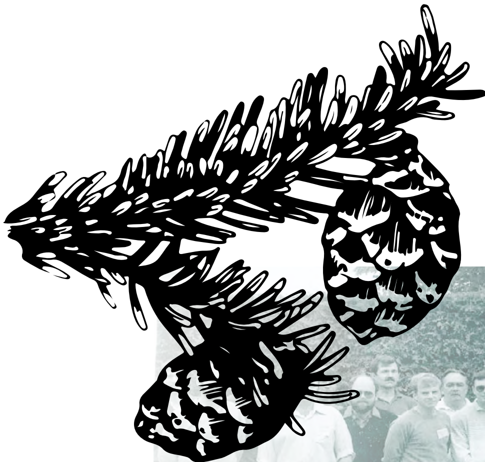

Tree Seed Working Group
News Bulletin

Canadian Forest Genetics Association
l'Association canadienne de génétique forestière

70
January 2021

SEED PREPARATION

Featured in this Issue:

Armchair Report No. 70

Hello, I hope everyone is staying safe, sane, and healthy under these very unusual times. This is our 70th edition of the Tree Seed Working Group News Bulletin, so happy platinum anniversary to us. This edition unfortunately comes with some sorrow as Dr. George Edwards passed away on November 26th from viral pneumonia at the age of 83. George played a huge part in the research and the extension of seed science and technology, provincially, nationally and internationally. He is certainly a figure that would be on our Mt. Rushmore of significant contributors to tree seed science and technology in Canada. An overview of George's many publications and a recording of the virtual service for George on December 5th can be found on his web page Forest Tree Beginnings. I have attempted to provide a suitable memorial in this edition, and others have also included some words of condolences and of gratitude for George's many contributions. One of those contributions is that George was the very first editor of this News Bulletin, back in 1983.

At our facility, we have not shut down during COVID-19 and were declared an essential service. There are many changes to how we work, interact, and these have been dynamic as we look forward to some light at the end of the tunnel. There has been a bumper crop year in BC, mainly from seed orchards, and this has proved to be challenging, especially with the need to hire new staff. I want to thank Marilyn Cherry, our Safety Officer++, for leading the charge and everyone else who helped maintain a safe workplace for us and our loved ones. I thought it might be a good idea if we all shared some of the changes or security measures that we have put in place to help combat the spread of this nasty virus. We currently are a mask-on facility for any movement through common areas, and access to our building is greatly restricted, except for staff who are part of our 'conehead bubble'. I thought I would include a few photos and

Banner photo of the 1987 Canadian Forest Service Tree Seed Testing Workshop, held in Chalk River, Ontario. Photo provided by Kim Creasey.

CFGA Tree Seed Working Group

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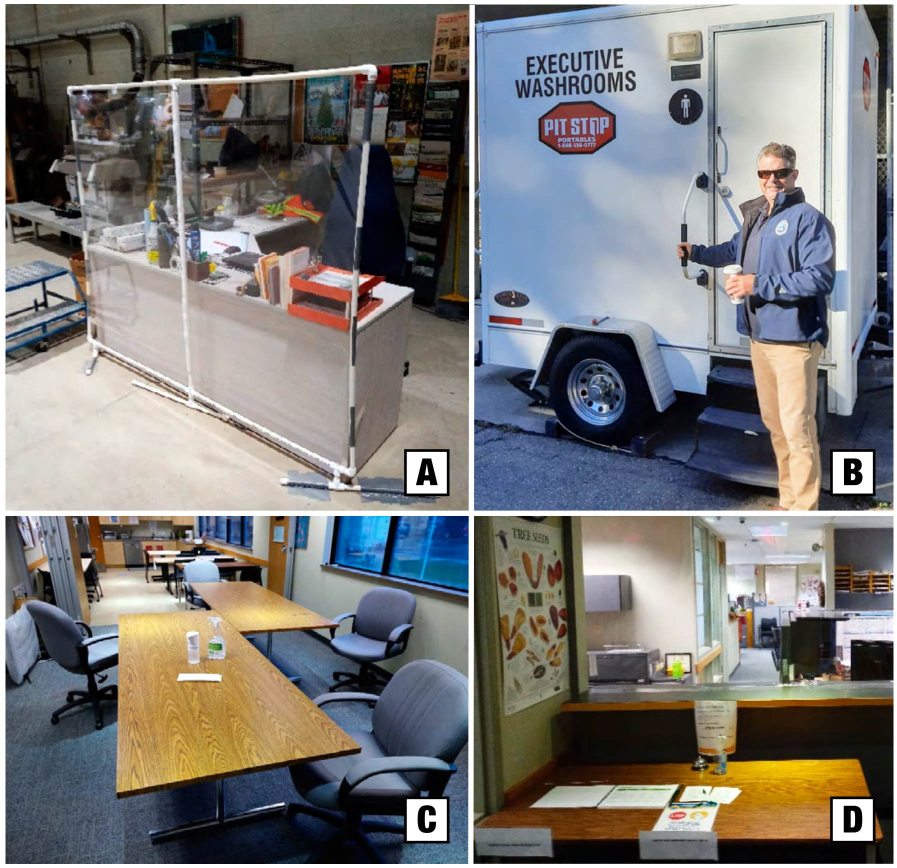
Deadline for Issue No. 71: June 15, 2021

We welcome any comments, suggestions and article submissions and will solicit active, subscribing members on occasion for content. Submissions may be edited for length. Authors are responsible for the accuracy of the material in their respective articles. The mention of commercial products in this publication is solely for the information of the reader, and endorsement is not intended by the Canadian Forest Genetics Association (CFGA).

All issues of the News Bulletin are freely available here.

The Tree Seed Working Group News Bulletin is published biennially. The Group's principle aim is to promote tree seed science and technology through

1. Seed research from bud initiation to seed utilization
2. Identification of seed problems relating to tree improvement and forest management
3. The exchange of information on seed-related problems, and by
4. Advising on implementation practices.



COVID-19 workplace safety measures at the BC Tree Seed Centre, including a) plastic around work stations in the Seed Centre, b) One of our Executives (Shane Berg) poking fun at the "Executive" washroom trailer for contractor use, c) distanced lunchroom and d) new protocols for visitors.

invite you to send along yours to illustrate what changes you have instituted to prevent the spread of COVID-19. Ours have included a great deal of plastic barriers at our entrance and in areas where employees may be within an unsafe distance, distancing and restricting physical meetings, renting a portable washroom for contractors and others coming onto our site. What have you done at your facility?

As many of us do this time of year, I have also been reflecting, on life, work and the News Bulletin and how they contribute to seed science and technology. My focus is on trying to bring some scientific rigour and experience to our decision-making but being part of an operational facility, one does not often have the luxury of designing and waiting for results; decisions need to be made with the best available information today! It also involves questioning past practices, and that is key if we want to truly claim to be involved in continuous improvement. It certainly is not change for the sake of change as a lot of effort and experience has gone into developing current practices, but times have changed, and the reality is that our product is also changing as we move to more and more to seed orchard seed in BC. I attempt to leave my ego behind, review all available information and provide the best

More physical COVID-19 barriers erected between work stations and Laura Boivin enjoying the view.

recommendation. Times have changed, but I often go back in time to my first manager, whose first question wasn't 'what are the "rules"', but 'what are the consequences'. There are always risks in what we do and although I don't want to encourage complacency, I am continually amazed by the robustness and resilience of tree seeds. I am fortunate to be working at an operational facility with people who care about and balance cone and seed quality, efficiency, and continuous improvement and that is truly a blessing; a dream job. I am truly thankful to be where I am.

I also think of my contributions as stepping stones or building blocks to improving our knowledge about cones and seeds which continues to evolve. Those before me–George Edwards, Ben Wang, Guy Caron and Carole Leadem–contributed the big building blocks when less knowledge was available, communications were more challenging. and reforestation programs were going through a huge expansion in Canada with more limited operational experience compared to today. These people filled the gaps on the BIG gray areas and although we still have lots of questions we should all feel far more comfortable with our current practices because of their contributions. Thank you to all those people who have been the stepping stones to the state of our knowledge today.

Stay safe, and hopefully 2021 will be a little more normal.

Dave Kolotelo
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Editor's Notes

Happy New Year to all! This was supposed to be a pre-Christmas read but I'm sure you'll enjoy it nonetheless. Of all the issues I've helped with, this is probably the most robust and feel-good after a challenging year. The coast-to-coast response from my last email was fantastic. For some, I realize it is daunting to writing an article no matter how much lead time is given, but we've all got a few photos of the bizarre reality we are still working through. Please enjoy the belated festive collage and poem compiled around some of the many images sent, and please send more for Issue No. 71; I do intend for them all to be included and two more issues delivered in 2021. It's a good time to be involved in seed and tree planting, as the rest of the world recognizes what we all know needs doing.

Though the Ontario policy announcement by Ken Elliott was immediately relevant, the next issue will hopefully be themed around "Assisted Migration and Climate Change Effects on Seed" in practice, so similarly to the casual email feedback on COVID-adaptations, I would like to hear from more nursery owners and long-time seed collectors or workers about what they've observed over time. We'll also check in on leading science, policy and tools. There is also a huge swell of activity around improving direct seeding again, by drones, seed pelleting, pucks or other means, so please reach out if you have research or information to share on that for a tentative No. 72 theme.

As one TSWG editor to another, a few days before I heard he had passed, I gave a silent thank you to Dr. George Edwards for helping me with seed germination testing training last fall at a business new to it. I used several of George's guiding documents, including material from the 1987 Tree Seed Testing Workshop, pictured in the banner image. In the 1987 workshop binder exercises, Dr. Edwards and Ben Wang made sure the big black holes were easy to see, avoid and solutions to implement. Whether by long-form math or now automated data management, problem-solving by their methodology is still a fast track to success and just needs a few tweaks with incremental results accumulated since. Given the number of memorials in the issues I've published and tomes they've left, one has to wonder what else remains to be discovered once the Canadian Mt. Rushmore of Seed Science is carved. I've been naive within these pages and group many times already, but I've learned who and where to ask. As intimidating as a mind like George's may have been, his model of patience for those on the curve is what will keep the regeneration of tree seed knowledge alive and well.

I am truly thankful to be past COVID quarantine (see page 14) and back at the National Tree Seed Centre (NTSC) full-time on the NRCan Interchange Program from the Forest Gene Conservation Association in Ontario. This is a dream come true for me. This arrangement will allow me more time to devote to NTSC testing and data, assist with operations and collections strategy, training, and presentations, at an accessible public facility. I look forward to working with many of you, and please reach out if NTSC can be of help.

Lastly, I'd like to point out two new photo guides of interest:

- Idžojtić, M. 2019. Dendrology: Cones, Flowers, Fruits and Seeds. 1st edition. Academic Press. doi:10.1016/C2019-0-00771-6.
- Ogle, J., Witsell, T., and Gentry, J. 2021. Trees, Shrubs, and Woody Vines of Arkansas. University of Arkansas Press. 539 pp. https://www.uapress.com/product/trees-shrubs-and-woody-vines-of-arkansas/

Errata in No. 69

- Misspelling of author's last name in my Editor's Notes and signature of the article "Eastern White Cedar Storage Experiment" should be Daigle, B.I., and Simpson, J.D. 2009. Collecting and processing Salicaceae seeds. Native Plants Journal 10(1): 49–51, and Bernard Daigle.
- Dave Flight (Manitoba Forestry Branch) informed me the operational seed bank formerly at Pineland Nursery was not transferred to the University of Winnipeg.

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Memories of Dr. George Edwards (1937–2020)

Condolences from Dave Kolotelo

With great sadness, I learned of Dr. George Edwards passing away on November 26, 2020. At the virtual memorial service and in email exchanges with others, I learned a few things about George that I didn't know. I didn't know we shared the same birth name – the DGW stands for David George Warrilow, although it seems he was always called George. We were both the oldest and first in our families to go to University. We also had some common interests outside tree seeds, including nature, gardening, photography and Monty Python humour. I entered the 'seedy' field just before he retired, but we continued to correspond about 'seedy' matters long after that.

You can see the large influence George had on seed science and technology through his impressive publication record https://ftb.ca/cv.php. It was also clear that George had a large influence on those around him, how he wanted to help others succeed, and loved to teach others what he had learned.

There was also plenty of ideas that didn't make it into the journals that influenced our procedures today. George's work on the use of long soak durations in western white pine and yellow cypress (up to 28 days) was the original light bulb for our current 14-day soak with western white pine. That step, the elimination of a warm phase and extension of cold stratification at elevated moisture contents, was a total game-changer in breaking dormancy in this deeply dormant species. Water uptake was certainly a key area that George was interested in starting with his PhD on the kinetics of water uptake in Noble fir. I still look back on our conversations of moisture uptake and the important question—when does moisture get to the embryo? We see that even after our standard soaks (24–48 hours) that water will continue to be absorbed into the seed, and for white pine, why we keep the seed surface wet for a period of time (a week for us; 28 days in Washington state) to allow full imbibition to occur. It's still a relevant question today. I've used it many times, but it came from George—don't be afraid of cold water—it has a much higher oxygen concentration than warm water.

Dr. George Edwards, 1937–2020.

Participants at the 1993 joint meeting of the BC Tree Seed Dealers Association and the Western Forest and Range Seed Council, with Dr. George Edwards circled in the back row. Photo provided by Don Pigott, with added note by Dave Kolotelo "Unfortunately us TSC participants hit the road before the photo was taken."

Moisture was a key interest of George's, but he really explored all aspects of tree seed science and technology – always questioning and searching for answers from the purely practical to the obscurely academic. I'll touch on a few key publications of George's (see above link for full citations) – some are very well known and others not so, but they all had a profound influence. Many people point to his *Abies* chapter in the Wood Plant Seed Manual, and it remains, and will probably always be, the definitive chapter on this genus from reproductive biology to seedling production. It screams of George's attention to detail and joy in digging for details, spanning 37 pages of text and 668 reference sources!

Probably the most referenced and influential journal article was the 1980 article in Seed Science & Technology titled "Maturity and quality of tree seeds – a state-of-the-art review". It still holds relevance today after 40 years and should be required reading for anyone dealing with conifer tree seed production. This scientific paper was the logical extension to "Guideline to Collecting Cones of BC Conifers" which George co-authored with other peers in the mid-1970s and had several revisions overtime in which George was part of. Continuing with the very practical, George's 1987 publication on Testing Tree Seeds cut through the International Seed Testing Association (ISTA) volume presenting methods and procedures in an easily digestible format. This was when seed exports in BC were common and the group at the Pacific Forestry Centre lead the way with the OECD certification of the seed. George was, of course, the expert to interpret the rules and provide recommendations. George was a long-standing member of the ISTA Forest Tree and Shrub Committee and that created a consistent connection between us. If you read his last paper in No. 63, "Pieces of Forest Tree Seeds...Pieces of Unscientific Nonsense in the ISTA Rules" (expanded with more diagrams on his website here) he did not leave ISTA quietly nor with a good taste in his mouth. Although our committee supported George's recommendations, the Purity committee, which is more agriculturally focused, simply did not want to change, and they had the final word.

One of the articles that perhaps does not get enough attention is his 1979 article "Cone collection and Processing – effects on seed quality and yield". Cone collection receives a great deal of subsequent attention, but processing is a topic that doesn't get much love and its potential impact generally underestimated. This wasn't lost on George, and he provides one of the best, easily read overviews of cone and seed processing, which again should still be, required reading for anyone engaged in these activities.

George had a long-standing involvement with the International Union of Forest Research Organizations (IUFRO). This used to be the organization for the exchange of tree seed knowledge internationally. George was involved in some of the truly classic symposiums of the various tree seed related working parties (Bergen, Norway 1973; Chalk River, Canada 1980; Chania, Greece 2002), chaired the Seed Physiology and Technology Research Group and was the driving force and editor of the 1991 symposium in Victoria BC that focused on dormancy and barriers to germination. Dormancy release was a career-long interest, and it needed to be if you started out with Noble fir as your guinea pig for your PhD thesis. His work, in conjunction with the work of Drs Carole Leadem and Yasoumi Tanaka, formed the basis for the stratification-redry procedure that we currently use to break dormancy in the deeply dormant *Abies* species. It was another breakthrough in seed science.

This is just my personal reflection on George and particularly his career, which was the basis of our connection. You can see from the memorial service and stories enclosed in this News Bulletin that George was so much more to so many, and I extend my condolences. His swan song on pure seed definitions was at the crankier end of his scale, and although it was a beautiful and detailed piece of work, I think his legacy should be of a more giving and caring person and scientist. Many of his classic works were before or in the infancy of the internet. You will not be disappointed by searching these out as George never published anything that he hadn't fully researched and thought through, more than twice. Thank you, George, for your contributions and our friendship—you have left a legacy to be proud of.

Condolences from Don Pigott

I first met George in 1979 when I worked for Mac Millian Bloedel. I was interested in being able to tell the difference between one and two-year-old cones of Yellow cedar. It sounds simple now, but at the time we were just starting to make large-scale operational collections of cypress, and had limited experience. He, Doug and Frank came up to my office at Yellow Point and put on a really great training session, as well as telling us about the seed work at PFC. We also collaborated with the trio, Doug Ruth and Al Hedlin, on *Abies amabilis* seed yields and handling. In 1982, I left M&B and became a "seed dealer" collecting and selling seed within BC and abroad. For the first few years, I contracted Frank Bernard at Western Tree Seed to process the cones for us in exchange for portions of the seed. George had re-introduced me to Frank when I went out on my own, and it t became a long-term business relationship and friendship.

I started accumulating seed processing equipment of my own, and one of the first things I built was an air seed separator based on one George designed in 1979. I have four now, and they are the backbone of our seed cleaning facility. I "upscaled" his design to do operational quantities, and subsequently, in my "spare time" built replicas for Reid Collins, Western Tree Seed, Weyerhaeuser, VIU, Sylvan Vale, two companies in Oregon, Ontario, and even one to a former classmate of George' in Britain. I am currently building one for the BC Ministry of Forest. (or whatever they are called this week). A bit of George's "seed ideas" scattered over the planet.

When I started exporting seed, I regularly saw George, Frank, Doug, and Don Craigdallie when I needed collections certified. It was always a pleasure to work with the whole team. They were always supportive of any issues the BC Tree Seed Dealer's had with either the biological aspects and the regulatory ones. The second photo is of the members of the BC Tree Seed Dealer's Association and the Western Forest and Seed Council four-day meeting in the Okanagan in 1993. George is in the back… in front of the birch tree, Frank is on his left (if you don't know what a birch tree is, you just failed dendrology).

In the late Spring of 1992, George and Al Mitchel went with me to Nimnim Lake in the Alberni Valley to collect Western Yew cuttings for some propagation trials. I had broken my leg six months before but got around in the bush pretty well with a cane. As I was climbing up a steep slope to the next tree, I heard the pair who were not used to bushwhacking, puffing away, and George said, "why don't we break his other leg."

We would occasionally see George and Eleanor in more recent years. On one occasion, they dropped in because George wanted to get one of my many surplus old crosscut saws to mount in the entry to their house. Eleanor did little to hid her eye-rolling. (It's a guy thing, Eleanor.)

It was a valuable experience to have known George both personally and professionally, and like all of the rest of you will miss him dearly.

Condolences from Doug Taylor

I worked with George as his technician for over 20 years. I am forever grateful he took a chance with me. In 1971, I was a recent chemistry graduate with little biology experience when I was hired as his technician. I look back fondly on those years at PFRC, and I consider myself so fortunate.

By 1970, I had completed two summer student terms at PFRC in the Soils Chemistry lab with Kevin McCullough and Bruce Weber. On completion of my Chemistry degree, I landed a few months of fieldwork with Jim Lee and Bob Roswell. I then became unemployed.

Things were pretty tough for new graduates in the early 70's. PFRC had just gone through a reorganization, and a few people were laid off. So, in January 1971, I was very grateful for a Term position with George and Pat Olsen. George took a chance as my experience in Biology was zero and less than that in conifer seed. My job was to set up germination tests for Western Hemlock. It involved counting seeds in lots of 100 and X-raying to determine if they were viable. It was pretty tedious work, but I must have impressed George with my counting as I was hired full time in July 1971. My lack of knowledge in biology wasn't a concern to him as he must have thought he could teach that. Something I did learn early on was to ensure coffee was ready on time. I had inherited the essential job from Pat and was instructed on how to make the drip coffee using Nabob Fine Ground coffee. Some things you never forget, such as five cans for $1 of Pacific Condensed Milk.

Over the years, I thought I learned to do the job quite well. George was a good teacher and very patient. I was a quick learner, and when he saw I understood something, he left me to it. He was always interested in what you were doing but never looking over your shoulder. He supported me in taking University courses in conifer biology, statistics and computer languages. This would have immediate benefits in analyzing our data. A simple Basic Language program I wrote eliminated the manual calculations for germination tests. I must confess this was mainly for my benefit. Later, at PFRC, a full-time statistician was hired, Clarence Simmons. He arrived with sophisticated statistical programs, ENB2 and UNC3. George used me as a go-between with Clarence, and I developed a rapport with him. Clarence modified my simple Basic Language program and tacked it onto his sophisticated statistical programs. This was a quantum leap. The Seed Lab had moved into the computer age! We were now able to statistically analyze the results of our germination tests without having to visit the old calculator room.

George was always looking at new ways to improve procedures. We were one of the first labs at PFRC to get a microwave. Officially, it was used to determine moisture content in Abies seed. We soon learned that there were hotspots in the microwave and mapped these so we would not fry our seeds. Unofficially, it was also great to reheat food. Another piece of equipment was purchased to accurately determine the moisture content of individual seeds. It used a vile-smelling Karl Fischer Reagent. I quickly learned not to run samples during or preceding coffee time.

Aaah, coffee time. A very important time during the workday. Our "Seedy "group grew and at some times was over a dozen, including students and visitors. It was a time for discussion, sometimes serious, but mostly about projects, hobbies, fishing and anything else of interest. Christmas time was a special time. The week leading up to Christmas offered special coffees, a different one each day. Those were the days management looked the other way when it came to alcohol. Actually, they made the rounds of the various labs and workshops to sample these special drinks. At one particular coffee time, Eleanor brought in some tapes of the Goon Show, a British Comedy favourite. It had her and George in stitches. The rest of us were gobsmacked. We could not understand a thing. The accents were so foreign; we did not understand a word. We had a good laugh, though, at George and Eleanor. They obviously thought it was hilarious.

It was not all about fun, however. Over the years, George developed treatments for Yellow Cedar and Abies that are used today. He became a world authority on Abies and was Canada's representative on the International Seed Testing Association (ISTA). For ISTA, he was responsible for rewriting the rules for conifer sampling and testing. Another assignment he readily accepted was to set up a seed lab in Baghdad, Iraq. He was very excited and spent months preparing for his assignment. Everyone was trying to talk him out of it, but to no avail. Relations between Iraq and Israel were deteriorating. Escalating rhetoric was making headlines. But George plowed ahead. He obtained his Diplomatic passport and was about to get his airline tickets when Israel attacked and destroyed a nuclear power plant just outside Baghdad. The timing could not have been better for everyone's sake. Maybe not for Iraq.

I can look back at the 20+ years working with George with many fond memories. I was so lucky to have known him. He was easy going and always concerned with the well being of others. He made the lab a great place to work.

Thanks for the memories, George. Rest in peace.

Condolences from Mike Meagher

On behalf of my wife, Birgitte, and myself, I wish to express our profound thanks for the invitation to contribute to the Memorial event for your father, George, and for the excellent job done by all of the contributors.

George and I were collaborators and confre'res from the early 1970s until his passing, despite his determination and dedication to rise from his wheelchair and resume his customary pursuit of "Seedy" knowledge (apologies for the seedy abuse of scientific terminology).

I was employed by the BC Forest Service as the first employee dedicated "Seed Orchard Forester" while I completed my PhD studies. All phases of seed "growing", maturity progress, collection phase and post-collection handling were of interest to George and discussed during meetings of the "Seed Orchard Group" of the Tree Improvement Committee.

Once crowned as PhD, I became a "shadow" to Dick Piesch, working with George in the PFRC facility after my appointment as the BC Forest Service's Western hemlock Breeder. More George in my life, continuing when I changed jobs and moved to PFC to become the breeder of Western white pine vs. the imported (not by choice) of the Asian "Blister rust of white pines". Then I "joined" the vaunted (by Frank Portlock's account during the Memorial) "Seedy Coffee Circle".

We continued the fun after retirement by collaborating in the collection of twig material of BC's only oak species: Garry oak. NB: The "Garry" is due to the Hudson Bay Company, of which Mr. Garry was a fort's Factor. In our first year, we collected from many BC locations, including along the Fraser River north of Hope. We had to reach the east bank of the River in late November, relying on a work crew of the CN Railway company, since there was then no road to follow in "our"/my van. Smooth trip to the site, where we collected from several trees and bagged our catch. Our CN chauffeurs had assured us of a return trip when their day was done, late in the day. Light fading and our confidence with it, we contemplated becoming our own transportation vehicles, requiring a dash through each of several tunnels. We had no idea of the regular train schedule, so we're planning the best way to shrink ourselves if we met an ongoing "smokey". Fortunately, our timidity saved us for the then-local "Uber".

The following year, our contract meant travel (again by my van) as far south in the US as northern California, being guided by local Forestry officers and "real workers". Our departure from Victoria coincided with a snowy squall that had George scanning the sky with more than a little concern, especially since the snowfall increased the farther south we reached. Our family van saw us through, challenged again by near-icy surfaces the next day—NOT the balmy USA in February we had planned on.

A different year and species of interest—whitebark pine—joined by Colin Wood, also retired and of PFRC fame, saw us facing "early snow" above the Okanagan Valley. This time cones were the payload. I had scoped stands during the summer, so our trip was known and any risks evaluated. Cones had to be pulled, twisted "with vigah" or cut from branches, mostly from the top tenth of the tree. "Whiskey jacks" were a regular companion while they bit off cones and were NOT good hosts. Luckily, they were hungrier than territorial, leading me to cohabit with more than one tree with a "jack".

I could have chosen my collaborators better; my slender frame and belt size meant I did most of the climbing while George and Colin, neither "slender", spotted the cones and bagged and tagged the bounty.

Last reference to Garry oak: BC funds for genetic studies of minor tree species generated a contract to study several species and report results in annual Colloquia. George and I became the "Andy" and "Hardy" of the event. I organized the sequence of presenters and handler for the technical adjustments of "visuals" while George introduced the successive presentation. Considering the audience, who would face the need to adjust to a new voice speaking in —often—a new accent, volume and cadence, George would haul out one of several hoary jokes to relax and assist in the adjustment. All for one low price.

Memories of such "family events", when George shone his humour on all and sundry, will certainly arise in our brains at irregular times and ignite a warm glow to share among the assemblage. Happy memories of a fine man.

Condolences from Dick Piesch

As one who traveled on occasion with George, I certainly enjoyed and appreciated Mike's telling of the stories [at the virtual Memorial]. Too bad you weren't with George, Frank and me, as we almost ended up in Revelstoke jail for picking a few cones for Petawawa.

One memory that I didn't share was the anticipation on Monday mornings amongst our PFRC coffee group to hear of George's experiences over the past weekend. It usually had to do with maintenance or home improvement issues on his home on Cedar Hill Crossroads. The home tended to be older than the rest of our homes and required quite a bit of upkeep. It seemed like no matter how small the job appeared at the beginning; it always evolved into a number of new issues that required repeated trips over the weekend to numerous building supply stores in the area. One tale (not really a tale) was his attempt to fix a runny faucet in the kitchen. That caused a problem with the pipes in the wall behind the faucet, which led to leaking pipes under the kitchen floor, which led to removing a large portion of the kitchen floor. But George, Margo, and family just took it in stride, like it was a normal way to spend the weekend. This project obviously was the source of several interesting Monday morning discussions over coffee. The rest of us would have thrown in the towel and called in the pros, but George just got on with it and tackled the problem(s). And George was great at recounting the episodes in detail, with all of us enjoying his stories as much as he enjoyed telling them.

Thanks again for the memories with George. No matter how far apart life takes us, the friends we've shared and the memories of them make life worth living.

Condolences from Kim Creasey

It was 1987 when I first met George, as part of a Tree Seed Testing Workshop, which he was co-leading with Ben Wang at Petawawa National Forest Institute. It wasn't until the early nineties, when I became more keenly involved with western tree seed species, that a more professional relationship developed as part of our family transition to British Columbia. Being the ever inquiring research scientist George was, there was always something new to consider when it came to looking forward to successful biological protocols and articulating their significance at the practical level, thus saving the end-users of the seed time, money and energy.

New protocols for Mountain Hemlock was one such example for us at Western Tree Seeds. After completing the initial stratification process, then germinating the seed in the dark, as recommended, surprising results became evident in the overall seed germination capacity and vigour. We then embraced the method as a standard protocol for our operational procedures within.

It's with great thanks and humble admiration that we acknowledge such pioneers, like Dr. George Edwards, who are out there and have that affinity to envision a myriad of potentials. They devise the practical methods, simplifying the biology and opening the minds of others, thus creating benchmarks to be built upon.

While the physical presence of George will be missed, his legacy and outreach will be appreciated for many years to come. May God bless you and keep you always, George.

Condolences from Rob Bowden-Green

So sad to here the news. George was such a unique person who provided so much to our world of tree seed. He was a great source of help to the BC Tree Seed Centre and to me personally.

Condolences from Joe Wong

Sad news but it also brought back good memories not because of days of me with black hair and no extra weight but the patience and tolerance that Dr. Edwards had for naiveté and ignorance that I carried.

Dr. Edwards taught me much about the influence and effects on seed germination, which I believed saved my arse a few times. Like most of us, I believe that folks like George were instrumental in the success of BC's seedling production program, without the heavy footprint in the sand.

2020 TSWG COVID-19 Collage

In the spirit of a challenging year, please accept this belated, "Christmas Card" (lost in the mail?) from the Editor. Thank you to all who submitted COVID-19 adaptation photos on short notice, and we welcome additional feedback and photos for No. 71 as the pandemic continues.

Inspired by Dr. Seuss' *How Did it Get So Late So Soon?*

T'was the week before Christmas,
And all through the town,
People wore masks,
That covered their frown.

The frown had begun
Way back in the Spring,
When a global pandemic
Changed everything.

They called it Corona,
But unlike the beer,
It didn't bring good times,
And it didn't bring cheer.

Contagious and deadly,
This virus spread fast,
Like a wildfire that starts
When fueled by gas.

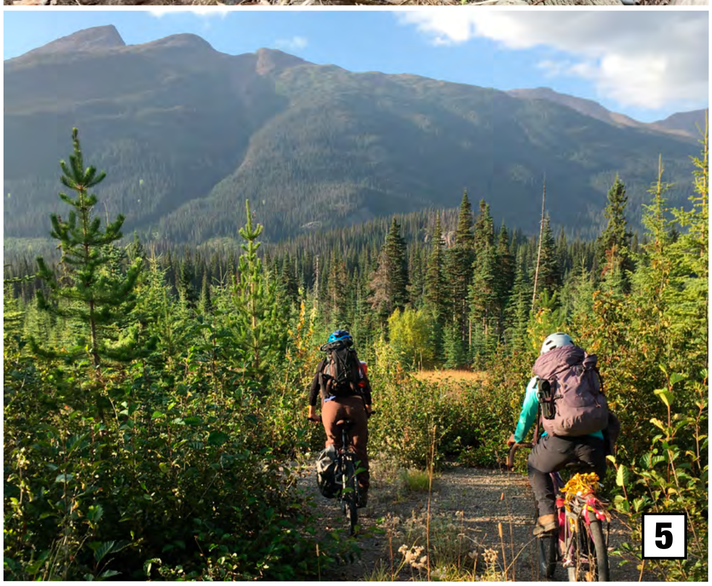
Airplanes were grounded,
Travel was banned.
Borders were closed
Across air, sea and land.

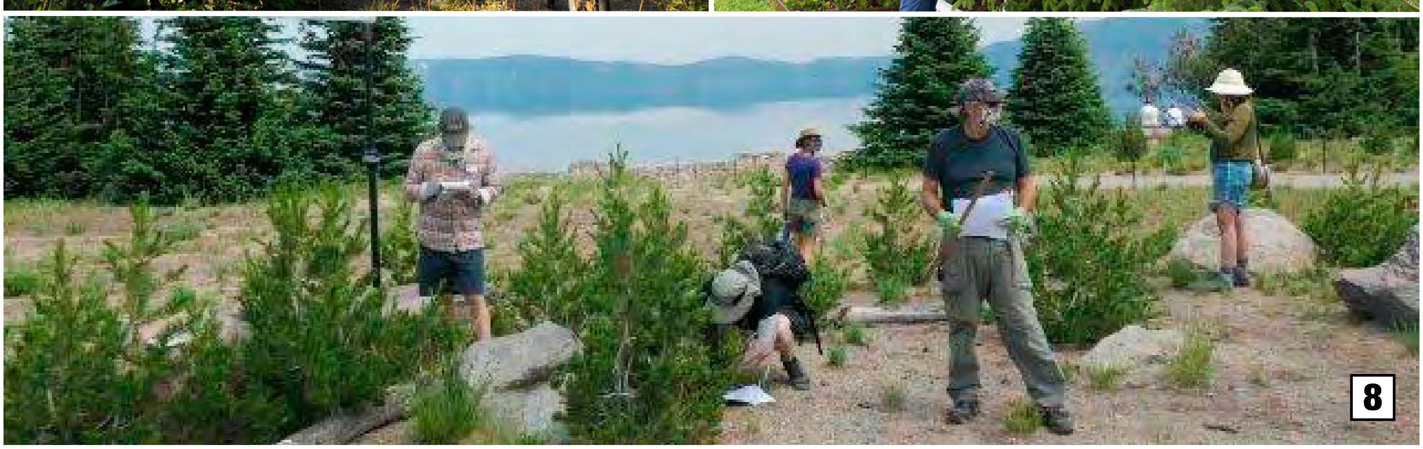
As the world entered lockdown
To flatten the curve,
The economy halted,
And folks lost their verve.

From March to July
We rode the first wave,
Some people stayed home,
They tried to behave.

(continued on page 12)

1. Transplant crew lead Itzel Corona poses in her workplace attire Spring 2020. No staff tested positive at Wester Forest Nursery, Washington Department of Natural Resources, Tumwater, WA this year. Photo by Nabil Khadduri. 2. Hardwood seedlings at the Green Legacy Nursery, Wellington County, Ontario, which had to adjust 15,000 lost volunteer hours in delivering 165,000 trees to residents. Photo by Jessica Trzoch. 3. COVID safety adaptations during Spring 2020 hardwood lift (poplars) at the Berthier Nursery, QC. Photo by Fabienne Colas, MFFP.





4. Stephen Smith, Urban Forest Associates, planting a parent-DNA-certified pure butternut (*Juglans cinerea*) seedling on a Toronto, ON ravine property, May 1, 2020. Photo by Sue Reimer. 5. Bulkley Valley Research Centre field crew (Alana Clason, Sheena Briggs) setting off for 10-year remeasurement of a no-longer-truck-accessible whitebark pine restoration and provenance trial. A socially-distanced camping trip in the Gosnell Valley. Photo by Sybille Haeussler. 6. The first *Fraxinus latifolia* sentinel planting being established for emerald ash borer monitoring at the Dorena Genetic Resources Centre (DGRC), Cottage Grove, OR, December 2020. Photo by Richard Sniezko. 7. Emma Creasy and Taylor Holt evaluating Sitka spruce phenotypes. Photo by Patrick von Aderkas, University of Victoria, BC. 8. DRGC technician, PhD student and researcher assess the whitebark pine restoration trial at Rim Village, Crater Lake National Park, OR, August 2020. Photo by Richard Sniezko.

But tree people were essential
The politicians said,
So nurseries still hustled
And cone kilns still fed.

Plastic shields for all,
Stay a hockey stick apart,
Millions of trees still planted,
Now that’s my kind of chart!

Campgrounds were busy
And gardens were full,
Some people remembered
Nature isn’t so dull.

But others craved friends,
After lockdown was lifted.
So away from caution,
Many folks drifted.

Now it’s December,
And cases are spiking,
Wave two has arrived,
Much to our disliking.

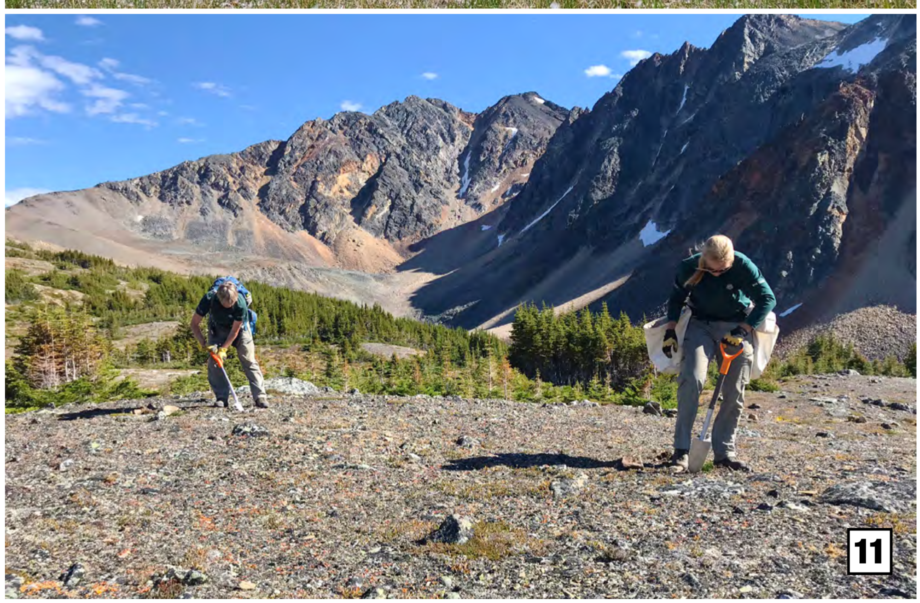
Front-line workers,
Doctors and nurses,
Try to save people,
From riding in hearses.

This virus is awful,
This COVID-19.
There is not yet a cure.
But soon … a vaccine!

It’s true that this year
Has had sadness a plenty,
So much research fieldwork
Cancelled in 2020.

And just ‘round the corner -
The holiday season,
But why be merry?
Is there even one reason?

(continued on page 14)



9. COVID safety adaptations during Spring 2020 hardwood lift (poplars) at the Berthier Nursery, QC. Photo by Fabienne Colas, MFFP. 10. Forestry technician Becky McLaurin laying out a white pine (*Pinus strobus*) assisted migration trial plot for the Forest Gene Conservation Association near Almonte, ON, May 12, 2020. Photo by Briana Barkley. 11. Barb Sharp and Traudi Golla planting whitebark pine seedlings near the Tonquin Valley in Jasper NP. Credit: Parks Canada, courtesy of Brenda Shepherd.

12. A COVID "bubble" of Roland Jarrett (far right), his children and their friends, and others from the Central Interior Mapping planting crew at the site of a new logdepole pine seed orchard planted in Spring 2020. Photo by R. Jarrett. 13. Propagation trials of *Corylus cornuta* phenotypes 'Bellis' and 'Ardrossan' at the Northern Forestry Centre (article in prep). Photo by Jessica Hudson, Natural Resources Canada. 14. DGRC staff Sean Parks and Scout Dahms-May prepare *Salix* cuttings for post-fire reclamation on the South Fork McKenzie Ranger District, Willamette National Forest, OR, burned by the 2020 Holiday Fire. Photo by Haley Smith. 15. Blister rust resistance screening of Alberta provenances of limber pine (*Pinus flexilis*) at the DGRC, with a number of new resistant families documented. Photo by Richard Sniezko. 16. Collecting white spruce seed in Abitibi, QC. Research by Viridis Terra continued in 2020, including genetic analyses of native species acclimating to reclamation site soils. Photo by Evgeniya Smirnova.

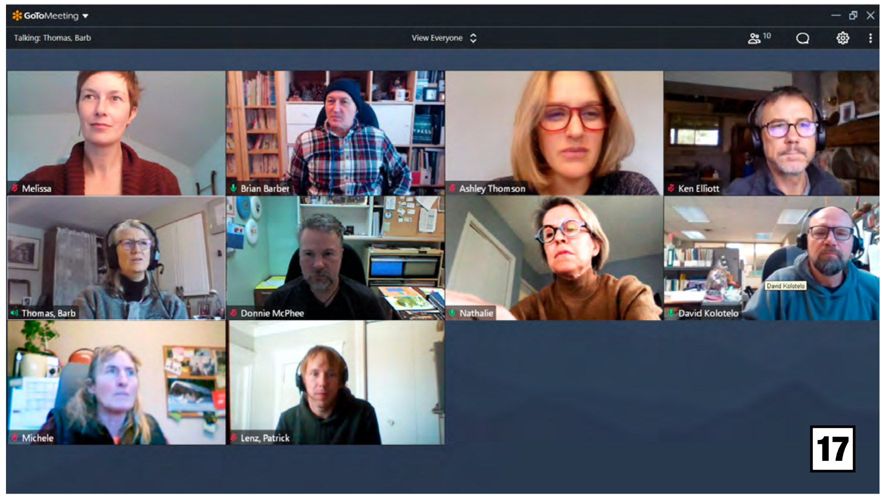
To decorate the house
And put up the tree,
When no one will see it,
No one but me.

But outside my window
The snow gently falls,
And I think to myself,
Let's deck the halls!

So, I gather the ribbon,
Hang the garland and bows,
Sing and laugh on Zoom,
And my happiness grows.

Christmas wasn't cancelled
And neither is joy or hope.
If we lean on each other,
We know we will cope.

This poem was a 2020 Internet 'meme' modified by Kim Creasey and Melissa Spearing. May 2021 bring us closer to meeting in person once again.



17. A November CFGA Executive video conference call to plan the 2021 virtual student and postdoc symposium. Present top to bottom (L–R): Melissa Spearing, Brian Barber, Dr. Ashley Thomson, Ken Elliott, Dr. Barb Thomas, Donnie McPhee, Dr. Nathalie Isabel, Dave Kolotelo, Michele Fullarton and Dr. Patrick Lenz. 18. Seed.TheNorth. staff member Colin Chudyk hugging a black cottonwood (*Populus trichocarpa*) near the site of their new seed extraction and pelleting plant in Hazelton, BC. Photo by Natasha Kuperman. 19. A collage of preprocessing collections made by Green Legacy Nursery. Photo by Jessica Tzroch. 20. TSWG Editor Melissa Spearing out of quarantine Christmas Eve in New Brunswick at the National Tree Seed Centre lab's cone display collection (large cone pictured is a Coulter pine, *Pinus coulteri*).

Michele Fullarton Retires

After 32 years with the New Brunswick Department of Resources and Energy Development (DNRED), Michele Fullarton is retiring!

Michele has devoted almost her entire career in Tree Improvement (TI) and has been the Coordinator of the DNRED TI team for the past decade. Michele has been an important part of DNRED's tree improvement efforts for over 40 years. She fully contributed to NBTIC, CFGA Tree Seed Working Group, FastTRAC, the soon-to-be AtlanTIC and other TI programs with many different agencies. Thanks to her work, and that of other TI specialists, we now have 2nd and 3rd generation genetically improved seeds for a variety of species in the province. Our seed orchards now produce sufficient improved seeds for New Brunswick's annual reforestation program.

I am sure Michele will be very happy to be able to spend more time on her other passion–dog sledding!

Michele's dog-sledding team.

I like to take this opportunity to welcome Shona Millican to the DNRED TI program. Shona brings a lot of TI experience to the job. She will be leading the TI team, taking over all internal and external TI involvements for the department.

Tom Ng
Acting Director, New Brunswick Department of Natural Resources and Energy Development
Island View, NB
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Seed Matters! Technical Note Series from ATISC Continues

The Alberta Tree Improvement & Seed Centre (ATISC) has released five additional technical notes in the 'Seed Matters' series. Seed Matters consolidates eight years of research results and experience in their seed technology labs, and provides information to industries, academia and the general public in an easy to understand and concise format. Links to all currently available PDFs are below.

Seed Matters 1: Recommendations for Aspen Seed Collection and Handling

Seed Matters 2: Extracting and Handling Five-Needle Pine Seed in Alberta

Seed Matters 3: Sowing Five Needles Pines from Alberta Seed

Seed Matters 4: Seed Imbibition Times for Sowing Alberta Pines and Spruces

Seed Matters 5: Lodgepole and Jack Pine Seed Treatments for Greenhouse Sowing

Seed Matters 6: Greenhouse Temperatures for Sowing Alberta Pines and Spruce

Seed Matters 7: Lodgepole Pine Cone Classes and Impacts on Seed Quality

Lindsay Robb
Alberta Agriculture & Forestry
Alberta Tree Improvement & Seed Centre
Smoky Lake, AB
Email: lindsay.robb@gov.ab.ca

New Lodgepole Pine Seed Orchards in BC

In 2020, Select Seed Company Ltd, owned by the Forest Genetics Council of BC, purchased its first property near Quesnel. Central Interior Mapping was contracted to prepare a 50-acre field on the property for a 5,000-ramet lodgepole pine seed orchard. This orchard, and two others being established by the BC Ministry of Forests and the Vernon Seed Orchard Company, will produce seed for northcentral BC. Approximately 1,400 grafts were provided

Figure 1. Jarrett Columbus, Kalamalka Forestry Centre, Ministry of Forests, Vernon, with lodgepole pine grafts. Photo by Brian Barber.

to each site by the Ministry and planted in Spring 2020 (Fig. 1). The balance of orchard grafts and seedlings will be planted over the next 2–3 years. It will take 8–10 years before the orchards to produce their first crops.

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BC Tree Seed Centre Recent Kiln Upgrades

The kiln used for cone opening at the BC Tree Seed Centre (TSC) was designed and installed in 1986. It consists of three chambers, though the individual chambers cannot be controlled separately (Fig. 1). Cones are loaded onto trays that are placed inside the chambers on wheeled dollies. Reversible fans above each chamber generate heat, and also circulate warmed air around and between the trays of cones. A natural gas burner is used in addition to the circulation fans during high-temperature kilns of serotinous species (mainly interior lodgepole pine, *Pinus contorta* var. *latifolia* Engelm.). Originally, plans were in place to allow for future expansion of the kiln, but the expansion never happened. Therefore, the burner is much more powerful than required for the current set-up, and kiln programming must account for this oversized burner.

The kiln is serviced and balanced annually. However, because of its specialized nature, we find it a bit of a challenge to get knowledgeable contractors on site. Improvements are made as needed, such as replacing the safety gas shut-off unit and burner components. A few years ago, an engineering analysis was carried out; it was determined that the outer shell of the kiln is in good shape, so improvements have been focused on internal components and monitoring.

Argus Control software is used for kiln programming and operation. The software was originally modified from greenhouse control software for our use. Kiln batches are often run during the evening, overnight, and on weekends, so the kiln operator needs a way to turn the kiln on and off from home, and to be able to monitor temperature and relative humidity (RH%) during a kiln run. Temperature and humidity probes within the chambers are hooked into the Argus program so that the operator is aware of internal conditions.

Up until 2017, a dial-up phone modem, with a blistering-fast port speed of 9,600k, was used to dial into the Argus control program. Dropped phone lines were common, especially during stormy weather. A few years ago, we upgraded to being able to remotely log in to the control computer, totally alleviating dial-up modems completely, and bringing us into the modern world.

Originally, only two temperature probes were installed to provide feedback to the control program. Newer probes were gradually added, and within the last decade, one temperature probe was installed within each of the three chambers; two of the three probes then also had the capability of monitoring RH%. In the last two years, all of the probes within the kiln have been replaced with newer, more robust, high-quality dual temperature and humidity probes, now with two probes per chamber. The kiln program set points are controlled based on the average temperature and RH% of all six probes. Thus the feedback controlling a program is much more precise and accurate than in the past.

In 2018, we began using small downloadable data loggers that could be placed anywhere within the kiln chambers

Figure 1. One of three kiln chambers.

Figure 2. A downloadable temperature and RH% data logger placed inside the kiln.

(Fig. 2). We discovered that temperature and RH% was uneven both within and between chambers, and fluctuated with fan direction. The location of hot or cool spots could now be pinpointed.

The reversible fans broke down from time to time. I personally witnessed a fan blade shearing off while the kiln was running, and crashing down the entire outer metal skin of the kiln—it was a truly terrifying noise (Fig. 3). Replacement parts were not always available when needed, so substitute motors and fan blades were installed that were not always equivalent to the old parts. Fan motor speeds varied, and fans had either three, four, or five blades. This resulted in uneven environmental conditions within the kiln. Last year, all motors and fan blades were replaced, to provide more uniform and consistent operation.

Other mishaps would occur; most notably the kiln doors occasionally popped open mid-run. Adjustment of the door latches and new door pin fittings has resolved this issue.

In 2019, we had a major software upgrade of the control program. Prior to the upgrade, feedback to the remote operator was based on temperature and RH% averaged over a 15-minute time span, and only 4 channels could be followed at once in a graph (Fig. 4a). The new software provides real-time feedback, and many channels can be observed at once, including conditions inside the building, within the kiln chambers, and ambient conditions outdoors (Figs. 4b, c). The operator now has the ability to note environmental conditions throughout the kiln, and to do a more refined job of running every kiln.

During our last two crop seasons, we have been using

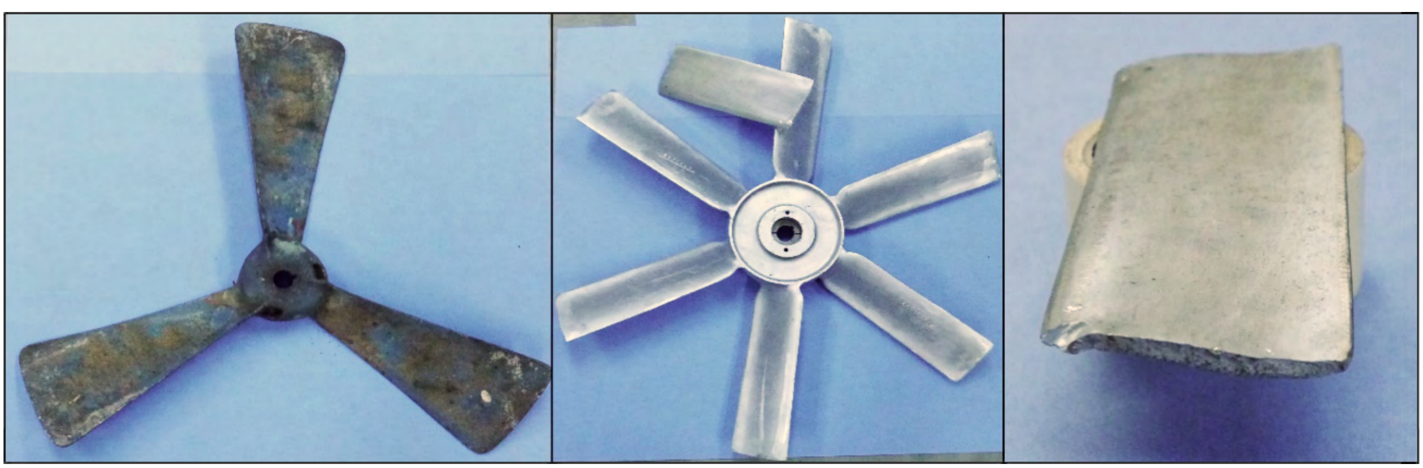

Figure 3. Kiln fans: the old, the new, and the broken blade.

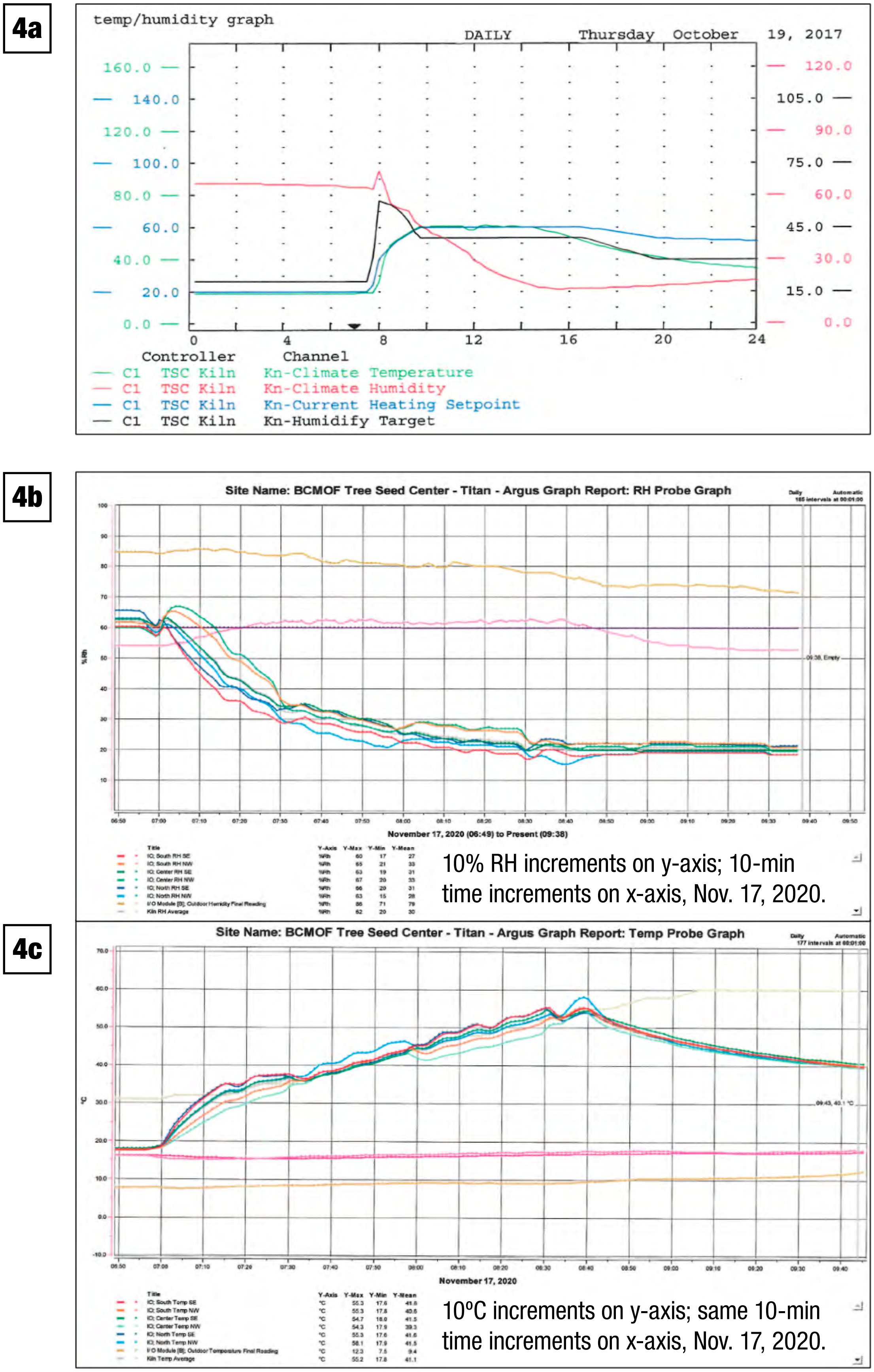

Figure 4. Kiln run graphs from the old (a) and new (b, c) software programs.

endoscopes to observe serotinous interior lodgepole pine cones breaking their resinous bonds. Not knowing how well these cameras could withstand high kiln temperatures, we selected inexpensive units from a large online distributor. The endoscopes are draped over the kiln door and clipped to a dolly tray inside the kiln (Figs. 5, 6). We can then watch the cones open in real-time on a laptop or tablet screen. This real-time info has really improved and refined our lodgepole pine kiln methodology and timing.

The kilning process is one of the major bottlenecks at the TSC. Cones must be biologically ready for kilning. Kiln dolly loading and unloading are labour-intensive activities that take the better part of a workday to complete. Only one kiln run per day can be carried out, and if cones are not in ideal condition, the time to complete a kiln batch may be prolonged over days. Recent improvements have aided in operational efficiency, and the ability to refine our processing.

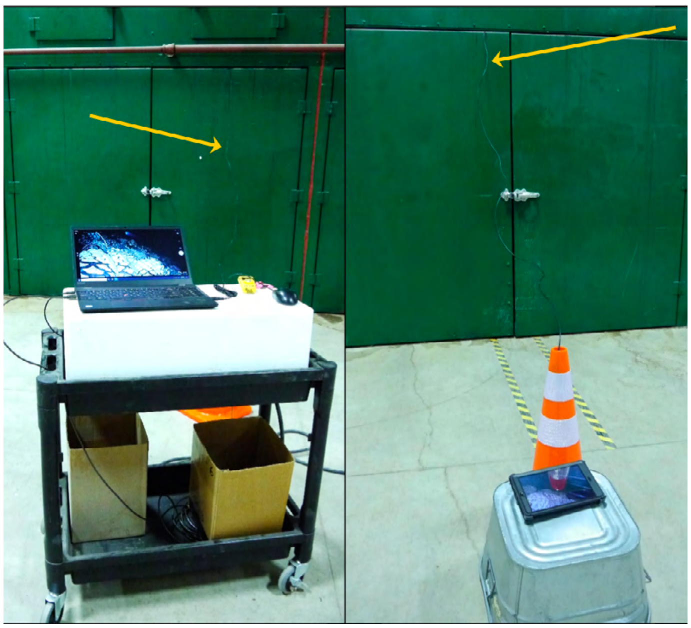

Figure 5. Using endoscopes to observe cone opening on a laptop and tablet.

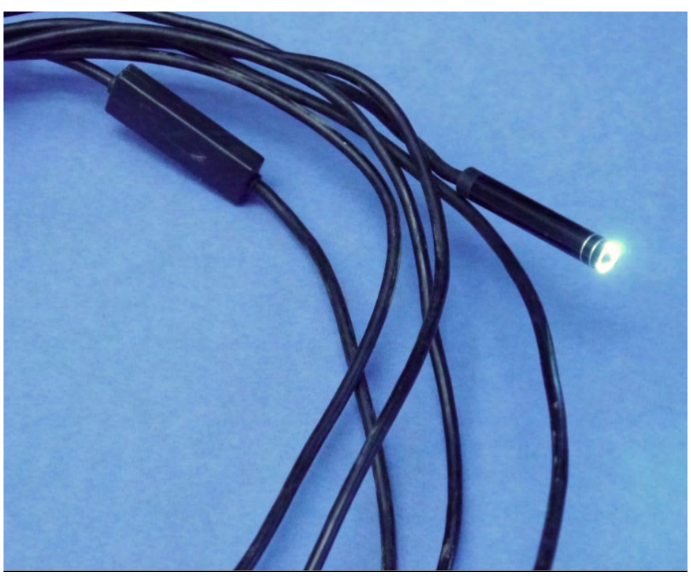

Figure 6. Endoscope used to observe cone opening.

We are always looking to make improvements, and our wish list for future upgrades includes adding in a more permanent and robust internal camera system, and engineering a better cool-down system.

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Stratification Moisture Content Monitoring in British Columbia

Introduction

For most commercial tree species we deal with in British Columbia, some degree of physiological embryo dormancy needs to be overcome by cold stratification. The primary exceptions are western redcedar (*Thuja plicata*) and red alder (*Alnus rubra*), which are pellet coated and sown dry at the nursery. At the BC Tree Seed Centre, we have been monitoring the stratification moisture content of seedling requests as part of our Quality Assurance (QA) programs in the lab and seed preparation areas since 1992 to develop a database of species-specific results, improve local practices and identify anomalies.

Stratification of species covered in this article are initiated with a 24-hour running water soak (48 hours in grand fir, *Abies grandis*), surface drying the seed, and then placing the seed in 2–4 mil (depends on bag size) polybags. Stratification is naked, without additional media, and the top of each bag is tied with a "two-finger" opening to allow for gas exchange. Our goal is to maximize internal seed moisture content through seed imbibition and then remove just the moisture on the seed coat to allow it to flow freely and be efficiently sown. Maximizing internal moisture will increase the rate of biochemical reactions involved in overcoming physiological dormancy under stratification conditions (2–5° C). If the stratification moisture content is too low, then embryo dormancy will not be overcome, and the germination will be reduced. There have not been many studies on minimal moisture content for breaking physiological embryo dormancy, but Gosling and Rigg (1990) for Sitka spruce (*Picea sitchensis*) and Downie et al. (1998) for white spruce (*Picea glauca*) estimated that 25% was the critical moisture content. At our facility, we looked at the effects of stratification moisture content on ten wild stand lodgepole pine (*Pinus contorta*) seedlots and germination seemed to peak at 30% moisture content, and a substantial drop in germination occurred at 15% moisture content. The speed of germination (peak value; Czabator 1962) continued to increase at higher moisture contents (Fig. 1; Hannam 1993). There has been research performed on moisture requirements and benefits of changing moisture levels during stratification for some *Abies* spp., but this is beyond the scope of this article (Edwards, 1986; Leadem 1986). The more specific methods and data collected for our other deeply dormant species (*Pinus monticola* and *Callitropsis nootkatensis*) are also beyond this article's scope.

Surface drying will allow for efficient nursery sowing, allow for free oxygen exchange and reduce the potential for seed-borne fungi to proliferate and reduce seed quality or cause seed handling problems. Surface drying is conducted at our facility using screened tables that connect to our ventilation system and basically vacuum moisture away through the surface of the seed mass (Fig. 2). It is critical that drying is uniform through the seed mass, and this technique necessitates some manual movement of the seed during the surface drying process. It is a quick process with one kilogram of seed, with movement, taking a few minutes on the drying table. There are a variety of ways this can be achieved, from the use of fans to the use of spin-dryers to remove surface moisture (Gosling et al., 1994); the key is to remove only surface moisture, not internal moisture, and to try to apply this surface drying as uniformly as possible to the mass of seed.

Moisture content testing was initially based on sampling seedling requests and performing a destructive test to estimate the moisture content at our facility. This was replaced by monitoring with weight; basically, the "target moisture content" concept promoted by Jones and Gosling

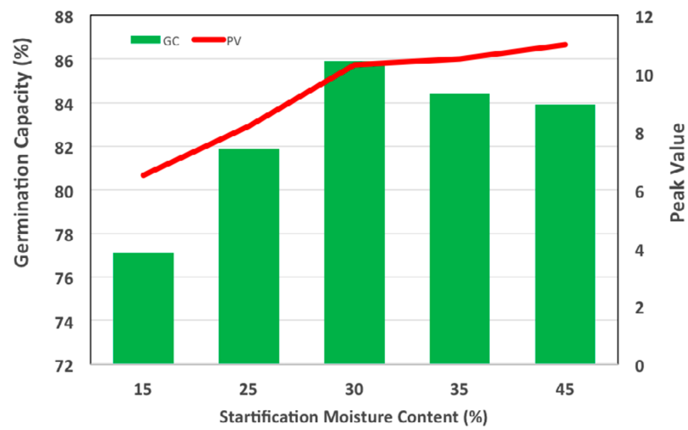

Figure 1. The mean germination and peak value of ten wild stand lodgepole pine seed lots stratified at 15, 25, 30, 35 and 40% moisture content (Hannam 1993). Note that seed quality is much higher than it was in the early 1990s.

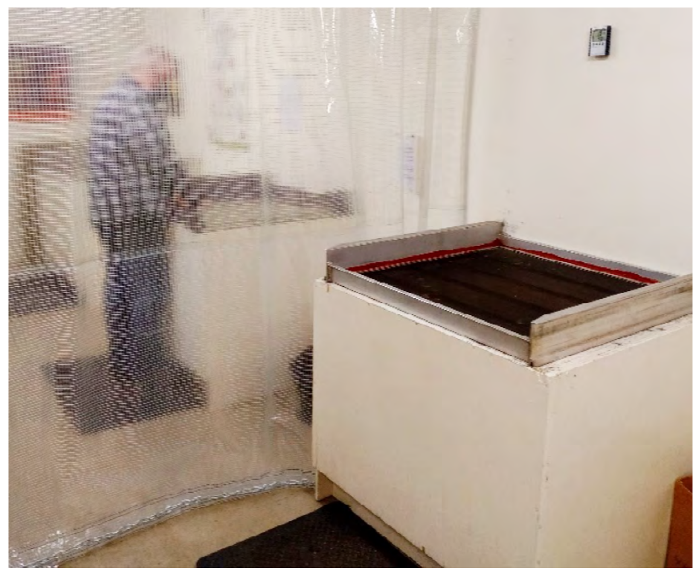

Figure 2. The surface drying tables used at the BC Tree Seed Centre. The clear curtain is used to separate the two technicians, for COVID-19 safety, who generally will each be managing two drying tables.

(1994). Since we know the storage moisture content of the seedlot and the initial mass of the seed being stratified, we could determine the oven-dry weight of that seed. We can then determine 1) the moisture content of the surface dry seed, or 2) if we had a specific moisture content target, we could determine the weight we want to surface dry the seed mass to. It is simply the rearrangement of the basic moisture content equation, as presented below.

- Moisture content = (fresh weight – oven-dry weight) ÷ fresh weight

- Oven-dry weight = fresh weight × (1 – moisture content)
- Fresh weight = oven-dry weight ÷ (1 – moisture content)

If one wants moisture content on a percentage basis, multiply the result by 100, but for the other two equations, remember to input moisture content in its decimal format. We cannot overemphasize the value of this methodology to our QA program. It is not only non-destructive but since it is based on the entire mass of seed, there is no sampling error present. We also cannot overemphasize the importance of uniformity; mathematically, you'll get the same result if all seed is at 30% moisture content or if half is at 20% and the other half at 40%. Uniformity in stratification moisture content will decrease variability in overcoming dormancy and subsequent germination timing, reduce crop variability resulting in a more uniform and easily managed crop.

In BC, stratification moisture content targets were initially the average of a rolling five-year average and to quantify variability, the 95% confidence limit range was added. The dataset used is based on a combination of seedling request weights gathered after surface drying, before stratification (MMC1) and that obtained at the time of shipping (QA). The MMC1 data is used to help 'calibrate' surface drying to only remove the minimal amount of moisture and is key to restarting a new season and training new employees. The QA moisture content estimate is calculated prior to shipping when a seedling request is sampled for germination testing as part of our QA program. Both are recorded in our local cone and seed processing (CONSEP) database program. When both variables were available on the same seedling request, we only used the QA value in the main analyses. These two variables represent the beginning (MMC1) and end (QA) of the stratification process, and when comparing results on the same seedling requests, the moisture content differences are very small. This pooling of the two variables was especially important to enable us to get a reasonable sample size for some of our less commonly used species. One of the key principles is the maximization of internal moisture content, so we are not as concerned with the higher values as long as the seed is in a surface-dry state. The lower values are concerning as removing too much moisture prior to stratification may result in incomplete removal of seed dormancy.

This average and confidence limit provided a target and estimate of variability as previously presented (Kolotelo 2018), but it didn't really address the question of what is an appropriate operational range, what is an outlier value worth looking into and when should corrective action be taken? During our current review, we used orchard-produced interior spruce as an example of our thought process so we present that (Figs. 3–5), results for all BC tree species by genetic class (Table 1), and add some discussion that includes some of the anomalies we have recognized through our QA monitoring programs.

Results

Interior Spruce Seed Orchard Example

From 2016 to 2020 sowing seasons (662 seedling requests), seed orchard interior spruce had an average moisture content of 27.9% and a 95% confidence range from 27.8 % to 27.9%. For the 41 seedling requests we had both MMC1 and QA data for, the seed moisture content increased by 0.07%, on average. The average stratification moisture content for wild stand interior spruce over the same production seasons was 31.1% (n=93), but no reduction in germination due to this has been observed.

We initially looked at adjusting the confidence limit ranges as a method to have more reasonable acceptable operational ranges. The 99% confidence limit range didn't help define an operationally acceptable range and only slightly adjusted it from 27.8% to 28.0%. A plot of all 662 moisture content data points is presented with horizontal lines representing the mean and 1×, 2×, and 3× multiples of the standard deviation on either side of the mean (Fig. 3). These plots, by species and genetic class (seed orchard vs. wild) plots, were used in conjunction with staff and experienced surface drying technicians to produce a table of acceptable stratification moisture content ranges after surface drying. Emphasis was on ensuring a minimum amount of moisture was present (>25% is our current cross-species minimum) and recommending a "reasonable" operational range that better reflects inherent variability in each species. The range selected for orchard-produced interior spruce was 26.0–30.0%. If requests fall outside this range, they would be looked at further in terms of past MMC1 or QA moisture content history.

A historic concern was that with very small seedling requests, these could dry much quicker and too low during the surface drying procedure. In Figure 4, the relationship between

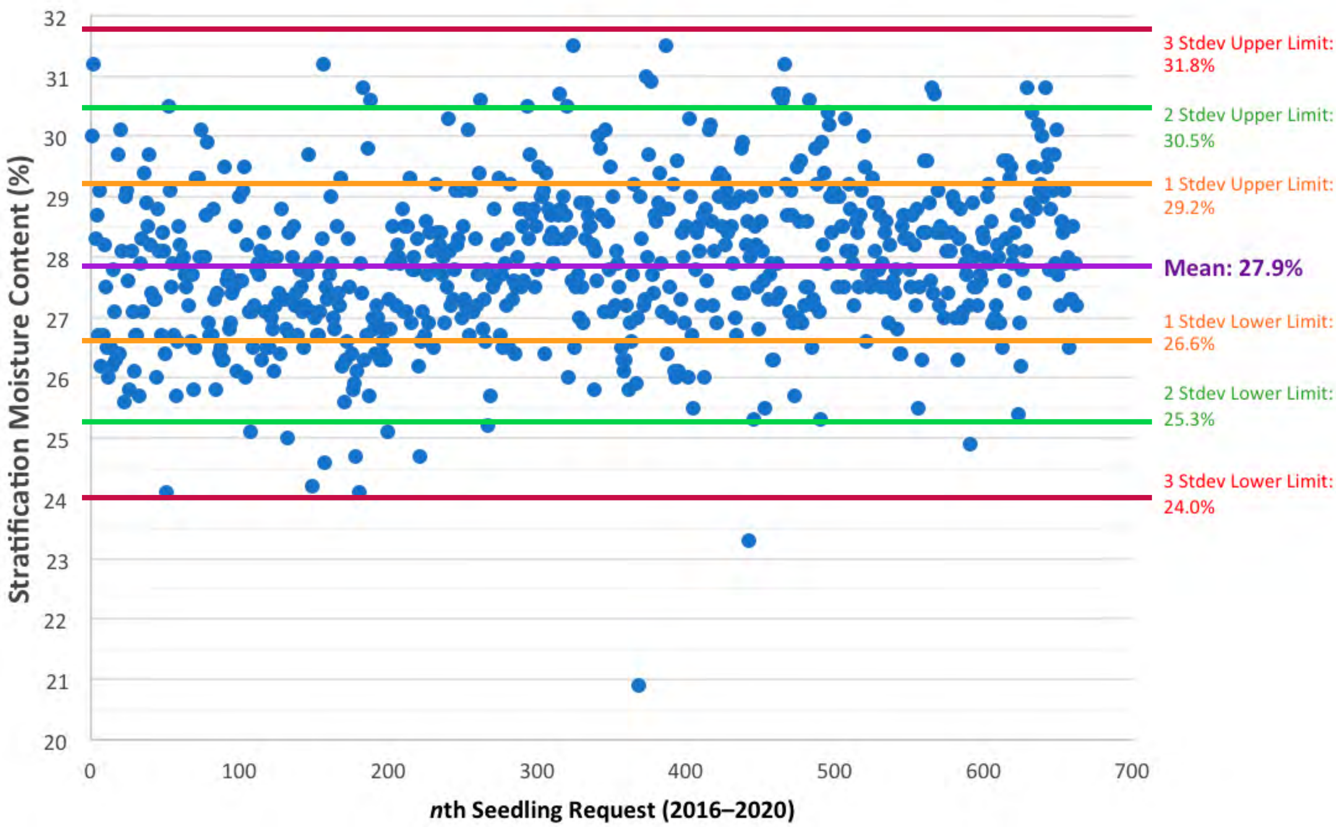

Figure 3. The stratification moisture content values for 662 seedling requests of interior spruce from the 2016 to 2020 sowing seasons. The mean and values for 1×, 2×, and 3× standard deviations on each side of the mean are presented.

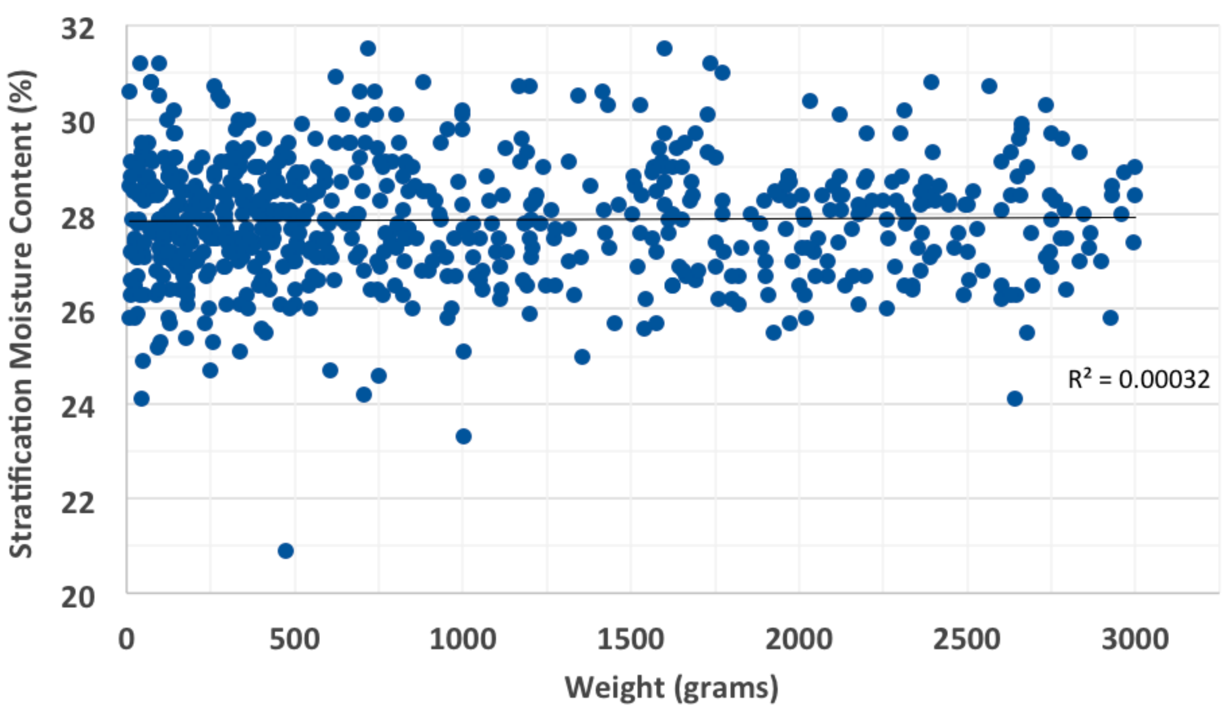

Figure 4. The relationship between seedling request size and stratification moisture content in interior spruce over ten sowing seasons (2011–2020).

request or bag size and stratification moisture content is presented and no obvious trend emerges. The cutoff of 3,000 grams is the maximum amount of interior spruce seed we would place in a single bag for naked stratification – all larger requests would have multiple bags of seed. Request size isn't currently an operational concern as long as technicians are monitoring the drying. These small requests may actually be easier to maximize moisture content uniformity. Those requests falling below 25% moisture content are a concern, but the concern would be greater in species considered to have deeper dormancy. Interior spruce is generally considered shallowly dormant, and therefore impacts of reduced stratification moisture content would be much less than in Douglas-fir, for example.

For interior spruce, we also looked at the annual average variability in stratification moisture content, and Figure 5 indicates those results over the past 11 seasons of seed preparation. There is no specific trend and although the plot looks jagged, the y-axis only represents a 1.4% difference between the extreme years. This could represent technical staff differences or environmental differences but are well within the current acceptable range for this species.

All Species Results by Genetic Class

The results for all species by genetic class are presented in Table 1, with the major difference from earlier reports being the identification of a practical operational range, which we will use for targeting our stratification moisture contents after surface drying. These ranges are based on both data and operational experience and will be updated periodically. They represent the range in which most (80-90%) of seedling requests have fallen into.

A consistent finding is that for some species (western hemlock, interior spruce, and Sitka spruce), the seed orchard seed consistently has a lower stratification moisture content after surface drying. This difference has been observed for a long time (>10 years) with Sitka spruce and western hemlock, and orchard seedlots of these species generally receive an additional four hours of soaking. The situation with lodgepole pine is a little more complicated as monitoring over the past two seasons has identified some specific seed orchard seedlots with low moisture contents (<25%) after a 24-hour running water soak. Some of these seedlots have received additional soaking, up to 24 hours, and left surface wet going into stratification. The results in Table 1 for seed orchard lodgepole pine represent the standard 24-hour running water (2014–2018).

This trend with seed orchard seed having a lower stratification moisture content has not been observed in western larch

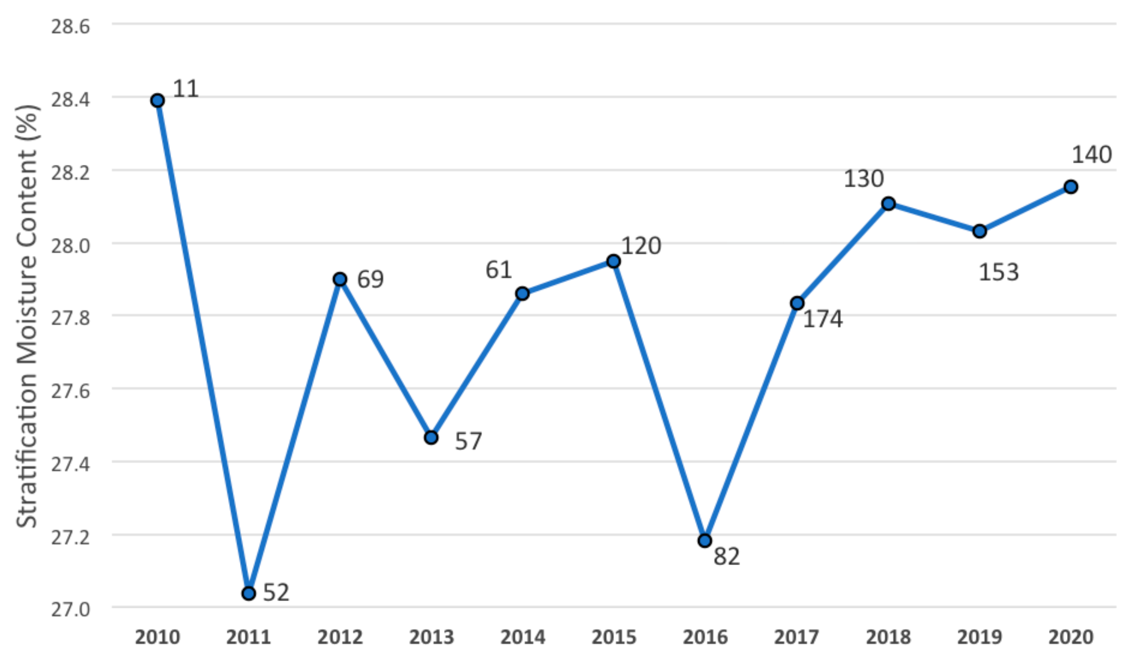

Figure 5. The average stratification moisture content and sample sizes of seed orchard interior spruce seedling requests over 11 sowing seasons.

Table 1. The stratification moisture content percentage results (surface dry status) for BC tree species, by genetic class from the 2016 to 2020 sowing seasons. The upper and lower limits are for operational implementation and the change estimate during stratification is based on the last 10 sowing seasons.

Species	Genetic Class	Samples	Mean (%)	Standard Deviation	Lower Limit (%)	Upper Limit (%)	Change Estimate
Abies grandis	Wild	25	34.3	1.77	33.0	36.0	0.04 (25)
Larix occidentalis	Wild	39	35.8	1.97	33.0	37.0	0.84 (21)
Larix occidentalis	Orchard	270	35.9	1.73	34.0	38.0	0.22 (49)
Picea engelmanni x *glauca*	Wild	96	31.1	1.98	29.0	33.0	-0.16 (21)
Picea engelmanni x *glauca*	Orchard	662	27.9	1.29	26.0	30.0	0.11 (51)
Picea mariana	Wild	14	30.8	1.60	29.0	32.0	0.11 (7)
Picea sitchensis	Wild	35	29.2	1.84	27.0	31.0	-0.01 (24)
Picea sitchensis	Orchard	56	27.2	1.75	26.0	29.0	0.37 (29)
Picea sitchensis x *glauca*	Wild	26	30.2	1.46	28.0	32.0	0.30 (25)
Pinus contorta var. *contorta*	Wild	12	28.7	2.97	27.0	31.0	-0.11 (10)
Pinus contorta var. *latifolia*	Wild	394	30.6	2.04	28.0	33.0	0.29 (31)
Pinus contorta var. *latifolia*	Orchard[1]	242	30.2	1.80	28.0	32.0	0.24 (31)
Pinus ponderosa	Wild	186	28.5	1.98	26.0	31.0	0.40 (1)
Pinus ponderosa	Orchard	8	28.6	2.68	26.0	31.0	0.54 (41)
Pseudotsuga menziesii var. *menziesii*	Wild	47	34.0	1.41	32.0	35.0	0.29 (11)
Pseudotsuga menziesii var. *menziesii*	Orchard	286	32.8	1.35	31.0	35.0	0.23 (38)
Pseudotsuga menziesii var. *glauca*	Wild	371	34.0	1.49	32.0	36.0	0.22 (31)
Pseudotsuga menziesii var. *glauca*	Orchard	231	33.0	1.06	31.0	35.0	0.27 (16)
Tsuga heterophylla	Wild	90	29.4	1.88	27.0	31.0	0.27 (16)
Tsuga heterophylla	Orchard	60	28.1	2.24	26.0	31.0	0.31 (20)
Tsuga mertensiana	Wild	18	33.7	1.84	32.0	35.0	0.22 (14)

[1]For orchard lodgepole pine the results are indicative of 2014-2018 sowing seasons.

(*Larix occidentalis*) or to any significant extent with Douglas-fir (*Pseudotsuga menziesii*). For Ponderosa pine (*Pinus ponderosa*), seed orchard seed data is limited and more variable, as it is a relatively new program with only one orchard. The amount of change in moisture content during stratification is estimated to be low in all species as a small gain except for wild coastal lodgepole pine and wild interior spruce seedlots.

Discussion

The stratification QA moisture content monitoring programs have been extremely helpful in setting species-specific targets, ensuring consistent results (both between years and with new staff) and identifying anomalies exhibited, particularly with the increased use of seed orchard seed. While we have been using these targets for over a decade the target range was less well defined and far too restrictive using the confidence interval as a guide. We also didn't want to expand the range, even at the high end, too far, so that our surface drying becomes lackadaisical. It was a conscious decision to use the data plots and standard deviations to help establish our target ranges but to adjust these based on operational experience. There are many other ways to identify anomalies. However, this simple approach meets our operational needs, which can be quite demanding for the 1,142 kg of seed (based on storage moisture content), just for lodgepole pine and interior spruce that needs to be surface dried and stratified over the winter.

We have become more comfortable with our practices and issues that were previously concerning, like small sowing requests, changes in moisture content during stratification, and extension of stratification. Reductions in germination have not accompanied the reduction in moisture contents for seed orchard seed, but they do seem consistent across a wide range of species. We can only hypothesize, and maybe someone would be interested in exploring this question in more detail. Is the transfer of species into drier habitats for seed production impacting the development of the seed coat or megaspore membrane? Are other cultural practices involved? Compared to historical records of collection timing, it seems like we are harvesting our seed orchard crops in BC early. It is hard to argue with collecting when seeds are being dispersed, but have our movements of species away from their natural habitats resulted in other changes in addition to a greater reproductive output? We will be observing the situation with lodgepole pine closely, and although we have not seen any detrimental impacts on seed quality, staff monitoring practices will be increased.

Our QA programs allow us to be in a proactive vs. reactive mode. We perform about 96% of the stratification for BC reforestation, so that is a big responsibility for a program that is currently peaking at about 300 million seedlings per year. We recover the costs for our services, but the big picture view is that it is the cheapest part of the reforestation program. Increasing variation upfront due to incomplete removal of dormancy, and all the other stratification benefits will be magnified as one moves through the seedling production system. We sometimes wonder if we are being too particular with our stratification moisture content guidelines and losing efficiency? It does take some effort to establish a QA program, but it becomes fine-tuned and fit-to-purpose over time. The key is actually doing something with the data one collects and not just collecting it out of habit. We can't claim 100% success in this regard, and sometimes data collection is for 'insurance' purposes, but we try to use the data we collect for the continuous improvement of practices.

Sometimes data has benefits that cannot be foreseen. We have been performing some activities to modernize the technology used in our coolers where we stratify seed. At the beginning of the year, our skilled technicians noticed that seed seemed to be drying out in stratification. This initiated some investigative work, including target moisture content assessments and made us refocus from a temperature emphasis on modifications to the impacts this modernization would have on air movement and relative humidity. This resulted in some changes to our modernization plans—being proactive vs. reactive, that's what quality assurance is all about. Invest in it.

References

Czabator, F. 1962. Germination Value: an index combining speed and completeness of pine seed germination. Forrest Science 8:386-396.

Downie, B., J. Coleman, G. Scheer, B.S.P. Wang, M. Jense, and N. Dhir. 1998. Alleviation of seed dormancy in white spruce (*Picea glauca* [Moench.] Voss.) is dependent on the degree of seed hydration. Seed Science and Technology 26:555-569.

Edwards, D.G.W. 1986. Special prechilling techniques for tree seeds. Journal of Seed Technology 10: 151-171.

Gosling, P.G., S.K. Jones and A.S. Gardiner. 1994. Spin-drying soaked tree seed before prechilling improved seed handling. Tree Planters' Notes 45:32-35.

Gosling, P.G. and P. Rigg. 1990. The effect of moisture content and prechilling duration on the efficiency of dormancy breakage in Sitka spruce (*Picea sitchensis*) seed. Seed Science & Technology 18:337-343.

Kolotelo, D. 2018. Moisture content monitoring of BC seedling requests (2013–2017). Tree Seed Working Group News Bulletin 66:5-6.

Leadem, C.L. 1986. Stratification of *Abies amabilis* seeds. Canadian Journal of Forest Research 16:755-760.

Hannam, K.D. 1993. The effect of various stratification moisture contents on the germination capacity and peak value of lodgepole pine seed. University of Victoria Biology Co-op program Report. 17 pp.

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A Review of the National Tree Seed Centre's Germination Guidelines

Background

The National Tree Seed Centre (NTSC) conducts regular germination tests on fresh and stored seedlots in the Active Research (AR) collection on the NTSC Seed List. Including data from exhausted seedlots, the 1970–2018 AR testing database contains 26,208 viability tests of 260 species and 227 treatment combinations that yielded ≥1% germinants, judged from 1970–1975 by the 4x rule (radicle four times the length of the seed), and after 1975, by Petawawa National Forest Institute (PNFI) high vigour germination classes 1–3 (Wang 1973, Simpson et al. 2004, Colas and Bettez 2016). Routine testing of most species is conducted every 10 years, to maintain current expected viability for those requesting seed, and to evaluate seed longevity curves under improved storage regimes (Simpson et al. 2004). There are also 11,595 AR test data records with moisture content, and 11,969 with thousand seed weight values with georeferenced coordinates and collection dates.

Currently, when researchers request seed from the NTSC of the most commonly tested or challenging species, a set of printed instructions is sent with the order, but this prescriptive guide is also not online to share with those solely interested in comparing dormancy-breaking treatments. This became apparent during the September 16th North American Forest and Conservation Nursery Technology Series webinar presented by Nabil Khadduri (Washington Department of Natural Resources) question and answer period regarding species we have extensively tested, such as ash (*Fraxinus* spp., with 1,043 AR tests of six species, four native, 71 different treatments). We decided to reproduce NTSC's guidelines in Table 1 as they currently exist, with minor modifications for clarity, and compare to the International Seed Testing Association Table 5A rules (ISTA 2012) for each species. Though Rule 5.6.4 allows for final count days to be extended or shortened, for the sake of this self-assessment exercise the NTSC's recommended final count day was taken to be exact. To be of value to growers, pretreatments exclude quick viability techniques such as removing pericarps (i.e. for *Quercus* spp.), tetrazolium and excised embryo.

To validate the NTSC's guidelines, Table 2 summarizes 23,634 records, showing the number of tests performed by this exact prescription out of the total for each species, median and range of seedlot test age (germination test year – seedlot collection year, 0 = fresh seed tested prior to storage), and resulting median high vigour germinants (HVG%). Median was used given the skewed data distribution of collection years and test results as lab standards evolved, particularly in the 1970–1982 period. HVG values with an asterisk (*) indicate this prescription ranks highest of all the NTSC has experimented with more than once in this 48-year period, regardless of seedlot age. The most recent test year this prescription was used is added for context considering this operational document's last revision date of December 2016. In-house experiments that led to current treatment success, and alternative treatments tried, are well documented in NTSC's 1998–2016 annual reports or available on request.

For those who have received this document with NTSC seed orders previously, the species are listed alphabetically instead of grouped according to prechilling requirements, to make ISTA Table 5A comparison faster.

NTSC Seed Germination Methods

The following information is intended to serve as a guide to assist you in achieving maximum germination of the seed which you received from the National Tree Seed Centre. The conditions listed below are those used at the Seed Centre when conducting germination tests. If seed is sown in order to grow seedlings, the same principles apply, particularly the need for a warm treatment and/or moist chilling.

Routine laboratory germination testing is conducted by placing seed on a moistened, inert substrate situated in a covered container which is placed in a germinator. Various substrates can be used such as Versa-Pak™, filter paper, or silica sand. In all cases, the substrate should be moistened with water. Tap water is fine provided it is neutral in pH and contains acceptable levels of minerals, etc. If the water is safe to drink it is probably fine to use. De-ionized water can also be used. The containers should be transparent to allow light to penetrate.

Best results are obtained when the seed is placed in a germinator, incubator or programmable growth chamber. Optimal settings for most species are 20°C for 16 hours without light and 30°C for 8 hours with light at 85%

humidity. Light is provided during the 8-hour period at an intensity of 750–1250 lux. Temperature regime variations are noted in Table 1.

Sometimes seed requires pretreatment before it will germinate. The most common pretreatment is moist chilling. Moist chilling is necessary to mitigate dormancy thereby allowing the seed to germinate uniformly. Seed can be readily moist chilled by placing it on the moistened germination medium in the container and placing the container in a refrigerator or cooler for the specified length of time.

Alternatively, seed can be wrapped in moist paper towel, placed in a sealed plastic bag and put in a refrigerator. Seed requiring longer durations (greater than 56 days) of moist chilling and seed requiring a warm treatment should be placed in moist peat moss (target 80% moisture content) inside a sealed plastic bag. The peat moss helps to control mold growth. The plastic bag should be opened monthly to allow for air exchange.

Discussion

Of the 54 species listed in Table 1, NTSC has aligned its recommended treatments for 15 species with ISTA Table 5A (2012), with good success primarily for species with little or no seed dormancy. In addition, NTSC offers recommendations for nine Canadian species not currently listed in Table 5A. For the 30 remaining species, NTSC results with Canadian provenances has required consistently applying only the stratified ISTA prescription for paired tests, or increasing the length or combination of moist warm and/or cold prechilling, which has often shortened final count day prescriptions. At any time, requests for NTSC to test according to ISTA or American Official Seed Analyst (AOSA) rules can be undertaken if required for a specific research project.

The simplistic method of ranking median high vigour germinants of all tests ≥1% by prescribed treatments differs from previous NTSC investigations into mean curvilinear longevity plots of all or the best seedlots by germination test age (Daigle and Simpson 2001, Simpson et al. 2004), or calculating linear seed deterioration rates (Kolotelo 2007a, 2007b, Simpson 2007). ISTA doesn't prescribe rules in Table 5A for older seed, so theoretically, the prescription should work on all seed of a species across time and space. But we know tree seed germination rates are incredibly variable; the references cited in this article, plus Bonner (1997) to note another, discuss maternal genetic effects in wild single-tree collections, collection timing, post-harvest handling, seedlot upgrading techniques, storage regimes, and repeated seedlot withdrawals, not to mention human resources over the course of a 48-year dataset. Not all NTSC germination tests report cutting open and looking for empty seed percentages either. Therefore, median HVG values of the AR collection are likely lower than what one would expect from fresh, high quality seed of the same species processed by today's best practices, but ranking all NTSC treatments was a useful exercise. One would expect with merged data from other centres or fresh NTSC collections tested according to the most complete dormancy-breaking prescription that the median HVG would rise in time.

The perhaps surprising proportion of tests performed according to these exact treatments for some species mostly reflects a variety of final count days allowed under Rule 5.6.4 (ISTA 2012). The same dormancy-breaking pretreatment counted seven days longer, almost always ranked slightly higher HVG%, or some younger seedlot batches concluded at 100% early. With more complex treatments, judgment calls made by NTSC staff to modify the length of warm or cold stratification yielded higher median HVG% according to seedlot age or cut it early at the sign of early germination in stratification. For species like white ash (*Fraxinus americana*) or sugar maple (*Acer saccharum*), 25 and 29 treatment combinations respectively were tried to determine what consistency delivers the most uniform results, and another bumper crop year has yet to present itself to add more tests of these species.

Though long-term seed conservation is NTSC's mandate, the advanced age of the NTSC Active Research collection for some important conifer species is becoming apparent in Table 2. The median collection year of all 14,876 AR seedlots is 1983, weighted heavily towards efforts made for range-wide provenance testing series, and for the 6,599 lots in 2018 with >0.1 grams of seed remaining, the median collection year was 1990. In the near future, NTSC will begin an internal protocol whereby a proportion of high quality AR seedlots from each region will be reserved in our Gene Conservation collection as a last resort. Though NTSC continues to add new collections each year, it is difficult to foresee retracing major sampling efforts of the 1970s and 1980s without significant collaboration across the country.

Table 1. Recommended seed pretreatments and testing conditions for commonly ordered species from the National Tree Seed Centre (NTSC), compared to ISTA Table 5A Part 2 rules (2012).

	Pretreament (h=hours, d=days)[1]		Moist Prechilling (at 1–5°C) Days[1,2]		Germination Temperature (°C)[1,3]		Final Count (Days)[1]	
Species	NTSC	ISTA	NTSC	ISTA	NTSC	ISTA	NTSC	ISTA
Abies amabilis	–	–	21	0 & 21	20«»30	20«»30	28	28
Abies balsamea	–	–	21	21	20«»30	20«»30	28	28
Abies grandis	–	–	21	0 & 21	20«»30	20«»30	28	28
Abies lasiocarpa	–	–	21	21	20«»30	20«»30	28	28
Acer pennsylvanicum	Soak 48h (4°C)	NA	112	NA	10«»20	NA	42	NA
Acer rubrum	–	–	56	–	20«»30	20	21	21
Acer saccharinum	–	–	–	–	20«»30	20	14	21
Acer saccharum	Soak 72h (4°C)	–	91	60	20	20	21	21
Alnus cordata	–	–	–	–	20«»30	20«»30	21	21
Alnus glutinosa	–	–	–	–	20«»30	20«»30	21	21
Alnus incana	–	–	–	–	20«»30	20«»30	21	21
Alnus rubra	–	–	–	–	20«»30	20«»30	21	21
Betula alleghaniensis	–	NA	21	NA	20«»30	NA	21	NA
Betula cordifolia	–	NA	–	NA	20«»30	NA	21	NA
Betula papyrifera	–	–	–	–	20«»30	20«»30	21	21
Cornus sericea	Soak 48h (4°C) + 56d (21°C)	NA	120	NA	20«»30	NA	21	NA
Fagus grandifolia	–	NA	120 or until germination starts	NA	4	NA	42	NA
Fraxinus americana	56d (21°C)	60d (20°C)	168 or until germination starts	210	20«»30	20«»30	21	56
Fraxinus nigra	56d (4°C) + 119d (21°C)	60d (20°C)	182	210	20«»30	20«»30	28	56
Fraxinus pennsylvanica	–	60d (20°C)	196	210	20«»30	20«»30	21	56
Fraxinus quadrangulata	56d (4°C) + 119d (21°C)	60d (20°C)	182	210	20«»30; 20	20«»30	28	56
Larix laricina	–	–	–	–	20«»30	20«»30	21	21
Larix occidentalis	–	–	21	0 & 21	20«»30	20«»30	21	21
Picea abies	–	–	–	–	20«»30	20«»30	21	21
Picea engelmannii	–	–	21	–	20«»30	20«»30	21	21
Picea glauca	–	–	21	0 & 21	20«»30	20«»30	21	21
Picea mariana	–	–	–	–	20«»30	20«»30	21	21
Picea rubens	–	–	–	–	20«»30	20«»30	21	21
Picea sitchensis	–	–	21	0 & 21	20«»30	20«»30	21	21
Pinus albicaulis	Soak 48h (4°C) + 56d (21°C)	–	112	28	25	20«»30	21	28
Pinus banksiana	–	–	–	–	20«»30	20«»30	14	14

Table 2. Results from 1970–2018 National Tree Seed Centre (NTSC) germination tests ≥1% following the exact treatments and final count days by species listed in Table 1.

	NTSC Active Research (AR) Germination Test Results (1970–2018)			
Species	# Prescribed Tests / Total	Median Seedlot Age (Min–Max) (Years)	Median HVG (Min–Max)%[1]	Most Recent Test Year
Abies amabilis	8 / 35	19 (1–28)	47.5 (2.5–72.0)	2018
Abies balsamea	16 / 506	29 (12–20)	61.5 (40.0–77.0)	2017
Abies grandis	2 / 55	11 (7, 15)	63.3 (55.0–71.5)*	1997
Abies lasiocarpa	4 / 53	16 (7–28)	52.8 (44.7–70.0)*	2018
Acer pennsylvanicum	12 / 98	11	71.0 (41.0–87.0)	2015
Acer rubrum	413 / 713	2 (0–29)	76.0 (1.0–99.3)	2017
Acer saccharinum	36 / 71	1 (0–2)	68.5 (2.0–99.0)	2013
Acer saccharum	4 / 248	10	88.0 (80.0–92.0)*	2018
Alnus cordata	5 / 5	7 (3–12)	51.0 (5.0–86.0)*	1993
Alnus glutinosa	42 / 45	7 (1–32)	43.3 (3.0–97.5)*	2016
Alnus incana	640 / 644	2 (0–34)	39.4 (1.0–100.0)*	2018
Alnus rubra	343 / 343	6 (1–36)	42.5 (1.0–100.0)	2018
Betula alleghaniensis	389 / 438	10 (0–46)	55.5 (1.0–97.5)	2016
Betula cordifolia	33 / 33	2 (0–12)	88.5 (10.0–99.0)*	2018
Betula papyrifera	419 / 424	8 (0–27)	71.0 (1.0–100.0)*	2018
Cornus sericea	4 / 11	6 (3–16)	56.9 (51.0–63.0)*	2013
Fagus grandifolia	12 / 45	1	50.0 (1.0–95.0)	2007
Fraxinus americana	21 / 226	11	83.0 (61.0–92.0)*	2015
Fraxinus nigra	63 / 188	1 (1–11)	45.0 (1.0–91.0)	2015
Fraxinus pennsylvanica	52 / 485	1 (1–24)	80.0 (22.0–97.0)*	2015
Fraxinus quadrangulata	15 / 18	2 (2–3)	16.0 (5.0–40.0)	2016
Larix laricina	750 / 827	17 (1–36)	59.0 (1.0–100.0)	2018
Larix occidentalis	22 / 25	8 (1–39)	59.8 (12.1–80.0)	2018
Picea abies	398 / 526	16 (1–53)	70.0 (1.2–100.0)	2018
Picea engelmannii	28 / 50	13 (1–34)	78.5 (10.5–98.0)*	2012
Picea glauca	5,976 / 6,538	18 (0–56)	77.5 (1.0–100.0)	2018
Picea mariana	1,100 / 1,990	19 (0–42)	92.5 (1.0–100.0)	2018
Picea rubens	598 / 673	9 (1–61)	85.5 (1.0–100.0)	2018
Picea sitchensis	139 / 162	17 (1–49)	79.5 (1.5–98.8)	2017
Pinus albicaulis	No AR results, guideline adopted from the Alberta Tree Improvement Centre. See new recommendations published in Seed Matters 3 (2020)			
Pinus banksiana	2,780 / 3,043	22 (0–67)	93.0 (1.0–100.0)*	2018

Table 1. (continued)

	Pretreament (h=hours, d=days)[1]		Moist Prechilling (at 1–5°C) Days[1,2]		Germination Temperature (°C)[1,3]		Final Count (Days)[1]	
Species	NTSC	ISTA	NTSC	ISTA	NTSC	ISTA	NTSC	ISTA
Pinus contorta	–	–	21	0 & 21	20«»30	20«»30	21	21
Pinus flexilis	–	–	70	21	25	20«»30	21	21
Pinus monticola	Soak 14d (4°C)		98	60–90	20«»30	20«»30	28	28
Pinus nigra	–	–	–	–	20«»30	20«»30	21	21
Pinus ponderosa	–	–	35	0 & 28	20«»30	20«»30	21	21
Pinus resinosa	–	–	–	–	20«»30	20«»30	21	14
Pinus rigida	–	–	–	–	20«»30	20«»30	21	14
Pinus strobus	–	–	28	0 & 28	20«»30	20«»30; 20	28	28
Pinus sylvestris	–	–	–	0 or 21[4]	20«»30	20«»30; 20	21	21
Populus spp.	–	–	–	–	20«»30	20«»30	10	10
Prunus pennsylvanica	Soak 72h (4°C) + 14d (21°C)	NA	140	NA	20«»30; 20«»25	NA	21	NA
Prunus serotina	Soak 72h (4°C) + 14d (21°C)	–	140	90–120	20«»30	20«»30; 20	21	28
Prunus virginiana var. *virginiana*	Soak 72h (4°C) + 14d (21°C)	NA	140	NA	20«»30; 25	NA	21	NA
Pseudotsuga menziesii	–	–	21	0 & 21	20«»30	20«»30	21	21
Quercus rubra	–	–	60	–	20«»30	20	21	28
Salix spp.	–	–	–	–	20«»30	20«»30	10	14
Thuja occidentalis	–	–	–	–	20«»30	20«»30	21	21
Thuja plicata	–	–	–	–	20«»30	20«»30	21	21
Tsuga canadensis	–	–	140	28	15	15	28	28
Tsuga heterophylla	–	–	28	0 & 21	20«»30	20	21	35
Tsuga mertensiana	–	NA	28	NA	20«»30	NA	28	NA
Ulmus americana	–	–	–	–	20«»30	20«»30; 20	14	14
Ulmus rubra	–	NA	–	NA	20«»30	NA	14	NA

[1]NA indicates a species for which ISTA Table 5A does not have a prescription. [2]NTSC uses a walk-in cooler which typically runs at 4ºC; ISTA paired tests of prechilled and non-prechilled samples are noted with &. [3]The «» symbols indicate alternating temperature regimes. 1st temperature is for 16 hours without light; 2nd temperature is for 8 hours with light. Constant temperature alternatives are provided with no significance to the order listing as to preference. [4]ISTA Table 5A recommends that "Eastern and Mediterranean provenances may require prechill 21 d".

Table 2. (continued)

Species	NTSC Active Research (AR) Germination Test Results (1970–2018) # Prescribed Tests / Total	Median Seedlot Age (Min–Max) (Years)	Median HVG (Min–Max)%[1]	Most Recent Test Year
Pinus contorta	385 / 533	13 (0–52)	83.5 (5.5–100.0)	2018
Pinus flexilis	No AR results, guideline adopted from the Alberta Tree Improvement Centre. See new recommendations published in Seed Matters 3 (2020)			
Pinus monticola	7 / 30	31 (20–41)	64.0 (38.0–81.5)	2013
Pinus nigra	35 / 35	5 (1–36)	71.5 (5.0–93.2)*	2017
Pinus ponderosa	8 / 42	15 (2–28)	86.3 (55.0–95.0)*	2018
Pinus resinosa	389 / 521	14 (0–56)	93.5 (2.5–100.0)*	2018
Pinus rigida	172 / 183	4 (0–32)	90.7 (2.0–100.0)	2018
Pinus strobus	667 / 1,093	11 (0–58)	80.5 (1.0–100.0)	2018
Pinus sylvestris	658 / 710	16 (0–44)	71.3 (1.0–100.0)	2018
Populus spp.	268 / 589	0 (0–49)	94.0 (3.0–100.0)	2018
Prunus pennsylvanica	4 / 4	1 (1–4)	37.5 (27.0–62.0)*	2015
Prunus serotina	17 / 20	16 (14–16)	94.0 (70.0–100.0)*	2018
Prunus virginiana var. *virginiana*	22 / 74	17 (6–19)	63.5 (39.0–88.0)*	2016
Pseudotsuga menziesii	115 / 148	14 (0–53)	75.0 (3.5–98.0)*	2017
Quercus rubra	6 / 13	1 (1–2)	66.0 (6.5–99.0)*	2015
Salix spp.	46 / 154	0 (0–6)	79.0 (6.5–99.0)*	2018
Thuja occidentalis	270 / 270	1 (0–24)	54.1 (1.0–97.5)*	2018
Thuja plicata	29 / 29	9 (0–39)	64.5 (1.8–92.0)*	2018
Tsuga canadensis	294 / 461	11 (1–29)	91.0 (4.0–100.0)*	2018
Tsuga heterophylla	6 / 34	21 (4–29)	72.3 (69.0–79.0)*	2018
Tsuga mertensiana	11 / 19	13 (2–25)	53.5 (12.0–92.0)	2018
Ulmus americana	87 / 109	10 (0–24)	92.0 (32.0–100.0)*	2018
Ulmus rubra	14 / 28	0	59.8 (30.0–87.5)	2015

[1]HVG = high vigour germination, as assessed by Germination Classes 1–3 (Wang 1973) for majority of reported tests. Asterisk indicates this prescription has consistently yield the highest average HVG over the 1970–2018 testing period, regardless of seedlot age.

This data demonstrates the need to reinvest in the Active Research collection to continue to assess degrees of fresh seed dormancy where data is lacking, and to consult with the research community on collection priorities designed for the challenges that lie ahead.

Like all operational documents, Tables 1 and 2 serve as a benchmark for continuous improvement, and staff will update it for success with any species or seedlot age group or region with significant varying dormancy patterns. We hope this article will spawn discussion, comparison and research interest on intra-specific variability in wild stand provenances as climate change progresses. Similarly to Kolotelo's comments in this issue on the changing nature of seed orchard seed as a "product", the NTSC seed testing database is an important baseline collection for comparing cumulative effects over many years, decades and changes in unimproved seed traits for forest change and vulnerability models. Beyond requesting seed, we welcome any researchers to investigate the data behind the jars as another value-added component of our long-term living library.

We would like to acknowledge the steady contributions of Dale Simpson, Bernie Daigle, Peter Moreland, Ben Wang, Sava Barudzija and many PNFI and NTSC technicians who have come before us to produce and manage this wealth of information.

Literature Cited

Bonner, F.T. 1997. Testing Tree Seeds for vigor: A review. Seed Technology 20: 5–18.

Colas, F., and Bettez, M. 2016. Tree seed testing overview. Tree Seed Working Group News Bulletin 64: 20–21. Article. doi:10.13140/RG.2.2.20623.59045.

Daigle, B.I., and Simpson, J.D. 2001. National Tree Seed Centre Annual Report 2000. Fredericton, New Brunswick.

ISTA. 2012. International Rules for Seed Testing. Edition 2012/1. International Seed Testing Association, Bassersdorf, Switzerland.

Kolotelo, D. 2007a. Broadleaf Seed Longevity. Tree Seed Working Group News Bulletin 45: 3–4.

Kolotelo, D. 2007b. Conifer Seed Longevity. Tree Seed Working Group News Bulletin 45: 4–6.

Simpson, J.D. 2007. Seed Longevity at the National Tree Seed Centre. Tree Seed Working Group News Bulletin 45: 6–8.

Simpson, J.D., Wang, B.S.P., and Daigle, B.I. 2004. Long-term seed storage of various Canadian hardwoods and conifers. Seed Science Technology 32(12): 561–572. doi:10.15258/sst.2004.32.2.25.

Wang, B.S.P. 1973. Laboratory Germination Criteria for Red Pine (*Pinus resinosa* Ait.) seed. Proceedings of the Association of Official Seed Analysts 63: 94–101.

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2018 Seed Germination Guidelines Used at the Ontario Tree Seed Plant

As a means of documentation, the last operational seed pretreatment guidelines used by technicians at the Ontario Tree Seed Plant (OTSP) are presented in Table 1, reproduced from a wall poster that hung at the Angus facility in 2018 (photo credit John Fisher), but reorganized by alphabetical Latin name instead of OTSP database code. Comparisons are made to the former Guidelines for Seed Pretreament (Creasey and Myland 1993), with species included in 1993 noted with an asterisk (*) and none were removed. Thanks to correspondence with former technician Sarah Drabble-Bisgould, now working at Somerville Seedlings in Everett, Ontario, clarification was provided on the background of this document. It hung in the seed lab in various formats

Table 1. Operational germination pretreatments and testing conditions used at the former Ontario Tree Seed Plant used until 2018. Species included in the 1993 Guidelines are noted with an asterisk (*). Unknown final count dates were noted with an "x".

OTSP Code	Species	Day to Put on Test	Scarification	Warm Stratification 2018 (20«»30°C)[1]	Warm Stratification 1993 (20–25°C)	Cold Stratification 2018 (2–5°C)	Cold Stratification 1993 (2–5°C)	Final Count (Days)
020	*Abies balsamea*					21		28
184	*Abies concolor*					45		28
177	*Abies fraseri*					45		28
034	*Acer platanoides*							21
032	*Acer rubrum*					28		21
033	*Acer saccharinum*					0		21
030	*Acer saccharum*					45		21
069	*Aesculus hippocastanum*					120		21
080	*Alnus crispa*					60		x
067	*Alnus glutinosa*					180		21
081	*Alnus rugosa*					60		x
212	*Amelanchier laevis*							x
118	*Amelanchier spp.*					120		x
159	*Aronia melanocarpa*					90–120		x
119	*Asimina triloba*					120		x
037	*Betula alleghaniensis**					30	21–30[2]	x
038	*Betula papyrifera*					21		21
120	*Betula pendula*					30		21
168	*Betula populifolia*							x
123	*Carya cordiformis*					90		x
089	*Carya glabra*					120		x
093	*Carya laciniosa*					90		x
124	*Carya ovata*					90		x
092	*Carya tomentosa*					120		x
171	*Castanea dentata*					120		x
172	*Castanea sativa*					120		21
077	*Catalpa speciosa*					120		21
205	*Celastrus scandens*							x
068	*Celtis occidentalis*					90		x
188	*Cephalanthus occidentalis*					14		x
125	*Cercis canadensis*		H_2SO_4 1 hr			60		x
199	*Cladrastis lutea*		H_2SO_4 30–60 min			90		x
082	*Corlyus cornuta*					90–120		x
191	*Cornus alternifolia*			60		60		x

Table 1. (continued)

				Warm Stratification		Cold Stratification		
OTSP Code	Species	Day to Put on Test	Scarification	2018 (20«»30ºC)[1]	1993 (20–25ºC)	2018 (2–5ºC)	1993 (2–5ºC)	Final Count (Days)
158	*Cornus amomum*					90		x
156	*Cornus canadensis*			60		120		x
190	*Cornus drummondii*					60		x
126	*Cornus florida*					120		x
157	*Cornus racemosa*			60		60		x
207	*Cornus rugosa*					90		x
127	*Cornus sericea* (syn. *stolonifera*)*					90	90[1]	x
129	*Elaeagnus angustifolia**		H_2SO_4 30–60 min			90	90[1]	no end date
131	*Elaeagnus umbellata**					90	90[1]	x
187	*Euonymus alatus*					90		x
189	*Euonymus europaeus*			60		60		x
044	*Fagus grandifolia*					90		x
046	*Fraxinus americana**			30	30[3]	60	60[3]	56
045	*Fraxinus nigra*							56
047	*Fraxinus pennsylvanica**			60	60[3]	210	210[3]	56
095	*Gingko biloba*					60		x
096	*Gleditsia triacanthos*	Friday	H_2SO_4 1 hr			21		21
133	*Gymnocladus dioicus*		H_2SO_4 24 hrs + 24 hr soak			0		x
176	*Ilex verticillata*			60		60		x
055	*Juglans cinerea*					120		x
054	*Juglans nigra**					90	90–120[3]	x
023	*Juniperus virginiana*	Friday				120		28
026	*Larix decidua**	Tuesday				21	21–30[2]	21
025	*Larix laricina**					60	21–60[2]	21
027	*Larix leptolepsis**	Tuesday				21	21–30[2]	x
180	*Lindera benzoin*					105		x
134	*Liquidambar styraciflua*					60		21
060	*Liriodendron tulipifera**					60	60–90 in medium; 140–168 when naked[3]	28
202	*Lonicera canadensis*							x

Table 1. (continued)

OTSP Code	Species	Day to Put on Test	Scarification	Warm Stratification 2018 (20«»30°C)[1]	Warm Stratification 1993 (20–25°C)	Cold Stratification 2018 (2–5°C)	Cold Stratification 1993 (2–5°C)	Final Count (Days)
114	*Lonicera diervilla*					120		x
201	*Lonicera dioica*							x
135	*Lonicera tatarica*					60		x
181	*Maclura pomifera*					30		x
136	*Magnolia acuminata*					120		x
183	*Mahonia aquifolium*					90		x
209	*Maianthemum racemosum*							x
160	*Malus baccata*					60		no end date
203	*Malus dolgo*							no end date
161	*Malus floribunda*					90		no end date
175	*Morus rubra*					60		28
137	*Nyssa sylvatica*					60		x
056	*Ostrya virginiana*			60		150		x
211	*Parthenocissus inserta*							x
138	*Physocarpus opulifolius*					30		x
015	*Picea abies**	Tuesday				21	21–30[2]	21
012	*Picea glauca**	Friday				21	21–30[2]	21
013	*Picea mariana**	Friday				14	14–21[2]	21
106	*Picea pungens*	Tuesday				21		21
014	*Picea rubens**	Friday				28	21–30[2]	21
003	*Pinus banksiana**	Tuesday				14	14[2]	14
108	*Pinus mugo*	Tuesday				14		21
006	*Pinus nigra*	Tuesday				14		21 (14)
002	*Pinus resinosa**	Tuesday				14	14–21[2]	14
001	*Pinus strobus**	Friday				60	60[1]	28
004	*Pinus sylvestris*	Tuesday				21		21 (14)
057	*Platanus occidentalis*					21		21
194	*Prunus americana*					90–150		x
058	*Prunus serotina*					90		28
186	*Prunus spinosa*					170		x
140	*Prunus virginiana*					120		x
021	*Pseudotsuga menziesii*					21		21
141	*Ptelea trifoliata*					120		x
040	*Quercus alba*					0		28

Table 1. (continued)

				Warm Stratification		Cold Stratification		
OTSP Code	Species	Day to Put on Test	Scarification	2018 (20«»30ºC)[1]	1993 (20–25ºC)	2018 (2–5ºC)	1993 (2–5ºC)	Final Count (Days)
042	*Quercus macrocarpa*					60		28
041	*Quercus rubra**					45	30–45	28
173	*Rhamnus frangula*					60		x
200	*Rhus aromatica*		H_2SO_4 30–60 min			90		x
182	*Rhus copallina*		H_2SO_4 1.5 hr			60		x
198	*Rhus glabra*		H_2SO_4 2 hrs			60		x
142	*Rhus typhina*		H_2SO_4 1 hr			60		x
061	*Robinia pseudoacacia**	Tuesday	H_2SO_4 1–1.5 hrs			30	30[1]	14
143	*Rosa multiflora*					90		28
197	*Rubus occidentalis*		H_2SO_4 1 hr	90		90		x
113	*Sambucus canadensis*			60		90		x
115	*Sambucus pubens*			60		90		x
078	*Sassafras albidum*					120		x
144	*Sorbus americana*					90		28
145	*Sorbus aria*					119		28
146	*Sorbus aucuparia*					119		28
147	*Sorbus decora*					90		28
204	*Staphylea trifolia*							x
185	*Syringa reticulata*					90		x
084	*Taxus canadensis*					270		28
192	*Taxus cuspidata*			120		365		28
022	*Thuja occidentalis**	Friday				21	21–30	21
024	*Thuja spp.*					21		x
051	*Tilia americana*		H_2SO_4 45 mins + screen rub			90		x
019	*Tsuga canadensis**					90	90–120[1]	28
050	*Ulmus americana*					90		14
206	*Vaccinium stamineum*							x
151	*Viburnum cassinoides*					90		x
152	*Viburnum lentago**			158	158[1]	63	63[1]	x
208	*Viburnum rafinesquianum*							x
153	*Viburnum opulus, V. trilobum and hybrids*			67	67[1]	35	35[1]	x

[1]Protocol was developed by the Ontario Tree Seed Plant. The 2018 alternating temperatures for warm stratification are due to the pretreatment occurring in the germination test room. [2]1993 protocol was developed or advised by the Petawawa National Forest Institute and National Tree Seed Centre. [3]1993 protocol were referenced from the 1974 Seeds of Woody Plants (USDA Handbook 450).

from at least 2002 onwards, and was modified when Ben Wang suggested new treatments and when the new Woody Plant Seed Manual was released (Bonner, Franklin and Karrfalt 2008). The "x" in the final count days column indicates that OTSP did not have a standard cut off day when germinating these species, and they would allow the test to run until germination slowed. Germination media at OTSP was half sterilized sand and half Perlite in Seedburo boxes, in a climate and timer-controlled germination room (Colas and Bettez 2016). Warm stratification was done in the room germinator with the alternating day and night-time temperatures test ran at, on the far wall, covered to keep seeds dark. Thank you Sarah!

The Editor would like to introduce two Ontario Ministry of Natural Resources and Forestry contacts responsible for developing the Ontario Tree Seed Archive, housed at the Ontario Forestry Research Institute in Sault Ste. Marie. An explanatory article of the Archive's plans is forthcoming.

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Literature Cited

Bonner, Franklin, T., and Karrfalt, R.P. (Editors). 2008. The Woody Plant Seed Manual: Agriculture Handbook 727. U.S. Department of Agriculture, Forest Service.

Colas, F., and Bettez, M. 2016. Tree seed testing overview. Tree Seed Working Group News Bulletin 64: 20–21.

Creasey, K.R., and Myland, T.R. 1993. Guidelines for Seed Pretreatment. Ontario Ministry of Natural Resources, Queen's Printer for Ontario. 45 pp.

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Extended Stratification Study of A-class Interior Spruce Seedlots

Background

An extended, 6-week stratification regime was compared to the standard, 3-week stratification regime used for A-class (seed orchard) interior spruce (*Picea glauca*, *Picea engelmannii* and their hybrids and back-crosses). Germination tests were conducted on 124 seedlots, resulting in 71 seedlots with an average 3.2% improvement in germination capacity and 0.6 increase in peak value after 6-week stratification.

Most seedlots stored at the Tree Seed Centre (TSC) require a period of cold stratification (moist chilling) for seed to break dormancy and germinate quickly. For decades, the default stratification regime for interior spruce, or Sx, seedlots has been a 24-hour running water soak followed by a 3-week cold stratification period at 2–5°C. During the 2019 sowing year, variable nursery germination of seedling requests from a single seedlot (63757) ranging from 81–99% prompted laboratory trials with different stratification regimes. An extended, 6-week stratification resulted in a 6% higher germination (94%), compared to the standard 3-week stratification (88%). This led us to question whether the germination of other Sx seedlots might be improved with extended stratification.

Previous evidence has shown that extended stratification of interior spruce can have a positive effect on germination. Trials on 20 wild stand and 6 orchard seedlots comparing 0, 3 and 6-week stratification demonstrated an increased rate of germination capacity in 23 of 26 seedlots after 6-weeks stratification, with 10 seedlots showing increased germination although average germination stayed the same (Kolotelo, 1994). Leadem (1993) tested different stratification durations (0, 3, 6 or 12-weeks) and growing temperatures (16°C, 24°C or 32°C) on a single Sx seedlot and found that 3 or 6 week-stratification allowed germination to reach the same level at a lower, suboptimal temperature (16°C) as at the optimal temperature (24°C).

The Tree Seed Centre has also had operational experience with extended stratification on interior spruce. Seedlots created from returned seedling requests receive at least six weeks of stratification (three weeks as a seedling request and three weeks in new seedlot testing). Out of 182 Sx "returned" seedlots, 55% have a germination result of 90% or above and 39% have a germination result of 80% or above (Kolotelo, 2019).

Given the past evidence and potential for improved germination, the TSC Seed Testing Laboratory began retesting Sx seedlots with 6-week stratification. A-class seedlots with high demand were prioritized to get results in time for the 2020 sowing season.

Materials and Methods

Each seedlot was tested according to International Seed Testing Association standards (ISTA 2016). A representative sample of 400 seeds was withdrawn from each seedlot and divided into four 100-seed replicates. Each replicate was soaked for 24 hours, then spread into a germination dish consisting of a piece of Kimpak, filter paper and 37 mL water inside a closed plastic dish. Germination dishes were kept in a cooler at 2–5°C for 3 or 6 weeks (stratification), then transferred to Conviron germinators set at 30°C with light for 16 hours, and 20°C with no light for 8 hours (Fig. 1). Germination dishes were observed three times per week for 21 days, during which germinated seeds were taken out and counted as "normal" if the radicle reached 4 times the length of the seed coat. The total number of normal germinants from each seedlot was divided by four replicates to calculate the germination capacity (GC). Germination rate was measured by Peak Value (PV), the point at which the average cumulative germination divided by the number of days in the germinator was the greatest. The higher the Peak Value, the faster the germination rate.

Seedlots stored at the TSC are retested regularly to maintain up-to-date germination results. A-class Sx seedlots are scheduled to receive the standard G10 (3-week stratification) retest every 40 months. Seedlots that were not due for retest (i.e. the seedlot had a G10 test result within the past 40 months) were not double-tested and only received a G12 (6-week stratification) test to maximize the number of seedlots investigated in this study.

Results and Discussion

A total of 124 seedlots have been tested out of the 180 active, A-class interior spruce seedlots. The remaining 56 seedlots were too small to be included in this study. For each seedlot, the test result with the higher GC (or PV if

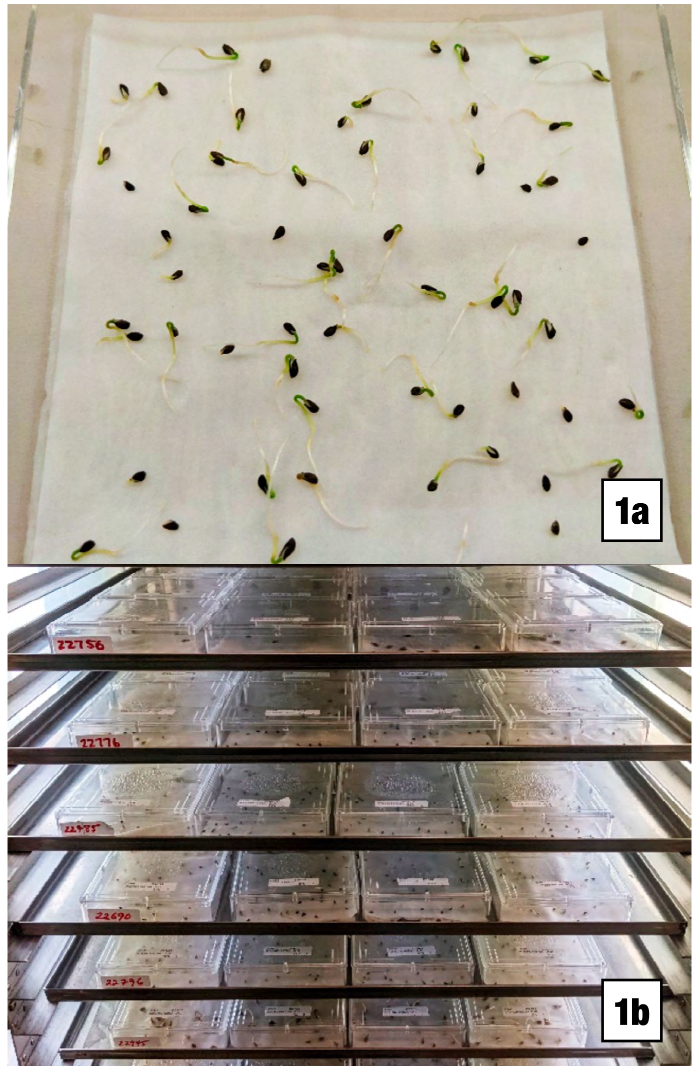

Figure 1. Interior spruce germinants in a germination dish (a) and germination dishes in a Conviron germinator (b).

the GC was unchanged) was "A-ranked" and uploaded to the Seed Planning and Registry Web Application (SPAR) as the default stratification regime.

The G12 test result was better than the G10 test result for 71 seedlots, with an average increase of 3.2% in germination capacity and 0.6 in peak value (Table 1). Though only 57% of the seedlots tested showed a benefit, the 71 seedlots make up more than 70% of the A-class Sx inventory kept at the TSC. For 53 seedlots (43%), the G10 result was better—2.7% higher in GC and 0.5 higher in PV on average. Five out of these 53 seedlots had "out-of-tolerance" tests (i.e. the result of one or more replicates was significantly higher or lower than the other replicates, rendering the test unacceptable) and were not retested because the average germination of the in-tolerance replicates was already below the G12

Table 1. Average Germination capacity (GC%) and Peak Value (PV) results of interior spruce seedlots by A-ranked test type

	Number of Seedlots	Average GC (%)			Average PV		
		G10	G12	Increase	G10	G12	Increase
Seedlots with G10 as A-ranked test	48	89.8	87.1	2.7	7.1	6.6	0.5
Seedlots with G12 as A-ranked test	71	86.3	89.5	3.2	6.6	7.3	0.6
Total / Average	119	87.7	88.5	3.0	6.8	7.0	0.6

Table 2. The number of seedlots with a G10 or G12 A-ranked test by seedlot age

Seedlot Age (Years)	Number of Seedlots	Number of Seedlots with a G10 A-ranked Test	Number of Seedlots with a G12 A-ranked Test	Percentage of Seedlots with a G12 A-ranked Test
0–1	3	0	3	100%
0–2	18	3	15	83%
0–5	32	8	24	75%
0–8	44	13	31	70%
0–10	50	19	31	62%
10+	52	25	27	52%

result. The out-of-tolerance tests have been omitted from the tables and figures.

Seed size did not determine which stratification duration was better for any given seedlot. The average seed size, represented by the number of seeds per gram (SPG), was similar for seedlots with A-ranked G10 tests (SPG=401) and G12 tests (SPG=407) (Fig. 2). Seedlots with smaller seeds and therefore smaller nutritive reserves which could potentially be exhausted more quickly were not negatively impacted by 6-week stratification. Seedlots with higher SPG (i.e. smaller seeds) were able to attain similar levels of germination to seedlots with fewer SPG (i.e. larger seeds). For example, seedlot 63772 had the smallest seeds (SPG=577) but still attained a G12 GC of 92%. Seedlot 63438 had the largest seeds (SPG=309), yet only had a G12 GC of 85%.

Newer A-class Sx seedlots performed better with extended stratification. The number of days spent in freezer storage was used to approximate seedlot age, excluding seedlots which were much older than recorded (e.g. returned seedlots). The younger the seedlots, the greater the proportion with a G12

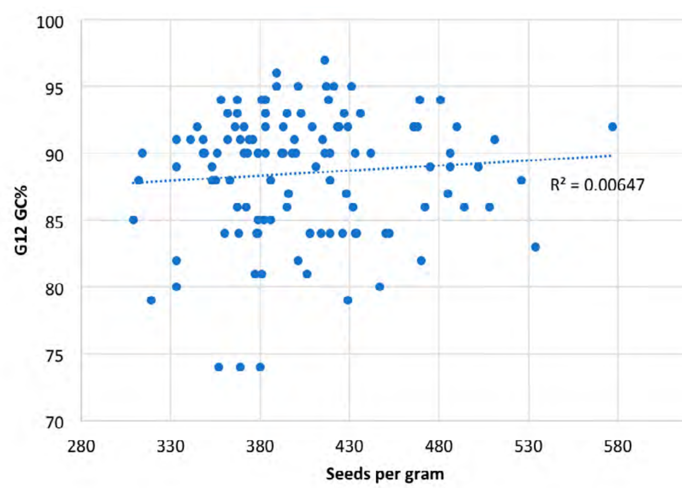

Figure 2. The Germination Capacity (GC%) and Seeds per Gram results of interior spruce seedlots which were tested with 6-week stratification.

test as the A-ranked test (Table 2). For example, 75% of seedlots 5 years and younger had a G12 test as the A-ranked result while only 52% of seedlots older than 10 years had an A-ranked G12 test. One possible hypothesis is that older seedlots which have spent more time in freezer storage at –18°C may have decreased dormancy and germinate more readily after only 3 weeks of stratification.

The majority of Sx seedling requests shipped during the 2020 sowing season received 6-week stratification. Quality assurance (QA) germination tests performed on requests sampled at shipping and nursery germination results (NGR) suggest extended stratification had no major detrimental effects. Though different seedlots were used each year, the average results of the 2020 sowing season (QA=91.3%, NGR=90.9%) were comparable to those of the 2019 season (QA=93.8%, NGR=89.5%).

Small increases in germination capacity and rate can translate to large savings for seed-buyers and nurseries. A higher GC means less seed and less nursery space is needed to meet a desired number of seedlings. Likewise, a higher PV could allow nurseries to lower greenhouse temperatures sooner, save on heating costs, and likely produce a more uniform crop. All new A-class Sx seedlots will receive a G10 and a G12 test as part of registration. We would appreciate any feedback you might have from growing Sx seedling requests which have gone through extended stratification.

References

Kolotelo, D. (1994). Response of interior spruce to extended stratification. Seed and Seedling Extension Topics, 7(1), 17-20.

Kolotelo, D. 2019. Extended Sx Stratification. Tree Seed Centre internal report. Unpublished.

ISTA. (2016). International Rules for Seed Testing 2016. The International Seed Testing Association, Zurich.

Leadem, C.L. (1993). Effects of stratification and temperature on germination of white spruce (*Picea glauca*). In Proc. 1992 Forest Nursery Association of British Columbia Meeting. Tech coord C.M Kooista. Penticton, B.C. Sept 28-Oct. 1, 1992. pp 9-16.

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The Evolution of the Forest Gene Conservation Association

2020 has certainly been a year of positive transformation for the Forest Gene Conservation Association (FGCA). From the people, to programs and even the trees, we look very different now than we did this time last year.

After 25 years at the helm of the FGCA, Barb Boysen has decided to transition into her well-earned retirement. Many of you are aware of Barb's incredible contributions to genetic diversity conservation here in Ontario and across Canada. I am fortunate to inherit and can expand upon the foundation Barb has built. I have several years' experience working on the FGCA Board of Directors already and working with folks like Brian Swaile (retired), Barb, and other prominent members in the afforestation and regeneration industry.

In addition to internal transformations, the FGCA has faced new opportunities and challenges in 2020:

- Release of Ontario's Tree Seed Transfer Policy
- Changes to the Ontario Endangered Species Act (ESA) with implications to butternut (*Juglans cinerea*)
- Federal Government's intentions to plant 2 Billion Trees
- Interchange Program with the National Tree Seed Centre

The FGCA and it's board have persevered through these changes by maintaining and enhancing our programs and in-house expertise, augmenting our network of professionals, and growing our staff complement.

As for the COVID-19 pandemic, we have made some significant changes to our operating plan and provided greater flexibility for staff and partners as we navigate this new normal. We can confirm we are well and staying positive as we move into the new year. As we step into 2021, our team of seven amazing staff, contractors, Board of Directors and our many delivery partners, will be working hard to wrap-up the first year of our new Strategic Direction (2020–2025) and executing our 2020–2021 Operating Plan.

Want to learn more about what we were up to in 2019–2020, or have ideas about how we could collaborate? Check out our annual report, follow us on Facebook @fgcaontario, or simply get in touch below. We hope you are all keeping well and look forward to working with you all in 2021.

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Ontario's New Seed Transfer Tools for Climate Adaptation

Ontario is the proud owner of a new Tree Seed Transfer Policy: https://www.ontario.ca/page/ontario-tree-seed-transfer-policy

As of September 4th, 2020, Ontario left behind its fixed seed zone approach and has moved on to a more flexible focal zone approach. Forest managers are encouraged to refer to an online tool that uses the interactive Tableau environment: https://public.tableau.com/profile/larlo#!/vizhome/SeedSourceOntario/Intro, or they can refer to the data tables: https://data.ontario.ca/dataset/ontario-tree-seed-transfer-policy-data

These sources provide foresters with science-based direction on the most suitable seed sources for their planting site or where seed they have collected may be best suited for utilization beyond the collection zone or ecodistrict. The MNRF, in collaboration with Natural Resources Canada, used the Seedwhere program (McKenney et al 1999) to analyze similarity between historic (1961–1990) and future (2011–2040) climate on all pairs of ecodistricts and seed zones. The climate variables identified by the scientists as the main drivers of genetic adaptation in forest genetics studies were mean annual temperature, growing season length, and minimum temperature of the coldest month. Although we know moisture influences tree growth and survival, precipitation does not drive genetic variation in Ontario trees in the same way as temperature-related variables. Ongoing research suggests that, in Ontario, precipitation is a more important factor in determining a species presence or absence than population-scale variation.

The climate similarity is measured on a scale of 0 to 1, where 1 is an exact match and 0 is the least similar comparison across the study area. The 0.9 threshold was determined based on analysis of provenance data for several Ontario species (black spruce (*Picea mariana*), white spruce (*Picea glauca*), jack pine (*Pinus banksiana*), white pine (*Pinus strobus*), and yellow birch (*Betula alleghaniensis*)) that showed <10% losses in growth and mortality. Climate projections were based on the lowest emissions scenario representative concentration pathway (RCP) 2.6. This RCP produced conservative transfer distances compared to those projected for an RCP 8.5 scenario, thus promoting early survival and growth, when trees, as seedlings, are most vulnerable to extreme climate events (e.g. false spring episodes, etc.).

This new policy provides foresters with the flexibility to identify and utilize other likely better seed sources along with, or instead of local seed which, in most cases, is becoming progressively less suited to their planting sites. It begins a new era of seed procurement and deployment where cooperation and sharing across license boundaries and wider geographies is needed to satisfy projects that utilize combinations of seed sources designed to increase survival and minimize growth risks while improving the odds of satisfying their silvicultural objectives.

Literature Cited

McKenney, D.W., Mackey, B.G., and Joyce, D. 1999. Seedwhere: a computer tool to support seed transfer and ecological restoration decisions. Environmental Modelling & Software 14(6): 589–595. doi:10.1016/S1364-8152(98)00095-4.

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USDA Forest Service Tree Seed and Genetics Happenings

Greetings from south of the border! The pandemic of 2020 has altered the workstyle for many employees: meetings and conferences have gone virtual, travel has been halted, and many employees are working from home on a regular basis. Wildfires from this unprecedented season are still burning while clean-up from a devastating hurricane season continues.

On a more positive note, the US has agreed to participate in the Trillion Tree Initiative which is expected to increase momentum related to reforestation and nursery production across the country (Executive Order was signed by President Trump, October 14th, so it's official). Assisted migration is also weighing on our minds as we seek new tools to maintain or enhance forest productivity in a novel climate. This is also an election year in the US, and a big one, which should be resolved by the time you are reading this. So much is happening and many of us are bearing witness from our dining room tables. Strange times.

The Eastern Region

This large region, consisting of 20 states in the Northeast and Midwest, is also known as Region 9 (R9). The headquarters for both the National Forest System and State and Private Forestry are now located in Milwaukee, Wisconsin (State and Private Forestry offices for these 20 states—formerly known as the Northeastern Area—relocated from their former office in Newtown Square, Pennsylvania in 2018). The Region has completed interviews for the R9 geneticist position, as Paul Berrang retired in December 2019. Nick LaBonte was recently hired, and has already started working, as the new Geneticist for the Eastern Region. Nick majored in Forestry at University of Wisconsin- Madison and earned his PhD at Purdue University where he studied the genetics of butternut canker disease resistance and chestnut genomics. Nick will be based in Milwaukee, Wisconsin at the Regional Headquarter Office.

The Oconto River Seed Orchard (ORSO), located in Langlade,Wisconsin, is continuing recovery work from a 2019 derecho (hurricane-force wind storm) which decimated several important seed orchards, including jack (*Pinus banksiana*), red (*Pinus resinosa*) and white pine (*Pinus strobus*). Other new seed orchards in development include white oak (*Quercus alba*), bur oak (*Quercus macrocarpa*) and swamp white oak (*Quercus bicolor*) to prepare for assisted migration at various National Forests. Seed collection areas of other hardwoods (hickory, *Carya* spp., and red oak, *Quercus rubra*) are being developed as well. A butternut (*Juglans cinerea*) progeny test, consisting of 2,400 trees, was planted in 2019 on land managed by the state of Wisconsin. The plan is to inoculate evenly-spaced "sacrificial trees," so that experimental trees receive only natural passive inoculation.

Screening for white pine blister rust also continues at ORSO, primarily of genotypes selected from northern Minnesota for planting at Superior National Forest. ORSO is also collaborating with the Northern Research Station to develop protocols for *Fraxinus* spp., to assist with propagating clones and seed collected from lingering ash, trees that survived the first wave of infestation of emerald ash borer.

Northern Research Station (NRS)

Resistance screening work is ongoing for several tree species at the USDA Forest Service's NRS. This work includes improving resistance in American elm to Dutch elm disease (DED) at the laboratory in Delaware, Ohio (see NRS-16). Several cultivars of American elm are available (Haugen and Bentz 2017), but the long-term goal for the next phases of research includes developing seed orchards, with improved resistance to DED, for restoration in natural forests. This will only be possible with a more reliable and rapid phenotyping protocol, which is also part of this next phase of research. In addition, research on lingering ash also continues at the Delaware lab (see NRS-16) to understand the genetic basis for these surviving trees, and to make crosses to stack genes further.

National Seed Lab (NSL)

Vic Vankus was recently promoted to the Director position at the National Seed Lab (NSL) in Dry Branch, Georgia. Vic's previous position at the NSL will be posted soon. In the meantime, the staff at the NSL have been testing seed storage conditions for a variety of tree and non-tree species: sagebrush, longleaf pine, wire grass, and red maple. They are evaluating seed moisture content, eRH and temperature regimes. They are also evaluating phytoagar as a medium for germination testing of tree and native species seed. The expectation is that this method, once approved, will provide a suitable alternative to existing media options for germination testing. This method costs less than other media types, and has the side benefit of reducing mold and fungus development in the germination dishes or trays.

In addition, the NSL continues to provide ex situ germplasm preservation for tree and native plant seed through long-term seed storage with the US National Plant Germplasm System. The NSL is an ISTA-accredited laboratory for testing germination of forest tree and shrub species.

Washington DC Office

Andy Bower, Geneticist with the Pacific Northwest Region, and Dana Nelson, Research Geneticist with the Southern

Research Station, are leading white papers on Assisted Migration and Genetic Modification, respectively, to guide USDA Forest Service policies on National Forest land. These efforts were initiated at the all deputy-area USFS geneticist meeting held in Albuquerque, New Mexico in November 2019, the first time this group met since the Gene Conservation meeting in Chicago in May 2016. The USFS geneticists will continue to meet on odd years, with next meeting planned for November 2021 at the Dorena Genetic Resource center.

Pacific Northwest

The Dorena Genetic Resources Center (DGRC), based in Cottage Grove, Oregon is working on several projects, with a focus on screening for resistance to various pests. Seed orchards of *Chamaecyparis lawsoniana* (Port-Orford-cedar, Lawson's cypress), developed with parents that are resistant to *Phytophthora lateralis*, are producing abundant seed for many of the 13 breeding zones in the northwest. Blister rust screening work continues on the eight white pine species (in western U.S.), most intensively with *P. monticola, P. lambertiana,* and *P. albicaulis*. Sadly, fires may have destroyed much/all of the R5 Happy Camp test site, which is home to many research trials of 5-needle pines.

Dorena also advises Hawaii on screening *Acacia koa* for wilt resistance, and the first seed orchards have started to produce seed. Also in Hawaii, the native ʻōhiʻa tree has is experiencing declines due to rapid ʻōhiʻa death, caused by *Ceratocystis* sp. (see https://cms.ctahr.hawaii.edu/rod/RESEARCH). Work to improve resistance in ʻōhiʻa against the pathogen has begun in Hawai'i.

Emerald ash borer has been devastating in the east, but its impact is expected to be felt on 16 *Fraxinus* species native to the western US soon as well. Tree seed collections, to conserve genotypes of *Fraxinus latifolia*, have begun. In addition, a field trial and a test for resistance is planned in conjunction with the Northern Research Station in Delaware, Ohio.

[Additional note of interest from Dr. Richard Sniezko].The genetics group at DGRC and entomologists throughout the West hope to begin looking at possible resistance to basalm woolly adelgid in subalpine fir and grand fir. As part of this project, we anticipate looking further at the capacity for gene conservation of this two species, by examining seed that has been stored twenty to forty years

Claire Ellwanger has been hired as a new zone geneticist serving the three National Forests in Washington State. Prior to moving to her new position in Wenatchee, Washington State. Claire worked as a biologist for the US Fish and Wildlife Service in Ashville, North Carolina, where she specialized in environmental planning and conservation of endangered plants. She holds a MS in Plant Biology and Conservation from Northwestern University and The Chicago Botanic Garden in Illinois.

Southern Region

Barb Crane retired in spring 2020, and Marcus Warwell was recently hired as the new Geneticist for the Southern Region. Marcus worked previously as a Research Geneticist with the Rocky Mountain Research Station in Moscow, Idaho. Marcus earned his PhD at the University of Minnesota where he studied genecology and phenotypic evolution of whitebark pine (*Pinus albicaulis*) and ponderosa pine (*Pinus ponderosa*). Marcus will be based in Atlanta, Georgia at the Regional Headquarter Office.

The National Forests in the south are dedicated mainly to the conservation of native plant and tree species. Much work is accomplished through partnerships such as the Shortleaf Pine Initiative and the Longleaf Pine Restoration Initiative, which include the USDA Forest Service's Southern Research Station (SRS). In addition, SRS is working with University of Kentucky on the WOI (White Oak Initiative) and white oak genetics program to improve regeneration success and performance of *Quercus alba*. This work is supported by the USDA Forest Service as well as the bourbon industry. This article describes the industry and challenges with white oak regeneration.

RNGR.net

Two recent articles discuss the new seed zones developed by the Eastern Seed Zone Forum (ESZF): the fall edition of Tree Planters' Notes (https://rngr.net/publications/tpn/) and Journal of Forestry (https://doi.org/10.1093/jofore/fvaa013). The next phase of the ESZF is aimed at developing a guidebook to assist with seed transfer decisions using the seed zones as a basis for origin. Our plan is to incorporate assisted migration based on current knowledge from provenance trials for major taxa in each of the major regions in the eastern US including the Great Lakes, Midwest, southern

Appalachians, New England/New York, Southwest, and Southeast.

COVID-19 resulted in the cancellation of all planned nursery conferences in 2020, so the RNGR team (Reforestation, Nursery, and Genetic Resources) team held a webinar series this past summer to continue advancing the science and practices of seedling production for restoration and reforestation. Five nursery associations joined forces to provide content: Canadian nursery growers, Intermountain Container Growers, Southern, Northeastern, and Western Associations. Webinars are archived at the Western Forestry and Conservation Association homepage.

The brand new Nursery Guide for the Production of Bareroot Hardwood Seedlings (2019) is also available at the RNGR site. A limited number of printed copies is available. Reach out to me at Carolyn.c.pike@usda.gov if you are interested in acquiring a hard copy. Lastly, we developed a new website that has information pertaining to butternut (*Juglans cinerea*) conservation https://butternut.rngr.net/.

Stay safe everyone – and may the forest be with you.

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Upcoming Meetings

BC Interior Technical Advisory Committee (ITAC) Extension Meeting (Virtual)
January 20, 2021, starting at 8:45 AM PST
https://www.gotomeet.me/OCFDivision/itac---forest-genetics-council
Contact Katherine Spencer for more information:
Katherine Spencer@gov.bc.ca

2021 Forest Genetics Association Virtual Student & Postdoc Symposium
May 19–20, 2021
https://pheedloop.com/forestgenetics2021/site/

For those who did not receive it through the CFGA Google Group, a portion of the eblast is reproduced below.

This virtual symposium will feature students and postdoctoral researchers, who represent the future of our forest genetics community. Their research, and its operational applications, will be showcased in oral and poster presentations over two days. Keynote speaker(s) and a panel will round out the agenda. The conference will also feature Q&A sessions, breakouts and chat rooms to facilitate networking and information exchange. No travel or PCR tests required!

Call for Abstracts

Forest genetics students and postdocs from across Canada, USA and overseas are invited to submit an abstract for an oral or poster presentation by February 28, 2021. The scope of acceptable topics is all-inclusive of forest genetics - from quantitative genetics to social sciences.

The Call for Abstracts page includes the submission form, instructions, presentation & poster guidelines, and deadlines. Professors, please encourage your students to apply!

Please direct questions regarding the Call for Abstracts to: lauren@podiumconferences.com

Awards

The following prizes will be awarded for the best presentations by undergrad, masters or doctorate students:

- W.B. Critchfield Award: WFGA prize for best oral presentation
- Carl Heimburger Award: CFGA prize for best oral presentation
- W.B. Critchfield Award: WFGA prize for best poster presentation
- Gene Namkoong Award: CFGA prize for best poster presentation

Registration

Registration will open on March 1, 2021. The early-bird registration fee is a reasonable CAD $40 per person until May 12.

All students and persons working in forest genetics, including academics and practitioners, are encouraged to attend to support our Next Generation. In addition to reconnecting with colleagues, you might meet your future employer or employee!

Sponsorship

Sponsorships are welcomed to help offset expenses for the conference platform (Pheedloop) and services provided by Podium Conferences. A virtual exhibit hall is available to promote your services, products and organization. Please visit the Sponsors website and click Learn More for details.

Further details and agenda will be available at a later date. Please forward this announcement to your colleagues and register early in March to assist us with planning and to receive direct communications. For updates in the interim, and if you are not already subscribed to CFGA's Google Group, send an email to the moderator deogratias.rweyongeza@gov.ab.ca.

Thank you to our scientific panel, organizing committee, support team and sponsors! We wish you a prosperous new year and look forward to "seeing" you at the Symposium.

Contacts:
Brian Barber, CFGA President
Email: brian.barber@selectseed.ca
Nicholas Ukrainetz, WFGA President.
Email: Nicholas.Ukrainetz@gov.bc.ca

9th World Conference on Ecological Restoration
June 21–24, 2021, Virtual
Registration opens: January 4, 2021
http://www.ser2021.org/

International Society for Seed Science Meeting
August 9–13, 2021
Brighton, UK
https://seedscisoc.org/dont-forget-to-register-your-interest-in-attending-isss-2021/
Contact: Louise Colville
Email: l.colville@kew.org

International Conference on Seed Dynamics and Tree Growth in Forestry
September 9–10, 2021, Virtual
Abstract Submission Deadline: January 28, 2021
https://waset.org/seed-dynamics-and-tree-growth-in-forestry-conference

Recent Publications & Online Content

Given the explosion of online content in 2020, this new standard subsection will be devoted to new, updated or recently archived online resources including webinars, courses, blogs, newsletters or grey literature of contributed by or of possible relevance to TSWG members. Some material may require payment (i.e. courses), but will endeavour to list as open access as much as possible. Links will be written for printed archival purposes. Please send over any material at any time to log here.

Recent Online Content

USFS Southern Research Station has released a free inertive course to support American Chestnut restoration, December 2020: https://srs.fs.usda.gov/products/courses/#chestnut

Interactive dashboard to accompany the latest report on the "Conservation status of native tree species in British Columbia", last updated Nov 26, 2020: http://climatebc.ca/cataloguing/default

FastTRAC Project Website, including presentations and virtual site tours: https://visitesvirtuelles.partenariat.qc.ca/fasttrac/en/accueil

Biodiversity International's page on "Trees for Seeds: Resilient forest restoration" including factsheets and seed supply survey results: https://www.bioversityinternational.org/trees-for-seeds/

2020–2021 BC Forest Genetics Council Newsletters including Seed Orchard Pest Management Posters: https://forestgeneticsbc.ca/home/news-and-events/

Simmons, M. 2020. Saving Western Canada's only endangered tree. The Narwhal [online news] https://thenarwhal.ca/saving-western-canadas-only-endangered-tree/

Great Lakes Forestry Centre (@GLFC.CFS) Seminar Series Fall 2020 featured several presentations on seed, seed dispersal and adapative silviculture involving assisted migration of seed sources to the Petawawa Research Forest: https://www.facebook.com/GLFC.CFS

2020 North American Forest and Conservation Nursery Technology Recorded Webinar Series (August 5–September 23, 2020): https://westernforestry.org/upcoming-conferences/2020-north-american-forest-and-conservation-nursery-technology-webinar-series

From the series above, in particular, Nabil Khadduri's September 16th webinar titled "Seed Preparation Techniques to Maximize Germination in the Nursery" is relevant to this issue's theme: https://vimeo.com/458771879

Nabil also produced a Padlet web app to log many additional resources and the results of the live polling from that webinar. https://padlet.com/nabilkhadduri/seedgermwebinar

Sniezko, R. 2020 (n.d.). Thwarting Invasives in the Pacific Northwest: Success Stories from the Field. Society of American Foresters, NW Office [online news]. http://www.nwoffice.forestry.org/content/thwarting-invasives-pacific-northwest-success-stories-field

Society of Ecological Restoration Open Access International Seed Standards Launch, September 3, 2020: https://www.ser.org/news/524574/Open-Access-International-Seed-Standards-Launch-Introductory-Webinar-and-Panel.htm

2020 Empowering Tribal Culture, Ecology and Food Systems Recorded Webinar Series (September 30–October 28, 2020) included several seed and nursery related webinars: https://westernforestry.org/upcoming-conferences/2020-empowering-tribal-culture-ecology-and-food-systems-webinar-series-free

University of Minnesota held a paid online short course titled "Assisted Migration in Practice" focused on seed transfer science, case studies and resources for practitioners, October 15, 22 and 29, 2020: https://sfec.cfans.umn.edu/2020-assisted-migration Contact Eli Sagor for information on future programs: esagor@umn.edu

Special issue of Samara, Issue 35, International Newsletter of the Millennium Seed Bank Partnership, featuring projects and research from the Global Tree Seed Bank Programme: https://www.kew.org/sites/default/files/2020-09/Samara%20Newsletter%20July%202020.pdf

SylvanSeeds: Germination Database of Temperate Broadleaf and Mixed Forests: https://efernandezpascual.shinyapps.io/sylvanseeds/

Natural Resources Canada's "Simply Science" Youtube Series, "Restoring Damaged Forests" podcast featuring Dr. Nicolas Mansuy, July 23, 2020: https://www.youtube.com/watch?v=m98iP6YZuks

Genome Atlantic News, "FastTRAC-ing better white spruce", July 20, 2020: http://genomeatlantic.ca/fasttrac-ing-better-white-spruce/

European Forest Genetic Resources Programme has published many 2020 newsletters, thematic publications, updated species technical guidelines and resources: http://www.euforgen.org/

Project report (12 pp.) including many tree species of conservation concern. Griffith, P., Beckman, E., Callicrate, T., Clark, J., Clase, T., Deans, S., Dosmann, M., Fant, J., Gratacos, X., Havens, K., Hoban, S., Lobdell, M., Jiménez-Rodriguez, F., Kramer, A., Lacy, R., Magellan, T., Maschinski, J., Meerow, A.W., Meyer, A., Sanchez, V., Spence, E., Toribio, P., Walsh, S., Westwood, M., and Wood, J. 2019. Toward the metacollection: Coordinating conservation collections to safeguard plant diversity. Botanic Gardens Conservation International-US (San Marino, USA). https://www.bgci.org/resources/bgci-tools-and-resources/toward-the-metacollection-coordinating-conservation-collections-to-safeguard-plant-diversity/

Northern Forest Atlas of high quality images including most eastern North American woody plants: https://northernforestatlas.org/

Peer-Reviewed Publications

Aghai, M., and Manteuffel-ross, T. 2020. Enhancing Direct Seeding Efforts With Unmanned Aerial Vehicle (UAV) " Swarms " and Seed Technology. Tree Planter's Notes 63(2): 32–48.

Ali, M.H., Sobze, J.-M., Pham, T.H., Nadeem, M., Liu, C., Galagedara, L., Cheema, M., and Thomas, R. 2020. Carbon Nanoparticles Functionalized with Carboxylic Acid Improved the Germination and Seedling Vigor in Upland Boreal Forest Species. Nanomaterials 10(1): 176. MDPI AG. doi:10.3390/nano10010176.

Almoguera, C., Prieto-Dapena, P., Carranco, R., Ruiz, J.L., and Jordano, J. 2020. Heat Stress Factors Expressed during Seed Maturation Differentially Regulate Seed Longevity and Seedling Greening. Plants 9(3): 335. MDPI AG. doi:10.3390/plants9030335.

Anamthawat-Jónsson, K., Karlsdóttir, L., Thórsson, Æ.T., and Jóhannsson, M.H. 2020. Naturally occurring triploid birch hybrids from woodlands in Iceland are partially fertile. New Forests: 1–20. Springer Science and Business Media B.V. doi:10.1007/s11056-020-09816-z.

Arruda, A.J., Silveira, F.A.O., and Buisson, E. 2020. A simple standardized protocol to evaluate the reliability of seed rain estimates. Seed Science Research: 1–6. Cambridge University Press. doi:10.1017/S0960258520000392.

Ballesteros, D., and Pritchard, H.W. 2020. The Cryobiotechnology of Oaks: An Integration of Approaches for the Long-Term Ex Situ Conservation of *Quercus* Species. Forests 11(12): 1281. MDPI AG. doi:10.3390/f11121281.

Bouchard, M., and Pernot, C. 2020. Climate and size of previous cone crops contribute to large-scale synchronous cone production in balsam fir. Canadian Journal of Forest Research: cjfr-2020-0054. Canadian Science Publishing. doi:10.1139/cjfr-2020-0054.

Brennan, A.N., and Jacobs, D.F. 2020. Seed propagation protocol for pure and hybrid butternut (*Juglans cinerea* L.). Tree Planters' Notes 63(1): 39–50.

Brito, W.A.D.L., Pereira, K.T.O., Nogueira, N.W., Torres, S.B., and Paiva, E.P. DE. 2020. Evaluation of viability of *Tabebuia aurea* seeds through tetrazolium test. Revista Caatinga 33(4): 993–999. Universidade Federal Rural do Semi-Arido. doi:10.1590/1983-21252020v33n414rc.

Bronson, M.T. 2020. Age and size effects on first cone production among white spruce trees. Canadian Journal of Forest Research 50(5): 519–522. Canadian Science Publishing. doi:10.1139/cjfr-2019-0365.

Burczyk, J., Sandurska, E., and Lewandowski, A. 2019. Patterns of Effective Pollen Dispersal in Larch: Linking Levels of Background Pollination with Pollen Dispersal Kernels. Forests 10(12): 1139. MDPI AG. doi:10.3390/f10121139.

Cano, V., Martínez, M.T., San José, M.C., Couselo, J.L., Varas, E., Bouza-Morcillo, L., Toribio, M., and Corredoira, E. 2020. Regeneration of transgenic plants by Agrobacterium-mediated transformation of *Quercus ilex* L. somatic embryos with the gene CsTL1. New Forests 51(6): 1003–1021. Springer Science and Business Media B.V. doi:10.1007/s11056-020-09771-9.

Charron, G., Robichaud-Courteau, T., La Vigne, H., Weintraub, S., Hill, A., Justice, D., Bélanger, N., and Lussier Desbiens, A. 2020. The DeLeaves: a UAV device for efficient tree canopy sampling. Journal of Unmanned Vehicle Systems 8(3): 245–264. Canadian Science Publishing. doi:10.1139/juvs-2020-0005.

Chau, M.M. 2020. Rapid Response to a Tree Seed Conservation Challenge in Hawai'i Through Crowdsourcing, Citizen Science, and Community Engagement. Journal of Sustainable Forestry 0: 1–19. Taylor and Francis Inc. doi:10.1080/10549811.2020.1791186.

Cobb, M., Woods, M.J., and McEwan, R.W. 2020. Assessing Seed Handling Processes to Facilitate a Community-Engaged Approach to Regional Forest Restoration. Forests 11(4): 474. MDPI AG. doi:10.3390/f11040474.

Coulter, A.E. 2020. Functional analysis of proteins in the conifer ovular secretion. PhD Thesis. University of Victoria. https://dspace.library.uvic.ca//handle/1828/12080

Daibes, L.F., and Cardoso, V.J.M. 2020. Effect of reduced water potential on seed germination of a forest tree: a hydrotime approach. Journal of Seed Science 42: 2020. Associacao Brasileira de Tecnologia de Sementes. doi:10.1590/2317-1545v42224519.

Davies, R.M., Hudson, A.R., Dickie, J.B., Cook, C., O'Hara, T., and Trivedi, C. 2020. Exploring seed longevity of UK native trees: implications for ex situ conservation. Seed Science Research 30(2): 101–111. Cambridge University Press. doi:10.1017/S0960258520000215.

Dement, W.T., Hackworth, Z.J., Lhotka, J.M., and Barton, C.D. 2020. Plantation development and colonization of woody species in response to post-mining spoil preparation methods. New Forests 51(6): 965–984. Springer Science and Business Media B.V. doi:10.1007/s11056-019-09769-y.

Dudley, N., Jones, T., Gerber, K., Ross-Davis, A.L., Sniezko, R.A., Cannon, P., and Dobbs, J. 2020. Establishment of a Genetically Diverse, Disease-Resistant *Acacia koa* A. Gray Seed Orchard in Kokee, Kauai: Early Growth, Form, and Survival. Forests 11(12): 1276. MDPI AG. doi:10.3390/f11121276.

Dumroese, R.K., Page-Dumroese, D.S., and Pinto, J.R. 2020. Biochar Potential To Enhance Forest Resilience , Seedling Quality , and Nursery Efficiency. Tree Planters' Notes 63(1): 61–68.

Fan, Y., Wang, L., Su, T., and Lan, Q. 2020. Spring drought as a possible cause for disappearance of native *Metasequoia* in Yunnan Province, China: Evidence from seed germination and seedling growth. Global Ecology and Conservation 22: e00912. Elsevier B.V. doi:10.1016/j.gecco.2020.e00912.

Feau, N., Tanney, J.B., and Hamelin, R.C. 2020. Could DNA-Based Detection Technology Help Prevent Conifer Seed-Borne Pathogen Diseases ? Tree Planter's Notes 63(2): 131–139.

Fernández-Pascual, E. 2020. SylvanSeeds , a seed germination database for temperate deciduous forests. Journal of Vegetation Science: jvs.12960. Wiley-Blackwell. doi:10.1111/jvs.12960.

Fernández-Pascual, E., Mattana, E., and Pritchard, H.W. 2019. Seeds of future past: climate change and the thermal memory of plant reproductive traits. Biological Reviews 94(2): 439–456. Blackwell Publishing Ltd. doi:10.1111/brv.12461.

Franić, I., Prospero, S., Hartmann, M., Allan, E., Auger-Rozenberg, M., Grünwald, N.J., Kenis, M., Roques, A., Schneider, S., Sniezko, R., Williams, W., and Eschen, R. 2019. Are traded forest tree seeds a potential source of nonnative pests? Ecological Applications 29(7). Ecological Society of America. doi:10.1002/eap.1971.

Garner, B.A., Hoban, S., and Luikart, G. 2020. IUCN Red List and the value of integrating genetics. Conservation Genetics 21(5): 795–801. Springer Science+Business Media B.V. doi:10.1007/s10592-020-01301-6.

Gasparin, E., Faria, J.M.R., José, A.C., Tonetti, O.A.O., de Melo, R.A., and Hilhorst, H.W.M. 2020. Viability of recalcitrant *Araucaria angustifolia* seeds in storage and in a soil seed bank. Journal of Forestry Research 31(6): 2413–2422. Northeast Forestry University. doi:10.1007/s11676-019-01001-z.

Golev, A.D., Bukhtoyarov, V.N., and Ivannikov, V.A. 2020. The practice of using a sieveless separator for pre-sowing treatment of common pine seeds (*Pinus sylvestris*). IOP Conference Series: Earth and Environmental Science 595(1): 12056. IOP Publishing. doi:10.1088/1755-1315/595/1/012056.

Han, Q., Kabeya, D., and Inagaki, Y. 2020. Reproduction affects partitioning between new organs of a pulse of ^{15}N applied during seed ripening in *Fagus crenata*. New Forests 51(5): 739–752. Springer. doi:10.1007/s11056-019-09757-2.

Hayatgheibi, H., Berlin, M., Haapanen, M., Kärkkäinen, K., and Persson, T. 2020. Application of Transfer Effect Models for Predicting Growth and Survival of Genetically Selected Scots Pine Seed Sources in Sweden. Forests 11(12): 1337. MDPI AG. doi:10.3390/f11121337.

Hayda, Y., Los, S., Yatsyk, R., Tereshchenko, L., Shlonchak, G., Mytrochenko, V., Neyko, I., Samodai, V., Smashnyuk, L., Klisz, M., and Mohytych, V. 2019. Seed orchards in Ukraine: past, present and prospects for the future. Folia Forestalia Polonica 61(4): 284–298. Walter de Gruyter GmbH. doi:10.2478/ffp-2019-0028.

Hudson, J.J., and Degenhardt, D. 2020. Stratification of beaked hazelnut (*Corylus cornuta*) seed improves germination. Seed Science and Technology. International Seed Testing Association. doi:10.15258/sst.2020.48.3.08.

Iakovoglou, V., Takos, I., Pantazi, G., Pipsou, A., and Neofotistou, M. 2020. Growth responses of seedlings produced by parent seeds from specific altitudes. Journal of Forestry Research 31(6): 2121–2127. Northeast Forestry University. doi:10.1007/s11676-019-01030-8.

Iralu, V., Barbhuyan, H.S.A., and Upadhaya, K. 2019. Ecology of seed germination in threatened trees: a review. Energy, Ecology and Environment 4(4): 189–210. article, Joint Center on Global Change and Earth System Science of the University of Maryland and Beijing Normal University. doi:10.1007/s40974-019-00121-w.

Khoury, C.K., Carver, D., Greene, S.L., Williams, K.A., Achicanoy, H.A., Schori, M., León, B., Wiersema, J.H., and Frances, A. 2020. Crop wild relatives of the United States require urgent conservation action. Proceedings of the National Academy of Sciences 117(52): 33351–33357. National Academy of Sciences. doi:10.1073/pnas.2007029117.

Kijak, H., and Ratajczak, E. 2020. What Do We Know About the Genetic Basis of Seed Desiccation Tolerance and Longevity? International Journal of Molecular Sciences 21(10): 3612. MDPI AG. doi:10.3390/ijms21103612.

Kijowska-Oberc, J., Staszak, A.M., Kamiński, J., and Ratajczak, E. 2020. Adaptation of Forest Trees to Rapidly Changing Climate. Forests 11(2): 123. MDPI AG. doi:10.3390/f11020123.

Kijowska-Oberc, J., Staszak, A.M., Wawrzyniak, M.K., and Ratajczak, E. 2020. Changes in Proline Levels during Seed Development of Orthodox and Recalcitrant Seeds of Genus Acer in a Climate Change Scenario. Forests 11(12): 1362. MDPI AG. doi:10.3390/f11121362.

Koenig, W.D., Knops, J.M.H., and Carmen, W.J. 2020. Intraspecific variation in the relationship between weather and masting behavior in valley oak, *Quercus lobata*. Canadian Journal of Forest Research 50(12). Canadian Science Publishing. doi:10.1139/cjfr-2020-0098.

Koutouan-Kontchoi, M.N., Phartyal, S.S., Rosbakh, S., Kouassi, E.K., and Poschlod, P. 2020. Seed dormancy and dormancy-breaking conditions of 12 West African woody species with high reforestation potential in the forest-savanna ecotone of Côte d'Ivoire. Seed Science and Technology 48(1): 101–116. International Seed Testing Association. doi:10.15258/sst.2020.48.1.12.

Lanthier, M., and Watts, C. 2020. Survey of Pest Problems and Pesticide Use in Canadian Forest Seedling Nurseries. Tree Planters' Notes 63(2): 104–111.

Li, X., Liu, X.-T., Wei, J.-T., Li, Y., Tigabu, M., and Zhao, X.-Y. 2020. Genetic Improvement of *Pinus koraiensis* in China: Current Situation and Future Prospects. Forests 11(2): 148. MDPI AG. doi:10.3390/f11020148.

Liu, J.-J., Sniezko, R.A., Sissons, R., Krakowski, J., Alger, G., Schoettle, A.W., Williams, H., Zamany, A., Zitomer, R.A., and Kegley, A. 2020. Association Mapping and Development of Marker-Assisted Selection Tools for the Resistance to White Pine Blister Rust in the Alberta Limber Pine Populations. Frontiers in Plant Science 11: 1404. Frontiers Media S.A. doi:10.3389/fpls.2020.557672.

Liu, W., Liu, J., Jiang, J., and Li, Y. 2020. Comparison of partial least squares-discriminant analysis, support vector machines and deep neural networks for spectrometric classification of seed vigour in a broad range of tree species. Journal of Near Infrared Spectroscopy: 96703352096375. SAGE Publications Ltd. doi:10.1177/0967033520963759.

Lichti, N.I., Dalgleish, H.J., and Steele, M.A. 2020. Interactions among Shade, Caching Behavior, and Predation Risk May Drive Seed Trait Evolution in Scatter-Hoarded Plants. Diversity 12(11): 416. MDPI AG. doi:10.3390/d12110416.

Loewe-Muñoz, V., Balzarini, M., Delard, C., Del Río, R., and Álvarez, A. 2020. Inter-annual variability of *Pinus pinea* L. cone productivity in a non-native habitat. New Forests 51(6): 1055–1068. Springer Science and Business Media B.V. doi:10.1007/s11056-020-09774-6.

Marcu, N., Budeanu, M., Apostol, E.N., and Radu, R.G. 2020. Valuation of the Economic Benefits from Using Genetically Improved Forest Reproductive Materials in Afforestation. Forests 11(4): 382. MDPI AG. doi:10.3390/f11040382.

Mattana, E., Peguero, B., Di Sacco, A., Agramonte, W., Encarnación Castillo, W.R., Jiménez, F., Clase, T., Pritchard, H.W., Gómez-Barreiro, P., Castillo-Lorenzo, E., Terrero Encarnación, M., Way, M.J., García, R., and Ulian, T. 2020. Assessing seed desiccation responses of native trees in the Caribbean. New Forests 51(4): 705–721. Springer. doi:10.1007/s11056-019-09753-6.

Mao, X., Fu, X.-X., Huang, P., Chen, X.-L., and Qu, Y.-Q. 2019. Heterodichogamy, Pollen Viability, and Seed Set in a Population of Polyploidy *Cyclocarya paliurus* (Batal) Iljinskaja (Juglandaceae). Forests 10(4): 347. MDPI AG. doi:10.3390/f10040347.

Matsushita, M., Nishikawa, H., Tamura, A., and Takahashi, M. 2020. Effects of Light Intensity and Girdling Treatments on the Production of Female Cones in Japanese Larch (*Larix kaempferi* (Lamb.) Carr.): Implications for the Management of Seed Orchards. Forests 11(10): 1110. MDPI AG. doi:10.3390/f11101110.

National Academies of Sciences, Engineering, and Medicine. 2020. An Assessment of the Need for Native Seeds and the Capacity for Their Supply: Interim Report. Washington, DC: The National Academies Press. https://doi.org/10.17226/25859.

Native Plant Materials Directory. 2020. Native Plants Journal 21(2): 188–261. University of Wisconsin Press. doi:10.3368/npj.21.2.188.

Notivol, E., Santos-del-Blanco, L., Chambel, R., Climent, J., and Alía, R. 2020. Seed Sourcing Strategies Considering Climate Change Forecasts: A Practical Test in Scots Pine. Forests 11(11): 1222. MDPI AG. doi:10.3390/f11111222.

Palomeque, X., Patiño Uyaguari, C., Marín, F., Palacios, M., and Stimm, B. 2020. Effects of storage on seed germination and viability for three native tree species of Ecuador. Trees 34(6): 1487–1497. Springer Science and Business Media Deutschland GmbH. doi:10.1007/s00468-020-02018-2.

Pedrini, S., Balestrazzi, A., Madsen, M.D., Bhalsing, K., Hardegree, S.P., Dixon, K.W., and Kildisheva, O.A. 2020. Seed enhancement: getting seeds restoration-ready. Restoration Ecology 28(S3): S266–S275. Blackwell Publishing Inc. doi:10.1111/rec.13184.

Pereira, L.C. V., Mayrinck, R.C., Zambon, C.R., José, A.C., and Faria, J.M.R. 2020. Storage of short-lived seeds of *Inga vera* subsp. *affinis* in osmotic medium. Seed Science Research 30(2): 156–160. Cambridge University Press. doi:10.1017/S0960258520000185.

Pike, C., Potter, K.M., Berrang, P., Crane, B., Baggs, J., Leites, L., and Luther, T. 2020. New Seed-Collection Zones for the Eastern United States: The Eastern Seed Zone Forum. Journal of Forestry 118(4): 444–451. Oxford University Press. doi:10.1093/jofore/fvaa013.

Pike, C.C., Williams, M., Brennan, A., Woeste, K., Jacobs, J., Hoban, S., Moore, M., and Romero-Severson, J. 2020. Save Our Species: A Blueprint for Restoring Butternut (Juglans cinerea) across Eastern North America. Journal of Forestry (4): 1–11. doi:10.1093/jofore/fvaa053.

Pinto, T.T., Geisler, G.E., Santos, M., and Paulilo, M.T.S. 2020. Germination of physically dormant seeds of *Colubrina glandulosa* Perkins (Rhamnaceae). Brazilian Journal of Botany 43(1): 91–97. Springer International Publishing. doi:10.1007/s40415-020-00591-x.

Pipinis, E., Stampoulidis, A., Milios, E., Kitikidou, K., Akritidou, S., Theodoridou, S., and Radoglou, K. 2020. Effects of seed moisture content, stratification and sowing date on the germination of *Corylus avellana* seeds. Journal of Forestry Research 31(3): 743–749. Northeast Forestry University. doi:10.1007/s11676-018-0852-x.

Potascheff, C.M., Oddou-Muratorio, S., Klein, E.K., Figueira, A., Bressan, E.A., Oliveira, P.E., Lander, T.A., and Sebbenn, A.M. 2019. Stepping stones or stone dead? Fecundity, pollen dispersal and mating patterns of roadside *Qualea grandiflora* Mart. trees. Conservation Genetics 20(6): 1355–1367. Springer Netherlands. doi:10.1007/s10592-019-01217-w.

Raghu, H.B., Ashwin, R., Ravi, J.E., and Bagyaraj, D.J. 2020. Enhancing plant quality and outplanting growth of *Acacia auriculiformis* in dry wasteland plantations by inoculating a selected microbial consortium in the nursery. Canadian Journal of Forest Research 50(8): 736–741. Canadian Science Publishing. doi:10.1139/cjfr-2019-0335.

Reddy, M., Sharma, L., Reddy, B.M., Chatterjee, M., Dhawan, S., and Pai, V. 2020. Influence of Mechanical Scarification and Gibberellic Acid on Seed Germination and Seedling Performance in *Pinus gerardiana* Wall. Int.J.Curr.Microbiol.App.Sci 9(4): 1356–1365. doi:10.20546/ijcmas.2020.904.161.

Sáenz-Romero, C., O'Neill, G., Aitken, S.N., and Lindig-Cisneros, R. 2020. Assisted Migration Field Tests in Canada and Mexico: Lessons, Limitations, and Challenges. Forests 12(1): 9. Multidisciplinary Digital Publishing Institute. doi:10.3390/f12010009.

Sirgedaitė-Šėžienė, V., Mildažienė, V., Žemaitis, P., Ivankov, A., Koga, K., Shiratani, M., and Baliuckas, V. 2020. Long-term response of Norway spruce to seed treatment with cold plasma: Dependence of the effects on the genotype. Plasma Processes and Polymers. Wiley-VCH Verlag. doi:10.1002/ppap.202000159.

Splawinski, T.B., Cyr, D., Gauthier, S., Jetté, J.-P., and Bergeron, Y. 2019. Analyzing risk of regeneration failure in the managed boreal forest of northwestern Quebec. Canadian Journal of Forest Research 49(6): 680–691. doi:10.1139/cjfr-2018-0278.

St. Clair, J.B., Howe, G.T., and Kling, J.G. 2020. The 1912 Douglas-Fir Heredity Study: Long-Term Effects of Climatic Transfer Distance on Growth and Survival. Journal of Forestry 118(1): 1–13. JOUR. doi:10.1093/jofore/fvz064.

Syamsuwida, D., Nurhasybi, and Sudrajat, D. 2020. Advance technology of tropical tree seed handling in Indonesia for high quality seed and seedling productions. IOP Conference Series: Earth and Environmental Science 522(1): 12017. Institute of Physics Publishing. doi:10.1088/1755-1315/522/1/012017.

Tang, Y., Zhang, K., Zhang, Y., and Tao, J. 2019. Dormancy-Breaking and Germination Requirements for Seeds of *Sorbus alnifolia* (Siebold & Zucc.) K.Koch (Rosaceae), a Mesic Forest Tree with High Ornamental Potential. Forests 10(4): 319. MDPI AG. doi:10.3390/f10040319.

Tsuyama, I., Ishizuka, W., Kitamura, K., Taneda, H., and Goto, S. 2020. Ten Years of Provenance Trials and Application of Multivariate Random Forests Predicted the Most Preferable Seed Source for Silviculture of *Abies sachalinensis* in Hokkaido, Japan. Forests 11(10): 1058. MDPI AG. doi:10.3390/f11101058.

Van der Walt, K., Kemp, P., Sofkova-Bobcheva, S., Burritt, D.J., and Nadarajan, J. 2020. Seed development, germination, and storage behaviour of *Syzygium maire* (Myrtaceae) , a threatened endemic New Zealand tree. New Zealand Journal of Botany: 1–19. Taylor and Francis Ltd. doi:10.1080/0028825X.2020.1794911.

Wang, H., Chen, L., Dai, S., Ma, Q., Wu, Y., Ma, Q., and Li, S. 2020. Seed coat anatomy of *Cercis chinensis* and its relationship to water uptake. Canadian Journal of Plant Science 100(3): 276–283. Canadian Science Publishing. doi:10.1139/cjps-2019-0164.

Wang, T., Smets, P., Chourmouzis, C., Aitken, S.N., and Kolotelo, D. 2020. Conservation status of native tree species in British Columbia. Global Ecology and Conservation 24: e01362. Elsevier B.V. doi:10.1016/j.gecco.2020.e01362

Wawrzyniak, M.K., Michalak, M., and Chmielarz, P. 2020. Effect of different conditions of storage on seed viability and seedling growth of six European wild fruit woody plants. Annals of Forest Science 77(2): 58. Springer. doi:10.1007/s13595-020-00963-z.

Zinsmeister, J., Leprince, O., and Buitink, J. 2020. Molecular and environmental factors regulating seed longevity. Biochemical Journal 477(2): 305–323. Portland Press Ltd. doi:10.1042/BCJ20190165.