the same time, demand for crop water (estimated separately) would increase. Subsequently, we used this projection of declining runoff as part of an assessment of projected changes in the region's water balance. The figure opposite shows that for a scenario of moderate population growth, combined with climate change, the combined effects of changes in runoff, demand for irrigation, and demand for residential water uses and in-stream requirements, would lead to a reduction in the surplus between supply and demand, and consequently, an increased likelihood of future water shortages within the Okanagan region.

This figure also shows potential savings from adaptation by residential water users. Adaptation measures, including conservation efforts by residential users, irrigators, and others, combined with new strategies for managing regional supplies and in-stream flows for fisheries, could be effective within these scenarios. However, it would be a management portfolio of increased complexity, and a challenge to local governance of water and planning of long-term regional development.


Irrigated fields in the Okanagan.

For further information, contact Stewart Cohen (scohen@forestry.ubc.ca), Younes Alila (younes.alila@.ubc.ca), or Tina Neale (tinan@interchange.ubc.ca). Dr. Cohen is with the Adaptation & Impacts Research Division (AIRD) of Environment Canada, co-located at the Department of Forest Resources Management at UBC. Dr. Alila is with the Department of Forest Resources Management. Tina Neale is with the AIRD, and is co-located at the °W. Maurice Young Centre for Applied Ethics at UBC. Cohen and Neale are the editors of a final report (Project A846) submitted to Natural Resources Canada in 2006. This follows earlier reports submitted in 2001 and 2004. Publications are available at www.forestry.ubc.ca/aird (navigate to projects completed). The project was funded by the Government of Canada's Climate Change Impacts and Adaptation Program during 2000-2006.

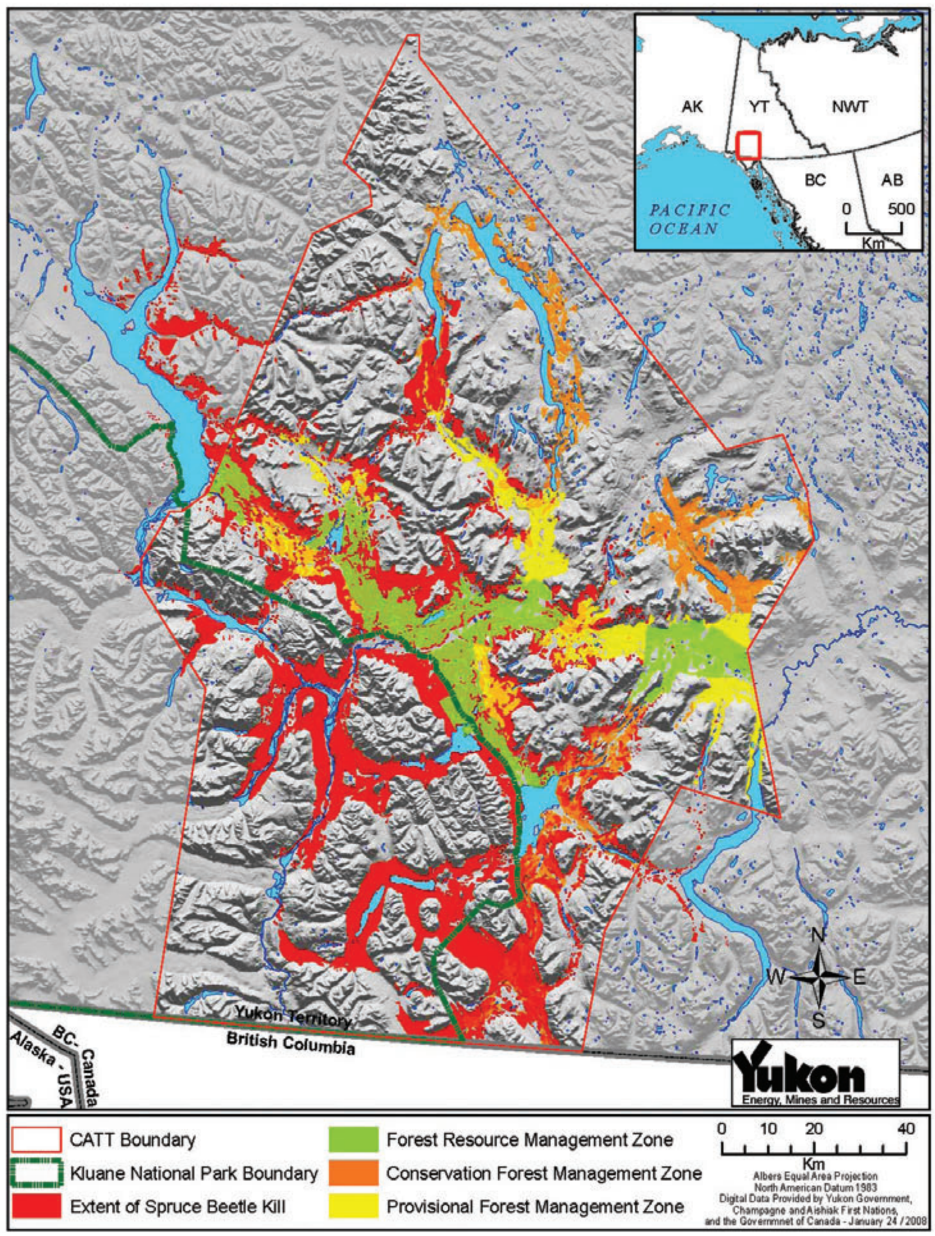
Northern forest management in a changing climate

NORTHERN FORESTED ecosystems are highly sensitive to climate change. In recent decades, northern boreal forests have experienced up to 1 degree of warming which has triggered significant ecological responses. Changes to the frequency and severity of fire, insect and disease outbreaks and forest productivity are some of the ecological impacts attributable to recent warming. The magnitude of climate change observed to date is relatively minor in comparison to what is projected to take place over the next century.

Northern forest-dependent communities are likely to be significantly impacted by these ecological changes because of their strong connections to forested ecosystems. One question for northern communities is how to manage forest resources sustainably in light of climate change so that they will continue to provide a steady flow of ecosystem goods and services upon which they depend. This question was the impetus for this project.

A logical starting point for climate change adaptation is to ensure that forest management plans reflect community goals and aspirations, that the goals and objectives are achievable in light of climate change, and that forest management plans incorporate the necessary measures to reduce vulnerabilities to climate change to ensure that management objectives are realized. Because of the irreducible uncertainties associated with climate change, it is prudent to identify and implement management practices and policies that have a higher likelihood of achieving forest management objectives across the wide range of potential climate futures.

The study area was the Champagne and Aishihik Traditional Territory (CATT) of southwest Yukon. Since the mid-1990s, a large scale spruce beetle outbreak has been driving forest management and planning efforts. The Strategic Forest Management Plan (SFMP) was jointly approved by the First Nations and Yukon governments and outlines the community-directed goals and objectives for forest management which include having functioning forest ecosystems and providing community sustainability and benefits. While climate change impacts are likely to affect whether

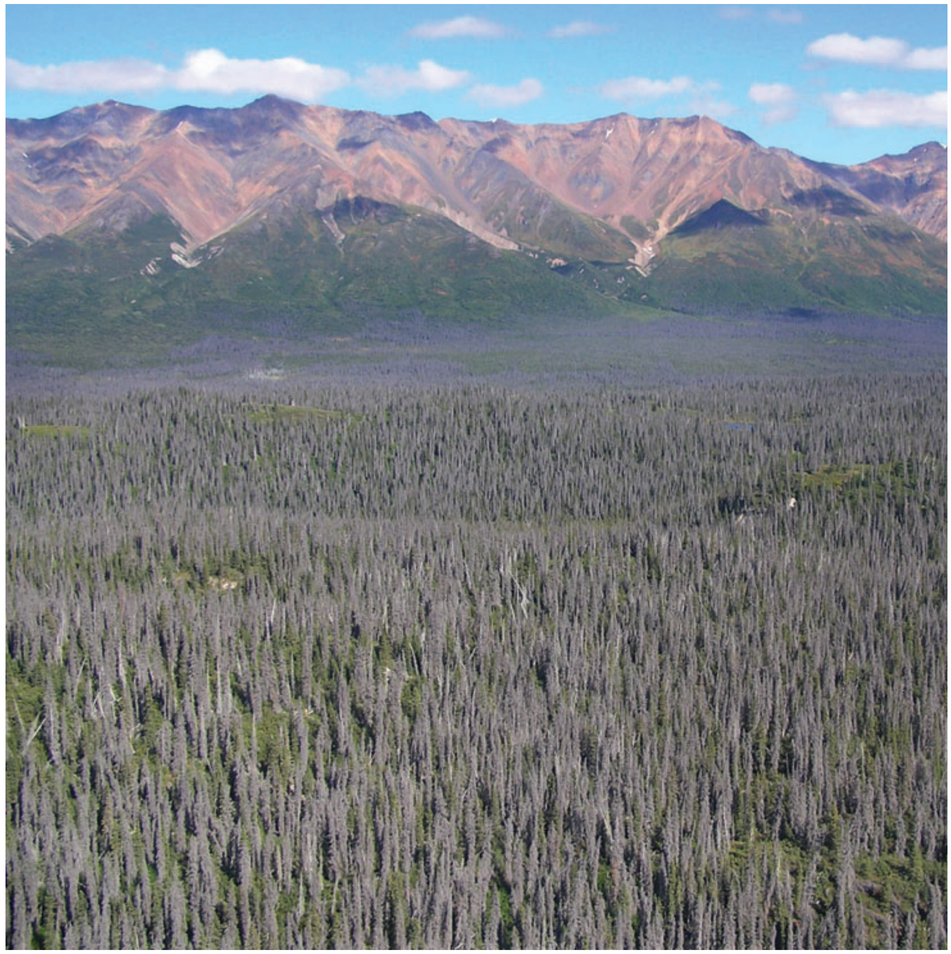


Study area.

or not aspects of the plan can be achieved, climate change was not an explicit consideration in the planning process.

Expertise and knowledge of climate change and resource management policy is not uniformly distributed amongst local residents, scientists and government agencies. Forest practitioners work at the interface of government, scientific and community knowledge and priorities and, as such, are experts of the local context. Tapping into the applied knowledge and experience of local practitioners is a good starting point for an assessment of adaptation options.

We engaged 30 local forest practitioners in working through a structured decision-making approach. From a list of over 80 adaptation options, they identified 24 "no-regrets" measures that they considered to be important to implement across three scenarios of future climate change. Despite clear management objectives for the CATT, practitioners differed over the importance of implementing the other adaptation options. The practitioners also assessed the performance of alternative strategies to re-establish the spruce-beetle affected forests. Results indicate that the applicability of alternative forest renewal adaptation strategies is strongly related to the objectives of forest management which differed across the forest management planning area. Since none of the forest renewal strategies were judged to perform highly across any of the scenarios of climate change, additional work is needed to explore whether a threshold of acceptability can be met even with the adoption of adjustments



Spruce beetle damage in the southwest Yukon.

to forest management policies and practices. If not, management objectives themselves may need to be revised. An extensive list of research and monitoring needs were also identified by the practitioners, an indication that climate change is providing the imperative for a more comprehensive research and monitoring program to support the sustainable management of forest resources in this region.

Climate change may alter visions of the future forest and expectations on what forest managers can realistically achieve. It may also be altering the balance between competing social, economic and environmental objectives of forest management. The choice of adaptation options will depend on local conditions, local vulnerabilities and overall management objectives for an area. Options that are available to a manager should be considered when preparing a management plan, and the structured decision-making approach appears to offer a suitable way to do this. Given the very large uncertainties, managers will need to monitor the effectiveness of their actions in maintaining the values that are considered important, and adaptive management techniques provide a suitable methodology to do this.

For further information on this project, please contact PhD candidate Aynslie Ogden at 867-633-7908, aynslie.ogden@gov.yk.ca or Dr. John Innes, Department of Forest Resources Management, at 604-822-6761, john.innes@ubc.ca

Meeting BC's carbon reduction targets with resilient communities

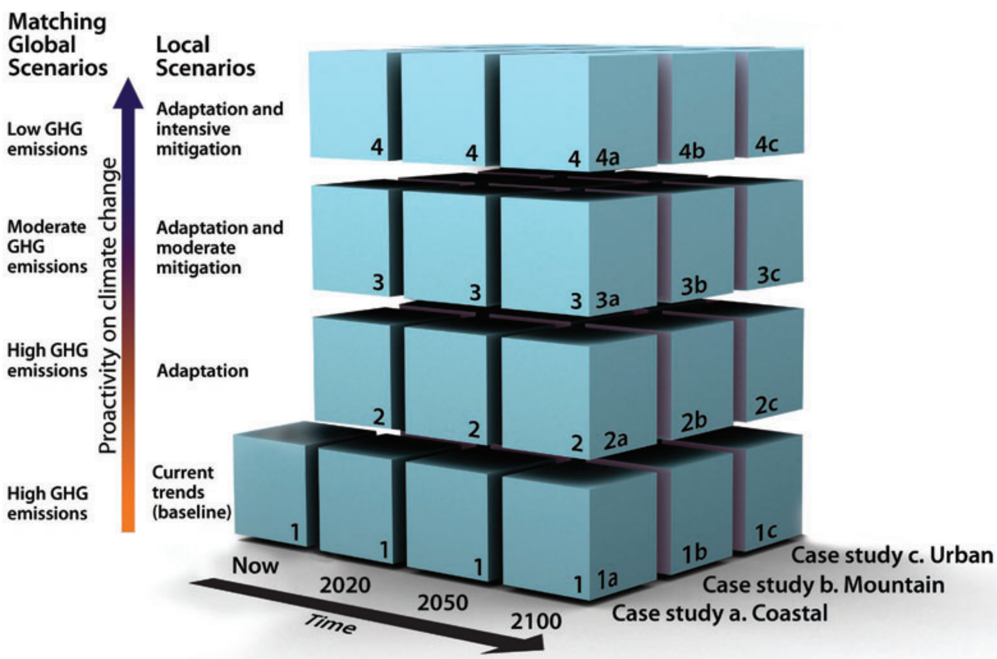


Figure 1. Conceptual framework for choosing BC climate change scenarios (1 – 4) to be visualized over time in different landscape types.

ONE OF OUR region's most urgent priorities is responding to global warming and its impacts on communities. In the 2007 Throne Speech the BC Government established aggressive targets for Greenhouse Gas (GHG) emissions (33% reduction from 2007 levels by 2020, 80% by 2050) and has previously identified priorities for adaptation to address unavoidable climate change impacts. However, GHG emissions are still rising along with risks due to climate change. How will these targets and challenges be met?

By some estimates, BC's communities influence over 45% of the Province's GHGs; municipalities also shoulder the burden of adapting to climate change, whether that is stabilizing their economy in the aftermath of pine beetle attack or safeguarding food and water supplies threatened by changing hydrological regimes across the west. UBC's Collaborative for Advanced Landscape Planning (CALP) is working with scientists, planners and stakeholders in the Lower Mainland to determine how these challenges can be faced, and what a resilient, low carbon community might look like. Since 2005, the research team has worked with two communities that confront different climate change challenges over the next 20-100 years (Figure 1): the coastal community of Delta facing sea-level rise (see Branch Lines Volume 18#2 September 2007); and the urban fringe on the Northshore mountains, affected by reduced snowpack/ water supply (Figure 2) and various increased hazards (described next).

Responses to climate change in a forest edge community

Working with urban forestry experts and engineers from the District of North Vancouver, MetroVancouver, and scientists from Environment Canada and other agencies, the project team developed alternative scenarios for the upper slopes of North Vancouver, Grouse Mountain, and the Capilano watershed (Figure 3). Like other upland communities with a forest backdrop, the analysis of local climate change impacts in a continuing high-carbon world suggests several trends of concern including: an increased fire risk from hotter and drier summers,

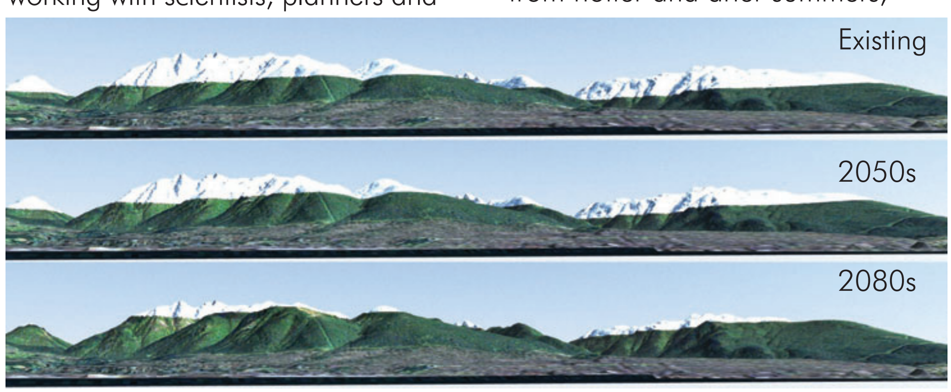


Figure 2. Illustrations of snowpack reductions on the Northshore mountains under a "Do Nothing" baseline scenario (showing average snow elevations on April 1st out to the 2080s), seen from Canada Place in Vancouver.

more windthrow in unmanaged hemlock-dominated forests due to increasing storm severity; reduced forest health; and increased terrain stability hazards and stream debris flows in susceptible zones (eg, ravine areas) due to more severe rainfall and run-off. Figure 4 shows GIS mapping of potential higher risk areas for fire and windthrow. Figure 5 shows what those areas might look like with windthrow along Mosquito Creek in 2020, and burned areas close to higher-elevation housing by 2050.

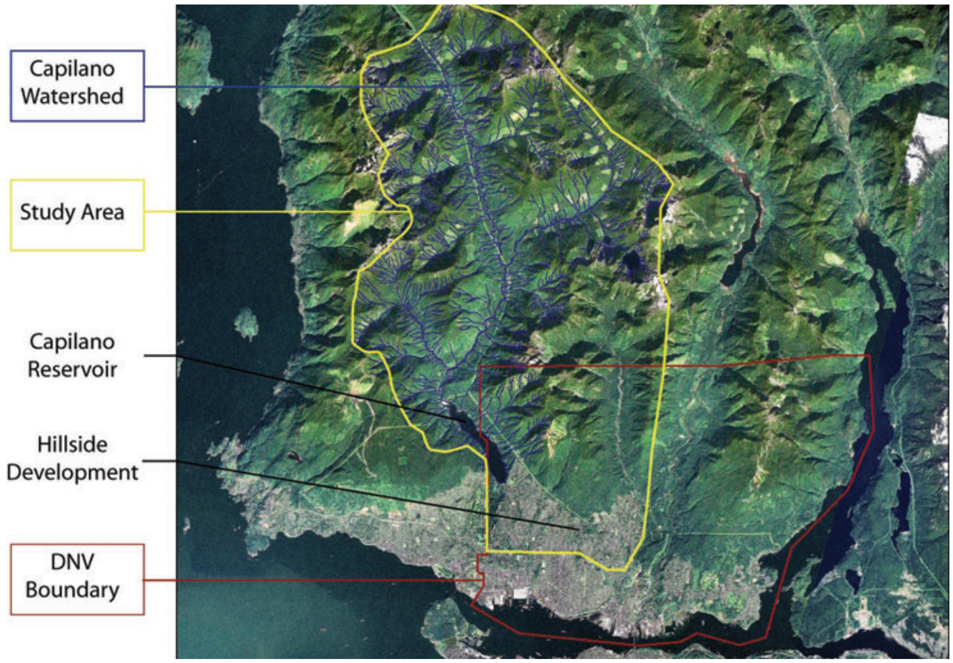


Photo: David Flanders, CALP

Figure 3. Aerial photograph showing the full Northshore study area.

With stand management to reduce fuel loadings in the forest, pest damage control, some tree removal near houses, and rehabilitation or set-backs of development from landslide zones along creek bluffs, future risks to property could be reduced. However, some of these measures would be controversial given city-dwellers' attachment to mature trees, local landscapes, and the wilderness appearance of the much-loved Northshore forests.

With assumptions of a lower carbon world where carbon emission reductions (like those required in BC's policies) are achieved globally, the risks of climate change would be substantially lower. Local measures to mitigate climate change could include: sustainable biomass harvesting from the forest slopes as a source of energy for local district heating systems; run-of-river projects to harness the energy of increased run-off in the Northshore creeks and reduce the streambed erosion and salmon habitat loss already taking place; and possibly wind turbines on the iconic Northshore skyline if wind speeds are found to be feasible. Single-family housing in areas vulnerable to climate risks and rapidly rising fuel costs would need to be substantially retrofitted to reduce energy consumption per capita and use of personal vehicles (Figure 6), with development of more walkable, self-reliant, live-work neighbourhoods and more drought-tolerant landscaping.

A new climate change planning process

Based on findings from the Local Climate Change Visioning Project supported by the GEOIDE Research network and other partners (described in Branch Lines 18#2), CALP is developing a process that any community in BC might use for envisioning and assessing local futures with climate change. It considers the causes, impacts, adaptation, and mitigation of climate change locally, using Geographic Information Systems (GIS), environmental modelling, and 3D visualization as decision-support tools. Together with regional climate modelling, expert advice, and local stakeholder workshops, these tools are used

Photo: David Flanders, CALP

Figure 4. Mapping of potential fire and blowdown hazards near Mosquito Creek (moderate to high forest fuel potential shown in orange; higher blowdown risk shown in cream). Adapted from information provided by District of N. Vancouver and Bruce Blackwell.

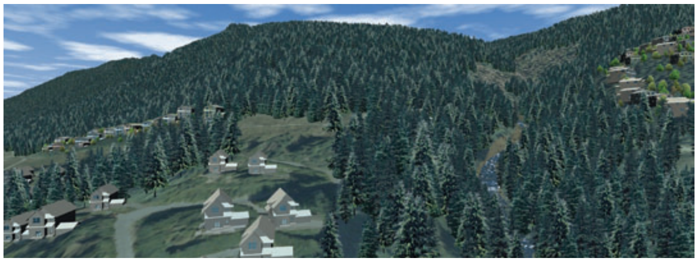


Figure 5a. Visualisation of the upper Mosquito Creek area in 2020 in the "Do Nothing" scenario, showing forest blowdown in susceptible areas along the creek, with increasing stream channel erosion.

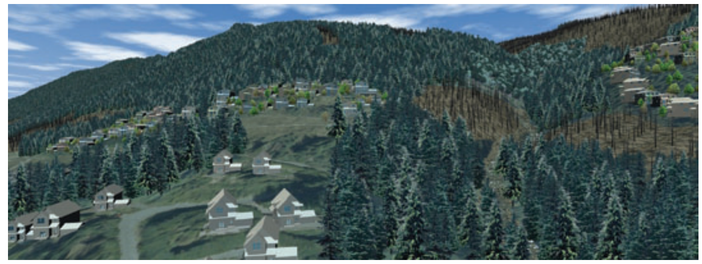


Photo: David Flanders, CALP

Figure 5b. Visualisation of the same area in 2050, showing burned forest conditions in areas of higher fire risk without proactive adaptation.

Figure 6a. Existing conditions in a "high-carbon", neighbourhood in North Vancouver.

Photo: Jon Laurenz, CALP

Figure 6b. Conceptual visualisation of a retrofitted "low-carbon" neighbourhood with neighbourhood offices and shopping, low-carbon transportation, passive solar energy, multi-family house conversions, limited local food production, etc.

to develop visioning packages for each community or neighbourhood, showing realistic depictions of different adaptation and mitigation strategies that reflect the best available data, science, and practices. These alternative scenarios are then assessed against carbon-reduction targets and other key sustainability/ feasibility criteria, and preferred scenarios are refined through community design charrettes or other public process. Community education, dialogue and input are vital throughout.

Based on results so far this new kind of process should:

- improve community engagement and capacity-building for responding to climate change;
- increase the acceptability of necessary community responses and
- dovetail with existing planning procedures to accelerate action on GHGs and adaption priorities, leading to altered planning/land management policies and more resilient communities with greatly reduced carbon footprints.

The future

CALP researchers are hoping to work with other extension agents in the Provincial government, regional agencies, industry, and NGOs to transfer knowledge (in both directions) and test new planning and visioning techniques with communities across BC that are trying to meet the government's challenge. For more information visit the CALP website (www.calp.forestry.ubc.ca) or contact Dr. Stephen Sheppard at 604-822-6582, stephen.sheppard@ubc.ca or Adelle Airey at 604-822-8912, adelle.airey@ubc.ca

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