Trees in our native and urban forests and forest plantations are invaluable for our survival and well-being. Understanding and utilizing the natural genetic variation that exists in our tree species allows us to manage some of the impacts from the biotic and abiotic stresses that trees face and to guide our future reforestation and restoration efforts.

The October 1995 issue of the Western Forester focused on forest genetics and its application in management of our nation’s forests, particularly in the Pacific Northwest (PNW). This vital work has continued in the ensuing 22 years, and in this 2017 issue some of those efforts are presented and expanded to include some work in the Inland Empire. With several PNW groups recently celebrating 50 years (and even 100 years for early research) of forest genetic and tree improvement related activities (see articles by St. Clair, Erickson, Crawford, Yanchuk), it is timely to note accomplishments and continued needs. With a changing climate and continuing accidental introductions of destructive non-native insects and diseases, it is the natural genetic variability within our native tree species that will be the basic resource to help restore unhealthy forests, maximize productivity of plantation forests, and help meet the diverse future needs of society.

Growing public awareness of genetics in general has brought forest genetics onto the list of forest resources that require active management and stewardship. Concepts of adaptation, innate disease or insect resistance (or susceptibility), and growth potential are now commonly understood to be largely controlled by genetic factors. Genetic conservation strategies are an important component of managing our food crop species, and they are equally important for our tree species. However, unlike most crop species, genetic considerations for some tree species involve not only their potential commercial use, but also the need for these species to continue to persist and evolve for generations in natural ecosystems. The awareness of forest genetics and value of tree improvement has been embraced by federal, state, county, tribal, and private land managers.

As an investment, applied forest

(Continued on page 2)
Genetics and our Northwest Forests (CONTINUED FROM FRONT PAGE)

Tree breeding programs are unique in that they are cumulative. Once parents of interest are identified and incorporated into seed orchards, gains achieved in traits such as growth rate, stem form, or disease resistance will be available for the next forest plantation without annual input, unlike recurring costs such as planting or fertilizing. Using tested parents as the basis for the next generation of improvement provides an ever-increasing catalog of data to help make future selections. What we do now will influence forests well into the future.

The seed collected, the field trials established, and the data gathered in forest genetic tests and tree improvement plantings provide baseline information on genetic variation in each of our native tree species and which sites the different populations (provenances or geographic sources) within a species may be best adapted (Harrington, Howe). As part of applied forest genetics programs, seed has been collected from tens of thousands of individual parent trees in the Pacific Northwest and Inland Empire, and many of the parent trees have been cloned by grafting into seed orchards or clone banks (Cress). Most of these selections are from the conifer species of highest economic importance, such as Douglas-fir and ponderosa pine, but extensive collections of seed and vegetative materials (for grafting or rooted cuttings) have also been made for species such as whitebark pine and Port-Orford-cedar. The seed of many of these species can be stored for at least several decades and provides a means of ex situ genetic conservation (a backup plan in case of disasters). The stored seed of individual trees provides an immediate source of material to evaluate genetic variation within these species as new disease or insect threats arise or as abiotic stresses from a changing climate become apparent.

While the level of federal funding for many applied tree improvement programs has seen severe cuts since the 1980s, the contributions of both genetic materials and expertise developed in those programs have continued to be major factors in the region. The large federal and state-owned acreage in the regions is well represented with selections of most major tree species, which often formed the immediate source of material to evaluate genetic variation within these species as new disease or insect threats arise or as abiotic stresses from a changing climate become apparent.

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but for other landowners, there are options such as Oregon Department of Forestry’s Seed Bank (see sidebar on page 4).

Most of the early work in forest genetics was undertaken with species of the highest commercial importance. However, understanding the genetic variation in other tree species such as whitebark pine, Port-Orford-cedar, foxtail pine and Pacific madrone have also been recently undertaken. The expertise and infrastructure developed for the commercially important species has helped make the work with these species more efficient. In some cases, such as with whitebark pine, restoration plantings on federal lands also serve as sentinel plantings. The project has been an informal cooperative project of several pathologists (WSU, ODF) and geneticists (USFS and British Columbia Ministry of Forests, Lands and Natural Resource Operations), with field sites provided by several organizations.

Pacific madrone (Arbutus menziesii) provenance trial on Starker Forests land is assessed for growth, survival, and foliage blight in fall 2015, four years after planting. A common set of 105 families representing seven ecoregions from central California to British Columbia were planted on sites in California, Oregon, Washington, and British Columbia to evaluate the adaptive genetic variation in this hardwood species and serve as sentinel plantings. The project has been an informal cooperative project of several pathologists (WSU, ODF) and geneticists (USFS and British Columbia Ministry of Forests, Lands and Natural Resource Operations), with field sites provided by several organizations.

shown on the y axis, variation in fourth-year height (cm) within and between Pacific madrone families from the seven ecoregions (x axis) represented in the provenance trial at the Starker Forests site (1-7 represent Cascades, Central CA Foothills and Coastal Mountains, Coast Range, Klamath Mountains, Puget Lowland, Sierra Nevada, and Willamette Valley ecoregions, respectively). Note the large variation in height among families within the same ecoregion (family = seedlings originating from seed of one mother tree).

Articles in the 1995 issue (posted at www.nwoffice.forestry.org/northwest-office/western-forester/2017) covered topics of importance to forest genetics and provides a synopsis of the early history, progress, and considerations in many of the forest genetic and tree improvement efforts needed to maintain healthy and productive forests.

Forest genetic and tree improvement programs are large and long-term undertakings (Lipow). Organizations have banded together in the form of cooperatives to carry out much of this work. In this issue, articles provide overviews of tree improvement programs, genetic resource management, and research efforts to provide the reader with knowledge of the history, benefits, and findings to help inform future decisions.

By its nature, the future is often uncertain. However, the needs of society for products from our forests, and the (continued on next page)
need for healthy forests for recreation and other services will continue to grow. Experience has taught us that we will likely see new destructive non-native pathogens and insects in our forests. A changing climate will place stress on our forests. Knowledge of the genetic variation of our tree species helps us to meet the increasing future needs of society and reduce the impacts of biotic and abiotic stresses that will come. For the most part, past tree improvement efforts in western North America utilize classical selective breeding techniques to increase genetic gain in traits of interest, but in the future a detailed understanding of genomic resources will help provide more precise knowledge to guide breeding efforts (Howe). Trees are on the landscape for decades and even hundreds of years or more. Foresters and those working to maintain forest health need to be thinking well into the future to ensure forests have the best chance to meet ecological and societal needs. Most of our planted forests have been influenced positively by the stewardship and contributions of the forest genetic community. The past record has been encouraging, and with continued support of the organizations involved, forest geneticists and tree breeders working with colleagues in silviculture, ecology, forest health, and other disciplines will ensure this continues.

Seed Available through the Oregon Seed Bank

The Oregon Seed Bank has long-standing agreements that allow it to obtain seed from a variety of breeding programs in the PNW including Oregon State University, US Forest Service, BLM, and Oregon Department of Forestry programs. These advanced genetic selections may be selected for disease resistance, enhanced adaptability, increased growth rates, enhanced timber qualities, or a combination of traits. In addition, the Seed Bank has statutory authority to purchase seed from any seed orchards established at the Oregon Department of Forestry Schroeder Seed Orchard complex. These arrangements provide family forest landowners equal access to seed. The Seed Bank sells seed of these advanced genetic selections, along with natural seed collections, from a variety species and seed zones to nurseries in Oregon. These nurseries then produce seedlings that are available for sale to family forestland owners and other customers. Additional information about the program along with listings of seed availability is located at www.oregon.gov/ODF/Working/Pages/Seed.aspx. 

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Why Grow the Seed to Grow the Seedling?

BY DAN CRESS

A lot of time and money has been devoted to improving a whole range of tree species. Cattle breeders use similar techniques to improve their dairy herds, but is it practical to address genetics during everyday silviculture? In a word: Definitely.

We plant high-elevation sites with noble fir instead of grand fir; that’s genetic selection. Douglas-fir isn’t resistant to laminated root rot, yet white pines and cedars are. Maybe plant the pines if you have access to rust-resistant stock and if the rust pressure isn’t too severe. Maybe use cedar due to its higher value, especially if those materials have been selected for resistance to deer browse. Consciously or not, silviculturists have been utilizing genetics for ages. Today’s technology just allows us to be even more targeted than we have been in the past.

Tree improvement isn’t cheap. An alternative would be to avoid planting entirely and hope for the best with natural regen. There are places where this might make sense, but this usually isn’t the case here in the Pacific Northwest. Seed zones are available for guiding woodsrun cone collections, so why do we go to great lengths to actually grow the seed to grow the seedlings? Millions of dollars are spent every year to create and manage seed orchards. We even go so far as to control the pollen that pollinates each orchard cone. Orchards can generate large seed with vigorous embryos, big cotyledons, lots of endosperm, and so on. Tree improvement programs are what we use to actually decide what is, or isn’t, included within these orchards. Think of orchards as an investment rather than an expense; we wouldn’t use them if they didn’t make financial sense.

The biggest costs in tree improvement come from breeding and progeny testing. We hand-pollinate female flowers with pure pollen so we know the pedigree of every seed that we sow to generate the test seedlings. Thousands of them are outplanted at a variety of sites where their performance is tracked for a decade or more. The very best selections from those tests are what we use to establish newer and better orchards over time.

Consider western hemlock from out on the coastal strip. The first-generation tests involved about 25,000 trees from each of five separate zones. The best of those materials went into seed orchards and were also used as the parents in a second-generation breeding program. Those pedigreed seedlings were deployed at new test sites spread all the way from Newport to the northern tip of Vancouver Island. This means 83,000 more selection options that can be used to establish the next round of seed orchards. Want to select for growth at various locations and ages? Want to consider stem form and wood properties? Do Tillamook families growing at Forks give us insights about how trees might respond to climate change? What crosses are we making for the third generation and beyond? The math gets complex, yet this is exactly the type of work that we do, for many species, on a daily basis.

What about seed zones? They imply that local seed will be the best seed. A cumbersome yet better description would be to say that “local seed is a safe bet in the absence of pedigreed data.” Woodsrun seed collected from a site is presumably well-adapted to that site, but there could certainly be something just as suited to that environment that grows faster, has better wood properties, has better stem form, and so on. Tree improvement is what we use to compare all of these options.

We have sound data on the performance of each test tree and that of its parents, its cousins, its siblings, etc. Great, so how does growth and adaptation within a test site compare to performance under operational conditions? Realized gain trials have been established to address such questions over time. By no great surprise, tree improvement is a success here in the west just like it has been for things like radiata pine in New Zealand and loblolly pine in the south.

The next step is to adjust the various growth and yield models so they take tree improvement into account. Another line of study is to optimize the trade-offs between traits such as growth, stem form, wood properties, and growth rhythm. These past 50 years’ worth of breeding and testing generated 128,000 second- and third-generation selection candidates for some new seed orchards that I designed earlier this year. We can make substantial gains, for an array of traits, when working with populations this huge. I can only imagine what folks will have available to them 50 years from now?

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An excellent Douglas-fir cone crop. The cones on these three branches can produce about 10,000 seed.
The Pacific Northwest (PNW), similar to other forestry areas growing temperate conifers, has a long history of applied cooperative tree improvement. With multiple landowners typically managing forestland within a given geographic area, it has been logical to pool resources for the expensive, long-term endeavor of field testing and breeding. Tree improvement leadership was first provided in the PNW via the Industrial Forestry Association and the US Forest Service PNW Research Station (jointly coordinating the Progressive Tree Improvement System) from 1966 to 1985 and after 1986 by the Northwest Tree Improvement Cooperative (NWTIC).

Establishment of first-cycle Douglas-fir tests began in 1967 and continued to 1993. A typical first-cycle cooperative tested 200-300 trees selected at an intensity of about three trees per 1,000 acres on 6-10 test sites. Local adaptation was emphasized leading to small breeding zones. In addition to testing programs designed as cooperative programs, four independent programs (Bureau of Land Management, Georgia-Pacific, Simpson, Washington State Department of Natural Resources) came later under the NWTIC umbrella. About 1,000 first-cycle Douglas-fir tests were established, in which approximately 30,000 first-generation selections were tested. The earliest full-sib second cycle test was planted in 1984, but the rest were planted after 1996 with establishment scheduled to continue through 2022.

Second-cycle Douglas-fir sites have been established from Skagit County in Washington near the Canadian border south to Curry and Douglas counties in Oregon (and eventually to the northwest tip of California).

Tree height was assessed from the first measurements around 1975, and diameter at breast height (DBH) from the first age-10 measurements. Stem defect (forking, ramiforms, and stem sinuosity) and wood density were routinely assessed from the early 1990s after those traits were shown to be heritable and measurement protocols established. Three additional traits (spring bud-break, second flushing, and fall cold hardness) are now being scored in second-cycle tests. Needle retention is assessed in the area of the northwest Oregon coast exposed to Swiss needle cast disease. Non-destructive acoustic tools for assessing wood stiffness in tree improvement became available around 2005, and so far about 32,000 trees have been assessed. Other traits (e.g., drought damage, top break) are assessed in certain tests.

Third-cycle breeding orchards were established starting in 2006. All the second-cycle cooperatives decided to proceed to third-cycle breeding and testing. Compared to a delay of 20-34 years from the start of individual first-cycle programs to establishment of second-cycle tests, the goal is to establish third-cycle tests within 15-20 years after second-cycle tests were planted. The first group of third-cycle tests was established in March 2017 on six sites on the Oregon coast.

Breeding and testing of western hemlock has been essentially a small-scale version of the Douglas-fir effort. First-cycle testing began in 1975, and a second-cycle program for the coastal strip of Oregon, Washington, and southwest British Columbia started in 1992. Age-10 data collection for all these second-cycle sites, testing 539 full-sib crosses, was completed by 2009-10. Third-cycle breeding is underway. There was also a small first-cycle testing program for noble fir.
Cooperative seed orchards play a vital role in advancing tree improvement. Many cooperators have too small an annual seed need to justify establishing their own seed orchard; other larger entities do not wish to add a specialized task such as seed orchard management, plus specialized staff, facilities, and equipment, to their forestry operation. Since seed production takes 8-15 years and can be affected by many factors (rainfall, soil type, incidence of frost, precipitation), it is often far safer to co-locate an orchard block on a known successful operation than take chances on an unproven piece of ground. Economies of scale also make concentrating seed production on a few productive sites more efficient. The Oregon Department of Forestry and the Bureau of Land Management have been the main hosts of cooperative seed orchards.

Based on responses from an NWTIC survey, the number of forest tree seedlings planted in western Oregon and Washington originating from tree improvement programs in 2017 (coastal DF, hemlock, ponderosa pine, noble fir, and western redcedar) stood at about 65.2 million with about 10.0 million woodsrun trees planted. The 2017 species summary (in millions) was 61.7 Douglas-fir, 7.9 western hemlock, 2.1 noble fir, 2.4 ponderosa pine, and 1.2 western redcedar.

NWTIC has a strong interest in realistic rotation-age estimates of realized gain in operational conditions, and as a result are investing heavily in establishing gain trials. Age-20 data have been obtained from the oldest realized genetic gain trial (Molalla, planted 1997), with the elite treatment showing 19.6% superiority over woodsrun in volume per acre at a tighter spacing. In the younger trial (Grays Harbor, planted 2005 and 2006), the best performing full-sib cross had age-9 realized gains of 19.9%, 20.3%, and 62.3%, respectively, for height, DBH and volume, based on 480 progeny planted on six sites. Second-cycle realized gain trials are currently being established for Douglas-fir and western hemlock.

NWTIC is an umbrella unit providing specialized, highly technical services that would be expensive and inefficient for each cooperator or regional cooperative to provide on their own. Data analysis is the most vital of those services, and includes advanced Best Linear Unbiased Prediction analyses, which has made it possible to provide predicted genetic gains and combine data across breeding zones or across generations. Detailed reports are provided that explain, visualize, and interpret the results.

Computer simulation and data re-sampling are routinely conducted for seeking optimal breeding strategies. Management of tree improvement data is also important: a very large number of records (including information on 3.38 million first-generation and 0.67 million second-cycle progeny) are now housed in an SQL Server database with a Microsoft Access interface.

Since 2001, NWTIC has aided the establishment/upgrading of high-gain 1.5-generation or second-generation production orchards, and has provided candidate selection lists for most of them. This impacts a substantial amount of current and future reforestation in western Oregon, Washington, and California. NWTIC faculty have been first authors or co-authors on 22 peer-reviewed publications and 40 conference and meeting presentations or other reports since 2000. NWTIC has also organized or helped organize workshops and short courses to take relevant, practical, technical information and make it accessible to busy practitioners in tree improvement and forestry. Finally, the NWTIC routinely pools resources with other university-based cooperatives to address questions important to plantation forestry in the region. For example, NWTIC, in collaboration with the Pacific Northwest Tree Improvement Research Cooperative, has initiated a genomic selection project on Douglas-fir; the preliminary results are promising.

Looking to the future, the next decade will see emphasis on establishing third-cycle progeny sites. We can anticipate some increase in species diversification, with recent interest in noble fir and western redcedar. Cooperatives will need to adapt to rapid changes in land ownership, which are generally disruptive to long-term projects; we look to find new participants for cooperative work—especially stable landowners with a strong stake in long-term forest health, productivity, and value improvement. To the extent supported by data, it will be possible to consolidate breeding zones and make them more efficient, increasing gain per unit cost and time.

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The Inland Empire Tree Improvement Cooperative (IETIC) was established in 1968 by a group of foresters who recognized the need for genetically improved seed sources to ensure healthy and productive forests for the future. IETIC uses classical plant breeding techniques including selection, testing, and breeding to identify superior genotypes for inclusion in production seed orchards.

Initial efforts were focused on ponderosa pine (Pinus ponderosa var. ponderosa) tree improvement and our first progeny tests were established in 1974. During that same year, members voted to expand IETIC to include additional species (western white pine, western larch, Douglas-fir, and lodgepole pine).

During the early years, members selected phenotypically superior “plus-trees,” collected open pollinated seed for progeny testing, and established and measured progeny tests. Our first-generation progeny tests have provided valuable data and genetic material for establishing seed and breeding orchards.

Recent efforts have focused on providing opportunities for IETIC members to join forces to produce genetically improved seed for their reforestation programs. While a few of our members had previously established their own seed orchards with IETIC genetic materials, many of our members have relatively small ownerships and the fixed costs associated with developing their own seed orchards were prohibitive. To remedy this, IETIC established new cost-share seed orchards that are funded by members who want to participate. Each member pays a percentage of the establishment and management costs and receives an equivalent share of the seed produced in return.

The first cost-share seed orchard established was a western larch orchard designed to produce seed suitable for eastern Washington and northern Idaho between 2,800 and 4,200 feet in elevation. This orchard was planted in 2007 and produced its first sizable seed crop in 2014. While still very young, the orchard has produced seed each year for the past three years. Trees are topped to 2.5 meters tall once they reach 4.0 meters in height. This technique promotes the development of pendent branches in larch, which tend to produce more flowers than typical lateral branches.

In addition, IETIC members have established a cost-share ponderosa pine orchard to produce seed for eastern Washington and northern Idaho from 2,400 to 3,800 feet elevation and a Douglas-fir orchard for 3,000 to 4,000 feet elevation in the same region. Efforts are underway to identify suitable sites for two more western larch cost-share orchards, one to serve high-elevation sites in Washington and Idaho, and one to serve member needs in Montana.

While these orchards are new, the cost share concept isn’t new to IETIC. For many years, IETIC members shared costs to manage the R.T. Bingham western white pine seed orchard located in Moscow, Idaho. This orchard, originally developed as a breeding arboretum by the US Forest Service, has produced more than 8,000 pounds of blister rust resistant western white pine seed for IETIC members since 1993. Seed from this orchard has been deployed by members in Washington, Idaho, and Montana with good success. Currently, efforts are underway to improve the blister rust resistance level of the seed from this orchard by: 1) establishing new orchard blocks using tested materials from blister rust resistance screenings conducted at the US Forest Service Coeur d’Alene Nursery; and 2) participating with the US Forest Service in second-generation breeding efforts designed to produce improved levels of blister rust resistance for the future.

With our first generation of progeny testing largely completed and the seed orchards developed from them beginning to supply genetically improved seed to our members, IETIC has begun to plan for the future. To ensure that our best genotypes from the progeny
tests are always available, we have been grafting them onto rootstock and planting them at the Russell H. Hudson Gene Archive located on the University of Idaho Experimental Forest. Russ was instrumental in the formation of IETIC and served as IETIC chair for more than 20 years. His leadership and commitment to the program have had a lasting impression.

In addition to preserving our best genetic materials for the future, members have recently become interested in launching new advanced generation breeding programs for two of our most important species, western larch and Douglas-fir. Breeding plans and operating agreements have been drafted and are being reviewed by members. These plans, focused on a traditional approach of full-sib crossing to produce offspring for progeny testing, are being designed to take advantage of new genomic-based tools and techniques as they become available.

As a small cooperative without a dedicated research budget, IETIC has established or funded several important studies to improve seed orchard management techniques or develop new tools to help further our efforts to develop improved seed sources for the future. Some highlights include:

1. Developing flower induction techniques to promote early flowering in western larch and ponderosa pine seed orchards. These techniques are being used in the Pullman Ponderosa Pine Seed Orchard with good success.

2. Establishing trials of stem injected systemic insecticides aimed at controlling high-value seed crops in seed or breeding orchards that cannot be easily treated using broadcast insecticide sprays.

3. Developing an illustrated publication on the reproductive biology of western larch to aid foresters and seed orchard workers interested in harvesting or producing larch seed crops. This publication is available at www.web-pages.uidaho.edu/ietic/.

4. Developing SNP (single nucleotide polymorphic) markers for western white pine in collaboration with colleagues at Oregon State University. These genetic markers represent single changes in the base sequence at a particular location on a chromosome. If SNP markers can be found that are highly correlated to the presence (or absence) of particular blister rust resistance traits, they could potentially streamline tree breeding efforts by providing early detection of genotypes with high (or low) levels of resistance.

5. Comparing growth characteristics of open pollinated clonal seed lots collected from seven western larch clones in the IETIC seed orchard.

While deployment of clonal seed lots is common in some species and regions, it has not been practiced to any significant degree with native conifer species in our region. Seed was collected in 2016 and recently sown for this study. The study includes both a nursery component to examine growth differences of seedlings and a long-term field study where the clonal lots will be outplanted in blocks along with an orchard bulk lot on three sites with two levels of competition control. The results of this study will help members decide if future crops from the orchard will be collected and processed by clone or bulked as an orchard lot.

If there is one thing that is certain about the future, it is uncertainty. Concerns about the impact of climate change on native forests and the challenges of competing in an increasingly large global marketplace will likely intensify the importance of our tree improvement efforts. A lot has changed since IETIC was founded nearly five decades ago. However, our members continue to realize the importance of improved seed sources to ensure healthy and productive forests for the future and are committed to cooperative efforts to maintain a broad genetic base and achieve genetic gains through shared responsibilities and shared costs.

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**Left:** The IETIC western larch cost-share seed orchard was established in 2007. Ramets are topped to promote the development of pendant branches and allow cones to be easily harvested using orchard ladders. **Right:** Male and female flowers on a pendant branch.

**PHOTOS COURTESY OF MARC L. RUST, IETIC**
Rich history of tree improvement in the Pacific Northwest exists, and British Columbia's involvement started with the pioneering work of Dr. Alan Orr-Ewing in the mid-1950s with inbreeding and wide-crossing studies of coastal Douglas-fir. British Columbia's Douglas-fir tree improvement program developed further in the 1960s with an enormous controlled crossing program. Currently, coastal Douglas-fir seed orchards are producing third-generation seedlings with predicted volume gains of 25% at rotation ages about 60.

In the late 1960s and 1970s, British Columbia's work expanded to include improvement programs for interior spruce and world-class provenance testing—under the auspices of the International Union of Forest Research Organizations—for lodgepole pine, true firs, Sitka spruce, coast and interior Douglas-fir, and other species of lesser commercial importance. While provenance trials were done primarily to identify superior provenances, this work was later instrumental for the delineation of seed zones. During this period, forest industry became much more interested in tree improvement and started to help the province with seed orchard establishment, test site selection, and funding for research. Various cooperative “councils” were formed to move the program forward, and for the past 20 years, the Forest Genetics Council of BC has served as the over-arching coordinator, reporting to the chief forester in BC, for tree improvement (www.fgcouncil.bc.ca).

The heyday of tree improvement in BC, and actually, even around the world, were the 1980s and 1990s. Universities were producing more forest geneticists and there was a small hiring pulse by the public and private sector during that time. However, the BC government slowly changed its fundamental funding structure for forestry investment: i.e., provincial forest tree nurseries were privatized and funding for tree improvement largely moved to third-party “crown corporation” agencies. Ironically, while we were enduring more government downsizing, there was pressure to develop improvement programs for lodgepole pine, western larch, white pine, and interior Douglas-fir as the number of trees being planted increased to over 200 million. Despite these fiscal pressures, tree improvement programs progressed nicely, with first- and second-generation breeding and seed orchards now in place. In 2017, over 260 million trees were planted in BC and about 75% of these were from seed orchards.

The science of tree improvement became more complex in the late 1990s when issues like biological diversity came to the forefront. Many questions were asked, including: “How do the products of tree improvement fit with provincial biodiversity conservation concerns?” and “How do we conserve genetic diversity in tree improvement programs while breeding for gains in volume?” and “How can tree improvement programs maintain or enhance adaptive capacity to changing environments?” To show that species diversity was also a part of the genetic improvement pro-
gram, projects were initiated for hardwoods (birch, alder, cottonwood, maple) and other softwood species of minor commercial importance, such as ponderosa pine. The establishment of high-quality genetics field trials are the mainstay of BC’s tree improvement program, and as of 2017, forest geneticists working with the BC government have planted approximately 1,500 trials in the ground, ranging from 1 to 50 years old, with 15 species.

Initially, early volume growth was the principal target trait for improvement in BC’s programs, but over time other traits were included in the selection and testing programs. For example, wood density, although a very important trait for structural wood properties, is now being measured to ensure this key wood property doesn’t decline during selection and breeding. During the 1990s many species were tested for disease resistance and with some species, such as white pine, “silviculturally” useful gains have been made for blister rust resistance. Over the last 20 years, tree improvement programs have placed significantly more effort on screening for disease and pest resistance including screening for resistance to spruce weevil (e.g., Sitka and interior spruce), pine rusts, and deer browsing (western redcedar), to mention a few. These efforts have focused on using the current disease and pests we now face as a “venue” to look for more durable resistance features of trees that could guard against future pests and diseases. New pests and diseases in eastern North American forests, such as birch bronze borer, butternut canker, and emerald ash borers, are examples of the new forest health challenges we can expect in the west. All in all, BC tree improvement programs are aimed at developing more durable trees!

Tree improvement programs in BC continue to be an important element of managing and conserving the forest genetics resource. Work is currently focusing in three major areas:

1. **Climate change.** Our current populations of trees may not be suitable for future environments, and we are proposing to model future environments based on the suitable “climate spaces” that each species has been tracking over their history in BC.

2. **Genetic conservation.** While breeding is another form of genetic conservation (e.g., we are developing multiple populations with multiple traits), geneticists are well aware of the value of the native gene pool that forms the basis of forests in BC. With climate change, and the introduction of new pests or disease, gene conservation populations in reserves, clone banks, or the seed center are valuable resources. It’s our form of forest insurance!

3. **Innovative tree breeding science.** Many new techniques are available to us, such as better analytical tools to evaluate the best parent trees, optimization software to balance genetic gain while minimizing inbreeding, more efficient field test designs, improved GIS modeling techniques for climate predictions, LiDAR technologies for measuring trees in our trials, and better wood quality assessment tools and genetic markers. Many of us envy the next generation of tree breeders; these new tools will go a long way to meet the challenges of climate change and keeping forestry as a key industry in BC.

The future for tree improvement remains exciting. Despite the reduction of forestry-related research in BC, the products of tree improvement are being widely used and appreciated, and most foresters view genetics as an important tool to combat the challenges that nature, and us humans, can throw at forests.

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The Bureau of Land Management (BLM), an agency within the United States Department of the Interior, administers 258 million acres of public lands, mostly in Alaska and eleven western states. Of this land base, 2.2 million acres in western Oregon are managed for forestry. As part of their effort to develop healthy, fast growing sustainable forests, the BLM made a major commitment over 50 years ago to tree improvement and forest genetics, understanding the long-term commitment required to meet their goals.

The BLM instigated tree improvement in 1965, establishing the Horning Seed Orchard on 320 acres south of Portland, Ore. Initially operated as a stand-alone program, it made selections based only on phenotypic characteristics, which did not employ progeny testing to analyze tree qualities. In 1968 the agency changed direction and joined the Cooperative Progressive Tree Improvement Program (which morphed into the Northwest Tree Improvement Cooperative, or NWTIC) to widen the genetic base for testing and help share the cost of progeny evaluations with industrial forest partners. The agency was highly involved in regional breeding programs and by 1987 had installed 209 progeny test sites in western Oregon. The BLM participated in tree improvement programs to enhance growth-and-yield in Douglas-fir, western hemlock, and noble fir, as well as working with the US Forest Service Dorena Genetic Resource Center to promote resistance testing of white pine blister rust in five-needle pines.

By the mid-1980s, the BLM greatly expanded their orchard footprint. Horning was expanded to cover the agency’s Douglas-fir, noble fir, western hemlock, western white pine, western redcedar, and sugar pine seed needs of northwest Oregon. Two additional Douglas-fir seed orchards were soon developed: Tyrrell covered the seed needs of west-central Oregon and the southern coast, while Provolt grew seed for southwest Oregon. By the early 1990s, the BLM managed an extraordinary 490 acres of Douglas-fir seed production orchards in western Oregon to cover reforestation needs of 1,300 lb/year.

Just as the BLM orchards were coming into production, a major change in federal forest management occurred, resulting in a dramatic decrease in seed needs for the agency. By the mid-1990s, it became apparent that the first-generation orchards, designed to meet the seed needs for the harvest levels of the 1970s and early 1980s, provided significantly more seed production potential than the BLM needed. As a result, the BLM developed their first seed orchard memorandum of understanding (MOU) at Tyrrell in 1998, providing industrial forestland owners and forest nurseries in western Oregon the opportunity to cooperate with the BLM in improved seed production. Over the next four years, similar MOUs were in place for the other three BLM orchards.
In 2006, decision makers recommended rightsizing the entire orchard program by closing Sprague and Provolt seed orchards in southwest Oregon, downsizing orchard staff, and redesigning the tree improvement program to maintain quality while continuing to look for efficiencies. Horning and Tyrrell were to become the future base of operations for the program, reestablishing new orchard blocks with genetic material from the closed facilities and developing advanced generation orchards as tested material became available. First-generation Douglas-fir breeding units in western Oregon were consolidated into more logical geographic regions based on progeny test analysis by NWTIC. This resulted in a significant reduction in the number of acres required for Douglas-fir seed production, falling from 460 acres in 1990 to 47 acres in 2010. A combination of 14 elite 1.5-generation and 2.0-generation orchards replaced 45 first-generation Douglas-fir orchard blocks planted in the 1980s.

Currently, the BLM has 26 cooperators in its seed production program covering federal, state, industrial, and tribal forestland between northern California and western Washington. Cooperators provide proportionate funding for their level of participation to cover all facets of seed orchard management, resulting in significant yearly support from the private sector to operate the facilities. In return, the cooperators receive their share of improved orchard seed. At Tyrrell alone, cooperators have received over 11,000 pounds of improved Douglas-fir seed over the past 19 years.

With 50 years behind it, the BLM continues to prepare for tree improvement in the next half-century. Major improvements to the orchard infrastructure, including updates of offices, storage buildings, and water systems, were recently completed. A new greenhouse/shade house was constructed for small-lot growouts and as a regional grafting center for cooperators, and a newly completed 50-person conference center will provide space for regional forestry and tree improvement meetings. An agency with a long history in working to improve forest genetics, the BLM continues to stay present and remain an active player in tree improvement in the Pacific Northwest.

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Genetic Resource Management in the USFS, PNW Region: Past, Present, and Future

BY VICKY ERICKSON

The Pacific Northwest Region (Region 6) of the US Forest Service encompasses 26.2 million acres in Oregon and Washington. The 16 national forests and grasslands support some of the most diverse ecosystems and flora in the US, with habitats ranging from the high deserts east of the Cascade Mountains in central Oregon to the rain forests of the Olympic Peninsula in western Washington.

The region's genetics program was launched over 50 years ago with the establishment of the Dorena Tree Improvement Center (now Dorena Genetic Resource Center [DGRC], Cottage Grove, Ore.) as headquarters for the white pine blister rust disease resistance program for western white pine and sugar pine. With an expanding focus on improved growth and productivity in coastal Douglas-fir and other commercial conifer species, the region also became an early member of the PNW Progressive Tree Improvement Program, which was established in 1966. The region's genetics program was further expanded throughout the 1980s with large investments in seed orchards and progeny test sites for priority species in eastern Oregon and Washington, including ponderosa pine, Douglas-fir, western larch, and lodgepole pine.

Fast forward to 2017, a changed landscape where reforestation needs in the region are no longer driven primarily by timber production objectives or regeneration harvest activities, but rather by responses to disturbances such as wildfires, insect and disease outbreaks, and wind storms. Regional genetics programs have responded to these changing conditions by evolving from a focus on tree improvement for enhanced growth and yield to today's broader emphasis on genetic resource management, genetic conservation, and ecosystem resiliency and health. This work is spread across numerous species, expanding in recent years to include non-commercial native conifer and hardwood tree species as well as native shrubs, grasses, and forbs that are important for restoration and land management priorities such as creation of fire resistant understories and enhancement of forage and habitat for wildlife, including pollinator species.

Staff and facilities

Geneticists: In addition to a regional geneticist, there are four area geneticists in the region. Each area geneticist serves multiple forests, but also provides specialized expertise, consultation, and training across the entire region on specific topics such as seed biology, cone collection, analysis of genecology studies and progeny test data, interpretation of molecular data, design and implementation of genetic conservation strategies, and more. Additional resources include the DGRC geneticist, as well as the five-needle pine and Port-Orford-cedar program managers. The regional geneticist provides oversight and support to the area geneticists, DGRC, and the regional Bend Seed Extractory (Bend, Ore.), and also serves as the regional native plant program manager.

Dorena Genetic Resource Center: This unique, multi-faceted facility houses a world-leading applied disease resistance testing program for non-native pathogens including white pine blister rust and Port-Orford-cedar root disease. Containerized Port-Orford-cedar seed orchards are maintained in DGRC greenhouses for operational production of disease resistance seed for reforestation in southwest Oregon and northern California coastal forests. Newly upgraded freezer storage facilities house genetic conservation seed collections for at-risk tree species, as well as a unique collection of seed from the over 40,000 parent trees represented in Region 6 progeny test sites and seed orchards. DGRC also produces small quantities of containerized seedlings for national forests and partner clients. Over 120 new species propagation protocols have been developed through this work. DGRC assists in regional trainings and is home to the USFS national Tree Climbing Program, a certification program to ensure safe and effective tree climbing for Forest Service and other agency work, including cone collection, red cockaded woodpecker nest placements, snag creation, smoke jumper training, and monitoring for Asian long-horned beetle. In 2016, DGRC celebrated its 50 years of accomplishments and shared with partners their current work and bright vision for the future.
Regional priorities and challenges

Described below are some highlights of Regional Genetic Resource Management program priorities and accomplishments, as well as several initiatives underway in response to new challenges such as expanding exotic pests and forest health issues, climate degradation, and the conservation of at-risk tree species.

1. Protect and maintain seed orchards, breeding orchards, and genetic test sites: These installations are invaluable and irreplaceable repositories for genetic conservation and use in future breeding efforts, and for monitoring the impacts of new insects, pathogens, or a changing climate. They also provide the most efficient and economical source of high-quality and genetically diverse seed for reforestation. At present, there are 50 seed orchard installations totaling over 1,900 acres on Oregon and Washington national forests. Significant investments are made annually across the region in priority maintenance activities such as orchard fence repairs and replacement, mowing, and fire protection.

2. Replenish reforestation seedbanks and re-initiate seed training programs: The region's reforestation seedbanks are aging and rapidly diminishing, particularly for those species and national forests frequently affected by wildfires. In addition, the region has lost many seasoned reforestation specialists experienced in seed use planning, seed biology, and cone collection procedures due to retirements. Consequently, the region has re-vamped online and in-person cone and seed training programs and established a new regional contract for cone collection. In 2016, Region 6 national forests made the largest cone collection in over two decades, with nearly 1,500 bushels of cones (425 pounds of cleaned seed) collected from six different species. Washington State Department of Natural Resources (WADNR) and several private companies also took advantage of the 2016 bumper crop through permits to collect cones in national forest wild stands and seed orchards.

3. Combat invasive pathogens and insects through development of genetically resistant planting stock for an expanded array of priority species and populations: DGRC’s disease resistance testing program has grown in recent years to now include 8 five-needle pine species and geographic sources from the US, Canada, and Mexico. One of the more prominent new focal species is whitebark pine, which has been proposed for federal listing under the Endangered Species Act. Port-Orford-cedar, another focal species, involves a vastly smaller geographic zone but is important to USFS, Oregon Department of Forestry, tribes, private landowners (industrial and non-industrial), NGOs, and the general public. The region has strong working partnerships with these groups and interest in resistant seed is growing. DGRC’s geneticist also provides technical assistance in developing programs elsewhere, such as the koa wilt resistance program in Hawaii.

4. Accelerate and expand genetic conservation and restoration efforts for highly vulnerable species and populations: Many ecologically important PNW conifer species are in decline due to insect and disease outbreaks, wildfires, climate change, and other disturbances and stressors. A recent regional assessment indicated that high-elevation species and populations in isolated areas or at the edge of a species distribution were at the highest risk of loss. The assessment identified priority species and geographic areas of special concern and set goals for seed collection and other conservation and restoration work. International collaborations with the U.K. Forestry Commission and the Millennium Seed Bank have been leveraged to help collect seed for genetic conservation, with seed from over 1,200 individuals from seven different species collected to date. The collection is stored locally at DGRC and at the USDA National Center for Genetic Resources Preservation (Ft. Collins, CO).

5. Develop climate-based solutions for seed deployment: Under any climate scenario, the selection of appropriate seed sources provides the foundation for successful reforestation. With predicted changes in future climates, the movement of seed sources during reforestation will become an increasingly important strategy for maintaining forest productivity and re-aligning species and genetic resources to cope with new stressors and site conditions.

In preparing for the future, geneticists are working with silviculturists and reforestation specialists to evaluate existing seed inventories and test new models such as the Seedlot Selection Tool (see Harrington and St. Clair article) to identify areas where seed may be well suited to future climates, or to choose the best seed source for a particular planting site under predicted climate scenarios. These and other related climate change adaptation activities are guided by a national USFS strategy document: “Genetic Resource Management and Climate Change: Genetic Options for Adapting National Forests to Climate Change.”

Looking ahead

Maintaining productive and resilient national forests into the future will require new tools, practices, and re-focused investments in all areas of land stewardship, including genetic resource management. Retaining expertise and a supporting plant production infrastructure (i.e., nurseries, seed extractories, disease resistance screening centers, and seed and breeding orchards), coupled with strong support from research, management, and our external partners are all vital elements for sustaining a strong and forward-thinking PNW Genetic Resource Program. Although there are many constraints and undoubtedly bumps ahead, the region is well-positioned to respond to the needs and challenges of the next 50 years and beyond.

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Forest genetics research in the Pacific Northwest goes back to the beginning of the 20th century. One of the first long-term studies undertaken by the US Forest Service, and one of the first forest genetics studies in North America, was a provenance study of geographical variation and trait inheritance of Douglas-fir. This study, called the Douglas-Fir Heredity Study, was established by Thornton T. Munger in 1915 at the Wind River Experiment Station and other sites in Oregon and Washington. It was recently remeasured, and is still providing insights more than 100 years later.

Another important study was the Wind River Arboretum, a study looking at non-native species for use in the Pacific Northwest. Both studies would prove to be highly influential on subsequent thinking about appropriate species and seed sources for reforestation. Meanwhile, poor natural regeneration after large fires in the early 20th century led to an interest in tree planting and the establishment of the Wind River Nursery in 1910. Early foresters, however, did not pay particular attention to their choice of seed source, resulting in poor growth and survival of many stands. Experiences with plantation failures and the results from the species and provenance trials ensured the preference for native species, and led to the development of seed collection guidelines and the first delineation of seed zones in the 1940s. By the 1960s, a seed source certification system was adopted, and in 1966, seed zone maps for Oregon and Washington were published.

Interest in forest genetics and tree improvement took off in the 1950s. An increase in logging as a result of the post-war housing boom led to an increased interest in production forestry and a shift from largely natural regeneration to planting. Foresters became keenly interested in planting well-adapted seed sources and in possible improvements through applied genetics. The Douglas-Fir Heredity Study was often used to demonstrate the importance of genetics by pointing to the large differences in growth among family row plots. In 1954, the Industrial Forestry Association (IFA) hired Jack Duffield to begin a program of Douglas-fir tree improvement. Also in 1954, Roy Silen established a research program on forest genetics and tree improvement at the USFS Pacific Northwest Forest and Range Experiment Station (now the Pacific Northwest Research Station [PNWRS]).

In the late 1950s, Alan Orr-Ewing began research on tree improvement and genetic variability of Douglas-fir for the British Columbia Forest Service (now the BC Ministry of Forests, Lands, and Natural Resource Operations [MFLNRO]). In Idaho, Richard Bingham began to breed for blister rust resistance in western white pine at the USFS Intermountain Forest and Range Experiment Station (now the Rocky Mountain Research Station [RMRS]). Meanwhile, the need for an organization to bring together researchers and practitioners to share information was recognized, and the Western Forest Genetics Association was established in 1955. It continues to be the primary forum for forest genetics in western North America.

Tree improvement programs grew over the next decades, particularly for Douglas-fir. A major obstacle for Douglas-fir, however, was the issue of graft incompatibility in clonal seed orchards. In 1966, Roy Silen proposed an alternative strategy to get around this issue by using seedling seed orchards created from full-sib crosses of parents in the field. The parents would be intensively selected from progeny tests of a large number of open-pollinated families from native stands. Under the leadership of Roy Silen and Joe Wheat of the IFA, this “progressive” tree improvement program brought together many public and private landowners to cooperate in selection and testing. This program later became the Northwest Tree Improvement Cooperative (NWTIC).

At about the same time, the British Columbia Forest Service expanded its work with a diallel crossing program of their Douglas-fir selections followed by field testing. The BC program later came under the auspices of the Forest Genetics Council. The Inland Empire Tree Improvement Cooperative (IETIC) was founded in 1968 to develop improved ponderosa pine in eastern Washington, northern Idaho, and western Montana, and expanded their program in 1974 to include several additional native conifer species. Weyerhaeuser initiated an independent research and tree breeding program. Other independent programs were begun that later came together...
under the auspices of the NWTIC. Today, tree improvement programs exist for a wide variety of conifers, including Douglas-fir, western hemlock, ponderosa pine, interior spruce, western redcedar, lodgepole pine, western larch, Port-Orford-cedar, and five-needle pines. The University of Washington and Washington State University had large research programs aimed at developing hybrid poplars, and several industrial landowners planted extensive poplar plantations in Oregon and Washington. Research on disease resistance continues at the USFS Dorena Genetic Resources Center, RMRS, and BC MFLNRO.

For most species, genetically improved planting stock is produced in seed orchards. Thus, seed orchard research has been an important component of forest genetics research in the Pacific Northwest. The problem of graft incompatibility in Douglas-fir was mostly solved by Don Copes at the PNWRS through a research and breeding program that led to the development of graft-compatible rootstock. Because of his efforts, clonal seed orchards are the foundation of Douglas-fir tree improvement, and nearly all seed orchard clones are grafted onto “Copes’” rootstock.

Other important seed orchard research has been conducted by the PNWRS, Pacific Northwest Tree Improvement Research Cooperative (PNWTIRC), BC MFLNRO, and Weyerhaeuser Company. Improvements have been made in orchard design (spacing and arrangement of clones), flower stimulation, crown management, supplemental mass pollination, pest management, and bloom delay to control pollen contamination. Tom Adams at Oregon State University (OSU) pioneered the use of allozyme genetic markers to understand and manage mating systems and pollen contamination in seed orchards, and this work was extended to SSR genetic markers by the PNWTIRC. The PNWTIRC has also studied the genetics of important traits such as growth, stem form, wood quality, cold hardiness, and drought hardiness; developed breeding approaches such as early selection; and developed genetic markers that are now being used by breeders. Approaches for advanced generation breeding, field testing, and data analysis were developed by Bob Campbell and Randy Johnson at the PNWRS, and later by the NWTIC.

Other forest genetics research focused on population genetics and geographic variation in adaptive traits. The advent of allozyme genetic markers gave us a better understanding of gene flow, population structure, and phylogenetics of several species. Genecology research was conducted using short-term common garden studies to understand how seedling performance is related to the climatic environment of their parents. The pioneering work of Jerry Rehfeldt at the RMRS, and Bob Campbell and Frank Sorensen at the PNWRS, provided an understanding of the geographic distribution of adaptive traits that was important for refining seed zones and breeding zones. This genecology research will become increasingly important as we grapple with climate change and to help us understand how forests will respond and what we can do about it. Recently, the PNWRS established a provenance test using a reciprocal transplant design in which seed sources from a wide range of climates were planted at test sites of a wide range of climates. Results from this study, called the Seed Source Movement Trial, are being used to simulate the effects of climate change, and to evaluate options for “assisted migration”—a strategy that involves moving populations to areas where they are expected to be better adapted to future climates.

Finally, we’ve entered a new age—the age of genomics. As in the past, new knowledge, approaches, and tools will continue to make tree breeding and adaptation to climate change more effective, less costly, and faster. We now have complete genome sequences for several important forest trees, with more to come. Millions of genetic markers are now available to tree breeders—in contrast to the 20 or so allozyme markers available in decades past. We can now directly study the expression of the genes that are important to adaptation to climate, disease resistance, or increased growth. In the PNW, this work has been active at the University of British Columbia, OSU, PNWRS, and RMRS. New approaches for gene editing (using CRISPR) have grabbed the attention of the biological sciences and the public. Although genetically modified trees are unlikely to be widely used in the Pacific Northwest, these technologies and their potential benefits are being studied by the Tree Biosafety and Genomics Research Cooperative at OSU.

The past 100 years has seen enormous progress in our understanding of forest genetics and our ability to breed trees—but we cannot rest. The future will bring even greater challenges, including climate change, the introduction of new pests, and greater demand for natural resources. Thus, we must continue to develop new forest genetics knowledge, approaches, and tools to help sustain our forests and society.◆

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Cooperative Brings Life to Tree Breeding Tools and Approaches

BY GLENN HOWE

The Pacific Northwest Tree Improvement Research Cooperative (PNWTIRC; www.fs.orst.edu/pnwtirc/) conducts forest genetics and tree breeding research that supports forest management by federal and state agencies and a multi-billion-dollar forest products industry. Over the years, our members have included private companies and governmental agencies in Oregon, Washington, and British Columbia. The focus of our research is on Pacific Northwest tree species and the development of new tree breeding tools and approaches. The knowledge and tools we develop are made available to breeders in reports, scientific publications, and through technology transfer meetings and workshops. Most of our research attention has been on Douglas-fir, but we also conduct research on other tree species such as western hemlock and western white pine. The PNWTIRC was formed in 1983 to address concerns that forest genetics research was not keeping pace with the rapid expansion of applied tree breeding programs. Today, the cooperative has 14 member organizations.

Tree breeding research

The initial focus of the PNWTIRC was to understand the genetics of Douglas-fir growth and stem form traits. How can we efficiently and accurately measure these traits? Are they heritable? How much genetic gain is possible if these traits are included in breeding programs? What is their relative importance—genetically and economically? Results from these early studies and subsequent research highlighted the importance of stem defects, particularly the loss in value caused by ramicorn branches, which are large, steep-angled branches that are often associated with second flushing in the summer. These early, short-term studies provided quick results to breeders because they were conducted in existing genetic tests owned by PNWTIRC members.

The next phase of the PNWTIRC focused on newly designed experiments, such as the early testing study. In this experiment, we grew Douglas-fir seedlings in outdoor nursery beds and greenhouses, and then compared their performance to siblings that had already been growing in the field for 15 years. This retrospective approach demonstrated that we can predict longer-term field performance by measuring families in their first or second growing season—at least well enough to practice early culling. Early culling is the removal of the poorest performing families at the seedling stage, before they are planted in long-term and expensive field tests. Thus, we can use this approach to lower tree breeding costs and increase the quality of the field tests by allowing us to plant smaller test plantations that have less environmental variation.

In the 1990s, the PNWTIRC concentrated on the genetics and physiology of adaptive traits such as cold hardness and drought hardiness. In keeping with the early testing theme, a main goal of this work was to develop early screening protocols for identifying cold hardy and drought hardy genotypes. We developed a cold hardness testing protocol that involves collecting cuttings from progeny tests and then testing them using artificial freeze tests in programmable freezers. These artificial freeze tests are now widely used to improve fall cold hardiness in Douglas-fir breeding programs.

We also developed a seedling testing protocol for drought hardness. This approach involves imposing drought stress in raised nursery beds and then assessing drought hardness by measuring foliage damage, diameter growth, and the loss of water flow through the stem caused by embolisms. Because of climate change, our work on drought hardiness continues with recently established genetic tests on hot and dry sites in southern Oregon.

Research by the PNWTIRC and others led to the adoption of new acoustic tools for measuring and improving wood stiffness in Douglas-fir breeding programs. Between 2005 and 2013, we conducted two major studies of Douglas-fir wood properties. Douglas-fir is renowned for its strong and stiff wood, but breeders are concerned that wood quality could decline because faster-growing trees are being harvested at younger ages. Thus, the aim of this research was to develop effective and cost-efficient ways to identify genotypes with stiff wood. Tools that measure acoustic velocity had already been used to sort mill logs based on wood stiffness. To predict stiffness, one can strike the log with a hammer and then measure the speed of the resulting sound waves. We demonstrated that these same tools (e.g., Hitman or TreeSonic) can be used on standing trees or logs thinned from genetic tests to identify superior genotypes in breeding programs. A core element of this project was a study in which we harvested trees from 25-year-old genetic tests and then milled nearly 400 of them into 2x4s to test our wood stiffness predictions. Later, we extended this research to much younger trees and western hemlock.

Seed orchard research & molecular genetic markers

In the Pacific Northwest, seed orchards are fundamentally important for capturing genetic gain and delivering it to the field. Improved genotypes from breeding programs are planted together in seed orchards where they can cross-pollinate to produce improved seed. Thus, seed orchard research has also been an important
part of our mission. For example, we studied seed orchard design and management, including tree spacing, crown management, early flowering, and the use of molecular genetic markers to understand mating patterns in seed orchards. We conducted a 15-year study of miniaturized seed orchards, which are alternatives to traditional seed orchards where trees are planted at a close spacing and maintained at a height of only 10 feet or less. Because of high per-hectare seed yields, miniaturized orchards are potentially desirable for capturing genetic gains at an early age. The small size of the trees also facilitates controlled crossing, supplemental mass pollination, overhead irrigation, and cone harvesting. The methods of early flower stimulation we developed as part of our miniaturized seed orchard program are widely used to increase the yields of genetically improved seed in Douglas-fir seed orchards.

In Douglas-fir, we developed genetic markers called SSRs that are being used by tree breeders to identify mislabeled trees in seed orchards, determine the parents of open-pollinated seedlots, and measure pollination contamination. Pollen contamination, which occurs when trees in nearby stands mate with the genetically superior orchard trees, reduces genetic gains and may lower adaptability. The Douglas-fir SSRs we developed are being used by seed orchard managers, breeders, and other forest geneticists, mostly through the genotyping services offered by the USFS National Forest Genetics Laboratory.

**Current focus & future research**

Currently, the PNWTIRC is helping to bring the latest genomic approaches to tree breeding. New, large-scale genomic technologies and advanced statistical approaches have already transformed crop and livestock breeding, and are likely to do the same for tree breeding. For example, we used genomic approaches to identify hundreds of thousands of genetic markers called SNPs (single nucleotide polymorphisms) in Douglas-fir. SNP markers are now being used to test an approach called genomic selection to improve growth and wood quality in Douglas-fir, and to enhance blister rust resistance in western white pine. These topics are discussed in greater detail in the article on forest genomics and biotechnology.

The fundamental mission of the PNWTIRC has been the same since 1983—to advance tree breeding and our understanding of native tree populations in the Pacific Northwest. The prospects for using genomics to enhance tree breeding are great and will be a key area of research into the future. At the same time, climate change imposes challenges to tree breeders and forest managers. Thus, it is particularly important to understand how trees are genetically adapted to climate. Future research by the PNWTIRC will continue to address topics such as seed zones and breeding zones, assisted migration, and the genetics of adaptation to cold and drought. For example, we are collaborating with the US Forest Service and the Conservation Biology Institute to develop a suite of tools that can be used to implement forest management practices designed to help forests adapt to climate change. The first of these tools is a web application called the Seedlot Selection Tool (SST; https://seedlotselectiontool.org/sst/). The SST is a GIS mapping tool designed to help forest managers match seedlots with planting sites based on selected climate change scenarios.

As a research cooperative, collaboration, teamwork, and the sharing of knowledge and resources are fundamental to what we do. Members of the PNWTIRC not only provide funds needed to conduct PNWTIRC research, but also field sites, plant materials, and the expertise and energy needed to make the research possible and relevant. Additionally, we have many outside partners and funding organizations that have contributed to our success.

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**The PNWTIRC conducts research on tree breeding methods and the production of genetically improved seed. This photo shows Jim Smith next to grafted trees that were part of a 15-year study on the establishment and management of Douglas-fir miniaturized seed orchards.**

**PHOTO COURTESY OF GLENN HOWE**

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Genetic Gain and the Economic Benefits of Tree Improvement

BY SARA LIPOW

A vital component of forestry today for most commercially important tree species is reforestation with genetically improved planting stock produced by tree improvement. Tree improvement is the process by which knowledge of tree genetics is coupled with knowledge of silviculture, economics, and wood science to select and reforest with trees that possess desirable traits. These desirable traits usually relate to increased wood yield or higher wood quality, which are the focus of this article. Other desirable traits such as disease resistance and forest health are discussed elsewhere in this issue.

Tree improvement is expensive and takes decades

Foresters are accustomed to long-term thinking. During reforestation, we make investments in site preparation and tree planting knowing that financial gain from these activities will not be realized until trees are harvested decades later. Tree improvement also takes decades, and its investment starts long before a tree is even planted.

Most tree improvement programs in western North America began in the 1950s to 1980s and followed a similar pattern. Trees growing in natural stands were identified and cones were collected from them. Sometimes these “parent trees” were selected after comparing them to other trees in a uniform stand, but sometimes they were simply good looking trees that were easy to collect cones from. Regardless, seeds from those parent tree cones (their progeny) were then grown in field trials, called progeny trials. These field trials were expensive: they were replicated across multiple sites with each tree individually tagged and measured several times. By measuring a large number of progeny from each parent tree, geneticists identified the parent trees that possessed desirable traits due to having desirable genes. Traits of interest, especially height and diameter, were typically measured at least until 15 years of age and sometimes longer.

This first-generation tree improvement testing allowed geneticists to identify families of trees that displayed desirable traits that were inherited and thus could be passed on. For most species, the best trees, either progeny or parent trees, were then grafted into a seed orchard and managed to produce seeds for reforestation. Seed orchards are managed more like fruit orchards than like forestry plantations; they are mowed, sometimes irrigated, and often treated with plant hormones or other methods to stimulate cone production. They are expensive to establish and maintain. The time it takes to produce seed from a seed orchard tree varies, but generally ranges from eight to 15 years for species such as Douglas-fir, ponderosa pine, and noble fir. Thus, production of genetically improved seed involves years of expenses for both tree improvement research and for seed orchard management. In addition, for some species, tree improvement has gone on to a second generation where the best trees from the first generation were crossed together, seeds from those crosses grown in another round of replicated progeny trials, and the best second-generation trees selected—again a decade’s long process. For a few species, including coastal Douglas-fir and western hemlock, a third generation of tree improvement is in progress.

Genetic gain

Most genetically improved seedlings planted in western North America during 2017 will be from some type of first-generation seed orchard. Those seedlings were produced by trees or their progeny that were found growing naturally in the forest—but identified through tree improvement as having desirable traits—and then raised in a seed orchard where they were pollinated by other, similarly selected trees. Given how “natural” these seedlings are, how much better are they compared to seedlings produced by “woodsrun” seed collected from natural stands? In other words, how much genetic gain do they achieve? The answer depends on many factors, especially the number of parent trees tested and the quality of the progeny testing.

The company I work for, Roseburg Forest Products Company, participates in tree improvement cooperatives for Douglas-fir that give us access to thousands of first-generation parent trees appropriate to our Oregon land base, and we have placed the top ones in intensively managed seed orchards. As a result, the first-generation seedlings we plant are expected, on average, to produce plantations that at age-15 are 8-15% taller with 15-40% more volume than if we had used woodsrun seed. These values are expressed for plantations that are 15 years old, which was a common age for the final measurement of many of the first-generation tests. All this genetic gain will not be recovered at rotation. Based on predictions from growth models and comparisons from other species, I conservatively estimate that half of this genetic gain will persist to rotation. For some of our land base, we have begun planting second-generation seed, which will yield even higher genetic gains.

Roseburg is not alone in achieving these high genetic gains. Similar values are expected for most landowners in
western Oregon and Washington that have invested in cooperative tree improvement for Douglas-fir and western hemlock. Genetic gains are usually lower for minor species, such as noble fir, which have lower investments in tree improvement.

**A high return on investment**

When many plantations are established using genetically improved stock, the increased wood production can be substantial, and this provides a strong economic motivation for investment in tree improvement programs. The return on investment can be quantified using discounted cash flow analysis: Landowners input tree improvement and seed orchard costs, when the costs were incurred, acreage to be planted, and the genetic gains achieved. Then, using a forest growth model, the amount of wood products produced over time using genetically improved seed versus woodsrun seed can be estimated and a monetary value assigned to those wood products. A “discount rate” (sometimes called the compounding interest rate) is included in the analysis to account for the time value of money, since money tied up for decades in tree improvement is not available for other investments. With this approach, projections of the future value of wood products can be discounted to arrive at a present value estimate for investing in tree improvement and seed orchards. Such economic analyses done for many tree improvement and seed orchards programs in western North America demonstrate a high return on investment under reasonable genetic and economic assumptions.

The economic benefits from tree improvement are realized in several ways. Plantations established with genetically improved stock have higher yields. They often also produce higher value wood products. Additionally, since they grow substantially faster, the wood can be harvested sooner, reducing the rotation age, and allowing the forestland to be cycled more quickly; this is captured in economic terms as increased land expectation value. Genetically improved stock can also result in more uniform stands, leading to lower harvesting and transportation costs. Inflation is also a consideration: when wood products experience positive real rates of inflation compared to other goods in the economy, this magnifies the genetic gains in yield and quality, making investment in tree improvement even more favorable.

The return on investment from a tree improvement and seed orchard program is tied to the size of the land base it serves. Whereas the costs of most silvicultural treatments are incurred on a per acre basis, (e.g., vegetation control and fertilization), many costs associated with tree improvement including selection, breeding, and testing occur at the program level. Therefore, landowners receive higher returns as they reforest more acres with genetically improved stock. This economy of scale has resulted in the formation of tree improvement cooperatives and accounts for their remarkable persistence despite many changes in land ownership, and thus cooperative membership. Moreover, genetic gains are cumulative across generations of tree improvement and across rotations of a plantation. Thus, whereas other silvicultural treatment must be repeated with each rotation, it is not necessary to repeat the costs of an entire tree improvement cycle for each rotation. For these reasons, continued investment in tree improvement and seed orchards, and continued economic benefits to its participants and the regional economy, is anticipated for valuable plantation species in western North America.

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Climate change in the 21st century is likely to dramatically alter the growing conditions that Pacific Northwest tree species experience. It has been suggested that foresters plan for these changes by moving seed sources to locations where the seed-source environment and the future climate will be similar. Some people have called this type of seed-source movement “assisted migration” with the idea that we are helping the plants move to better suited sites faster than they would naturally. But it is important to realize that people have moved seed sources to new locations for centuries without using this term. Think of David Douglas, the early botanist, plant collector, and the one for whom Douglas-fir is named, who sent thousands of seeds back to the British Isles for propagation.

But when it comes to establishing forest stands, rather than ornamental plants or small plantings of exotic species, foresters wonder how far it would be safe to move trees. Should we select seed lots most similar to the current climate, or the climate in 20 years, or the climate in 40 years? After all, if the climate hasn’t changed much yet, what would be the benefits or risks in planting seed lots which were adapted to a different climate (say one warmer or drier than the one at the outplanting site) as opposed to local sources?

In 2009, we put out a call to land managers to work with us on a new research trial designed to help answer questions about seed-source movement by providing combinations of seed sources and test sites where we can evaluate various aspects of plant adaptation. We received a great response and currently have 10 organizations involved: Bureau of Land Management, Cascade Timber Consulting, Giustina Land and Timber, Hancock Forest Resources, Lone Rock Timber Company, Port Blakely Tree Farms, Roseburg Resources, Starker Forests, USDA Forest Service Stone Nursery, and Washington Department of Natural Resources. In addition, we have students and faculty from Oregon State University, Evergreen State College, and the University of British Columbia working with us.

We collected from 60 diverse populations selected from natural stands in California, Oregon, and Washington (see Figure 1); these were from coastal and inland sites and represented a range in elevations. We planted the seedlings on nine sites in Washington and Oregon in the fall of 2008 or spring of 2009. All the sites were fenced to prevent browsing by deer and elk and were treated operationally (site preparation or vegetation control treatments) by our partners prior to or after planting.

The seed sources cover 12 geographic regions: three in California, three in southern Oregon, three in central Oregon, and three in Washington. A map of the locations of the seed sources and outplanting sites is shown in Figure 1. The data from the second growing season show that trees from coastal families in each latitudinal band grew better than those from inland low elevations sources or high elevation sources.

In general, trees from the coastal families in each latitudinal band grew better than those from inland low elevations sources or high elevation sources.
has been reported many times from other studies, but it’s good to see it repeated in our current trial.

Sometimes mild sites are not the best. For example, the sites that had cool weather in the fall had less cold damage to artificial cold events than the site which had mild weather in the fall as trees on the milder site did not get the “slow down” signals of temperatures close to freezing before they experienced a freeze event.

It has been reported for several horticultural plants that warmer winters result in earlier dates of flowering or budburst. However, coastal sites in southern Oregon and California do not currently experience many chilling hours in the winter and Douglas-fir has an obligate chilling requirement; thus, warmer winters in the future on sites with currently mild winters could result in no advancement in date of budburst or even delays in budburst as the trees wouldn’t experience enough cool temperatures to burst bud promptly in the spring.

(Continued on next page)

Early Provenance Trials Lead to Contrasting Conclusions

BY KEITH JS JAYAWICKRAMA

Compared to Europe, where many resources were invested in studying provenance variation in forest trees, little was done in the Pacific Northwest through the heyday of forest tree improvement in the 20th century. Just two Douglas-fir trials were established, one trial for ponderosa pine was established, and none for western hemlock, western redcedar or noble fir west of the Cascades in Oregon and Washington. The low emphasis on provenance trials was partly due to lack of interest in importing and testing species from outside the PNW, and partly due to a strong commitment on the part of foresters and tree improvers to emphasize local seed sources.

The 1912 Douglas-fir Heredity Study was one of the first forestry provenance tests in the USA, and was established by Thornton T. Munger. In 1915 and 1916, progeny from 120 parents from 13 provenances were planted at six sites. Measurements were taken over the next 100 years (with credit for later measurements to Roy Silen); the trial was last measured in 2013. The original objectives were to determine the best type of tree to be used for seed collections for artificial reforestation and for seed trees, as well as to determine the influence of provenance on tree growth. Munger was primarily interested in how progeny differed between sound versus infected, old versus young, and low- versus high-elevation parents; thus, the study became known as the Heredity Study, although later emphasis switched more to provenance variation. The trial was used in the 1960s to make the case for a large-scale tree improvement program for Douglas-fir and to argue for small breeding zones for this species.

The other Douglas-fir trial was coordinated by Kim Ching at Oregon State University. Seeds were collected in 1954-1956 from 16 provenances from southern Oregon to northern Vancouver Island. Fourteen to 89 parent trees were chosen at random for each location for seed collection. The 16 seedlots were outplanted in 1959 on 16 sites (located in the vicinity of seed collections) in a reciprocal design where one provenance is native to each site. Each planting site was within a 40 km radius and 60 m in elevation of a seed collection site. Many sites were abandoned due to frost, snow, drought, and fire. The sites were measured on a regular schedule through age 25. Close to rotation (46-52 years from seed), total height and DBH were measured at six of the 16 sites (on 7,600 trees). Trial data were used for many publications; in contrast to the Douglas-fir Heredity Study, the case for small seed zones was not compelling.

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Our two dry sites in southern Oregon did not have needle diseases when surveyed in 2015. On the other seven sites, all the trees had Swiss needle cast—but some seed sources seemed to tolerate it and grew well. On the other hand, there was a big difference in the frequency of Rhabdocline (another needle cast disease) by seed source with the sources which burst bud early most impacted by Rhabdocline. We suspect that the disadvantage of having new foliage available during the time period when many of the fungal spores are dispersing could be a reason why trees from some cool, wet geographic areas—such as the Washington coast—have evolved to burst bud late in the spring.

We learned different things each year. For example, the very hot early summer in 2015 changed the pattern of diameter growth (see Figure 3). In most years diameter growth occurs throughout the year from spring through fall. But in 2015 at our J. Herbert Stone Nursery site near Medford, Ore., many of the trees that were hosting our electronic dendrometers showed the trees stopped diameter growth in late June and didn’t start again until the following spring. This would have not only reduced the total amount of diameter growth for the year, but also reduced the percentage late-wood produced (which could impact drought hardiness and wood quality). Sometimes people ask us what future date or climate projection we would suggest they use to plan for the future. An easy answer at this point is to suggest you plan for the conditions we experienced in 2015 (no models needed!).

We also learned that these sites are great for field visits and tours—and not just ones led by scientists. The differences in survival, growth, or susceptibility to insects or diseases are striking and both we and our collaborators have used these sites for many formal tours and informal visits. Foresters can take interested folks (shareholders and board members from the participating companies, regulators, other researchers, and natural resource professionals) to the sites and SHOW them why we do this and related research projects on evaluating and moving seed sources and understanding tree responses to their growing environments. A picture may be worth a thousand words, but a field demonstration is worth a whole lot more than that!

We plan to continue this study for as long as our cooperators will host our sites. The specific types of factors we can study will change over time. We have enjoyed taking detailed measurements on young trees, but also look forward to taking measurements on older trees of other variables that foresters are also interested in (such as branching, wood quality, stem taper). If you would be interested in working with us, or just in suggesting topics we might consider for evaluation in the future, please contact either of us.

Constance (Connie) A. Harrington is a research forester and tree physiologist in Olympia, Wash., and Brad St. Clair is a research geneticist in Corvallis, Ore.; both work for the USFS Pacific Northwest Research Station. Connie can be reached at 360-753-7670 or charrington@fs.fed.us. Brad can be reached at 541-750-7294 or bstclair@fs.fed.us. Connie and Brad are both SAF members.
Access, Easements, Rights-of-Way and Timber Trespass: What Every Forest Manager Needs to Know, Sept. 20, Olympia, WA. Contact: WFCA.

OSAF Science Workshop, Oct. 3, Linn County Fairgounds, Albany, OR. Contact: Noelle Arena, noelle.arena@weyerhaeuser.com, www.oregon.forestry.org/content/2017-fire-water-health-workshop.

CESCL: Erosion and Sediment Control Lead Training 2-Day in Oregon, Oct. 9-10, Eugene, OR. Contact: NWETC.

Seedling Success in the Field: Linking Nursery and Outplanting Practices, Oct. 11-12, Corvallis, OR. Contact: WFCA.

The Hagenstein Lectures—Emerging Voices in Forestry, Oct. 15, World Forestry Center, Portland, OR. Contact: Rick Zenn, rzenn@worldforestry.org, www.hagensteinlectures.org.

Forest Carnivores and Their Habits: A Focus on Fisher, Marten, and Fox, Oct. 19, Linn County Fair and Expo Center, Albany, OR. Contact: Julie Woodward, 503-807-1614, woodland@ofri.org, ofricarnivore2017.eventbrite.com.

6th Field Technology Conference, Nov. 7-8, Portland, OR. Contact: WFCA.


Environmental Forensics-Site Characterization and Remediation, Dec. 5-6, Tigard, OR. Contact: NWETC.

Mapping the Course: Timberlands, Forest Products Processing and Fiber Issues for 2018, Jan. 24-25, Vancouver, WA. Contact: WFCA.


OSAF annual meeting, April 18-20, Bend, OR. Contact: Ron Boldenow, rboldenow@cocc.edu.

WSSAF annual meeting, May 2-4, Longview, WA. Contact: Ellie Lathrop, eslathrop@comcast.net.

Con Schallau 1931-2017

Con Schallau was born and raised in Iowa. He died peacefully in Oregon on July 6 after a long struggle with dementia. He met his beloved wife of 60 years, Leanah, while playing in the Iowa State Orchestra; him, the oboe and her the violin.

He was kind, thoughtful, and always greeted others with his wonderful smile. While growing up in the Midwest, his dream was to raise a family amongst the tall trees and rugged mountains of the west. Out of college, he began cruising timber in the forests of northern Michigan. His career as a research forest economist spanned 30 years from Portland to Washington, D.C.

When he retired, he and Leanah volunteered together at the various Presbyterian conference centers around the country, from Sitka, Alaska, to Stone Point, New York.

They finally settled in Spokane, where they continued their volunteering together at Deaconess Hospital and the Ronald McDonald House. They were also active in the First Presbyterian Church. Con was an SAF member for 63 years and was elected an SAF Fellow in 1989.

Con was 85 and was preceded in death by his wife Leanah and siblings John, Wilma, Hollis, and Kay. He is survived by his children Pam and Dan, grandchildren Hannah and Consei, and numerous nieces and nephews.

He was a veteran of the USAF. Any memorials in his honor may be sent to First Presbyterian Church, 318 S. Cedar St., Spokane, WA 99201.
Forest biotechnology refers to the use of biological processes at the molecular or cellular level to make products or technologies useful to society. Here, we discuss the use of forest biotechnology to enhance tree breeding, focusing on molecular genetic markers, gene discovery, and genetic engineering.

Molecular genetic markers have been used for at least two decades to enhance the production of genetically improved seed. Most molecular genetic markers are proteins (e.g., allozymes) or DNA segments that are used to track the inheritance of particular chromosomal locations. Markers can be used to simply determine how trees are related to one another, or to track specific genes. In the 1980s, allozyme markers began to be used to: (1) identify mislabeled trees in breeding populations and seed orchards; (2) determine the parents of open-pollinated seedlots; and (3) manage pollen contamination in seed orchards. Later, the Pacific Northwest Tree Improvement Research Cooperative (PNWTIRC) developed simple sequence repeat (SSR) markers for Douglas-fir that are now widely used by breeders. SSRs largely replaced allozymes because they are easier to measure and are more accurate and precise for measuring genetic differences. Recently, the PNWTIRC developed hundreds of thousands of SNP (single nucleotide polymorphism) markers for Douglas-fir. Because SNPs are single-letter changes in the DNA code, they are easy to measure using automated technologies, and there is a vast number of them in the genome. SNPs have also been developed for interior spruce and lodgepole pine by the University of British Columbia’s AdapTree project.

SNP markers are particularly good for a breeding approach called genomic selection, where superior genotypes are identified by using thousands of SNP markers per tree. First, we construct a prediction equation using a training population of trees that has both SNP and trait data. Then, we apply the prediction equation to other populations (e.g., seedlings) where the traits have not been measured. Thus, instead of selecting trees based on measuring the traits directly, we can use SNPs. Eventually, it should become possible to use genomic selection to reduce field testing, select for mature tree traits (e.g., wood quality) at the seedling stage, and speed genetic improvement by reducing the length of the breeding cycle. While cost is still a key constraint, the cost of using DNA markers continues to decline because of advances in technology. In Douglas-fir, genomic selection is being actively studied by the PNWTIRC and Northwest Tree Improvement Cooperative using funding from the USDA Northwest Advanced Renewables Alliance.

Sometimes it is important to know about specific genes. For example, single genes with large effects are occasionally found in native tree populations, and it is valuable to know exactly which genes these are. Once the genes have been discovered, genetic markers for these genes can be developed and used to guide tree breeding. This approach is being taken to develop SNP markers for the Cr1 gene in sugar pine, a gene that confers resistance to white pine blister rust. Knowledge about single genes can also be used to alter the characteristics of trees using genetic engineering. This can be accomplished by inserting genes from other species, or by changing the expression of native genes in the target species.

Two approaches are commonly used to discover genes of interest. The

These eight-year-old poplars, genetically engineered for containment, are undergoing testing in a field trial at OSU. For scale, shown is six-foot-tall Thomas Howe.
first approach is to look for correlations between gene expression and the trait of interest. The second approach is to look for genetic cosegregation using a genome-wide association study (GWAS). Using GWAS, we can test many thousands of genes to see which are inherited with particular traits from one generation to the next.

The first step in the pathway from gene to phenotype (the observable characteristics of a tree) is the synthesis of messenger RNA (mRNA). If we find a strong relationship between the amount of mRNA in a tree and a particular trait, the underlying gene is likely to be at least partly responsible for the resulting phenotype. Advanced technologies for mRNA sequencing now make it possible to conduct these studies on a genome-wide scale, using a method called transcriptomics. Tree samples are collected from particular tissues at specific times; mRNAs are isolated in the laboratory, the amounts of specific mRNAs are determined using sequencing machines, and the underlying genes are identified. We used this approach to discover genes associated with cycles of growth and dormancy in black cottonwood, and scientists at the USFS Pacific Northwest Research Station used a similar approach to study adaptation in Douglas-fir. The genes that we discovered are good candidates for influencing traits important to tree breeders, including genes associated with cold hardiness and drought hardiness.

Similar transcriptome studies by the Tree Biosafety and Genomics Research Cooperative (TBGRC) were used to identify genes involved in flowering, pollen formation, and seed production. The TBGRC used RNA sequencing to identify genes expressed in the developing flowers, pollen, and fruits of poplar and eucalypt trees. The transcriptome-identified genes are now being studied using genetic engineering.

A major TBGRC project is to develop reliable methods for preventing the spread of exotic and genetically engineered trees when required by regulations or for social license. Two highly effective genetic engineering methods are being studied, RNA interference (RNAi) and gene editing using CRISPR-Cas9 nucleases. Both methods are also widely used in medicine and agriculture, and are highly specific and efficient. RNAi poplars have been produced and found to be healthy and fully sterile in field trials. Gene-edited trees have been produced in both poplar and eucalypt species, and are currently being studied in the greenhouse.

A current effort in the forest biotechnology laboratory at OSU, funded by a major grant from the National Science Foundation (NSF), is to use GWAS to identify the genes that control capacity for genetic engineering in black cottonwoods. Many tree species and genotypes, even within poplars, are very difficult to genetically engineer, and the reasons are largely unknown. By identifying the genes involved, researchers will gain new insights into the nature of the constraints and produce new "gene reagents" that could be used to overcome barriers in poplar or other species.

TBGRC and forest biotechnology staff are also active in education about GMOs in general, and genetic engineering of trees in particular. As part of the new NSF grant, we are developing new methods for teaching high school students and teachers about genetic engineering methods and impacts. This work, broader outreach efforts, and stewardship technology such as genetic containment methods, are essential to develop the social license to use genetic engineering in forestry.

Glenn Howe is director of the Pacific Northwest Tree Improvement Research Cooperative and associate professor in the Department of Forest Ecosystems and Society at Oregon State University in Corvallis. He can be reached at 541-737-9001 or glenn.howe@oregonstate.edu. Steve Strauss is director of the Tree Biosafety and Genomics Research Cooperative and professor in the Department of Forest Ecosystems and Society at Oregon State University in Corvallis. He can be reached at 541-737-6578 or steve.strauss@oregonstate.edu.

SAF National Convention Coming to Portland in 2018

Mark your calendar for October 3-7, 2018, when the largest gathering of foresters in the country will converge on Portland for the annual SAF national convention.

While the 2017 national convention in Albuquerque is right around the corner, Northwest members should be aware of this national convention planning effort as many may be interested in volunteering and attending while it’s in our backyard.

Tammy Cushing is the general chair for convention. Volunteer opportunities will be available before and during the convention. From organizing field trips to staffing the raffle, there will be chances for members to contribute. If you are interested in volunteering, send an email to Tammy at tamara.cushing@oregonstate.edu. Volunteer service is a great way to meet people and show Northwest hospitality.

Convention typically draws over 1,600 professionals and students, and we are expecting a larger crowd in Portland. Foresters and natural resource professionals gather at this meeting to hear the latest research results, network, learn about local forest management and practices, get outside and attend field trips, present posters, chat with vendors showing new technologies and services, gain continuing education credits, and collaborate for the future.

Be sure to take advantage of the convention being in the Northwest and let’s show forestry professionals from around the nation our amazing forest resources. Additional information will be shared as we get closer to the event.

Tammy Cushing
Some of our native tree species are under attack, and some face a perilous future. Forest pathogens and insects are causing high levels of damage or mortality that imperil the commercial viability of some species or the ecosystem function and biodiversity of our natural forests and urban forests. In many cases, the “villains” are non-native pathogens (and the associated diseases that they cause) or non-native insects; in other cases, a changing climate, change in forest management, or unknown factors have altered the balance in favor of a native pathogen or insect. Land managers around the world are facing these issues and are asking for solutions. A potential natural solution is to utilize the natural genetic variation in our native species to help counter the damage by these pathogens and insects.

Genetic variation within a species is a key to its potential to evolve in the face of biotic and abiotic threats, including threats caused by pathogens and insects in the cases where they can’t be eradicated or controlled by other means. In the case of insect or disease threats, it generally comes down to genetic resistance of our native tree species and how we can use that resistance to keep forests healthy or restore unhealthy forests.

Basic questions arise such as:
(1) Is there genetic resistance?
(2) What is the level of resistance?
(3) What types of resistance are there?
(4) What is the frequency of resistance across the range of the species?
(5) Is the level of resistance sufficient for immediate use or will breeding be required?
(6) Is the resistance durable (will it last for decades or hundreds of years)?
(7) What is the timeline and effort needed to make use of the genetic resistance?

In the cases discussed here, we are looking only at resistance already present in our native species and the use of classical selective breeding, not the potential for genetically engineered resistance.

In the Pacific Northwest, white pine blister rust (caused by the fungus _Cronartium ribicola_) and Port-Orford-cedar root disease (caused by _Phytophthora lateralis_ pathogen) are two of the most well-known examples of non-native forest tree diseases that have caused significant mortality in our forests. All eight species of five-needle pine native to the western US are highly susceptible to white pine blister rust (WPBR). Port-Orford-cedar is the only forest tree species currently known to be highly susceptible to _P. lateralis_. Damage to spruce by the native white pine weevil (_Pissodes strobi_) is a notable example of insect damage that greatly impairs the use of Sitka spruce and interior spruce in reforestation. Fortunately, there is some genetic variation in our native tree species and breeding programs are underway in the US and British Columbia.

Breeding programs to develop blister rust resistance in sugar pine and western white pine started more than 50 years ago by the US Forest Service (USFS), with more recent efforts in western white pine in British Columbia. There are USFS regional resistance programs for the Pacific Northwest, Pacific Southwest, and Interior West (with rust screening facilities at Dorena Genetic Resource Center in Cottage Grove, Coeur d’Alene Nursery, and Placerville Nursery).

In many areas, land managers are reluctant to plant these species without the availability of resistant seedling stock since greater than 95% of seedlings can be killed on sites of high incidence of blister rust. In the rust resistance programs, trees were selected across an array of land ownership, and seedling offspring of these parent trees were inoculated (infected) with the rust pathogen to identify parents and families with resistance. Seed orchards of resistant trees have been established by various groups including the USFS and Bureau of Land Management (BLM), as well as state, tribal, and private organizations. Recent data suggest the BLM Horning seed orchard, composed primarily of parents from the western Cascades area of northern Oregon and southern Washington, produces seedlings with the highest level of rust resistance in western white pine, suitable for planting in many areas of western Oregon.
and Washington. In the Rocky Mountain Region, where western white pine forests once dominated moist, mid-elevation sites, landowners have been planting resistant seedlings for decades. Many of these stands are well stocked and are approaching harvest age, while others have succumbed to intense rust pressure or failed for other reasons. Additional cycles of resistance breeding are underway to further increase the level of resistance in the orchard seed available to forest managers.

In addition to breeding for rust resistance, the programs strive to maintain both genetic diversity and adaptability within the species, and the geographic range of each species is divided into breeding zones to help facilitate this. The product for reforestation is thus generally a genetically diverse mix of seed from orchards using many parent trees from the breeding zone to be planted. Field trials of the resistant seed lots play an important role. One notable series of field trials of western white pine seed lots established by the Washington State Department of Natural Resources and other partners and cooperators examines blister rust resistance as well as the adaptability of seed lots from different geographic areas on sites from Oregon to British Columbia. In addition, the field trials serve as sentinel plantings to monitor for other damaging agents and as demonstration plantings for conservation education.

Programs to develop blister rust resistance in whitebark pine started more recently, but are making great strides. Whitebark pine, a high-elevation conifer in western North America, is proposed for listing under the Endangered Species Act, with a decision expected in 2019. The identification of resistant parent trees and development of blister rust resistant populations would greatly facilitate success of restoration of the species. Restoration plantings of whitebark pine using rust resistant seedlings have been started on USFS and National Park lands, and genetic trials and conservation plantings on BLM, WA DNR and British Columbia Ministry of Forests, Lands and Natural Resource Operations lands. More limited resistance screening of the other five western species of white pines is underway.

Spruce is an important species for reforestation. The program to develop resistance to the white pine weevil is based in British Columbia. Seed is now available from orchards for both Sitka spruce and interior spruce, and an increased use of these species for reforestation has occurred. For interior spruce, over 40 million seedlings from orchard seed are being planted annually in Canada with an estimate of approximately 30% less weevil damage relative to unimproved (wild stand seed lots) stock in the areas of highest incidence of the weevil. Increased levels of resistance are anticipated as the orchard is rogued and new resistant parents are added.

Port-Orford-cedar is a conifer native to northern California and southwestern Oregon but has been grown horticulturally (often referred to as Lawson’s cypress) in many places around the world. The root disease threatens not only the native stands of Port-Orford-cedar but also many of the horticultural plantings in both North America and Europe. The program to develop genetic resistance, based at Dorena Genetic Resource Center, is a joint endeavor of the USFS and BLM with technical assistance from Oregon State University and with cooperation from many land managers. The program is one of the fastest developing applied forest disease resistance programs in the world, and significant increases in resistance are available. The geographic range of the species has been divided into 13 breeding zones, and innovative containerized seed orchards are now producing resistant seed for many of these zones. Resistant seed is being used for reforestation and restoration on USFS, BLM, National Park Service, state, county, tribal, and private lands. Breeding is underway to increase the level of resistance further.

Resistance is not immunity. In most cases, only a percentage of seedlings from orchards will be resistant, and it varies by species. For resistance, success is a journey. The programs in the Pacific Northwest are world leaders in development of populations of trees with genetic resistance to diseases or insects. With a true integration of research, applied tree improvement, smart reforestation and restoration, and support of the public, the road to successfully maintaining these species in our forests continues and illuminates the pathway to follow as new invaders affect our forests. The future is sometimes cloudy, but resistance is an important tool in the path to future healthy forests.

Richard Sniezko, an SAF member, is a geneticist for the US Forest Service Dorena Genetic Resource Center in Cottage Grove, Ore. He can be reached at 541-767-5716 or rsniezko@fs.fed.us.
Regional Partnerships Deliver on Value

BY BRIAN KLEINHENZ

W hen I first started working in Alaska, I read an amazing account of a timber cruiser in the late 1930s. This forester was dropped off on the north end of a remote island in early June. He was given a rough map, a few weeks’ worth of canned food, and the promise of resupply twice in that summer via air drop. This pioneer walked the berth and width of that island all season collecting timber inventory data along the way. He spent all summer in contact with not a single soul, and after being picked up on the beach at the far end of the island in the fall, spent all winter working up his data. In this digital age, few of us can even imagine being left alone long enough to do all this. Where were his deadlines? Why didn’t the world stop turning when he missed his daily backup to the cloud? Many foresters relish our alone time and cherish the peace of the woods. However, we are very lucky to have comradery and companionship with our fellow professionals in a way impossible to that early Alaskan timber cruiser.

Foresters throughout the country are more connected than ever. We often work on regional and national scales, and changing locations several times during a career is commonplace in both the public and private sectors. The Northwest Office of the Society of American Foresters is an excellent example of how our profession has embraced this new reality of connect- edness and used that energy to enrich the traditional chapter, state, and national levels of SAF organization.

In the Pacific Northwest, our four state societies have banded together to form a joint administrative structure in the form of the Northwest Office (NWO). In a climate of stagnant membership, it has been very useful for the societies to pool resources and share services. The NWO has two primary deliverables. The first is the Western Forester, our very own regional publication that covers issues relevant to forestry professionals in the Pacific Northwest. This has been a hugely popular publication both with members and advertisers. Second, the NWO provides a common source for administrative services. The NWO maintains an active website, interfaces with National SAF, hosts conferences, serves as a stable point of contact for questions from members and the public, and facilitates communication between the various levels of SAF’s organizational structure.

Together the Oregon, Washington State, Inland Empire, and Alaska Societies can support a stable, professional staff to provide continuity in knowledge and services that a volunteer base struggles with. With a modest annual budget of around $80,000, the NWO delivers excellent service and maintains an office at the World Forestry Center in Portland, Ore. Member assessments along with revenue generated by NWO publications and activities make this possible. A 17-member committee with representatives from all four societies guides the activities of the Northwest Office. This committee leverages a broad range of experience to coordinate efforts on things like policy action and fundraising in a very effective manner. One of the most progressive efforts is the annual leadership conference organized by state societies with support from the NWO. We collectively recognize the importance of nurturing and supporting the next generation of leaders within the forestry profession and dedicate special annual training for this purpose.

As a member of the Alaska Society and Juneau Chapter, I have found that participation in the Northwest Office has enriched and expanded my experience with SAF. While regular chapter meetings are still the bedrock of my interface to SAF, exposure to the NWO has provided opportunities for collaboration and leadership at a larger scale. It creates a much tighter knit and more effective Society. In many ways, the NWO has served to bridge the gap between local reality and national context. Our actions, position papers, fundraisers, and events are all much better with the input of regional and national partners.

A century ago our vocation was characterized by individuals working alone in the forest. Now we are collaborators and innovators finding ways to work across geography. We can be proud that our Society is keeping pace with these exciting times. I encourage each of you to support our very own Northwest Office and get to know the network of energetic individuals that share your passion for forestry. Your dues and energy make this all possible. By reading the Western Forester and engaging in regional events you will supercharge your career and forge some valuable connections that will enhance your personal and professional life.

Brian Kleinhenz is past chair of the Alaska SAF. He can be reached at bkleinhenz@terraverdeinc.com.
Editor’s Note: To keep SAF members informed of state society policy activities, Policy Scoreboard is a regular feature in the Western Forester. The intent is to provide a brief explanation of the policy activity—you are encouraged to follow up with the listed contact person for detailed information.

SAF Hosts Riparian Science and Management Workshop for Policy Makers. Spurred by the trend of increasingly restrictive policies for riparian areas in the Pacific Northwest, a group of SAF and other natural resource leaders organized a regional workshop on state-of-the-art riparian science and management focused on policy makers and their staff. The all-day workshop was held on August 10 in Portland at the World Forestry Center for an audience of 105 that included a notable number of local, state, and federal officials and staff. The program was fully sponsored by SAF and several other groups so that participants could attend at no cost. A $3,000 Foresters’ Fund grant was awarded in support of the event. Technical experts reviewed recent study findings, and landowners and managers provided first-hand accounts that highlighted many complexities and challenges in managing these unique areas in the broader landscape. These observations helped show how simplistic or overly restrictive approaches and policies for managing riparian areas can lead to missed opportunities for improving watershed conditions and resources, as well as some significant unintended consequences for both people and resources. Contact: Paul Adams, OSAF Policy chair, adamspaulw@gmail.com.

OSAF to Review Pesticides Position Statement this Fall. With the coming expiration of OSAF’s position statement “Using Pesticides on Forest Lands” (Dec. 2017), the statement will be reviewed for potential changes and updates to the discussion and supporting references. The use of pesticides on forestlands remains a very important issue that continues to stir public controversy and concern, particularly aerial spraying. For example, although its legality remains in question, a ballot initiative that bans aerial spraying was narrowly approved this spring by voters in Lincoln County, Ore. All OSAF members are invited to review the existing statement (www.oregon.forestry.org/oregon/policy/general) and pass along any comments to your local chapter officers or the Policy Committee. Contact: Paul Adams, OSAF Policy chair, adamspaulw@gmail.com.

New Western Oregon Riparian Rules Now Effective, Other Regions to be Considered. With the Oregon Board of Forestry’s (BOF) decision to increase restrictions in riparian areas on private forestslands in western Oregon, the Oregon Dept. of Forestry (ODF) finalized the specific rule language and related guidelines, which became effective on July 1. Because of persistent concerns about the proposed rules and related research and science concepts, OSAF submitted written input during the public comment period that preceded the final rulemaking. Among the key messages: the added restrictions and complexity of the new rules are likely to discourage rather than encourage resource improvements through active management by landowners and managers. In addition, the new rules rely heavily on tree basal area as a surrogate for stream shade and do not provide explicit allowance and methods for shade-centric management alternatives, which reflects limited consideration of more cost-effective policy to maintain cool stream temperatures. Such concerns generally persist with the new rules and as potentially similar rules are considered by the BOF elsewhere in Oregon. Details about the new western Oregon rules can be found at www.oregon.gov/ODF/Pages/LawsRules.aspx and the ODF website should provide updates on rules considered for other regions. Contact: Paul Adams, OSAF Policy chair, adamspaulw@gmail.com.

OSAF Updates Commercial Timber Harvest Statement and Position Statement Booklet. Earlier this year the OSAF Executive Committee approved an updated version of the position statement on Commercial Timber Harvest on Public Lands in Oregon. The revised text includes more recent facts and figures about economic benefits of timber harvest as well as some fine-tuning of the overall text. The commercial harvest issue remains very timely given widespread management needs and costs on federal forests, as well as the statutory and long-held economic obligations to communities with large areas of nearby state or federal forests. Contact: Paul Adams, OSAF Policy chair, adamspaulw@gmail.com.

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