


By Sally Aitken, PhD and
Jack Woods, RPF, MSc

Are Our Forests' Genes Behind the Times?

Forest professionals have long known that natural tree populations are adapted to their environments — particularly to local climates. The first provenance trials were established in Europe more than two centuries ago and clearly demonstrated differences among provenances in broadleaves such as oaks, as well as conifers such as Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris L.*). In BC, continuing in this tradition, we have long practiced a "local is best" approach to seed transfer, with "local" defined using data from comprehensive provenance trials. Forestry is well ahead of other fields, such as ecological restoration in this regard. The Chief Forester's Standards for Seed Use continue to support the use of seed from local sources, including both class-B seed from natural stands and class-A selected seed produced in seed orchards. Most forest professionals are very comfortable with this approach.

While forestry in BC has gained from understanding and respecting local adaptation, we are now facing a huge challenge. Climate change is creating a mismatch between local populations and the environments they inhabit. Local environments are not the same as they were last century and the differences between past and new climates are increasing. As a result, local seed sources are becoming less optimal for survival, growth and health. The fossil pollen record and genetic data show that species and populations have migrated in response to past climatic changes (e.g. Since the last ice age), but the maximum rates of natural migration are far too slow to keep up with anthropogenic climate change.

Provincial seed transfer guidelines have been modified to encourage more seed transfer from warmer to colder locations, but these changes only tweak the existing policy framework. We need a new seed transfer policy framework that can be adjusted over time to climate warming, and will not require re-invention every decade. We also need a system that recommends transfers for both selectively bred class-A seed, and for wild stand class-B seed. The Ministry of Forests, Lands and Natural Resource Operations is developing such a system and various research groups have projects underway to help inform this effort.

To develop a climate-based seed transfer system, several types of data are required. First, we need climatic data for past, current, and the full range of projected future climates, and these data need to be available for every reforestation site in the province. Fortunately, these data are already available through the open access software, ClimateBC. This software allows you to estimate average climatic conditions for a large number of variables for the past 100 years for any location in the province. You can also select among general climate models and carbon dioxide scenarios to predict future conditions over time. ClimateBC is available at http://cfcg.forestry.ubc.ca/projects/climate-data/climatebcwna/#ClimateBC

Second, we need to better understand the relationships between climate and genetics for each species. What climatic factors have had the strongest effect on natural selection? In general, we find that temperature drives patterns of variation more than precipitation for many species, but precipitation effects are still significant. Are mean temperatures more important to consider, or are temperature extremes driving patterns? We find evidence of both. Do populations vary more with summer climatic conditions such as warm temperatures or precipitation, or are patterns of variation more strongly related to the length of the frost-free period and the depth of freezing events? Again, we find all of these factors are associated to some degree with local adaptation.

Provenance trials are the gold standard for assessing these patterns of adaptive variation, and BC has some of the most comprehensive provenance trials in the world. However, they take decades to complete, and we do not have large trials adequately representing all species and areas. As part of the AdapTree Project (http://adaptree.sites.olt.ubc.ca/), we are using short-term seedling trials in growth chambers, outdoor nursery experiments and field experiments to understand adaptation to climate in both lodgepole pine (*Pinus contorta*) and Interior spruce. In these trials, we study climate-related traits like the timing of growth and dormancy, assess cold hardiness in artificial freezing tests and test drought hardiness under controlled conditions. These traits are difficult to study in the field. Seedling studies can quickly generate information on growth and stress tolerance of provenances and we can compare these results to the performance of provenances in long-term field tests, where available. This field validation step is critical as it allows us to look at tree growth in the real world and compare results for seedlings with growth and health of more mature trees (up to 40 years of age). We are also comparing natural and selectively bred trees to determine if selection for faster growth has indirectly selected for changes in climate-related traits.

New genomic tools are available for studying genetic variation between and within provenances at the DNA level. The genomic revolution and "next-generation" sequencing technologies have provided us with the ability to study genetic variation in DNA sequence in approximately 25,000 genes simultaneously in the genomes of both lodgepole pine and Interior spruce. Within these genes, we are looking at variation in millions of DNA 'letters' to determine if that variation affects important climate-related traits, and if it is correlated with climatic gradients. This research has thus far revealed tremendous complexity in the genetics of adaptation, with hundreds of genes affecting most traits and tens of thousands of small changes in DNA sequence associated with climatic and geographic variables. These genetic markers also allow us to quantify the capacity of populations to adapt to new climates.

In addition to understanding genetic differences between provenances, we need to determine how much variation exists within provenances and orchard seedlots. Is the variation great enough that some trees will be able to thrive in future climates even with climate change? How many generations will it take for natural selection to adapt populations to new climates without human intervention? Should we be increasing genetic diversity in the genetic materials by planting two or more seedlots? This is one way to address uncertainties around future climate, high levels of year-to-year variation in weather and

FORESTS' GENES continued on Page 30

FOREST PATHOGENS continued from Page 19

2005 and 2006 (R. Reich pers. comm.). Comandra blister rust infections are reported to occur in wave years but three consecutive wave years of infection in this trial represent a change in disease behaviour. Earlier reports of this same pathogen in central BC in the 1980s and early 1990s suggested that the disease was uncommon. On the landscape scale, three surveys of 60 or more randomly selected juvenile lodgepole pine stands in the west central Interior show an almost three-fold increase in combined hard pine rust incidence and a six-fold increase in the proportion of stands, with rust incidence over 20% between two surveys conducted in the late 1990s and a subsequent survey of the same population in the late 2000s. The pathological landscape in BC's managed forests is not the same as it was even two decades ago.

There are other pathogens that respond to environmental extremes and it appears that the forests of central BC are also being challenged by these. A recent widespread occurrence of top dieback in lodgepole pine in the central Interior may in part be linked to an abrupt (40°C) drop in temperature in the fall of 2010, following a drier than average summer. That combination of environmental conditions is considered a trigger for *Cenangium ferruginosum* and this opportunistic pathogen is believed to be at least in part responsible for the extent of top dieback in lodgepole pine in the western portion of BC's central Interior. This example further emphasizes how environmental change can drive biotic disturbances leading to unforeseen forest conditions in what we have considered a stable predictable forest management system.

When pathogens attack the smaller, weaker trees in managed stands they have minimal impact. When they attack the dominant trees and create gaps, they expose the Achilles heel of traditional growth and yield theory. No single factor has a larger influence on managed stand productivity than unexpected mortality or loss. Managed stands in much of the Interior are experiencing losses in healthy stocking due to forest pathogens. To a degree these losses are expected. The extent to which these losses are already accounted for, though, depends on the incidence of damage agents (which evidence suggests is increasing), the size of the trees affected (which covers the entire range of tree classes and is not limited to the small and weak) and the ultimate fate of non-lethally damaged trees (which remains uncertain but is not as rosy as that of undamaged trees). Post-free-growing monitoring has provided evidence of considerable timber losses to biotic and abiotic damage agents. In the same areas data from these same monitoring programs suggest that the healthy trees are growing at least as fast as earlier predicted. Data from both Stand Development Monitoring (SDM) and Young Stand Monitoring (YSM) require dedicated analysis and a sharpened focus on understanding the implications of the findings which must then feed back and inform both policy and practice.

BC has a distinct advantage over other forest-dominated jurisdictions to conduct innovative and proactive climate change activities. Our forest land base is overseen by a single land steward. This sets BC apart from most other forested jurisdictions including our neighbours to the south, where there are many more landowners and decision makers, which make co-ordinated decisions on a landscape scale more difficult. We can actively manage our plantations for climate change mitigation more so than in much of the boreal forest where tree species options for planting are few and where large tracts of undeveloped forests are left to fend for themselves. The most effective management decision we can make to facilitate the creation of more adaptable future forests occurs at stand initiation. We can plant species that may be better adapted to future conditions. We can also plant greater densities and a greater diversity of species to lessen the threat posed by any single insect or pathogen or abiotic factor. Over 170,000 ha of forest land in BC were planted in 2012/2013. That is a significant area of land on which we can directly influence future forest conditions and the ability of those forests to both adapt to and mitigate against climate change and its associated bothersome externalities. ❧

Alex Woods is a research forest pathologist for the BC Ministry of Forest Lands and Natural Resource Operations based in Smithers. For the past 20 years he has investigated the impacts of forest diseases on managed stand productivity with an increasing focus on the implications of climate change.

FORESTS' GENES continued from Page 23

uncertainty about what life stage we should target (e.g. seedlings or saplings) to best match trees with climate for productive rotations.

Finally, to move to a climate-based seed transfer system that aims to put climatically well-adapted seedlings in the ground, we need to gain acceptance of this approach from silviculturalists and other forest professionals. In forestry, unlike in some other fields, we have done such a good job of convincing people that "local is best" that it's hard to leave this principle behind. A climate-based seed transfer system will need to roll out changes that are initially small, and then gradually increase transfer distances as climates warm and experience and knowledge increase. Maintaining resilience and productivity will require a shift from our local-is-best history of genetic resource management to one that uses the sophisticated tools and information at our disposal. ❧

Sally Aitken, PhD, is a professor in the Department of Forest and Conservation Sciences at UBC. Sally is project leader for AdapTree and director of the Centre for Forest Conservation Genetics. She studies local adaptation to climate, population structure and genetic diversity in native tree species, and teaches forest biology, alpine ecology and conservation genetics.

Jack Woods, RPF, MSc, is program manager for the Forest Genetics Council of BC, a government/industry cooperative that provides a forum for collaborative business planning and policy advice to FLNRO on all forest genetic resource management activities. Jack also leads a council-owned company called SelectSeed Ltd. that produces Class-A seed for sale within BC.