Tree Seed Working Group News Bulletin

72

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Canadian Forest Genetics Association
l'Association canadienne de génétique forestière

SEED AUTOMATION TECHNOLOGIES

Featured in this Issue:

Banner photo of a DeLeaves drone sampling maple (*Acer* spp.) Source:: https://www.deleaves.com/news/cef-fertilization

Armchair Report No. 72

Hello, best wishes to all and hopefully 2022 is a great year for you.

We are seeing a loosening of mask and vaccination mandates and greater ease of travel to/from many places—hooray. The pandemic moving to an endemic will bring a new normal, but unfortunately COVID is no longer the biggest headline in the news. The invasion of the Ukraine brings another war the world doesn't need. We see the direct impacts at the gas station, but my heart goes out to those having to flee from or defend their homeland. Both my paternal grandparents immigrated to Canada from the Ukraine and although I have no direct contact, I still feel somewhat connected. Both IUFRO (https://www.iufro.org/news/article/2022/03/08/letter-by-the-iufro-president-and-executive-director/) and the ISC (https://council.science/current/news/isc-statement-ukraine/) have released statements and science also suffers. It also makes me think of all the people in the world having to leave or defend their homeland to put food on the table, maintain their cultural identity or for their personal safety… which don't make the mainstream news.

Much of my focus right now is planning our tree seed tour on Vancouver Island (June 23–26) and Tree Seed Workshop at our facility on June 27th. The theme is a recurring one **"Challenges to our Future Tree Seed Supply"** and one I have tried to actively promote over the past year. The program and information regarding accommodations, transportation and other attractions can be found here: https://docs.google.com/document/d/1zc1r5iqZiEmcOayfP44izQ-GIRHXpB_M/edit.

The purpose of this tree seed meeting is to address a key bottleneck in the highly ambitious global reforestation goals—the sustained availability of high quality and adapted tree seed. Challenges to our future tree seed supply are real and begin with a lack of educational coverage, research funding and interest, and continued infrastructure investment. The tree seed supply system is taken for granted and unsustainable in its

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Deadline for Issue No. 73: October 30, 2022

We welcome any comments, suggestions and article submissions and will solicit active, subscribing members for content. Submissions may be edited for length. Authors are responsible for the accuracy of the material in their submitted content. 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
4. Advising on implementation practices

current form. One of the meeting goals is to build strong relationships between organizations involved in this highly specialized field: IUFRO 2.09.03: Seed Physiology and Technology; International Seed Testing Association Forest Tree and Shrub Committee, International Seed Federation Tree and Shrub group and our Canadian Tree Seed Working Group. Prioritization of efforts needs to consider the whole spectrum of activities from tree seed science to production and processing and ultimately the provision of the best seeds and information to the global tree seed market. We have put together a program to showcase "beautiful British Columbia" that highlights our forests and tree seed facilities, allows for scientific and technical exchange and attracts people globally that are involved in our highly specialized field. There will be plenty of natural marvels to see and fun to be had, but the goal is to build relationships among those that want to co-operate and improve the existing tree seed systems in place. The hope is that we can build on this meeting and create synergies and opportunities to ensure a clear and informed message is provided to decision and policy makers worldwide to increase awareness and address our challenges.

Registration is through Eventbrite: https://www.eventbrite.com/cc/challenges-to-our-future-tree-seed-supply-2022-287309 . There are a variety of participation options with the main ticket being the Thursday workshop, and accompanying lunch, and the other activities are indicated as add-ons. This format allows the in-person registration process to be completed on one page. At the checkout you will be also asked about special dietary needs and whether there is anything else we can help to make your visit enjoyable. The timing of the meeting is intended to promote long-distance attendance, even under these uncertain times, by tying in with the BC Seed Orchard Association meeting on June 28 and 29 (https://forestgeneticsbc.ca/bcsoa/) and the CFGA/WFGA field tour day on June 30th.

In terms of my activities over the past several months promoting tree seed, (Armchairs are for shameless self promotion) the positive part of virtual meetings is for organizers to simply press the "Record' button and produce a permanent record of the presentation. As part of IUFRO World Day several of us put together a video promoting Working Group 2.09.03 Seed Physiology and Technology to increase awareness and foster participation. It was a fun and quickly put together video that turned out way better than I expected (https://youtu.be/aay6WPJYBvo). As part of the IUFRO Pacific Northwest Conifers I spoke on Deployment Bottlenecks: Cone and Seed Processing, Storage and Inventory Management which I am quite concerned about, especially with the high reforestation goals being set to try and reduce the rate of global warming (https://www.canal-u.tv/video/rtr_midi/deployment_bottlenecks_cone_and_seed_processing_storage_and_inventory_management_dave_kolotelo.65337). I was also fortunate to speak at our BC Forest Nursery Association meeting (https://www.dropbox.com/s/yw9jgqp5fnojr2c/Thurs%20Sept%2023%2C%202021.mp4?dl=0).

I was saddened to learn of the passing of Don Fowler late last year http://www.mcadamsfh.com/obituaries/158705. Don was my primary inspiration for pursuing further education in forest genetics. We shared an interest in Picea phylogeny and he certainly mentored me in both the practical and scientific aspects of tree breeding. Looking back I remember one summer when our team had to inventory a freezer of exotic tree seed. Having mainly worked with small spruce and tamarack seed, I was mesmerized by these huge pine seeds and it certainly planted a you know what in me. RIP Don. I would also like to acknowledge the passing of Michel Vallee from Vancouver Island University who was a professor for 30 years and responsible for teaching students about conifer reproductive biology, seeds, silviculture and a wide range of forestry topics. https://www.tributearchive.com/obituaries/23724228/michel-joseph-hubert-vallee

Throughout COVID, our facility was designated an essential service, so we've been on board throughout contrasting with many who worked from home. It was a relatively small cone and seed processing year in 2021, but it is already obvious that the potential for a large Douglas-fir crop exists for 2022. Our planting program is still at a high level with us in the process of preparing and shipping seed for 290 million requested seedlings. An area that is developing quickly is the 'restoration' activities surrounding whitebark pine, and also limber pine in Alberta. This year we shipped about 42 kg of whitebark pine seed to nurseries (15 kg was the previous high) and registered 23 new seedlots. The blister rust screening program, grafting, seed orchard site selection, maintenance and planting have all been happening this past year with many dedicated people contributing. Whitebark pine has been a species providing a bridge between the reforestation and restoration communities of practice.

Last, and thankfully least significant to our facility is that our former "Ministry of Forests, Lands, Natural Resource Operations and Rural Development" went through a reorganization. Fortunately, it was an atypical reorganization that did not result in jobs being lost. Our branch stayed intact, and we are now simply part of the Ministry of Forests, again.

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Don Fowler, 1932–2021.

Michel Valee, 1950–2022.

Franklin T. Bonner 1936–2018.

Editor's Notes

It's almost summer, hard to believe. I'll make this short as I'm sure you'd rather read the articles. I need to contact more of you to update your Membership information or successors since 2019. I'm also helping where I can organize the June 2022 BC workshop, and excited to attend in person. Hooray for face-to-face time.

The theme of this issue was intended to be "Seed Automation Technologies" and it turned out well. I appreciate those who answered the call this winter, especially the ensemble of direct seeding experts and innovators. Beyond that, we have explorations in magnetic resonance imaging, biochar trials, and improvements in sugar maple mini-cell sowing. On seed technology upgrades, both Berthier and NTSC received new Kubtec Xpert80 digital X-ray machines this winter. I note a new pest that may impact sugar maple seed production and yield. Brian Barber and Jodie Krakowski highlight their 2021 wins and challenges, and Kim Creasey gives us a cone riddle. For my MScF project I have been reviewing electrical conductivity as a good-in-a-pinch tool, but Recent Publications are loaded with other potential seed technologies adoptable from agricultural seed testing to get others thinking. ***Let's make seed sexy again.***

In recent sad news, Nancy Shaw alerted me to a research station and seed samples destroyed in the Ukrainian war. While the main facility was not harmed, it emphasizes the necessity of planning for back-up and emergency planning to conserve any genetic resource collections. I hope there is no further damage or samples lost.

Dave and I also learned of Dr. Franklin T. Bonner's passing in late 2018, formerly from the USDA National Seed Lab in Georgia and a long-time contributor to this group. Frank remains one of the top cited authors in the Bulletin with his role in coordinating the monumental revision of Agricultural Handbook No. 747, aka The Woody Plant Seed Manual (2008). For many, it's the "big blue bible" we've come to rely on (plus the TSWG!). Dr. Bonner, your legacy carries on and we are grateful to easily "carry" the free PDF.

Retirements, COVID-era job shifts and well wishes are given to the following members, associates and experts:

- Atlantic Canada: retiring, Barry Linehan (Newfoundland Centre for Agriculture and Forestry Development), Tannis Beardmore (CFS-AFC), Kathleen Forbes (CFS-AFC). New job, Simon Bocksette (July 2020, Nova Scotia Dept. of Natural Resources and Renewables).
- Ontario and Québec: retiring, Lise Caron (Canadian Forest Service-CWFC), Marie Deslauriers (Canadian Forest Service-LFC), Ken Elliott (NDMNRF), Ed Patchell (Ferguson Tree Nursery), Marie-Josée Mottet (MFFP du Quebec), Krystina Klimaszewska (MFFP du Québec)h. Moved on, Michel Jacques (MFFP du Québec).
- Prairies: Glenn Goodwill (PRT Prince Albert). New job, Holly Aggas (summer 2020, Government of Saskatchewan Forest Service).
- Western Canada: retiring, Sally John (Isabella Point Forestry Ltd). Retired, Lee Charleson, ATISC. New job, Dasviner Kambo with CFS-NFC (and congrats on the new baby).
- International: Patrick Baldet (IRSTEA, France) who advanced research about water activity for tree seeds.

<u>Please add tswgcanada@googlegroups.com to your favourite email contact list!</u>

1. The switch to our new TSWG Google Groups system caused a number of email clients to spam/junk-flag our new address. I will continue trying to alert people via my NRCan email so you don't miss out.
2. There will be a new Membership profile form launched on the TSWG page soon. This can be a tool to promote active members with the skills, facilities and expertise to manage tree seed.
3. Sabina Donnelly adjusted a setting on the BC web page our past TSWG Bulletins are posted. All our content is being found by search engines now. I'll concentrate on building up the CFGA YouTube channel: send me any seed, nursery and training videos we can playlist.
4. The format of the Bulletin may change later, but is stable for now. Thank you to Carrie Pike last fall for her advice in knowledge extension publishing workarounds.

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Magnetic resonance imaging provides insights into the structures of Scots pine seeds and their characteristics

Two-dimensional radiography, i.e. X-ray imaging, is a well-established method for inspecting tree seed quality both operationally and for research purposes. The benefits of this conventional imaging technique include its speed and non-destructiveness allowing the simultaneous investigation of multiple individual seeds, and further follow-up investigations, such as laboratory germination tests. For most common tree species, the interpretation of radiographs is also easy and can be learned with minimal effort. However, a downside of radiography is its two-dimensionality as, for example, multiple overlaying structures can hinder the visibility of smaller structures. Furthermore, X-ray techniques provide little information about the composition of the various tissues inside a seed. Because contrast in X-ray-based techniques is dependent on the thickness and density of the imaged anatomy, compositionally different tissues, such as fatty and starchy structures may appear similar or even homogeneous. One potential option to circumvent some of these limitations in seed imaging is the use of magnetic resonance imaging (MRI), an imaging modality most familiar from the field of medicine.

As a non-destructive and non-invasive method, MRI provides information originating from atomic nuclei, most typically hydrogen (^{1}H) present in a detectable configuration in water and lipids, to name a few. Contrary to X-ray-based methods, MRI does not produce an ionizing radiation dose. In MRI, a sample (for example, a patient or a seed) is placed in a strong magnetic field inside a scanner and excited with radio frequency pulses, after which the signal generated by the nuclei can be measured, resulting eventually in an MR image. Different MRI pulse sequences (i.e., different procedures and excitations for MR imaging) can be utilized to obtain datasets and images with various contrasts. These, in turn, could assist in the interpretation of the seed structures and tissues as well as provide some implications on their composition. The mobility of ^{1}H plays an important role in signal formation. For example, structures with limited free water, such as the seed coat, provide a low signal in MRI (dark regions in MR images) whereas numerous soft tissues can be differentiated (different gray values in MR images). MRI data can be 2-dimensional slices or entire 3-dimensional image sets, and as such is a versatile technique to provide information throughout structures without obstruction from superimposed layers. A more in-depth theoretical background for MRI has been extensively covered in literature and is not presented here (Brown and Semelka 1999; McRobbie et al. 2017).

In a collaboration between the University of Eastern Finland (UEF) and Natural Resources Institute Finland (Luke), Scots pine (*Pinus sylvestris* L.) seeds were collected from a commercial seed orchard and investigated with MRI. ^{1}H MRI was utilized to both anatomically (structural images) and quantitatively (relaxation time maps) investigate

Figure 1. MRI scanner with 11.74 T magnetic field strength. Sample is lowered to the center of the cylinder from the top using an airlift. Magnetic field is created by a current running in a loop of superconducting material cooled using liquid helium (4 Kelvin, −269°C). Helium evaporation is minimized with nitrogen (77 Kelvin, −196°C) surrounding the helium.

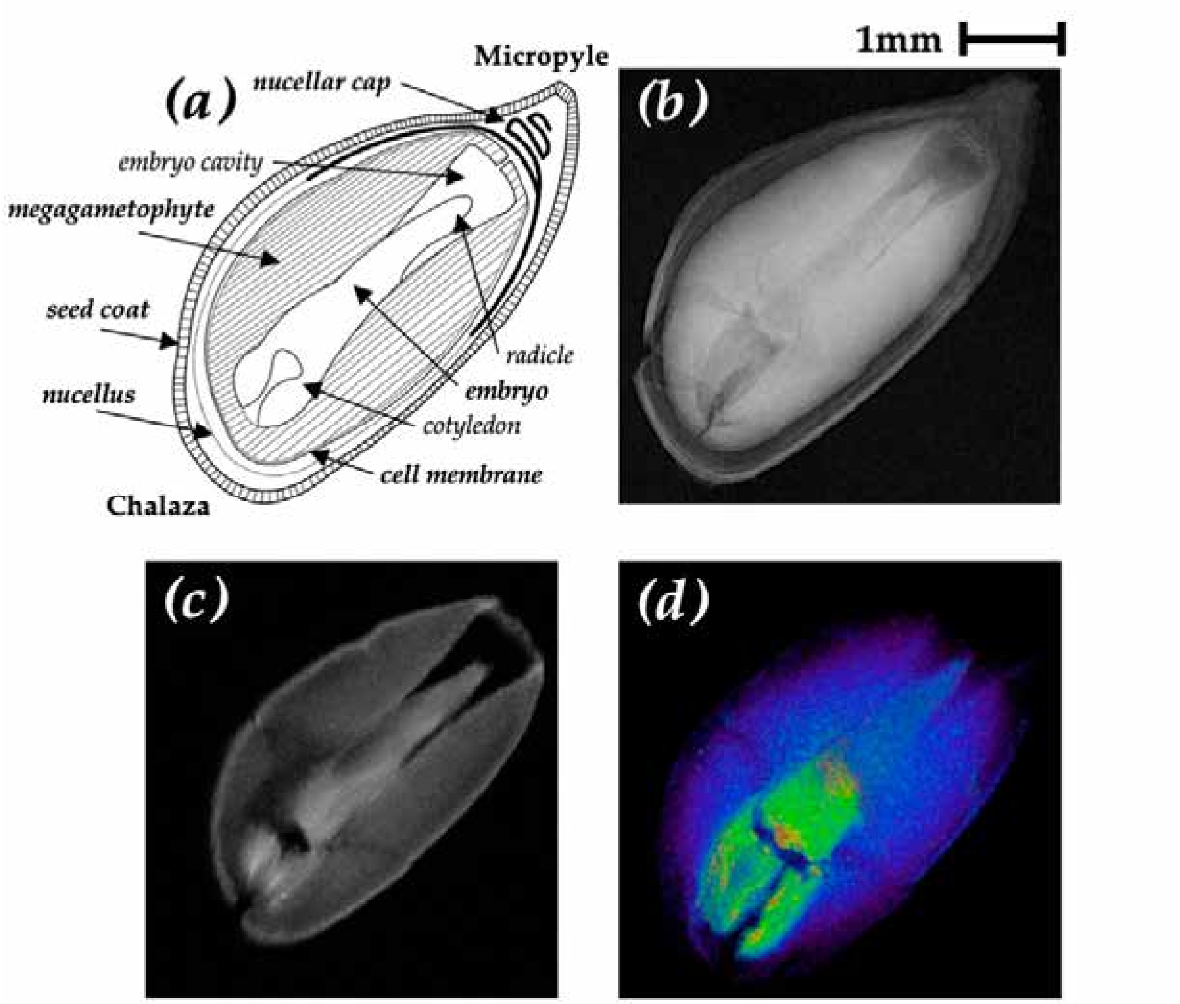

Figure 2. Seed structure visibility of a fractured Scots pine seed. (a) Schematic of seed structures. (b) X-ray image. (c) MR image slice (RARE pulse sequence). (d) Pseudo-color volume rendering of 3-D MRI data (ZTE pulse sequence). Scale is approximate.

the capabilities of the modality to assist in seed quality evaluation and seed germination assessment. The imaged seeds were collected at maturity, but they were of varying quality. As such, full, empty, and mechanically damaged seeds were examined. MR imaging was conducted in batches of 10 seeds. In addition, a single mechanically damaged seed was investigated separately with a higher image resolution and image quality. The MR images were compared to conventional digital radiographs of the same individual seeds, and the seeds were subsequently germinated. Radiographs were obtained with Faxitron MultiFocus (Faxitron Bioptics LLC, Tucson, Az, USA) using 18 kV tube voltage and 4 s exposure time. MR imaging was conducted using a pre-clinical research MRI scanner (Bruker 500MHz Ultrashield) with microimaging capabilities at 11.7 T magnetic field strength presented in Figure 1.

MRI provided a noticeable contrast between the embryo and megagametophyte, not observable with the conventional X-ray imaging (Figure 2 and Figure 3). The importance of imaging parameters as well as the pulse sequence should also be carefully considered during study planning since, for example, with a multiple gradient echo (MGE) pulse sequence the signal from the megagametophyte is virtually non-existent, whereas with the zero echo time (ZTE) pulse sequence megagametophyte is clearly visible (Figure 3). It should be noted that the seed coat, prominently visible in X-rays, is entirely absent in MRI likely due to its mechanically hard structure and limited mobility of ^{1}H as mentioned earlier. The mechanical damage seems to extend excessively to the megagametophyte observable as a diminished MR signal near the cotyledons in Figure 2d. Furthermore, because the water content of the studied

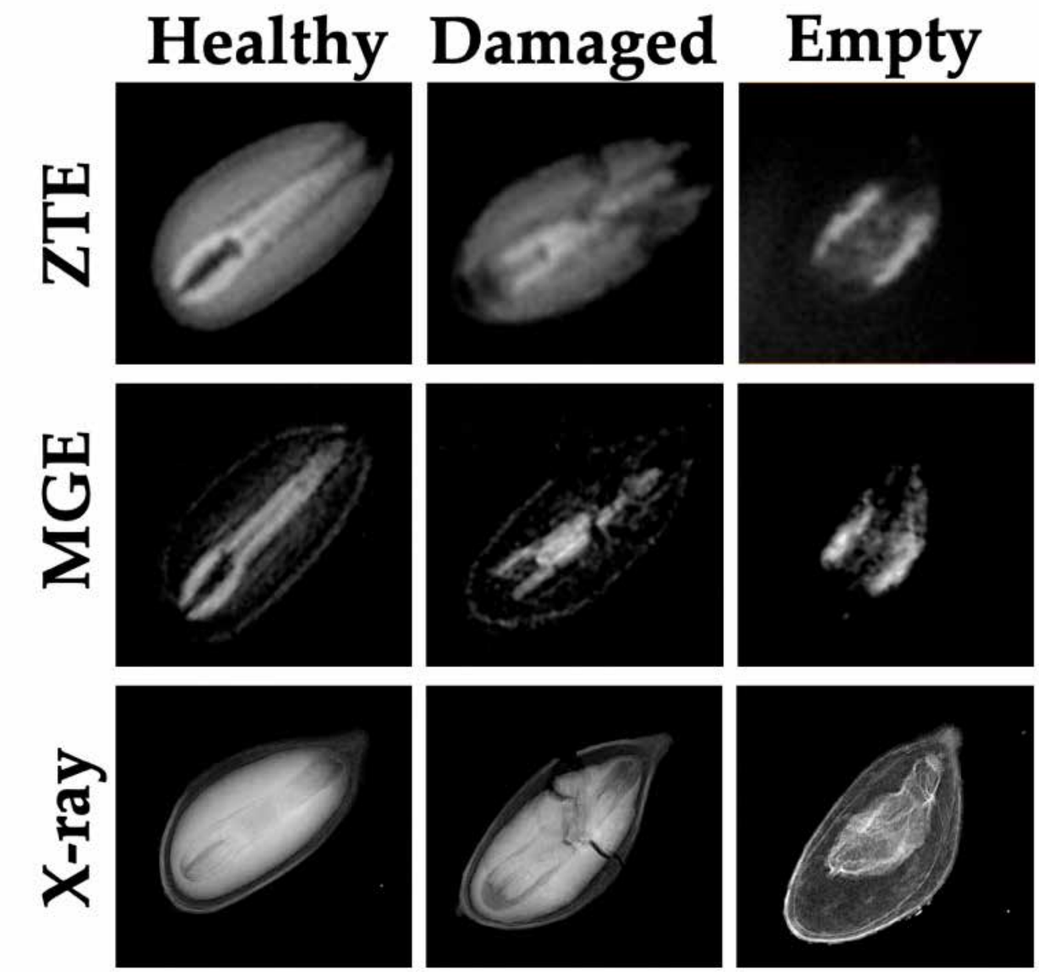

Figure 3. Visibility of healthy, (mechanically) damaged and empty seeds with different MRI pulse sequences and plain X-ray imaging. First row: ZTE MRI pulse sequence, second row: MGE MRI pulse sequence and last row: X-ray images.

seeds was approximately 6%, and Scots pine seeds have been shown to have a much more profound lipid content of 28–33% (Tillman-Sutela et al. 1995), the origin of the detected ^{1}H and subsequent MR images may be in fact predominantly from lipids rather than water.

As discussed earlier, MRI can provide 3-dimensional or slice-specific information on seed structures not obtainable with 2-D X-ray imaging. Moreover, 3-dimensional X-ray-based methods do exist (namely computed tomography, CT) but its use in the interpretation of seed structures may be limited (homogeneous contrast between the structures) and could in some instances even reduce germinability due to the inflicted radiation dose. However, limitations regarding MRI also exist, as only a small number of seeds can be imaged simultaneously (with the presented device and setup) and the scan time spans from minutes to even several hours depending on, for example, the desired image quality and image size. Because MRI is a heavily physics-based imaging method, knowledge for its appropriate inclusion to tree seed research requires expertise not only on seed biology and physiology but on the modality as well. As such, collaboration between these two fields may be more or less a necessity when combining MRI with seed research. Furthermore, the initial setup and maintenance costs for MRI are higher compared to radiography, as for example refills of helium (4 K) and nitrogen (77 K) are required to keep the superconducting magnet cooled. This in turn, can make MRI seem unreachable in seed research in some cases. Thus, the use of MRI in operational seed production is quite limited but may be warranted in a research setting, where MRI and radiography can complement each other.

For more information on the quantitative MRI (relaxation time maps) as well as other aspects of the conducted study, the reader is referred to the published paper "Quantitative magnetic resonance imaging of Scots pine seeds and the assessment of germination potential" in the Canadian Journal of Forest Research (DOI: 10.1139/cjfr-2021-0273). The related data set in its entirety can be found at https://doi.org/10.5281/zenodo.5541369.

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Considering Direct Seeding as a Forest Restoration Option

Introduction

Direct seeding with tree species has been an ongoing silvicultural practice in forest restoration programs for centuries. The first reference discussing direct seeding, as a reforestation practice, goes back to the 14th century (cited by Willoughby et al. 2004). Direct seeding evolved into an option for sustainable forestry programs with many methods discussed by Toumey (1916) (i.e., broadcast or drilled seeding in strip, line, hole or spot distribution patterns) still considered standard practices today. Prior to the development of large-scale nursery programs to produce seedlings, direct seeding or partial seeding (i.e., a combination of direct seeding and leave-seed trees) was considered a 'best practice' for forest regeneration programs to re-establish a forest stand (Smith 1962). With the potential expansion of worldwide forest restoration programs to help address deforestation and global climate change, direct seeding is being considered as a restoration option (Fischer et al. 2016). Direct seeding as a forest restoration option was recently reviewed (Grossnickle and Ivetić 2017). The following are findings from this review.

Merits of Direct Seeding

Direct seeding may be a viable option under certain restoration scenarios, such as:

1. rapid coverage of large disturbed areas,
2. opportunity to re-establish the site before the development of competing vegetation,
3. planting of inaccessible sites,
4. enrichment planting in secondary forests having inadequate natural regeneration, and
5. use in low-budget restoration programs.

Direct seeding also avoids all costs involved in planting seedlings (i.e., reduced labour, less equipment, no nursery infrastructure, limited handling costs, minimal operational plans). The average cost of direct seeding per hectare is 30% to 38% (ranging from 9% to 51%) of the cost for planting seedlings, depending on seed price and seeding rate. If one just defines reforestation success as 'putting plant material into the ground', then direct seeding costs are considerably lower than planting seedlings.

Direct Seeding Performance in Restoration Programs

Direct seeding trials from the past 25 years indicate that it is not always a successful forest restoration option. The overall average establishment rate (i.e., the survival rate after at least one growing season per total number of seeds planted) was 21% across all studies ranging from 0% to 92%, with it at 17% for tropical species, 28% for temperate hardwoods and 16% for temperate conifers (Figure 1). Reasons for low success rate are:

1. tree species and seed quality,
2. timing of seeding,
3. planting practices,
4. microsite environment,
5. vegetative competition, and
6. seed predation.

Some combination of these factors determines whether direct-seeded material successfully goes through the three stages of initial stand development; germination, establishment during the first growing season, and survival and growth over succeeding years.

Two main options available for forest stand establishment are either direct seeding or planting of seedlings. Trials comparing these options found that planted seedlings had a significantly higher establishment rate than direct seeding (i.e., up to 40 to 60% higher). The main reason is that seedlings from direct seeding are smaller than planted seedlings after establishment (Figure 2). This smaller size results in slower growth compared with planted seedlings during initial forest stand development, especially on sites having vegetative competition. Site preparation or vegetation management practices can alleviate site resource competition. However, seedlings need to be large enough to capture site resources and maintain growth that exceeds the plant competition. To be a successful restoration option, direct seeding needs to establish seedlings that grow quickly and become large enough to capture site resources.

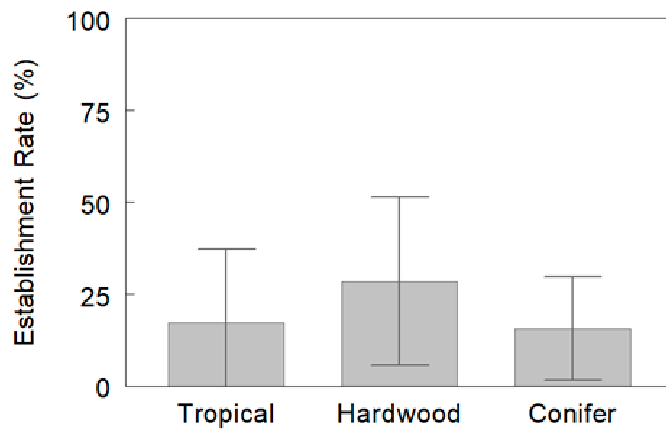

Figure 1. The establishment rate (i.e., survival rate after at least one growing season per / total number of seeds planted) for direct seeding forest restoration programs using tropical (n= 46 trials), hardwood (n= 51 trials) and conifer (n= 40 trials) (mean +/- STD) tree species (adapted from Grossnickle and Ivetić 2017).

Figure 2. Comparison of a coastal Douglas-Fir (*Pseudotsuga menziesii*) fall planted 1+0 container-grown seedling (left) and a seedling resulting from direct seeding (right in circle) after one growing season (Grossnickle unreported data).

Operational Direct Seeding Practices

Direct seeding is currently only a marginal component of forest restoration programs in most developed countries, with the largest direct seeding programs (as a percent of the total restoration acreage) at 13% for Ontario, Canada, 15% in Serbia, and 22% in Finland. A number of developed countries have defined direct seeding rates to ensure a fully stocked stand in forest restoration programs. For example (range related to species recommendations), spot seeding rates are 10,000 to 30,000 seeds ha^{-1}, furrow seeding rates are 5,000 to 25,000 seeds ha^{-1}, and broadcast seeding rates are 18,000 to 300,000 seeds ha^{-1}. Along with high seeding rates, factors that define program success are seedbed receptivity (i.e., number of ideal seeding microsites), the delivery of seed to seedbed sites and seed dispersion (i.e., seed spread across the site). These factors determine whether a direct seeding program can create an established forest stand.

Direct seeding is a suitable low-cost option for ecological restoration, especially in developing countries with limited seedling production capability (Pandey and Prakash 2014). If large amounts of low-cost seed is readily available, direct seeding can create a forest structure somewhat similar to natural regeneration sites (Freitas et al. 2019; Raupp et al. 2020). This greater control of species composition and stocking levels can increase species diversity compared with "passive restoration" (Brancalion et al. 2016).

Seed Usage: Direct Seeding versus Seedling Production

As tree improvement programs start to produce 1^{st} to 3^{rd} generation seed in many developed countries, the cost of seed production does not make direct seeding a viable option. For example, for all tree species in British Columbia Canada the seed used in the provincial seeding program typically has a germination capacity of >85% (Kolotelo personal communication). It is logical to use this high-quality seed in seedling production programs where >90% of the seed is turned into plantable seedlings when grown in nursery programs under controlled environmental conditions (Landis et al. 1998). In addition, there is a forecasted seed supply shortage (i.e., both improved and wild seed) to meet anticipated demands for seedlings required to achieve goals of expanded forest restoration in developed (Fargione et al. 2021) and developing (Di Sacco et al. 2021) countries. The question is whether direct seeding is the best seed usage option to meet these forest restoration goals in the coming decade.

Final Thoughts

Ultimately one must define what is meant by forest restoration success. If success is defined as a fully stocked forest stand (i.e., meeting 80% restocking standards (Mitchell et al. 1991)), then planting seedlings is a more viable option than direct seeding. With currently available technology, direct seeding should focus on restoration scenarios where rapid deployment, difficult or inaccessible sites, and seedling production capability and cost concerns determine the restoration option. To expand the use of direct seeding, one needs to create more effective seed dispersion, increase seedbed receptivity via a more favorable microsite environment, and minimize seed predation to increase seedling establishment. In addition, development of seed enhancement technologies is required that package seed to deliver materials such as nutrients, microbial inoculants and protection agents or hydration treatments to enhance germination, emergence, and/or early seedling growth. Once these new technologies show that direct seeding can meet standards for successful forest stand establishment, this practice can be applied to a broader array of forest restoration programs.

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New direct seeding technology improves seedling emergence

Direct seeding of Scots pine (*Pinus sylvestris*) has a long history as a popular regeneration method in Finland. In the peak year 1964, the total direct seeding area was over 77,000 hectares, covering 30% of all forest regeneration. Although the direct seeding area today is only 25,000 hectares, its share of all forest regeneration is still more or less the same as before.

Mechanization of direct seeding started in Finland in 1980's, and today over 80% of seeding is done mechanically in combination with soil scarification. Disc trenching is a common method, but patch scarification with Bracke-mounder or excavator is also used.

High seed consumption

The seed use efficiency in mechanical direct seeding is currently very low. As the target density of young Scots pine stand is 5,000 seedlings per hectare, at least 50,000 seeds (~300 g) must be sown per hectare to achieve that target. For this reason, almost 8,000 kg of high-quality seed is needed annually for direct seeding in Finland.

Low seedling establishment is mainly due to the seed bed structure that current scarification methods create, and to random positioning of the seeds on these seed beds. Sown seeds may remain visible for a long time on the top of the mineral soil patch or furrow, which exposes them to drought, predation, and soil erosion. On the other hand, seeds may also be buried too deep in the soil.

Special excavator bucket for seeding

In 2015, Finnish Forest Research Institute, Forest Centre, and Finnish machine manufacturer ViperMetal – Ajutech ltd. started a joint project to develop a new type of excavator bucket (later direct seeding bucket or DSB), with which it would be possible to scarify soil, sow seeds and, most importantly, cover them with a thin layer of soil. The aim was to increase seedling emergence and thus decrease the annual amount of seed needed for direct seeding.

The prototype of the direct seeding bucket was introduced in summer 2016. It was also introduced in TSWG News Bulletin 64. Externally DSB resembles normal V-shape ditching bucket, but it has integrated, hydraulically driven

Figure 1. Improved version of the direct seeding bucket (DSB) equipped with a separate scarification blade.

Figure 2. Fresh mineral soil patch, which is made, sown, and covered with mineral soil and humus using the direct seeding bucket (DSB).

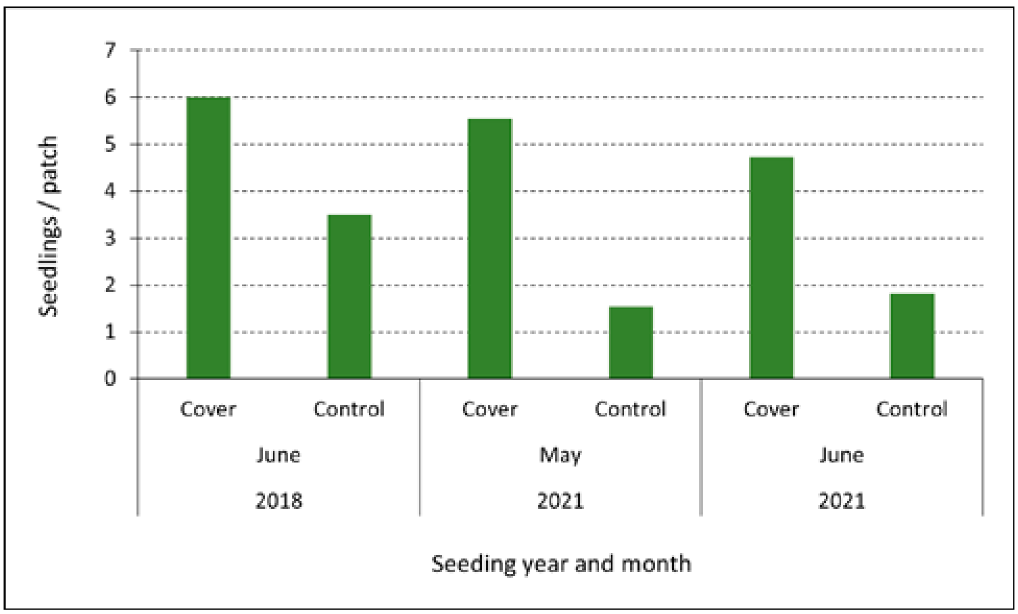

Figure 3. Average number of Scots pine seedlings after the first growing season in covered und uncovered (control) patches in different seeding years and months.

rotator, and electrical seeding device.

An improved version of the direct seeding bucket was finished in 2021. It is equipped with a separate scarification blade attached to the bottom of the bucket (Figure 1). In addition, a video camera is installed in the bucket and the screen in the cockpit for selection of suitable sowing places and for monitoring of the seeding device.

The working principle of the new DSB is as follows:

1. Surface soil is taken into the bucket for cover material.
2. A shallow mineral soil patch is made with the scarification blade on the bottom of the bucket (with the prototype patch was made using the cutting edge).
3. Seeds are sown on the surface of the patch with the seeding device.
4. The rotary screen is used for covering the seeds with a thin layer of soil (Figure 2). With bucket full of soil, it is possible to cover at least 10 patches.

Field tests show promising results

The first large-scale field test with the DSB was carried out in central Finland in June 2018. The second field test with the improved version was carried out likewise in central Finland in May and June 2021. In both years over 1,000 test patches were made using the DSB. Half of the patches were sown with the bucket and immediately covered using the screen mechanism with a thin (~1 cm) layer of mineral soil and humus. The other half were sown without cover as a control treatment. The number of emerged seedlings was counted after the first growing season.

In 2018, counts of emerged seedlings were 72% higher in covered patches compared to uncovered patches, whereas in 2021 it was 266% and 166% higher in May and June seeding, respectively (Figure 3). The much higher increase in seedling number in 2021 compared to 2018 is probably due to higher proportion of mineral soil in the covering layer and, also to lower precipitation during the growing season in 2021.

These results indicate that much smaller number of seed is needed when seeds are covered immediately after seeding. According to visual observations, covering also increases height growth of seedlings during the first years after the seeding.

Versatile tool for artificial forest regeneration

Even though the DSB is especially designed to improve direct seeding results, it can be used also for mounding and ditching on moister sites suitable for planting.

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Flash Forest: Drone Seeding Post-Fire Sites

Flash Forest is Canada's first drone-based reforestation company, with headquarters in Mississauga, Ontario and operations across the country. Flash Forest was founded in 2019 with the clear goal of seeding one billion trees by 2028 (without stopping there) to make a meaningful impact on greenhouse gas sequestration. We don't focus only on establishing tree plantations; our goal is full ecosystem recovery. To this end, we hope to expand our capacity to include the seeding of shrubs and herbaceous plants where applicable in the future. We are not currently offering site preparation or thinning, but we have conducted trials on older fire sites that were mulched to improve seedbeds. The results were very promising (over 40% germination and 18% establishment after the first growing season in some cases), but this combination of treatments may not be economically feasible for all sites.

We use automated drones to plant 'seed pods' that are designed for the environmental conditions and tree species that are specific to the sites we seed. Our seed pods are designed to provide ideal germination conditions and improve early growth of the seedlings. We achieve this with a combination of seed treatments and seed pod ingredients.

Seed pod production facility

We produce our seed pods in-house at our Mississauga facility. The process of producing and seeding our pods is almost fully automated already, with the remaining automation expected by the end of 2022. We are currently able to produce and seed 180,000 pods per day and are expecting to multiply our capacity over the next few years. Our pods can be stored at room temperature for long periods of time, so we can produce them in the off-season and seed them when required. We are continuously conducting experiments with new pod recipes and species to improve germination and early survival under adverse conditions in the field. We apply what we learn indoors to field trials first before using new recipes in commercial operations. We believe that our continued investment in improving seed pods will be the most important distinguisher for our business, and are already finding germination and establishment rates well beyond aerial seeding techniques.

Restoration focus

We are well aware that reforestation is not as simple as dropping seeds and walking away. We make sure to pick areas where we can have the most impact: sites where manual planting is not economically feasible or is too dangerous. Not having to send people or heavy equipment into the stand allows us to leave burned trees standing, which provides habitat for cavity nesters, bark foragers, and other key species as well as protection for the young seedlings. Eliminating machinery in the stand reduces erosion and compaction of the soil. In alignment with a popular expression in forest restoration, we plant the right trees in the right spots for the right reasons.

Current work

We currently focus on stands that have been impacted by intense wildfires (Figure 2), where there is little to no seed bank left and natural regeneration is expected to be insufficient. We also focus on those areas that are not suitable for salvage logging due to concerns about inaccessibility or limited remaining marketable timber. Drone reforestation has a high potential in areas that are otherwise inaccessible or not economically feasible for manual planting . We can greatly accelerate the speed of reforestation in those areas.

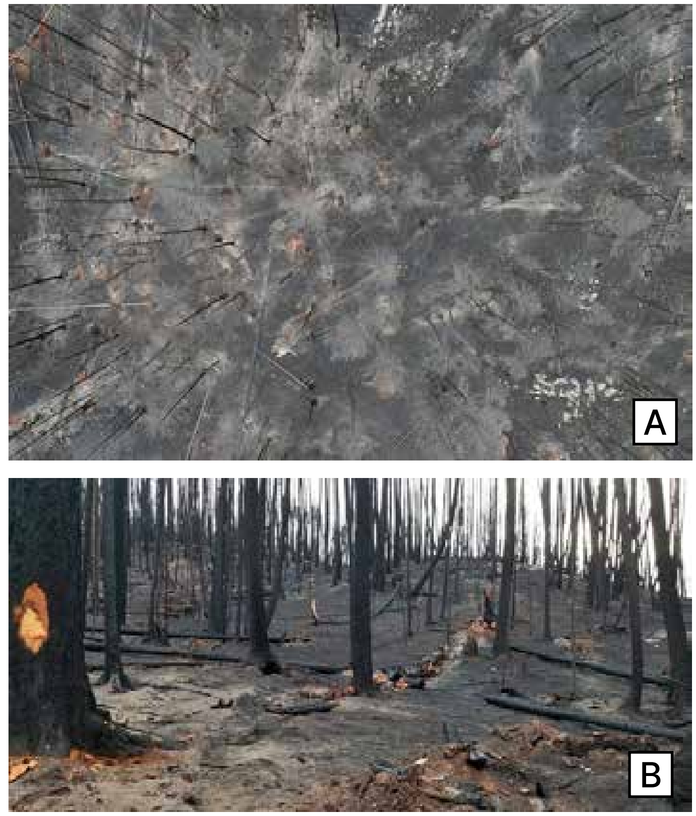

Figure 2. A typical forest stand after high-intensity wildfire in Central British Columbia, a) aerial view from the drone and, b) the operator's view.

Our technology allows us to fly above the canopy and we can eliminate the need for workers in the stand which greatly increases the safety of reforestation work in dead timber. We have to date conducted field trials on Vancouver Island, the Prince George and Williams Lake areas in British Columbia, close to Fort McMurray in Alberta, Barrie and Elk Lake areas in Ontario. For more details on our current focus of operations see Table 1. We have seen varied success based on site, species and weather conditions in the first year after deploying our pods. Despite the heat dome in Western Canada throughout 2021, it was our most successful operations yet, with our greatest successes found in Boreal and Sub-Boreal ecosystems. Our next priority is to build consistency across all sites.

We monitor the emergence and growth of our seedlings closely, partially to be able to report results to our partners and customers and partially to be able to continuously improve upon our technology. This currently means that we assess emergence in the first summer after seeding and we assess establishment of seedlings in the fall of the first few years. We also continuously improve our ability to target microsites with our seed pods to avoid seed waste by only embedding pods in microsites where the seeds have a chance to germinate. Early emergence results from 2021 are promising. In line with the literature on direct and aerial seeding, our establishment rates after the first growing season showed some mortality, but we are taking losses in the first few years into account when determining seeding densities.

As with traditional aerial seeding, much depends on a good seedbed. We are able to improve conditions with our seed pods, but good seedbed conditions at our planting sites greatly improve the success. The seedbed requirements vary significantly between species. We are learning a lot from reports of previous seeding trials but in many areas we are conducting our own research to fill gaps in the knowledge and to compare how our seed pods perform in comparison to direct seeding and manual planting.

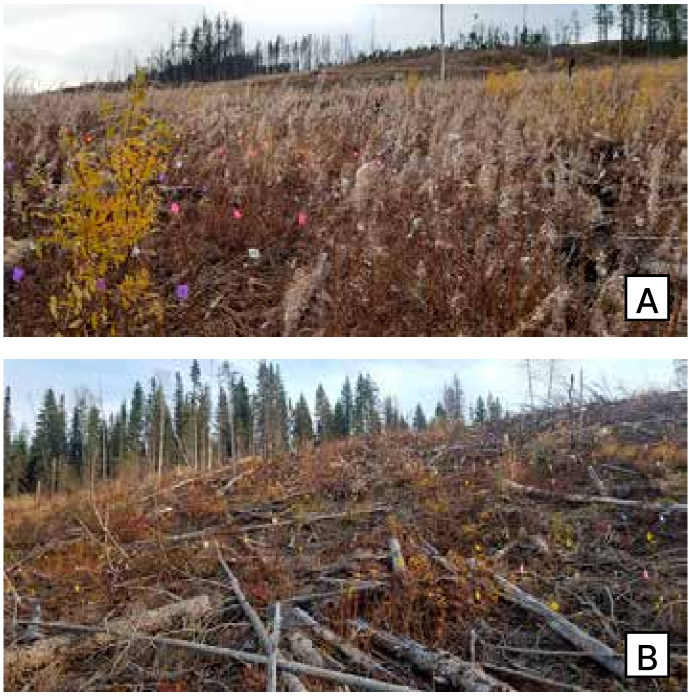

Figure 3. Field trials in British Columbia with, a) flagged seed pods at a 2-year old wildfire, and b) flagged seeds pods at a logged site.

Successes

Post-wildfire sites often provide good seedbeds, especially in boreal forests. At sites in the [Fort McMurray area that burned in the 2016 Horse River fire](), we had good success by seeding pods from above the burned canopy. We found similar positive outcomes in northern Ontario with jack pine. Protection by an open canopy of shrubs or remaining standing snags greatly helps to reduce the drought stress on young seedlings. This also highlights the potential for adding shrubs and deciduous tree species into the mix wherever they are not returning naturally.

Challenges

Maybe unsurprisingly, we have had high seed predation rates in our early trials. Predator deterrents that we have since added to the seed pods help to deter rodents and other seed predators and give our seeds the highest possible chance to germinate. Early results are promising.

Dry summers like the unprecedented heatwave in 2021 in Western Canada pose a challenge for all reforestation efforts and we felt the effects as well. We plan our operations right after the last frost date to give the seedlings as much time as possible to germinate and get established during the spring. We select seeds based on provincial guidelines which in all provinces allow for or even require considerations of assisted migration. Wherever we are able and it makes ecological sense, we select seeds from further south than our planting sites.

Not all species germinate readily and we are constantly improving our seed treatments to achieve higher and more synchronized germination. In addition to stratification, we apply and experiment with processes more commonly used in agriculture. Even the “standard” procedure of stratification allows for a lot of variation, and we are always curious to learn from experienced technicians about how to improve. Achieving good germination is a major step towards achieving good establishment.

Seed Supply Needs

We are well aware of the challenges around seed supply and we are aiming to reduce seed use greatly compared to traditional aerial seeding. By using things like predator deterrents, moisture absorbing polymers, seed treatments, targeted placement, and embedding of seed pods, we give as many seeds as possible the chance to germinate. We are working on building the seed supply needed to meet the reforestation needs determined by federal and provincial initiatives like the 2 Billion Tree campaign. This involves looking for partnerships to increase our capacity for seed harvesting. Seed shortages are already of concern for some species (Douglas-fir, red pine, alders and maples) and will only be aggravated by an increased demand for reforestation. Our goal is to increase the total available amount of tree seed and we are looking for license holders and cone collectors to collaborate with us to accomplish this (Table 1). We are also very interested in finding partners to work on seeding local shrubs and perennials. These plants usually have less established harvesting and trading supply chains and less commonly available protocols for seed germination.

Table 1. Flash Forest seed needs planning for 2022–2024.

Province	Species	Seed Procurement Zone	Seed Need per Species per Zone
BC	Fdi, Pli	SBS, IDF	10M viable
AB	Sw	CM, DM, LBH	10M viable
ON	Pj, Sb, Sw	4S, 3S, 2W	10M viable

Drone Reforestation is only the latest tool in reforestation. In addition to current manual tree planting, we are able to add to the total annual area of reforestation by operating in non-salvaged wildfire areas, steep slopes and under dead canopy where manual tree planting is not feasible. The demand for tree planting is already increasing massively and will continue to do so. We aim to help meet the growing disparity between demand and supply of reforestation services in Canada and internationally.

Please be in touch if you have any questions or potential seed availability by contacting me below or visit our website at https://flashforest.ca

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DeLeaves Drones Aiming Towards Seed Collection

DeLeaves is a Canadian company that develops and commercializes robotic drone-compatible devices to achieve physical tasks on trees and plants. Starting back in 2018, the DeLeaves tree sampling system has been developed in collaboration with forestry companies and research groups to meet safety and efficiency requirements to help speed up tree sampling operations. This unique sampling system can be suspended under a drone to collect valued samples in the upper tree canopy that may have been difficult or impossible to reach (Figure 1). The rugged design has been thoroughly tested in various environments ranging from the boreal forest to the tallest trees in the Pacific Northwestern forests, enabling the operator to remotely collect branches.

The tool has also been thoroughly tested by the National Ecological Observatory Network (NEON) during their sampling campaigns to measure foliar traits (leaf mass per area, moisture content, and chemistry) as well as to help to monitor change in foliar properties over time. This innovative tool is redefining how samples are collected, and as such, it has been integrated to their sampling procedures. The DeLeaves tree sampling system will allow the collection of tree canopy samples coming from one of their 81 field sites distributed across various environment in the United States. (https://www.neonscience.org/impact/observatory-blog/branching-out-again-remote-controlled-canopy-sampling).

More recently, the DeLeaves has been involved in pest management in Maine, USA (https://www.themainemonitor.org/cutting-edge-aerial-technology-could-help-combat-browntail-moths/). This specific application has demonstrated the potential for industrial operation, aiming to remove the largest number of nests in sensitive areas. With only one month of operations, it has reached an efficiency one nest/minute, with thousands of nests removed so far.

The DeLeaves tree sampling tool has also been used to collect tree seeds by companies and research institutes located all over the world such as Tree Breeding Australia, Scion, Weyerhaeuser, and Forestry Corporation of NSW (Australia). These entities are working with a variety of tree species such as radiata pine (*Pinus radiata*) blue gum (*Eucalyptus globus*), blackbutt (*Eucalyptus pilularis* (Figures 2 and 3)), Douglas fir (*Pseudotsuga menziesii*), and Loblolly pine (*Pinus taeda*), showing again the great versatility of this innovative tool. The tool has allowed our partners to greatly speed up their seed collection process. However, we have discovered challenges with Australian eucalypts that have much harder wood than North American hardwoods. They are testing different saws optimize cutting samples for these species.

Looking for Canadian research partners

DeLeaves is currently seeking for partners to demonstrate the potential of this technology for cones and seeds collection in Canada. There can be opportunities to adapt the technology to specific use cases, adding new features and automation such as using artificial intelligence to detect and automatically collect cones.

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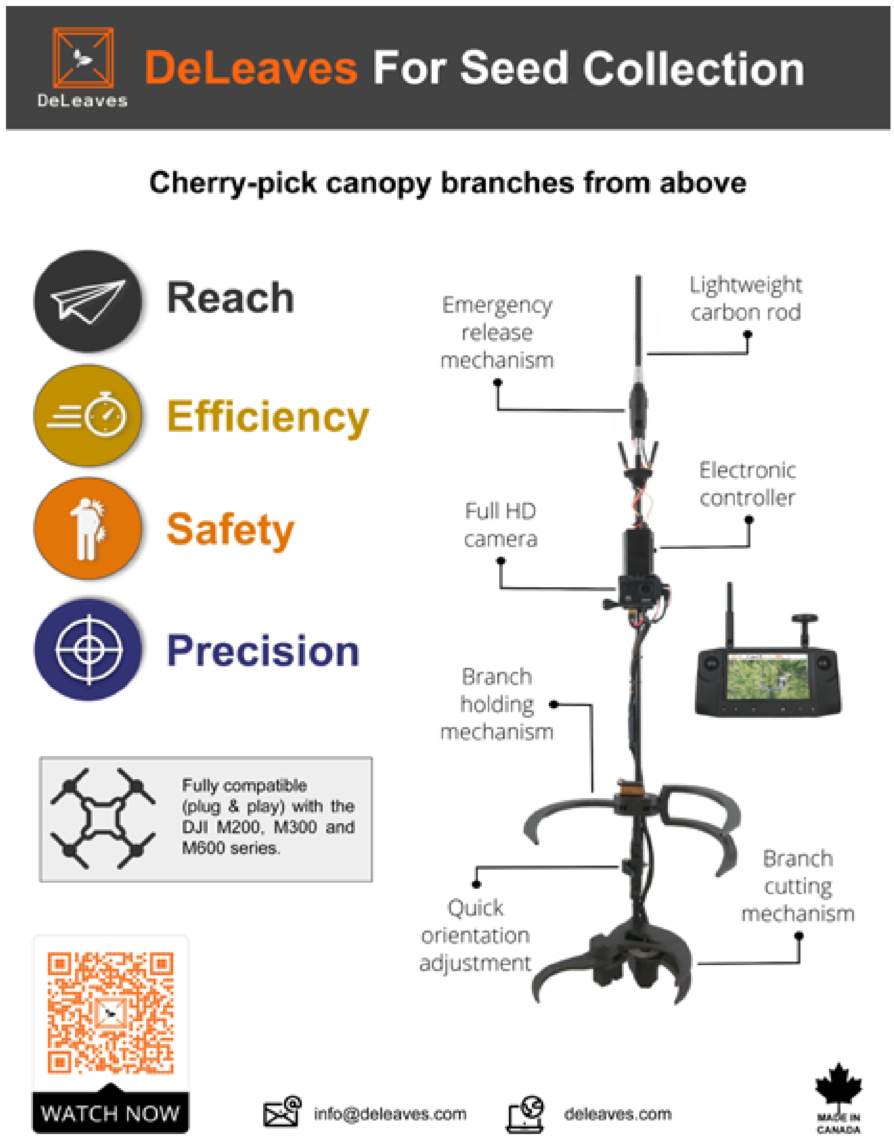
Figure 1. The sampling tool being demonstrated on Virginia pine (*Pinus virginiana*).
Figure 2. M210 flying *Eucalyptus pilularis* used for sampling trial. Credit: Mike Sutton, Forestry Corporation of NSW.
Figure 3. Seed collected with the DeLeaves during a test flight in a eucalypt seed orchard (Mike Sutton (left) and Tim Hitchins (drone pilot, right). Credit: Mike Sutton, Forestry Corporation of NSW.



Sugar maple mini-cell trials at Berthier Nursery

The Berthier Public Forest Nursery is the only public nursery that produces sugar maple seedlings (*Acer saccharum*, érable à sucre, ERS) in Quebec. These last five years, the average annual production is nearly 350,000 plants produced in containers for delivery one year later.

In our current production scenario, ERS seeds are manually sown, pregerminated after stratification. Seeds are soaked for two weeks at 3°C, then placed in trays for stratification and protected from air and light (Figure 1a–d, Bettez and Colas 2003). After three to five weeks of stratification, germination begins at 3°C and is then repeatedly estimated. When it reaches 25 to 30%, the manual sorting begins. The pregerminated seeds are then manually sown in 28–340 Styroblock containers (Figures 2 and 3) which are transferred in a tunnel where seedlings continue their development. Considering that the radicle must not exceed 10 mm, the sorting must be done regularly to avoid seed losses. This operation is excessively demanding in terms of time and work force and can last up to three weeks, depending on the seedlots and the production targets. However, this method is only possible with a very good germination rate.

ERS seeds can be very dormant, especially the first few years after harvest. The Berthier Tree Seed Centre (BTSC) adapted the ERS germination test conditions based on research by Janerette (1978, 1979) to be compatible with the current production method above. A 125 g sample of seeds is soaked for 14 days, then divided into two bundles (2 replicates) which are wrapped in Kimpak and placed in a closed tray to avoid light and air, in a cold room. Once germination begins, seeds are counted between day 7 to day 28; the germination peak is obtained after about 20 days. After each count, samples were returned to the cold room.

In order to determine if we could obtain higher germination rates, we compared different methods used to determine germination of ERS seeds:

- ISTA (2012): 3-day cold soak, 2 months stratification (1–5°C), then 21 days of germination at 20°C.
- National Tree Seed Centre (Donnie McPhee, pers. comm.): 3-day soak at 4°C, 91 days stratification (1–5°C), then 21 days of germination test at 20°C.

The obtained rates were both higher than what we were used to. It has been therefore decided to extend the duration of seed test (Figure 4). The optimal duration to maximize germination was 48 days. These tests demonstrated that it was possible to have high rates, regardless of the age of the seedlots, which allows to consider the possible mechanization of ERS seedling production.

For nearly 10 years, the Berthier nursery has also developed the production of conifer seedlings in mini cells for the germination phase. These mini cells are then transplanted into conventional containers using a robot. Producing ERS seedlings in mini-cells before transplanting them mechanically would enable to save time and increase efficiency. Our objective was to see if it was possible to produce ERS seedlings in mini cells in order to avoid manual sorting without affecting the quality of the seedlings while maximizing each seedlots' germination.

First trial (2020)

In May, after a 2-week soaking, seeds were sown in 288-10 trays (mini-cells), covered with vermiculite, and then placed directly in a tunnel. Germination was poor, at barely 50%.

During the summer, at BTSC, 14-days-soaked seeds were sown in mini cells, then left at 4°C. Counts were made twice a week to determine the germination percentage. When germination rate stabilized, the trays were transferred in a germinator where they continued their development (Figures 5 and 6). After three weeks, we obtained similar good germination rates as obtained with the prolonged test (48 days). This first confirmed that the germination phase must be done in the cold before the tunnel transfer.

Second trial (2021)

In March, 14-days-soaked seeds were sown in 105 trays 288-10 (equivalent of 14,500 potential seedlings). The trays were left at 4°C for 48 days and then transferred in a tunnel. Germination was good but some of the seedlings had to be discarded because they were growing out of the cavity due to too long roots (Figure 7). Transplanting was done by hand since the robot we had at this moment did not enable automatic transplanting without breaking the seedlings. The seedling release rate (percentage of compliant seedlings with the production target) was similar for seedlings from mini-cells or from regular production. This result was disappointing since we hoped to improve it. The tests were

Figure 1. Preparation of the trays for cold stratification. Alternative layers of aluminium foil, (a) wet Kimpak, (b) mosquito net, (c) seeds, and wet Kimpak are settled in the trays. (d) Final layer is a plywood sheet maintained by blocks.

Figure 2. Pregerminated seed.

Figure 3. Manual seeding in 28-340 Styroblock.

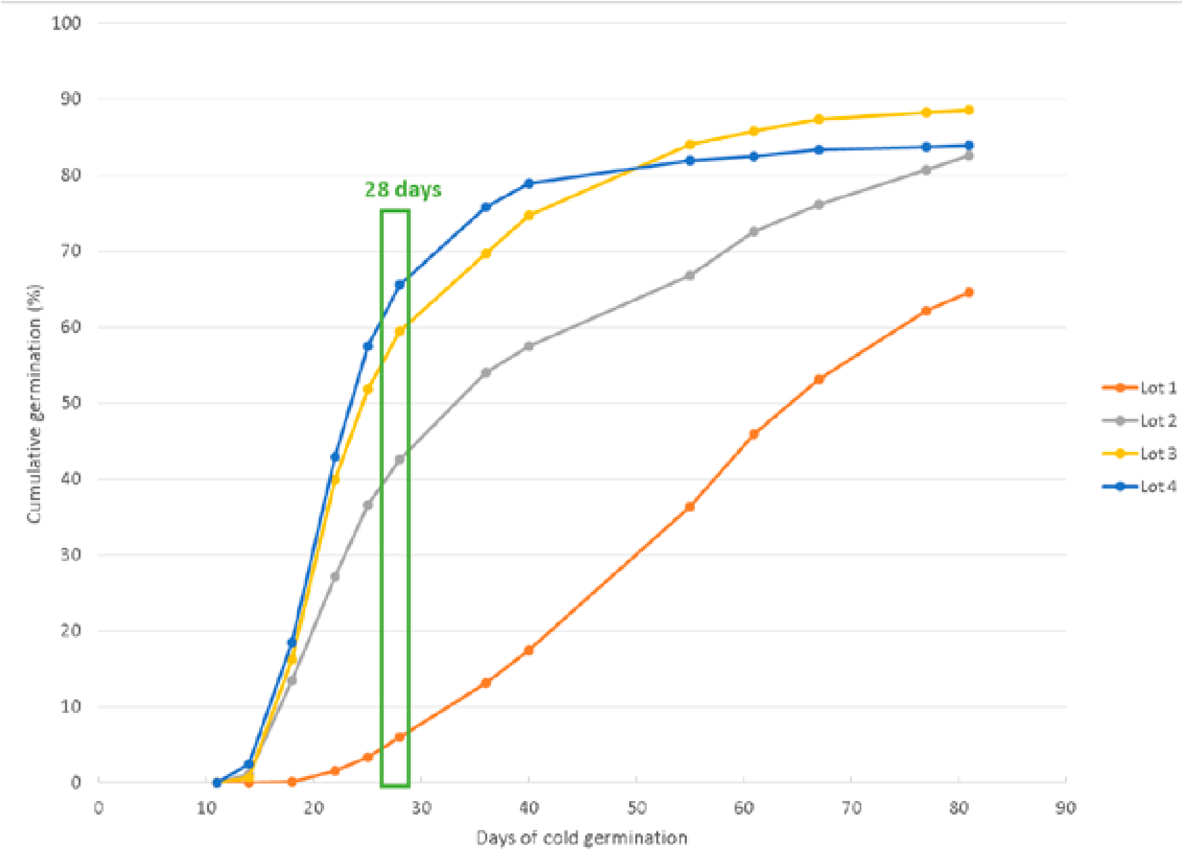


Figure 4. Cumulative germination curves for four seedlots at 4°C.

Figure 5. Mini cells in the germination cabinet (20°C for 8 hours and 10°C for 16 hours).

Figure 6. Seedlings after three weeks in the germination cabinet.

Figure 7. Seedlings that will be discarded due to too long roots.

Figure 8. Berthier's new Visser transplanting machine.

continued during the summer at the BTSC by adding a mosquito net on the trays to avoid the de-anchoring of the seedlings due to too long root. This was effective.

Third trial (2022)

We are still working on the deployment of this production on a larger scale this year (565 trays), equivalent to 62,200 seedlings). The Berthier nursery now has a new transplanting robot (Visser Horti Systems Pic-O-Mat Redline model, Figure 8), which should be able to transplant ERS seedlings without breaking them. It can indeed catch the seedlings from the side, instead by the top which avoids breaking the leaves.

We are optimistic we can succeed, and we have to, since like many nurseries, we face a big problem with worker recruitment for the season. Mechanization is the key to maintain our production targets.

Acknowledgements

Sylvie Carles (DGPSPF, MFFP) for her helpful comments.

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A New Seed Pest in Maple?

There is a potential new maple seed pest of note in Eastern Canada. In January 2021, Dave Kolotelo circulated an X-ray image from Katri Himanen from Natural Resources Institute Finland (Luke) (Figure 1a). In an intra situ gene reserve stand (established outside the natural distribution) of Norway Maple (*Acer platanoides*), Luke had noted approximately 1 to 2% seeds infested with an unknown larvae. Without any comparable samples, initial Canadian expert guesses were possibly a chalcid (*Megastigmus* spp.) or gall midge (family Cecidomyiidae) larvae.

Sugar maple (*Acer saccharum*) is one of the National Tree Seed Centre's most in-demand research species and it was on our 2021 target list to boost sampling coverage and quantity. It was a relatively good crop year for sugar maple from New Brunswick through to Ontario and we kept Luke's X-ray image in mind while forecasting wild stands. A number of nurseries Melissa visited in Southern Ontario in September and October had never seen maple seed insect damage but we found similar looking larvae in multiple lots. The highest estimate was approximately 30% of samara pairs infested in Peterborough area field cut testing samples. A few weeks prior to typical maturity, there was no exterior signs except uneven ripening in the clusters (Figure 2). Frass was obvious when cut and the larvae often tunneled into the second typically-aborted samara cavity (Figure 3). The larvae were 1 to 2 cm long when uncurled and exposed (Figure 4). Putting seeds in the NTSC cooler (1–5°C) stimulated larvae to exit the seed to pupate as we do with ash curculio weevil. Nevertheless, some larvae remained inside after dewinging and were stored as they could not be aspirated or picked from the lot. Though not evaluated for damage percentage in the field, there were several seedlots with exit holes from southern New Brunswick after processing.

Several pupae were provided to a new lab technician working with Martin Williams to initiate PCR analysis in November 2021. Upon obtaining a new digital X-ray at the NTSC February 2022, staff examined a number of 2021 stored seedlots that had evidence of exit holes. Many seeds still contained larvae, now dead at –20°C. (Figure 1b).

In follow-up emails Fall 2021, Luke suggested their preliminary PCR results pointed to scarce maple piercer (*Cydia inquinatana*). This species is deemed rare and restricted to continental Europe except the southern Balkan and Iberian peninsulas. A historical reference to "Lepidoptera of Belgium" (1799) noted the rarity then but also found larvae feeding on seeds of hedge maple (*Acer campestre*) and sycamore maple (*Acer pseudoplatanus*). Entomologists have recently discovered it in Great Britain, where it seems to be breeding beyond its historical range (Higgot and Harvey 2010).

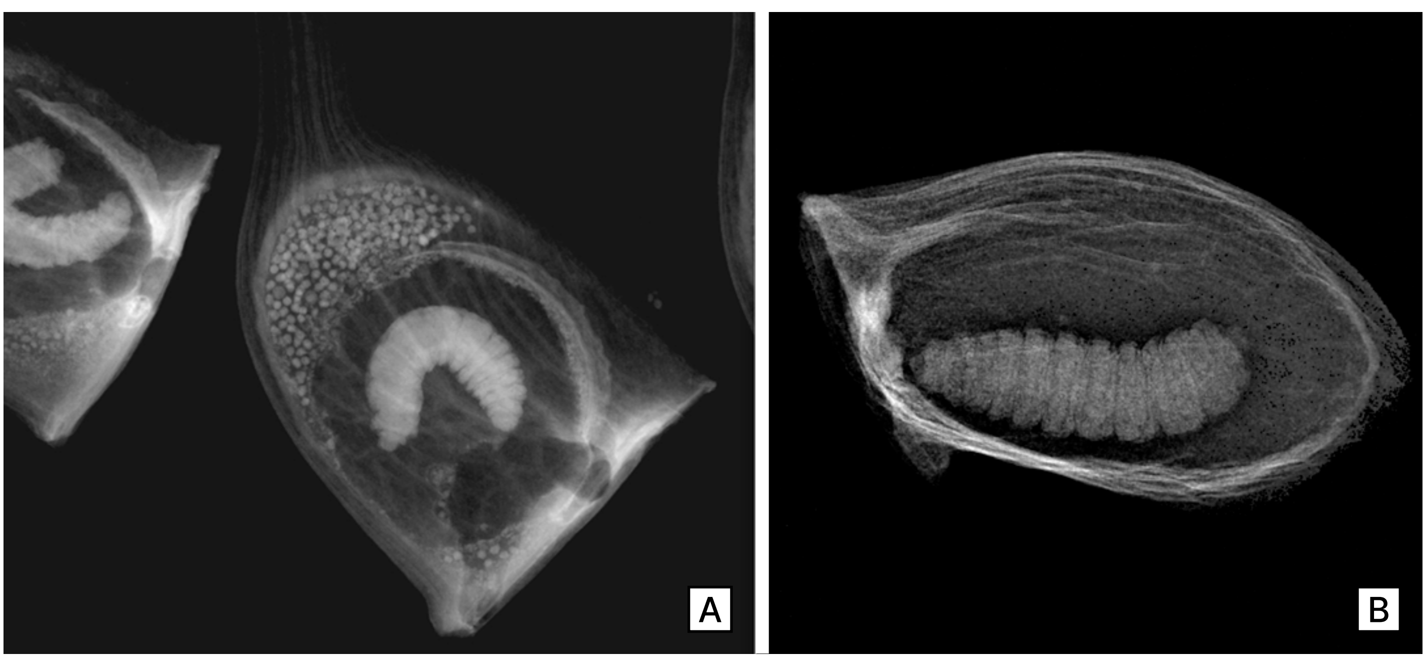

Figure 1. Comparative radiographic images of seed pests in maple (*Acer* spp). a) in Norway maple, January 2021 courtesy of Luke, Finland, b) in sugar maple from Ontario (seedlot 202130375.0), February 2022, National Tree Seed Centre.

Figure 2. Early and uneven ripening in sugar maple due to the suspected insect larvae, Cavan, Ontario, September 29, 2021.

Figure 3. Unidentified larvae preparing to pupate in the empty pair of the samaras, Cavan, Ontario, September 29, 2021.

Figure 4. Larvae showing a more distinctive head and thoracic legs than *Megastigmus* or Cecidomyiidae larvae.

For Canada's native maples, it is unclear if this insect is one of many native North American codling moths (*Cydia* spp.) or if it is a potentially introduced species through international seed trade (Cleary et al. 2019). The latter would be worrisome but perhaps not surprising given the long history of horticultural production of Norway, hedge and sycamore maple in Canada.

Nurseries and seed collectors who have seen this pest or have infestations in new Canadian maple collections are invited to submit a sample to the National Tree Seed Centre for X-ray analysis and future research (minimum 500 seeds). Entomologists who can confirm or narrow down the identification are most welcome to reach out to us as well.

Acknowledgements

Thank you to Katri Himanen for sharing the original X-ray images to put us on alert and compare.

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Biochar and tree seeds: a good combination?

Biochar—the contemporary term for charcoal designed for and used as a soil amendment—has received enormous research attention in recent years, particularly in agriculture and materials science, and as a means to enhance ecosystem carbon sequestration. In ecosystems with a natural fire regime, trees germinate and establish in soils strongly affected by fire residues, including wood ash and charcoal. One might thus expect that fire-adapted tree species, which include many boreal and north-temperate trees, would show adaptations that allow seeds and seedlings to thrive in the presence of fire residues. However, many questions arise. Is there empirical evidence that biochars benefit seedlings? What mechanisms are involved? Do different types of biochar vary in their effects? What are the prospects for biochar use in large-scale seedling production?

Tree responses to biochar additions

There is now a large literature on biochar effects on plant growth generally, with an emphasis on agricultural applications. Comprehensive meta-analyses published in agriculture have found a pooled mean biomass growth enhancement of ~15% (Schmidt et al. 2021). Growth responses in trees appear to be generally higher: in a 2015 review, we found an average 41% increase in biomass in tree biomass in biochar treatments relative to controls, though with notably high variation in responses among tree species (Thomas and Gale 2015). A likely explanation for this higher growth response in trees is that forest soils are generally poorer than agricultural soils (lower nutrient status, more acidic) and thus more likely to benefit from any soil amendment. In addition, hardwood trees generally showed larger growth responses than conifers, and higher responses were observed in pot trials compared to field trials (Thomas and Gale 2015).

These generalizations have mostly been confirmed in recent studies. In particular, conifer seedling trials have commonly found minimal or even negative growth responses to biochar additions (e.g., Sarauer and Coleman 2018; Sarauer et al. 2019; Bieser and Thomas 2019); in contrast, positive growth responses have generally been found in trials with hardwood seedlings (e.g., Pluchon et al. 2014; Noyce et al. 2017; Aung et al. 2018). However, large positive growth responses of some conifers to natural post-fire residues have also been documented (Gale and Thomas 2021).

Variability in biochars

Biochar properties can vary immensely depending on feedstock, production methods, and post-production processing. Unless produced at extremely high temperatures, biochars retain most elements inherited from feedstock material; wood-derived biochars are typically high in K, with variable quantities of P, Ca, Mg, and other ions important in plant physiological processes (Gezahegn et al. 2019). Both feedstock chemistry and biochar production characteristics (in particular pyrolysis temperature) strongly affect pH. While most biochars are moderately to strongly alkaline (pH 8–9), this also varies considerably; charcoals that have aged in-situ for decades can be strongly acidic (Thomas 2021b). In addition to mineral nutrients, biochars will generally concentrate elements of toxicity concern from feedstocks, and phytotoxic organic compounds can also be generated by the pyrolysis process. There are thus a variety of standards (both legal and voluntary) that govern biochar production, sale, and utilization (Meyer et al. 2017). In Canada, biochar offered for sale as a soil amendment is regulated by the Canadian Food and Inspection Agency under the *Fertilizers Act* and must meet certain product standards.

Biochar and seedling development

Seedlings in the strict sense (i.e., that depend on seed reserves for development) are expected to show responses to the soil environment distinct from those of established plants. Seed germination and radicle extension are particularly sensitive to chemicals that degrade the seed coat and also to ions in the soil solution; specific hormonal effects can also trigger germination and affect early seedling development. Developing seedlings are susceptible to toxic compounds, and freshly produced biochars can retain a wide range of organic molecules produced during pyrolysis, some of which are phytotoxic.

Recent germination studies on agricultural seeds have found that leachates from slow-pyrolysis biochars strongly stimulate radicle extension growth, while leachates from fast-pyrolysis biochars are inhibitory (Figure 1, Gezahegn et al. 2021). Early in the pyrolysis process hemi-cellulose in wood mostly produces “wood vinegar”, which contains mostly volatile fatty acids (VFAs): carboxylic acids of six

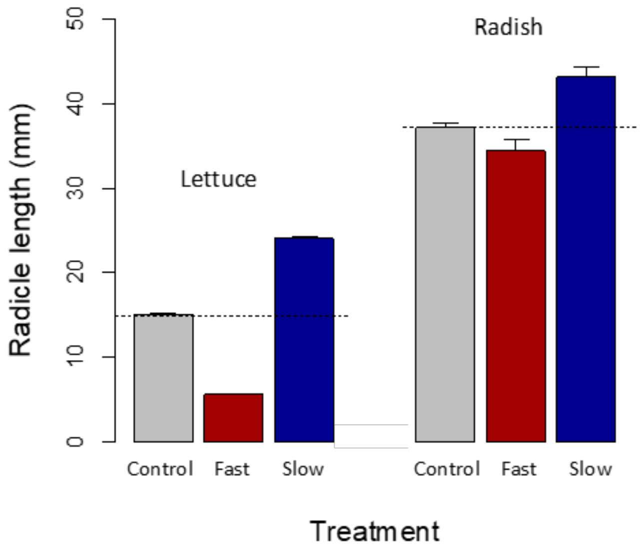

Figure 1. Evidence for positive effects of slow-pyrolysis biochars, and negative effects of fast-pyrolysis biochars on early seedling development. Radicle extension in lettuce and radish seeds is plotted by treatment with data pooled from trials with 100 slow pyrolysis and 10 fast pyrolysis biochars. Means are plotted ±1 SE. (Figure modified from Gezahegn et al. 2021).

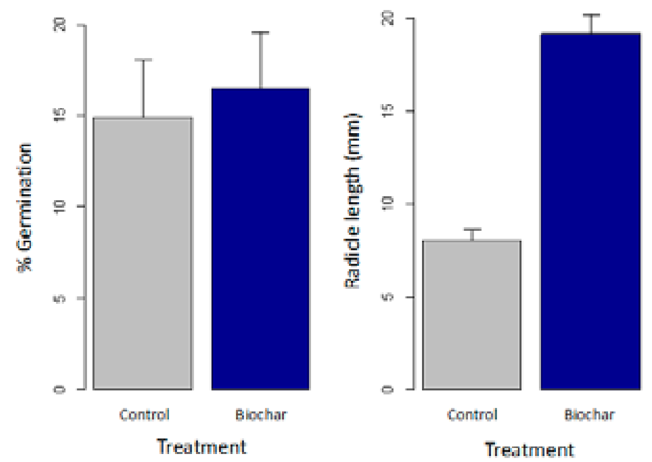

Figure 2. Species-pooled responses of (a) seed germination and (b) radicle extension to biochar addition in field trial involving 14 temperate tree species in central Ontario (Figure modified from Thomas 2021a).

carbons or fewer such as acetic and propionic acid. In fast pyrolysis, these molecules don't have time to escape from the porous char matrix. Although there are other potentially phytotoxic organic molecules in some biochars (including polycyclic aromatic hydrocarbons), VFAs are perhaps the most common "problem molecules" present in biochar (Gale et al. 2016; Gezahegn et al. 2021). However, VFAs can be reduced by heat treatments and aeration, and are also readily consumed by soil microbes; thus, biochar post-processing may overcome this problem (Thomas 2021b). Hydrochars produced by hydrothermal carbonization processes have similar phytotoxicity issues as fast-pyrolysis biochars, but these also can potentially be alleviated by post-processing (Hitzl et al. 2018).

Biochar and seed germination

Available data on germination responses of tree seeds suggest that biochar generally has relatively little average effect on germination success, but strongly enhances germinant development as quantified by radicle elongation (Figure 2). As with biochar effects on plant growth at later stages there is high variation in responses among species; however, the median response is >100% and a number of species show >500% increases in germination index values (Table 1). While very promising, published studies to date examining biochar effects on germination and early seedling development have not been conducted specifically in the context of nursery production.

Mechanisms for effects on seedlings

Biochar has multiple properties that can potentially strongly influence seed germination and seedling development; while these multiple benefits are a plus, this also complicates research aimed at elucidating mechanisms (Joseph et al. 2020). Biochar will commonly increase pH of the growth medium, and supply ions that are utilized osmotically during early seedling development. Due to their high porosity and surface area, biochars generally have a high water-holding capacity that is expected to keep growing media moist during seedling development. In addition, biochar applications to growth media reduce bulk density and vulnerability to compaction.

In some cases, organic molecules sorbed by biochars during pyrolysis may play a hormone-like ("hormetic") role in triggering germination. Biochars have specifically been found to contain karrikins (Kochanek et al. 2016), a group of heterocyclic organic compounds produced during incomplete combustion that can act to stimulate germination, particularly in fire-adapted species.

Table 1. Biochar addition effects on tree seed germination, quantified in terms of the relative effect on germination index (% germination x radicle length).

Type / Test	Scientific Name	Common Name	% Change in Germination Index	Reference
Conifers				
Field	*Abies balsamea*	balsam fir	-22%	Thomas (2021a)
Field	*Picea mariana*	black spruce	+83%	Thomas (2021a)
Field	*Pinus resinosa*	red pine	+145%	Thomas (2021a)
Field	*Pinus strobus*	white pine	+41%	Thomas (2021a)
Hardwoods				
Lab	*Acacia gerrardii*	grey-haired acacia	-2–3%	Alshahrani and Suansa (2020)
Lab	*Acacia ampliceps*	salt wattle	+3–6%	Alshahrani and Suansa (2020)
Field	*Acer pensylvanicum*	striped maple	+>500%	Thomas (2021a)
Field	*Acer saccharum*	sugar maple	+258%	Thomas (2021a)
Field	*Betula alleghaniensis*	yellow birch	+5%	Thomas (2021a)
Field	*Betula cordifolia*	mountain paper birch	-93%	Thomas (2021a)
Field	*Betula papyrifera*	paper birch	+301%	Thomas (2021a)
Field	*Fraxinus americana*	white ash	+>500%	Thomas (2021a)
Lab	*Lagerstroemia speciosa*	giant crepe myrtle	+86–191%	Gogoi et al. (2020)
Field	*Ostrya virginiana*	ironwood	+>500%	Thomas (2021a)
Field	*Prunus virginiana*	chokecherry	+125%	Thomas (2021a)
Lab	*Trewia nudiflora*	pitalu	+20–238%	Gogoi et al. (2020)
Field	*Ulmus americana*	American elm	+471%	Thomas (2021a)

Biochar and "problem soils": salt, toxic metals, and allelochemicals

Due to their high surface area and presence of negative surface charges, biochars sorb a wide variety of chemicals in the soil solution; this has motivated interest in use of biochars in treatment of contaminated substrates and wastewater (Xiang et al. 2020). Tree seed germination in-situ may commonly be impacted by saline soil conditions or presence of toxic metals; these challenges are particularly common in urban soils and in the context of restoration. Biochars have recently been founds to sorb and reduce the bioavailability of allelochemical compounds as well (Sujeeun and Thomas 2017; Alshahrani and Suansa 2020), including compounds produced by common invasive species in Canada such as garlic mustard (*Alliaria petiolata*) and yellow sweet clover (*Melilotus officinalis*) (Bieser et al. 2022). In some cases, additions of biochar can result in "rescue effects" where complete inhibition of seed development is overcome. Biochars have similarly been found to sorb and reduce bioavailability of soil-persistent herbicides and pesticides (Kookana 2010).

Prospects for applied biochar use with tree seed and nursery production

One potentially important "niche" for biochar use is as a substitute for peat and/or vermiculite in germination bedding in production nurseries and similar applications. While one recent study found negative effects of biochar on containerized Douglas-fir seedlings (Sarauer and Coleman 2018), positive effects have also been obtained in European containerized stock trials (Köster et al. 2021) and in cutting propagation trials of hardwoods (Fornes and Belda 2019). Root growth is often a principal goal in nursery production, and a recent meta-analysis indicates particularly large positive effects of biochar amendments on roots, with the largest increases observed in trees among plant growth forms (Zou et al. 2021).

Take-home points for practitioners

Biochar remains a very active research topic; this short review gives only highlights of recent work relevant from a tree seed perspective. Nevertheless, some general guidelines for biochar use can be provided based on the current literature.

- Biochar properties vary greatly; thus, pre-screening to find the right biochar for the right application is important. Fast-pyrolysis biochars and hydrochars should generally be avoided.
- Biochar has promise as a replacement for non-sustainable materials (peat, vermiculite) in tree nursery culture, but results are somewhat mixed.
- One can generally anticipate better responses to biochar among hardwoods than conifers.
- Biochar should specifically be considered as a means to enhance early seedling performance on "problem soils", such as saline soils or those impacted by heavy metals, persistent herbicides, or allelopathic species.

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2021 Wins and Challenges

Orchard Establishment

SelectSeed Co. Ltd., which is owned by the Forest Genetics Council of BC., continued establishment of its new lodgepole pine seed orchard near Quesnel during the COVID-19 pandemic unimpeded—almost. Vole damage occurred under the snow and above the root-collar protectors last winter. Khowutzun Freegro TreeShelters, made in Duncan BC, were purchased and installed to protect the trees this summer for the upcoming Winter. The shelters consist of a 24" nylon netting tube, two metal rings and a wooden stake. The BC Ministry of Forests will supply the balance of grafts to complete this 5000-ramet orchard in Spring 2022.

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How many "pine cones" to grow a tree?

The interesting the thing about the cones is, while working with MNR, curious, uninformed peoples would often ask "How many pine cones do we need to collect to grow a tree?" Everything to them was a pine cone no matter the species. My photo is a visual cue for the original question (cheeky answer is 2 Norway spruce cones for every pine tree).

So why the egg? It was also placed in the same warm spot as the Norway cones, to see if anything would emerge from it, after being found on the ground from the nest above. Just a interesting life test! Does this get anyone thinking about how we communicate to the outside world how the experts hatch, handle and grow the good eggs?

Kim Creasey
Sharon, Ontario
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Photo 1. SelectSeed Board of Directors and Staff (left to right): Rod Willis, Dr. Sally John, Jack Woods, Kerry McGourlick, Jim Burbee, Hilary Graham and Brian Barber. Photo 2. Khowutzun Freegro TreeShelter on a grafted lodgepole pine parent tree supplied by the BC Ministry of Forests. Photo 3: What will hatch first, the "pine cones" or the egg?

Whitebark pine cones, wildfires, and heat domes

The Whitebark Pine Ecosystem Foundation of Canada received a 3-year grant for a gene conservation project in the Willmore Wilderness, a remote protected area north of Jasper National Park. We also secured a special limited exemption in our permit from Alberta Parks waiving the helicopter access restrictions for a couple of days a year during the cone collecting window. In the permitted collection region, whitebark pines are accessible only by helicopter: there are no trails and major river crossings are required.

We were lucky to find a helicopter that wasn't fighting fires. We first surveyed stands for cone crops, because whitebark pine cones must be caged with protective mesh to deter predation, and then collected in fall when ripe. Circumstances conspired against us: it was a poor cone year, the heat dome challenged the loaded helicopter at high elevation with a crew of five plus field gear, and thick wildfire smoke meant we had to travel up and down valleys to access sites instead of flying directly up and over, which took much longer and added significantly to trip costs. We had to abort this mission and re-try.

Determined to succeed, we found an available heli and lined up the field crew for a trip a couple of weeks later. Astoundingly, most of the cones on the couple of stands with collectible cones in the permitted area had already been predated by Clark's nutcracker, six weeks earlier than usual. This heavy pressure was likely because of the poor cone crop, lack of nearby Douglas-fir seed (their main alternate food in the region), and extensive dead whitebark pine stands from prior mountain pine beetle outbreaks and wildfires. We had to work fast to make up for lost time and to beat those nutcrackers, which were everywhere! We caged trees in two stands and were able to collect from them in late September. In total, we got about 0.9 kg of seed, and will be comparing viability with cone crop abundance across areas for the next two years. Due to the remote access, small seed crop and extra trip, these might be the most expensive whitebark pine seeds ever collected. Here's hoping for better crops and access in the future.

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Challenge #1. Predated whitebark pine cone: no seeds left!

Challenge #2. Caging cones in Willmore during the smoky summer of 2021.

Climate Change and Pollen Phenology

Editor's Note: Steve D'eon has been taking to Facebook to educate his personal followers about trees, seed, climate change and other pressing forest issues. Reproduced with permission from Steve D'eon, Facebook photos and dataset.

One of the more interesting long-term projects I have been involved in is when our native conifers flower in the spring. You know, that annoying dump of pollen.

The project was started by the genetics and tree breeding team at PNFI in the 1950s and continued by Peter Copis of the PRF. I and others continued it after Peter retired.

Peter taught us to consistently judge peak pollen release dates from local wild native species. Wild is important as planted trees may have a different genetic makeup than native wild trees. Native wild trees should be adapted to local conditions.

So what climate change trends are observed? The expected trend would be warmer springs = earlier flowering. Some species also have photoperiod controls added to degree days so hold off until the days are long as well as warm enough = no or slight change. The theory being flower too early and frost can get you. Flower too late and you shorten the season to go from flower to a ripe cone. Remember these conifers have been at this for 180 million years so they know how to have sex.

I kind of failed keeping white spruce going as there isn't a convenient wild population close to my house. But you can see up to 2008 white spruce (Figure 1, blue, Sw) trend was one to two weeks earlier (the Y axis is number of days since Jan. 1st: lower numbers mean earlier flowering). Red pine (Pr, green) a bit earlier. Jack pine (red, Pj) lots of variability but trend is no change. 1998 (a big El Nino year) the earliest year, 2019 a recent late spring year.

Yesterday (May 14, 2022) the Pj male flowers were still green and hard, so a few more warm days before they start to ripen. Pr male flowers start to emerge as the shoots elongate. Female

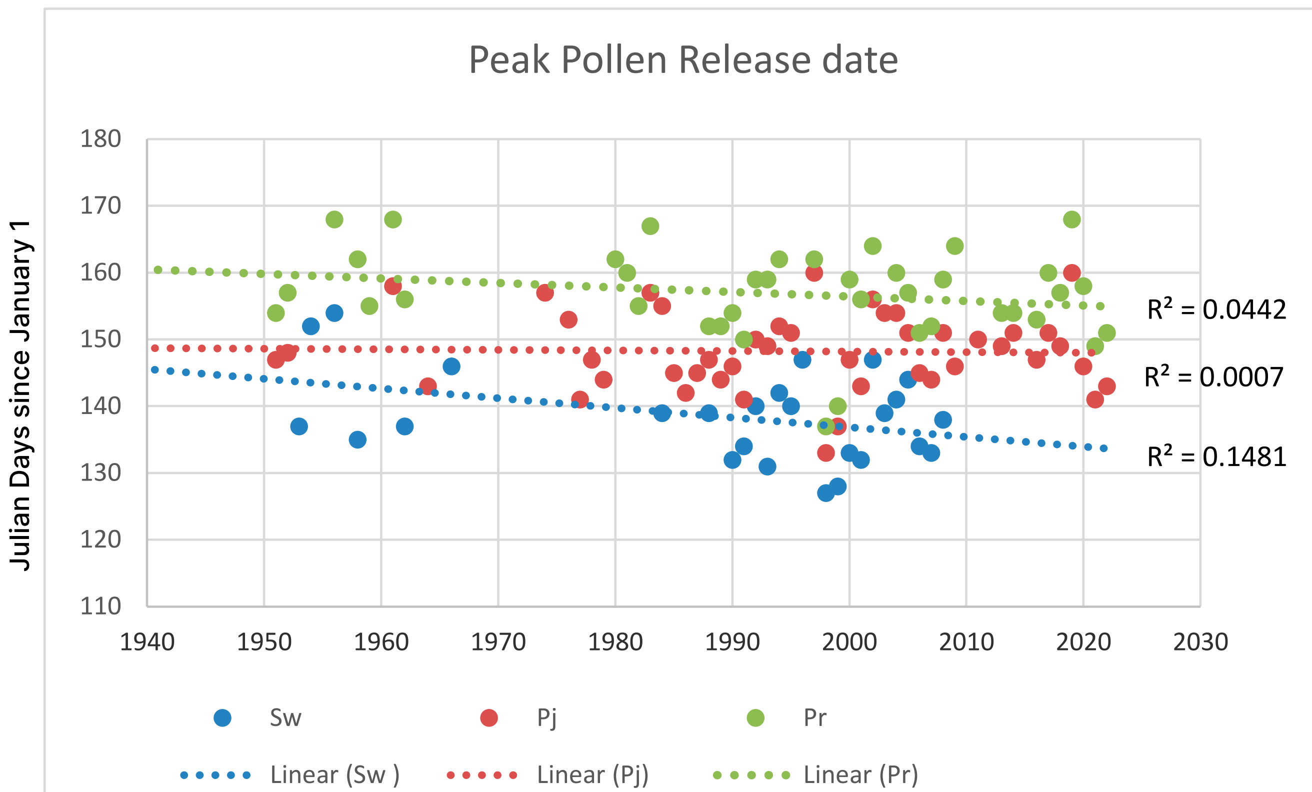

Figure 1. Tracking of peak pollen release in wild stands for white spruce (*Picea glauca*, Sw), jack pine (*Pinus banksiana*, Pj) and red pine (*Pinus resinosa*, Pr) from 1951–2022.

Figure 2. Jack pine female strobili (flowers) not yet emerged in Deep River, May 14, 2022.

Figure 3. Female strobili from the same tree, May 20, 2022.

flowers are quite small and show at the tips of elongated shoots so none visible yet (Figure 2). These female flowers will form cones for 2023 (Figure 3).

What's this all mean? Our native flora and fauna have ingrained mechanisms to stay in sync with the climate they know. These mechanisms might prove right or wrong in them surviving and thriving in the climate we are creating.

Either way long-term studies are cool. Trees are cool.

Steve D'eon
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Challenges to Tree Seed Supply: Speaker Program

We encourage those who still can to join us in-person. However, we are now able to make Zoom connectively available for these two sessions. Costs to support the program will be $30 each session plus Eventbrite fees.

Thursday June 23, 2022, from the Mary Winspear Centre, Sidney BC

8:30 AM: Dave Kolotelo

- Welcome/ Building Relationships / Roundtable Introductions
- Name / Affiliation/ Country
- Tree Seed interests
- What do you want to get out of this meeting?

9:00 AM: Øyvind Meland Edvardsen
Introduction to the ISF Tree and Shrub Group

9:10 AM: Dr. Steve Jones
International Seed Testing Association Overview (video)

9:20 AM: Dave Kolotelo
TSWG / IUFRO 2.09.03 / ISTA FTS Overview

9:30 AM: Brian Barber
Tree seed production and use in British Columbia: past, present and future

9:45 AM: Melissa Spearing
OECD Forest Seed and Plant Scheme in Canada: 2020-2022 Updates

10:00 AM: Break

10:30 AM: Dr. Greg O'Neill
DIY Climate Based Seed Transfer

10:50 AM: Sabina Donnelly
BC Seed Planning Tools Overview

11:10 AM: Dave Kolotelo
Reproductive Biology – Why is it important??

11:20 AM: Dr. Michael Stoehr
Seed Production Efficiency Practices

11:35 AM: Dr. Hayley Tumas
The potential for molecular tools in seed provenance identification

11:50 AM: Dr. Nicolas Feau
Demonstration of the field PCR tool for seed pathogen detection

12:00 Noon: Lunch, included in in-person ticket.

Monday June 27, 2022, from the BC Tree Seed Centre, Surrey BC

8:30 AM: Dave Kolotelo
Welcome/ Recap / Exchanging information

8:45 AM: Dr. Marilyn Cherry
Evolution of Seed Extraction Practices

9:00 AM: Fabienne Colas
Challenges with Processing, Storage and pre-treatment of recalcitrant tree species

9:15 AM: Cone and Seed Processing Panel Q & A

- Jeff deGraan, WA State Reforestation Specialist
- Johanna Gårdebrink, Svenska Skogsplantor
- Don Pigott, owner Yellow Point Propagation Ltd.
- Michael Postma, Manager BC Tree Seed Centre

10:15 AM: Break

10:45 AM: Dr. Marcela Vanloo
Supply of forest reproductive material in Austria

11:00 AM: Don Pigott
A brief history of cone and seed processing and looking to the future in BC.?

11:15 AM: Dave Kolotelo
Continuous Improvement: beyond the buzzwords

11:30 AM: Nabil Khadduri
Where the rubber hits the road: using greenhouse germination data to create a feedback loop with lab testing

11:45 AM: Dr. Richard Hamelin
PCR detection of tree seed pathogens (video)

12:00 Noon: Lunch, included in in-person ticket.

1:00 PM: Equipment Demonstrations

- Field PCR tool for pathogen detection
- Drone seeding – static demonstration
- Fandrich harvester or rake possibility
- Water activity

Register at: https://www.eventbrite.com/cc/challenges-to-our-future-tree-seed-supply-2022-287309

Any questions about the program can be directed to Dave Kolotelo
Email: Dave.Kolotelo@gov.bc.ca

Training & Meetings

BC Seed Orchard Association 2022
June 28–29, 2022, in-person and virtual options
June 30, 2022, CFGA/WFGA field day
Vernon, British Columbia, Canada
https://pheedloop.com/BCSOA/site/home/

2022 Joint Annual Meeting: Southern And Northeastern Forest Nursery Associations
July 18–21, 2022, in-person and virtual streaming
Charleston, South Carolina, USA
https://westernforestry.org/upcoming-conferences/2022-joint-annual-meeting-southern-and-northeastern-forest-nursery-associations

Northern Forest Genetics Association Meeting
August 18–19, 2022, in-person
Delaware, Ohio, USA, USFS Northern Research Station
The agenda will consist of state updates and volunteer presentations – please let me know if you have a topic you'd like to present. I will try to accommodate remote attendees via Microsoft Teams for the indoor sessions. We plan to tour the laboratory, where ash and elm resistance work is taking place, and visit a few nearby field sites. No registration fee will be charged but we'll set a meal fee to cover cost of lunches.
Contact Carrie Pike: carolyn.c.pike@usda.gov

Seed Ecology VII
September 6–9, 2022, in-person
Gijón/Xixón, Asturias, Spain
Registration closes June 30, 2022
https://www.unioviedo.es/seedecol7/

ISTA Workshop on Seed Sampling & Quality Assurance in Sampling
September 5–8, 2022
Bursa, Turkey
https://www.seedtest.org/en/workshops-and-webinars/ista-workshop-on-seed-sampling-quality-assurance-in-sampling-product-10020.html

The Reforestation Pipeline in the Western United States
September 27–29, 2022
Missoula, Montana
More information coming: https://rngr.net/resources/events/the-reforestation-pipeline-in-the-western-united-states

The Forest Nursery Association of BC 2022 Conference & Annual General Meeting
September 27–29, 2022, in-person
Prince George, British Columbia, Canada
More information coming: https://www.fnabc.com/upcoming-events

ISTA Seed Symposium 2022
November 2–4, 2022
Athens, Greece
In all sessions we welcome papers on established and novel seed testing methods, and on tropical and temperate crop species, wild species, flowers, trees and shrubs, including species with potential for use in plant breeding and in habitat regeneration.
https://www.seedtest.org/en/annual-events/seed-symposium-2022-product-10012.html

Recent Publications

Books

Baskin, C.C., and Baskin, J.M. 2022. Plant regeneration from seeds : a global warming perspective. In 1st edition. Academic Press. 346 pp.

Plant Regeneration from Seeds: A Global Warming Perspective comprehensively reviews the effects caused by climate change on global plant regeneration, growth and seed germination. Initial chapters discuss specific geographical regions such as steppes, the Arctic, boreal and alpine zones, dry and tropical forests and deserts. Subsequent chapters explore special seed-related topics like fire, soil seed banks, crops, weed emergence, and invasive species Written by leaders in the field of seed germination and plant growth, this is an essential read for researchers and academics interested in plant growth, plant regeneration, seed germination and the effects of these in relation to climate change.

Peer-reviewed publications

Ali, A., Zhang, J., Zhou, M., Chen, T., Shah, L., Rehman, S.U., Hayat, S., Shi, J., and Chen, J. 2021. Chitosan Oligosaccharides Stimulate the Efficacy of Somatic Embryogenesis in Different Genotypes of the *Liriodendron* Hybrid. Forests 12(5): 557. Multidisciplinary Digital Publishing Institute. doi:10.3390/f12050557.

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