16th International Christmas Tree Research and Extension Conference

August 11-16, 2024

Kerteminde, Denmark

Proceedings

UNIVERSITY OF COPENHAGEN

IUFRO

COMMITTEE

Professor Dr. **Bert Cregg**, Michigan State University, USA

Chloé Gendre, Club agroenvironnemental de l'Estrie, Canada

Senior Researcher Dr. **Inger Sundheim Fløistad**, The Norwegian Institute of Bioeconomy Research (NIBIO), Norway

Associate Professor Dr. **Jing Xu**, University of Copenhagen, Denmark

Assistant Professor Dr. **Justin Whitehill**, NC State University, USA

Associate Professor Dr. **Ole Kim Hansen**, University of Copenhagen, Denmark

Senior Researcher Dr. **Ulrik Braüner Nielsen,** University of Copenhagen, Denmark

Program

Sunday 11 August	
16:30-18:00	Registration of arrival
19:00-21:00	Informal get together

Monday 12 August			
8:00-8:45	Registration late arrivals		
9:00-9:05	Welcome		
Session 1: Marketing and post-harvest needle retention	**Moderator: Ulrik Braüner Nielsen**		
Time	**Title**	**Country**	**Presenter**
9:05-9:30	The European Christmas tree market in numbers	DK	Claus J. Christensen
9:30-9:55	Oregon Christmas tree cycles and changes	US	Chal Landgren
9:55-10:20	A bioassay method for treatments to prevent needle loss due to ethylene response	US	Richard S. Cowles
10:20-10:45	*Coffee break*		
Session 2: Insect studies in Christmas trees	**Moderator: Gary Chastagner**		
10:45-11:10	Effect of methyl jasmonate (MeJA) on Fraser fir defense responses	US	Sai K. Gade
11:10-11:35	Experiences with the Bark beetle *Cryphalus piceae* - a Danish summary	DK	Mathias J. Justesen
11:35-12:00	The path toward development of insect resilient Fraser fir Christmas trees	US	Swapna P. Rajarapu
12:00-13:00	*Lunch*		
Session 3: Christmas tree breeding I	**Moderator: Ross Whetten**		
13:00-13:25	Genetic variation in Susceptibility to Silver Fir Woolly Adelgid in Nordmann fir	DK	Jing Xu
13:25-13:50	Selection of 2nd generation plus trees - strategy and gain	DK	Ulrik B. Nielsen
13:50-14:10	*Coffee break*		
14:10-14:35	Early performance of seedlings in CoFirGE2 plots in Washington, Idaho, and California	US	Gary Chastagner
14:35-15:00	Second cycle breeding and testing strategy for Fraser fir (*Abies fraseri*) and the NC State Christmas Tree Genetics Program	US	William H. Kohlway
15:00-17:30	Art Museum		
19:00 -	*Dinner at Tornøes*		

Tuesday 13 August			
8:00-12:30	Field tour: Grower visit Christmas tree farm, somatic clone trial and demonstration of mechanical leader control		
12:30-13:30	*Lunch*		
Session 4: Christmas tree breeding II	**Moderator: Chal Landgren**		
13:30-13:55	Genomic tools for breeding, conservation genomics, and pest/disease management of Christmas trees	US	Ross W. Whetten
13:55-14:20	Development of SNP markers and use in Christmas trees	DK	Kedra Ousmael
14:20-14:50	Hybrid breeding	DK	Ole K. Hansen
14:50-15:15	*Coffee break*		
Session 5: Extension and marketing in Christmas trees	**Moderator: Bert Cregg**		
15:15-15:40	Utilizing Norway spruce SE pipeline to produce Christmas tree varieties	SF	Mikko Tikkinen
15:40-16:05	Indicators of Climate Change Impacts in Southern Ontario Christmas Tree Farms	CA	Kelsey Leonard
16:05-16:30	Grower assessment survey to determine future research and extension objectives	US	Bill Lindberg
16:30-17:00	Evergreen Growth: Crafting a Marketing Blueprint for Michigan's Christmas Tree Farms (Online)	US	Kevin Chastagner
18:00-19:00	*Dinner at Tornøes*		
19:00-22:00	*Social*		

16th International Christmas Tree Research and Extension Conference

Wednesday 14 August			
8:30 -10:20	**Poster session**	**Moderator: Ole Kim Hansen**	
	Title	**Country**	**Presenter**
1	The genome sequence of a highly aggressive *Phytophthora cinnamomi* strain that threatens endangered Fraser fir (*Abies fraseri*)	US	Adarsha Devihalli
2	*Delphinella abietis* is a great challenge in the organic Christmas tree production in Norway	NORW	Inger S. Fløistad
3	Grazing to control fungal diseases in Norwegian Christmas trees	NORW	Inger S. Fløistad
4	Top dieback on spruce in young forest stands and Christmas tree fields	NORW	Inger S. Fløistad
5	Mock UAV pesticide application trial shows very variable coverage in Western North Carolina Christmas tree field	US	Jamie Bookwalter
9:00	*Coffee provided*		
6	Effect of methyl jasmonate (MeJA) on Fraser fir defense responses	US	Sai Karthik Gade
7	Second cycle breeding and testing strategy for Fraser fir (*Abies fraseri*) and the NC State Christmas Tree Genetics Program	US	William H. Kohlway
8	Impacts of nursery culture on transplant quality and subsequent out-planting performance in Abies Christmas tree plantations	US	Bert Cregg
9	Crossing the hydrophobic layers of conifer needles: how to improve foliar fertilization practices in Nordmann fir	DK	Sylwia Głazowska
10	Precision growing of Christmas trees – a new project	DK	Jing Xu
11		US	Jeffrey Owen
Session 6: Cultivation in Christmas trees		**Moderator: Inger Fløjsted**	
10:20-10:45	The Ecology of UK Christmas Trees. A 2022 Study	UK	Colin Palmer
10:45-11:10	Establishment of Fraser fir Christmas tree plantations in response to mulch and root dips	US	Bert Cregg
11:10-11:35	Establishing a link between normalized difference vegetation index (NDVI) and balsam fir nutrition using uncrewed aerial vehicles and multispectral sensing	CA	Mason T. MacDonald
11:35-12:00	Weed Control and Tolerance of Fraser x Balsam Fir Hybrid to Topramezone Herbicide	US	Jatinder Aulakh
12:00-13:00	*Lunch*		
Session 7: Disease in Christmas trees		**Moderator: John Frampton**	
13:00-13:25	Control of Neonectria canker on fir (Abies)	DK	Iben M. Thomsen
13:25-13:50	Deciphering the mechanism of Phytophthora root rot resistance in Abies species	US	Adarsha Devihalli
13:50-14:15	Climate-Induced Stress and Root Diseases in PNW Christmas Tree Plantations	US	Gary Chastagner
14:15-14:40	*Coffee break*		
14:40-15:05	Accelerated climate change and increased spread of oomycete root rot pathogens in southern Appalachia impact Christmas tree based rural bioeconomies	US	Caleb Cothron
15:05-15:30	Controlling Clopyralid Resistant Common Ragweed in Christmas Tree Production by Alternative Integrated Weed Management Strategy (Online)	US	Debalina Saha
15:30-17:00	Business meeting		
19:00-	*Gala Dinner at Tornøes*		

Thursday 15 August	
8:00-12:30	Langesø fair
12:30-13:00	*Sandwiches at parking lot*
13:00-18:30	Grower visit Hvidkilde Estate
19:00	*Dinner at Tornøes*
Friday 16 August	
8:00-13:00	Seed orchards at Tuse Næs
13:00-14:00	*Lunch at Levinsen Seed A/S*
14:00-15:30	Tour at seed facilities Levinsen Seed A/S
15:30-17:00	Departure for Copenhagen/airport and Goodbye
17:30	Potential return to Tornøes hotel

Participant list

	First name	Last name	Country	Institute/Company
1	Adarsha D.P.	Gowda	United States	North Carolina State University
2	Bert	Cregg	United States	Michigan St. University
3	Beth Ann	Bossio	United States	Reliable Source Seeds & Transplants
4	Bill	Lindberg	United States	Michigan State University
5	Caleb	Cothron	United States	North Carolina State University
6	Carl Johan	Larsen	Denmark	Larsen A/S Christmas tree farm
7	Chal	Landgren	United States	Oregon State University
8	Christian	Ladefoged	Denmark	Danish Estate production at Hvidkilde Estate
9	Claus Jerram	Christensen	Denmark	Danish Christmas Tree Association
10	Colin	Palmer	United Kingdom	British Christmas Tree Growers Association (BCTGA)
11	Debalina	Saha	United States	Michigan State University
12	Dominique	Choquette	Canada	Ministry of Agriculture, Fisheries and Food (MAPAQ)
13	Else	Møller	Denmark	University of Copenhagen
14	Gary	Chastagner	United States	Washington State University
15	Gunnar Friis	Proschowsky	Denmark	Nature Agency
16	Helle J	Martens	Denmark	University of Copenhagen
17	Iben M	Thomsen	Denmark	University of Copenhagen
18	Inger S	Fløistad	Norway	Norwegian Institute of Bioeconomy Research (NIBIO)
19	Jake	Nicholson	United States	The Ohio State University
20	James	Rockis	United States	Reliable Source Seeds & Transplants
21	Jamie	Bookwalter	United States	North Carolina State University
22	Jatinder	Aulakh	United States	Connecticut Agricultural Experiment Station
23	Jeffery	Owen	United States	North Carolina State University
24	Jing	Xu	Denmark	University of Copenhagen
25	Joe	Freeman	United States	Mistletoe Meadows
26	John	Council	United States	NC State University
27	John	Frampton	United States	North Carolina State University Forest Biotech
28	Karl	Schuster	Austria	Lower Austrian Christmas Tree Producers
29	Kedra	Ousmael	Denmark	University of Copenhagen
30	Kelsey	Leonard	Canada	University of Waterloo
31	Kenneth M	Klausen	Denmark	Danish Christmas Tree Association
32	Kevin	Chastagner	United States	Hope College
33	Kurt	Lange	Germany	Pflanzenschutzberatung (Plant protection advice)
34	Mark	Schmidlin	United States	Real Christmas Tree Board
35	Martin	Rasmussen	Denmark	Danish Estate production at Hvidkilde Estate
36	Mason	Macdonald	Canada	Dalhousie University
37	Mathias Just	Justesen	Denmark	University of Copenhagen
38	Maximilian	Engelhardt	Austria	Lower Austrian Christmas Tree Producers
39	Mikko	Tikkinen	Finland	Natural Resources Institute Finland (Luke)
40	Ole K	Hansen	Denmark	University of Copenhagen
41	Richard	Cowles	United States	CT Agricultural Expt. Station
42	Robert	Moore	United States	Double Four Tree Farm
43	Ross	Whetten	United States	NC State University
44	Russell	Barr	United States	Barr Evergreens of NC, LLC
45	Sai Karthik	Gade	United States	North Carolina State University
46	Sandra	Nitsch	Germany	Chamber of Agriculture North Rhine Westphalia
47	Swapna Priya	Rajarapu	United States	North Carolina State University

	First name	Last name	Country	Institute/Company
48	Sylwia Emilia	Glazowska	Denmark	University of Copenhagen
49	Tony	Haywood	United States	North Carolina State University
50	Tracy	Taylor	United States	North Carolina State University
51	Ulrik B	Nielsen	Denmark	University of Copenhagen
52	Ulrik Kejser	Nyvold	Denmark	Levinsen AS
53	William	Kohlway	United States	North Carolina State University

Content

Oral presentation

The European Christmas Tree market in numbers

Claus Jerram Christensen
Danish Christmas Tree Association

Europe consists of some 49 countries with a total of 746 million inhabitants speaking more than 150 different languages with German (18%), English and Italian (13%) and French (12%) as the most important. The European Union consists of 27 countries, holds 450 million inhabitants (200 million households) and represents 24 languages.

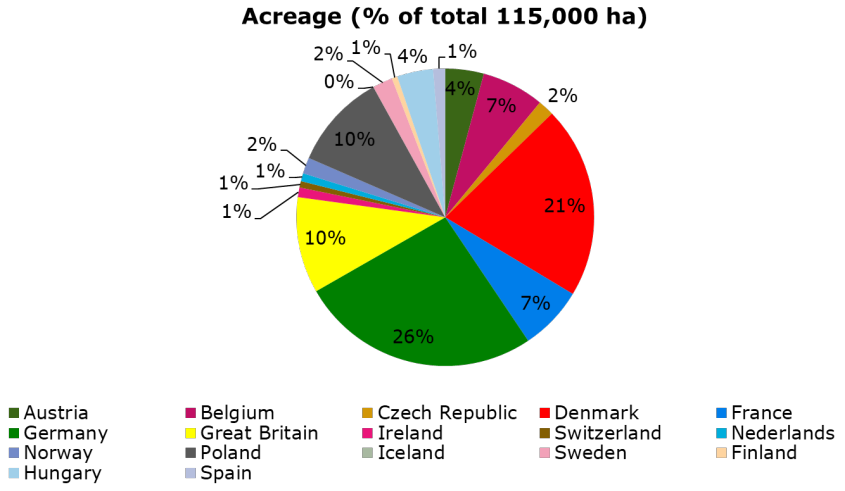
The statistics for the Christmas tree market in Europe are difficult to estimate since no Europe-wide report system is in place. Therefore, overall figures for the production are based upon national reports and these figures can be variable too due to Christmas trees being considered either forest trees or agriculture crops.

In 2016, The Christmas Tree Grower Council of Europe conducted a market survey among 18 selected countries from the EU, Norway and Switzerland. These data form the basis for the estimates of the European Christmas tree market given.

The Christmas tree tradition in Europe is strong as approximately 65 % of all households have a natural Christmas tree. This indicates a total market for natural Christmas around 90 million trees harvested each year. However, only 70 million are sold on the commercial market since 20 million are sold in barter deals. The annual turnover for the industry is approximately 1,5 billion EUR. With a total market of 140 million trees used each year artificial trees add up to 50 million or 35 % of the market with large country-to-country variation depending on the Christmas tree tradition.

Christmas trees are produced by approximately 12,000 growers on some 115,000 ha in Europe resulting in an annual production of approximately 70 million Christmas trees. True firs make up for 50 million trees each year with Nordmann fir being the most important species. Spruces make up for 15 million trees each year with Norway spruce and blue spruce as most used. Finally, pine makes up for 5 million trees each year with Scots pine and black pine as most common.

Most countries in Europe have some kind of Christmas tree production, but Germany has the largest production in Europe producing approximately 22 million followed by Denmark, Great Britain, Poland, France and Belgium.



Christmas tree producing countries in Europe (percentage of a total acreage of 115,00 ha)

The industry requires approximately 125,000 man-year and in the harvesting season from 5th November to 5th December 25,000 employees work daily – including weekends. The industry uses labor from Eastern and southern Europe (also from non-producing countries). It is getting increasingly difficult to attract qualified labor to the industry.

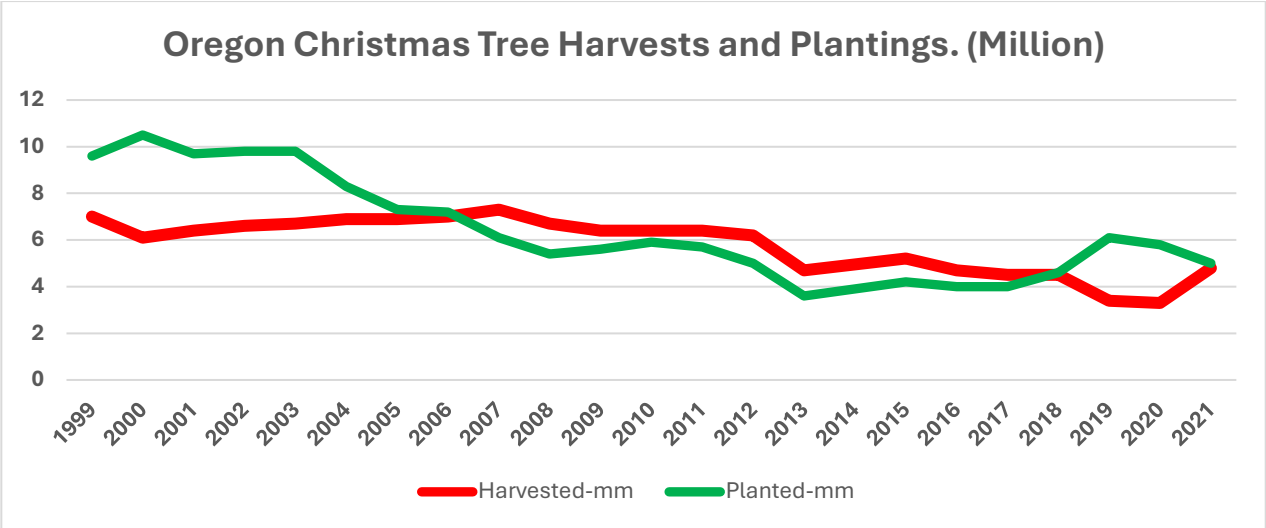
The European Christmas tree industry is experiencing challenges with changing consumer preferences from changed demographic with more single households and requirements for certified/documented production. Finally, the market share of plastic trees is increasing in many markets due to consumer convenience.

Oregon Christmas tree cycles and changes

Chal Landgren
Oregon State University, Christmas Tree Specialist, Retired

Denmark and Oregon experience boom and bust cycles in Christmas tree production. Danish growers have remarked that our respective cycles are offset such that what happens in Oregon and the Pacific Northwest (PNW) now will hit Denmark in around 6 years. Predicting future trends in Denmark via Oregon may be a fool's errand but I've retired, so here we go.

Plantings and harvests –



# of Growers/Memberships- In 2008, grower membership in the PNW Christmas Tree Association stood at 375. In 2023 the number of PNWCTA grower members stands at 130. Typically a quarter of the licensed growers in Oregon also have a membership in PNWCTA.

Tree prices- Too many trees chasing a static market from 2008-2013 showed an Industry-wide price decline. Prices began to increase in 2017, from an average industry price of $21(USD) to around $32 (USD) in 2021.

Industry structure-Over the past 10 years the largest companies have evolved in different ways. The largest, Holiday Tree Farms, is now managed by the family's 3rd generation, Yule Tree farms no longer exists, Noble Mountain is now owned by a Venture Capital Group from Brazil, McKenzie Farms is co-owned by Happy Holiday Christmas Trees of N. Carolina forming the largest consolidated Christmas tree company in the US. Smaller U-Cut farms have done well over the decade, wholesale grower numbers have declined. Between 2015-2020 Oregon's acreage in Christmas tree production has declined by 10,000 acres with much of this now planted to Hazelnuts, grapes, and other crops.

Below outlines where Farm-Grown Christmas trees were purchased across the US in 2022.

- Choose & Cut Farm: 30.80%
- Chain Store: 19.38%

- Nursery: 16.61%
- Retail Lot: 15.92%
- Non-Profit (Boy Scouts, churches, etc.): 7.61%
- Online: 7.27%
- Other: 2.41%

The total US Market is around 22.3 million trees. Average retail price $80. Artificial trees numbers are roughly the same as US total market. (National Christmas Tree Association. https://realchristmastrees.org/news-media/industry-statistics/ (accessed 5/22/24))

Notes on source materials: Where possible, the number of Oregon growers, trees planted and average prices are selected from US Department of Agriculture, National Agricultural Statistics Service from 2001,2003,2005,2008,2009,2010,2016 and 2020 surveys.

A bioassay method for treatments to prevent needle loss due to ethylene response

Richard S. Cowles

Connecticut Agricultural Experiment Station, Valley Laboratory, Windsor, CT USA

Previous research has demonstrated that a primary factor leading to needle loss in Christmas trees is endogenous production or exogenous exposure to ethylene gas. Stress arising from the trauma of cutting the tree or drying may result in generation of ethylene, which then signals enzymes involved in degrading plant tissues at the abscission layer. The biochemistry of endogenous ethylene production is well known: methionine is converted to SAMe, then via ACC synthase and ACC oxidase to ethylene. These enzymatic steps can be manipulated (either enhanced or repressed) and the effects of ethylene itself can be counteracted. Several test systems were investigated to observe the effects on needle retention in true firs, including subjecting cut shoots to solutions of amino acid precursors to methionine, additional calcium ions, ACC (the commercial Accede product) or ethephon. All methods produced the expected result of accelerated needle loss. Chemicals counteracting these effects mostly had the anticipated predicted responses. From a strategic perspective, esters of synthetic auxins may be most useful because they can block ethylene's effects, whereas other compounds that block earlier steps in ethylene biosynthesis will fail to protect against needle loss if there is an exogenous source present for ethylene. Because they are readily absorbed into foliage, they could be applied effectively at micromolar concentrations prior to harvest. For postharvest preservatives, chemicals could be "stacked" to block every step in the synthesis and response to ethylene. Active compounds include acetyl salicylic acid (blocking ACC synthase), 2-aminoisobutyric acid (blocking ACC oxidase), and a synthetic auxin (e.g., triclopyr, to counteract ethylene effects), along with other candidates. Whether completely blocking ethylene is wise needs to be determined, as this may force stomates to open, which should increase water consumption. Advances in this subject area will complement efforts of genetic improvement, as trees genetically unlikely to drop needles may still be responsive to ethylene signals when harvested under warmer than optimal conditions. Additional research is encouraged to determine whether methods that prevent needle loss in firs are useful for preventing needle loss in other genera.

Effect of methyl jasmonate (MeJA) on Fraser fir defense responses

Sai Karthik Gade[1], Priya Rajarapu[1], Angela Chiang[1] & Justin G. A. Whitehill[1]

[1]Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, North Carolina, USA

Fraser fir is native to the southern Appalachian Mountains and the most preferred Christmas tree in the US. Fraser fir is described as the "perfect" Christmas tree due to its pleasant aroma and elite post-harvest needle retention. However, Fraser fir faces significant biotic challenges including multiple piercing-sucking insect pests. The most concerning of these for NC Christmas tree growers is the elongate hemlock scale (EHS; *Fiorinia externa*). EHS is an invasive piercing-sucking insect introduced to the US from Japan in 1908. EHS feeds on the underside of needles causing a mottled appearance to foliage. The aesthetic value is diminished while salability is impacted as many states prohibit the importation of EHS infested plant materials. Chemical control measures and integrated pest management (IPM) practices are not very effective against EHS. However, planting insect resilient trees is recognized as the most effective management strategy. Conifer resilience against insects integrates multiple overlapping defense strategies. Generally, conifer and plant defenses against insect pests can be mediated through signaling cascades involving phytohormones such as jasmonic acid (JA) and salicylic acid (SA). Exogenous application of JA/SA has been shown to impact conifer defenses in several systems, but no information is available for Fraser fir. We evaluated the effect of MeJA (an analogue of JA) on defense responses in three Fraser fir genotypes. Clonal grafts of each genotype were treated with MeJA or a negative control treatment. Current year needles were collected from all treatment x genotype combinations 8 days post treatment for analysis using bright field microscopy. Anatomical differences were observed between both genotypes and treatment groups. Most notably, morphology of polyphenolic (PP) cells differed between treatment groups. ImageJ analysis of needles revealed significant differences in the abundances of phenolic bodies between treatments and resin duct area among genotypes. Most notably, the quality, type and total number of PP cells significantly differed between treatments and genotypes respectively.

Experiences with the Bark beetle *Cryphalus piceae* - a Danish summary

Mathias Just Justesen

University of Copenhagen, Department of Geosciences and Natural Resource Management
Rolighedsvej 23, 1958 Frederiksberg C, Denmark

Bark beetles (Scolytinae) that only attack weakened trees can have a significant economic impact if they kill trees that would have recovered in their absence. On the other hand, some bark beetles only target trees that are irreversibly stressed and have no chance of survival, regardless of the presence of bark beetles. Distinguishing between these two types of bark beetles is important for optimal pest management, and thus economic profitability.

Cryphalus piceae (Ratzeburg, 1837), is a bark beetle species reported as economically problematic, attacking weakened or even healthy trees. In 2012 this species started appearing in dead *Abies procera* Rehder, 1940 trees in Danish greenery plantations. Therefore, the damaging capabilities of *C. piceae* was evaluated.

This was done by monitoring its activity, tree-health appearance, and tree moisture levels in an *A. procera* stand weakened by *Heterobasidion annosum* s.str.

We compared *A. procera* trees attacked by *H. annosum* to healthy *A. procera* trees, allowing us to assess the degree of tree weakening before *C. piceae* colonization. Additionally, wood core samples were taken to evaluate tree health prior to C. piceae colonization. Our results suggest that *C. piceae* can only locate and colonize very weak or recently dead trees, thereby confirming that the species has had little to no effect on the survival of the studied *A. procera* trees. This highlights the importance of future studies on the damaging properties of secondary bark beetles.

The path toward development of insect resilient Fraser fir Christmas trees

Swapna Priya Rajarapu, Sai Karthik Gade, Angela Chiang, & Justin. G. A. Whitehill
Department of Forestry and Environmental Resources, North Carolina State University, Raleigh, NC

Fraser fir (*Abies fraseri*) is a native to the Southern Appalachian Mountains primarily located in North Carolina with small pockets located in southern Virginia and eastern Tennessee. Fraser fir is the premier Christmas Tree in the US. Consumers prefer the Fraser firs "perfect" Christmas tree characteristics including its pleasant aroma, strong and dense branches, soft needles, and elite post-harvest needle retention. However, Fraser fir production faces significant biotic and abiotic challenges. Increasing temperatures that favor biotic challenges such as emerging pests and disease are the primary factors impacting the Fraser fir Christmas tree industry in North Carolina. Surprisingly, the majority of pests that impact Fraser fir tree health include insects with piercing-sucking mouth parts. This is notable as piercing-sucking insects are not often associated with causing significant challenges to conifers and very few studies explore the complex interactions between these organisms. Piercing-sucking insects, such as the Elongate Hemlock Scale (EHS; *Fiorina externa*) feed on needles by sucking fluids out of individual cells using their mouthparts which function like a very long and thin needle. Piercing-sucking insects like EHS are generally sessile and will "settle" on a single feeding site throughout their development. Continuous feeding by pests like EHS can cause symptoms that include needle mottling which decreases the aesthetics and ultimately commercial value of a tree. If infestations become severe, they can result in premature needle drop and ultimately death of the tree. Recently, the Whitehill lab – Christmas tree genetics program found that natural variation in susceptibility of individual Fraser fir families varies among insect pests. Identification of the mechanisms underlying this variability will lead to the development of resilient Christmas trees. On the other hand, identifying the physiological mechanisms underlying pest biology can also contribute to developing resilient trees efficient in disrupting these functions. We conducted a greenhouse experiment to identify the variable resilience of Fraser fir families to EHS. Evaluation of molecular, anatomical, and biochemical changes in trees infested with the EHS relative to uninfested trees will provide novel insights into the mechanisms of EHS resilience in Fraser fir.

Genetic variation in Susceptibility to Silver Fir Woolly Adelgid in Nordmann fir

Jing Xu[1], Gary Chastagner[2], Mathias Just Justesen[1], Ole Kim Hansen[1], Ulrik Braüner Nielsen[1]

[1] University of Copenhagen, Department of Geosciences and Natural Resource Management Rolighedsvej 23, 1958 Frederiksberg C, Denmark

[2] Washington State University, Research and Extension Center, 2606 West Pioneer, Puyallup, WA 98371 USA

Denmark is a leading producer of Nordmann fir Christmas trees in Europe, supported by a breeding program since 1992 to select high-quality trees. Susceptibility to the silver fir woolly adelgid (SFWA) (*Adelges* (Dreyfusia) *nordmannianae*) is a key criterion. This collaboration between Washington State University (WSU) and University of Copenhagen (UCPH) aimed to quantify genetic variation and assess the consistency of genetic responses to SFWA across different sites. The study included two species (*Abies nordmanniana* and *A. bornmülleriana*), 8 and 2 provenances at WSU and UCPH, respectively, 6 half-sib (HS) families at WSU, 20-23 HS families from three provenances at UCPHU (including the 6 at WSU), and 22-68 clones grafted in clonal seed orchards (CSOs) at KU. The 6 WSU families were also included in the UCPH study.

At WSU, trees were naturally infested by SFWA at age six, and damage was evaluated at ages 7-9 using a scale from 0 (no damage) to 3 (severe damage). At UCPH, HS-trees were artificially infested at age 3, with damage assessed by counting progredientes and sistentes during the 4th to 5th growing seasons. Needle curling was evaluated on a scale from 0 (no curling) to 5 (most curling). In 2005, after ten growing seasons, a new evaluation of SFWA damage was conducted at UCPH, measuring SFWA counts on an east-facing branch in the second uppermost whorl, curled needles, and needle discoloration severity on a scale from 1 to 5.

For the three Danish clonal seed orchards (CSOs), damage levels were quantified using a score from 0 to 2, evaluating needle yellowing and curling during winter 2014, 14-20 years after grafting.

Results indicated significant genetic variation in SFWA susceptibility, with no significant genotype by environment interaction. Discoloration scores ten years post-infestation correlated highly with early SFWA counts, supporting the reliability of early assessments. High correlations (average 0.77) between CSOs' clone values and parent clone breeding values highlighted CSOs' utility in studying SFWA susceptibility among families. These findings elucidate the genetics of SFWA susceptibility and emphasize CSOs' potential in identifying SFWA-resistant breeding material.

Selection 2nd generation plus trees - strategy and gain

Ulrik Braüner Nielsen, Jing Xu, Kedra Ousmael, Ole Kim Hansen

University of Copenhagen, Department of Geosciences and Natural Resource Management
Rolighedsvej 23, 1958 Frederiksberg C, Denmark.

A Danish Christmas tree breeding program was initiated in 1992 motivated by securing continuous seed supply and superior genetic material. Mass selection in two Danish Nordmann fir stands within the Ambrolauri gene pool resulted in two 1st generation clonal seed orchards. Two commercial stands, each comprising 20.000+ trees and originating from one of these seed orchards (FP.266 Skibelund), were chosen for 2nd generation plus tree selection. Both stands were at the fringe of the first Christmas tree harvest at age six and seven from planting. The concept of "Ad hoc breeding" was applied using SNP markers to establish parentage and quantifying relatedness. At each site the 2% best trees were selected evenly distributed over the stand area using an established block, and for each selected tree two adjacent trees were used as unselected reference trees. Selection criteria were: superior Christmas tree quality, moderate growth, narrow tree, upright branch angle and no damages like needle loss. Parentage was established using SNP markers on 692 selected and 1371 reference trees. Breeding values were estimated for parents and progenies using the relatedness matrix and ASReml-R. No genotype by site interaction was detected. Genetic parameters were estimated based only on the reference trees. Predicted breeding values were based on the full material. For final selection of 2nd generation trees, based on breeding values for 14 traits, numerous combinations of traits combined into an index as well as independent culling levels for single traits were evaluated. Finally, trees were selected into three pools making the base for new 2nd generation orchards and the breeding pool: 1) Classic trees 2) Narrow trees and 3) Adelgid resistant trees. In principle 50 trees for each pool - and 128 in total. Specific culling levels were used for each pool and thereafter single-trait selection for Christmas tree quality. Threshold values for relatedness were applied using the program OPSEL. Gains for each of the new breeding pools was estimated reflecting the purpose 1) Classic 2) Narrow and 3) Adelgid resistant: +17, +14, +10 percent for Christmas tree quality, -3, -6, -2 percent branch length, and -4%, -6% and -38% for adelgids. All pools have a gain in post-harvest quality of 30-35%.

Early performance of seedlings in CoFirGE2 plots in Washington, Idaho, and California

Gary Chastagner[1], Marianne Elliott[1], and Chal Landgren[2]

[1]Washington State University, Research and Extension Center, 2606 West Pioneer, Puyallup, WA 98371 USA
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The 2013 Collaborative Fir Germplasm Evaluation (CoFirGE) project identified sources of Turkish and Trojan firs that have the potential to make high quality Christmas trees, particularly in the Pacific Northwest. To further evaluate the regional adaptability and performance of Trojan, Turkish, and Nordmann fir as Christmas trees, additional seed was collected from the mother trees in Turkey that produced top performing families of Trojan fir in the CoFirGE trial. Two-year-old seedlings from these families, along with seedlings from families of Nordmann (16) and Turkish (3) firs, and single families of balsam, Canaan, Fraser, and noble fir trees were used to establish a new series of replicated CoFirGE2 plots in various Christmas tree production regions across the United States in 2023. To obtain information on the early performance of seedlings in CoFirGE2 plots located at WSU Puyallup and commercial farms near Harrison, ID, and Placerville, CA, data on seedling survival, growth, bud break, and damage associated with low winter temperatures and late spring frost collected. The growth data at WSU Puyallup includes an assessment of the effect of fertilization with BEST PAKS® 20-10-5 (Simplot Professional Products, Lathrop, CA) at the time of planting on the growth of seedlings. The susceptibility of seedlings from the 12 families of Trojan fir to Phytophthora root rot is also being assessed at WSU Puyallup.

Second cycle breeding and testing strategy for Fraser fir (*Abies fraseri*) and the NC State Christmas Tree Genetics Program

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Fraser fir (*Abies fraseri*) is the most popular Christmas tree species in the U.S. Fraser fir is adapted to cool, moist environments and geographically constrained to high elevation montane ecosystems. When grown as Christmas trees, Fraser fir is generally planted well below its natural climatic niche which adds stress to the tree, decreases productivity, and increases its sensitivity to pests and pathogens. To develop Fraser fir better adapted for use in the production of Christmas trees, the College of Natural Resources in North Carolina State University initiated a Fraser fir breeding program in the late 1970's. Two separate breeding populations have been established over the course of a 40+ year timeframe. The first breeding population was established using progeny from a subset of founder trees originating from four of the six natural provenances. Elite selections were identified for fast growth and quality as a Christmas tree. The second breeding population was initiated in 1994 as part of an intensive range-wide collection of founder trees to capture the depth and breadth of diversity for Fraser fir. Results from the first generation progeny tests found that on average the genetically improved Fraser fir families grew one foot taller and had $40/tree higher choose-and-cut value than unimproved seed sources following seven years of growth in the field. Despite the success of the first generation, the next generation of Fraser fir genetic improvement faces significant challenges: 20-30 years per breeding cycle cannot keep pace with the cascading effects of a warming climate. Therefore, to accelerate genetic improvement for the next generation we plan to implement a rolling front breeding strategy combined with molecular breeding that utilizes genotyping tools to improve genetic pedigrees. Also, we aim to further reduce costs and speed up breeding with pollen polymixes in conjunction with diallel crosses to combine elite-unrelated individuals from both breeding populations. Ultimately, we aim to limit inbreeding and maximize genetic gain. Additionally, we plan to implement a similar strategy for exotic Christmas tree species including Turkish (*A. nordmanniana* subsp. *bornmuelleriana*) and Trojan fir (*A. nordmanniana* subsp.*equi-trojani*) to rapidly develop the next generation of climate-resilient Christmas trees.

Genomic tools for breeding, conservation genomics, and pest/disease management of Christmas trees

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Fraser fir (*Abies fraseri*) is endemic to the southern Appalachian Mountains of the eastern US, and has become the premier Christmas tree in the US over the past 40 years. Fraser fir now accounts for 38% of all live Christmas trees sold in the US, with a market value estimated to exceed one billion US dollars annually. The Christmas Tree Genetics (CTG) Program at NC State University began range-wide collections from natural stands in the 1980s and has since established first generation clone banks, seed orchards, and first and second generation progeny tests. The overall goal is to improve tree growth, Christmas tree quality, needle retention, and resistance to pests and diseases. Analysis of progeny test data has identified variation among Fraser fir families for growth, quality, degree of insect infestation, and susceptibility to deer browse. The spread and severity of a root rot disease, caused by a complex of *Phytophthora* and other oomycete pathogens, is causing increased concern amongst Christmas tree growers while the elongate hemlock scale (*Fiorinia externa*) - an exotic insect pest – is posing challenges to commercial production. The CTG program is now beginning the second cycle of mating and progeny testing, with the goal of integrating current breeding methods to accelerate genetic improvement of this economically important and ecologically endangered forest tree.

Modern breeding methods require genome information, so we constructed draft genome assemblies of both Fraser fir and *Phytophthora cinnamomi*, the most aggressive and wide-spread root rot pathogen on Fraser fir. The Fraser fir genome assembly will allow development of SNP markers for breeding applications. Genome annotation is ongoing, utilizing RNA-seq data, protein alignments, and *de novo* gene prediction to enable functional analysis of genes involved in pest and disease resistance, enhanced needle retention, and other economically and ecologically important traits. Resistance to root rot and insect pests varies within and among Asian and Mediterranean fir species, and a comparative biology approach will facilitate a better understanding of resistance mechanisms in these species to help integrate disease and pest resistance into Fraser fir.

Development of SNP markers and use in Christmas trees

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Established clonal seed orchards (CSOs) are cornerstones in Nordmann fir Christmas tree breeding in Denmark, enabling various progeny trials and plantations. To implement genetic thinning of the CSOs (backward selection) and select superior progenies in the plantations (forward selection), parentage analysis was needed. However, the absence of genomic resources, notably a reference genome or identified SNPs, presented a challenge to conducting both forward and backward selections effectively. Thus, we aimed to develop a method for SNP identification in Nordmann fir, a species with a large and complex genome. Four individuals, two each from the Borshomi and Ambrolauri gene pools, were used. Seed Megagametophytes were used as a source of DNA. We employed a combination of reference-based and reference-free approaches. A genome assembly from the closely related Silver fir (*Abies alba*) and a de novo assembly of low-copy regions of the Nordmann fir genome were used as references. A combination of approaches enabled the identification of a high density of reliable SNPs. Reference-based methods identified two million SNPs in common. A subset of 200 SNPs was used to genotype 342 individuals from the FP.266 CSO, validating these SNPs in the context of identity analysis. Furthermore, the identified SNPs were used to address Current Season Needle Necrosis (CSNN) through parentage analysis and ad hoc breeding. Two types of materials were used: First, 1545 randomly selected reference trees from two plantation stands (689 from Tørring and 856 from Mariager), established with seeds from FP.266 CSO, were used. Secondly, to specifically screen for CSNN, 495 moderately to severely damaged trees were additionally selected from the most affected area in the Mariager stand. Parentage analysis showed that 55.6% of affected offspring came from 20% of the parents, indicating specific clonal parents were more susceptible. Breeding values were predicted using the reference trees via an ad hoc approach. A moderate overlap was found between parent rankings based on breeding values estimated using reference trees and the ranking based on the frequency of affected offspring per parent. The findings suggested a selection strategy combining these rankings to identify and select susceptible parents.

Hybrid breeding

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Nordmann fir is the dominant species in the Danish Christmas tree production. However, the Mediterranean *Abies* species complex comprises other interesting species - and some contain attractive characteristics in relation to Christmas trees. In 2014, a crossing series was made, generating a unique plant material with hybrids between *A. nordmanniana* and species like *A. bornmülleriana*, *A. equitrojani* and *A. alba*. This material was established in a field trial with single-tree plots in autumn 2017 and was evaluated for Christmas tree quality and growth in 2023-2024. The material has further been applied to test the susceptibility of the hybrids to the silver fir woolly adelgid, *Dreyfusia nordmannianae*, which is the biggest pest problem in the Danish Christmas tree industry. For this purpose, an experimental infestation test was made in the nursery, using rooted cuttings of the most interesting hybrids. The potted rooted cuttings were infested with twigs with *D. nordmannianae* in May 2023 before flushing and has been evaluated for the presence of adelgids through counting both in summer 2023 and 2024. The talk will present the material and experiments and give some first results.

Utilizing Norway spruce SE pipeline to produce Christmas tree varieties

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Natural Resources Institute Finland, Luke

Ideal stock plants for Christmas tree production in Norway spruce cannot be taken for granted, because the Christmas tree traits differ from the breeding traits of industrial wood. Additionally, tree phenotypes, seed quality and availability may vary significantly among and within seed lots.

Somatic embryogenesis (SE) has been recognized to have vast potential to produce plant material with desired traits. Yet only few commercial applications have been achieved in conifers. Recent developments in Norway spruce (*Picea abies* (L.) H. Karst.) SE in Finland, e.g. high initiations rates, high recovery from cryopreservation, and short in vitro germination, have developed into a SE pipeline, which can be applied to genetically wide materials. This development has led to establishment of series of field tests, where differences in genetic tree traits are studied. In addition, SE materials have been produced from spruces with special growth form.

In EU partly funded project, Finnish Christmas tree producers identified several genotypes from a field test established in 2019, which could be suitable to be used as Christmas tree stock plants. At the same time SE technology is being scaled up in Business Finland funded project, where laboratory and field-testing results are utilized to produce elite conifers in large scale with a reasonable price. Could we hit a jackpot and find an excellent Christmas tree variety among these varieties prone to SE production?

Keywords: Picea abies; Forest regeneration material; vegetative propagation

Indicators of Climate Change Impacts in Southern Ontario Christmas Tree Farms

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The University of Waterloo Christmas Tree Lab, under the leadership of Dr. Kelsey Leonard, is dedicated to supporting Christmas tree farmers through an integrative approach that bridges social and natural sciences. The Lab collaborates with local farmers and researchers across Canada to address the challenges posed by climate change, providing locally relevant research and practical solutions. Given the scarcity of research on Christmas trees in Ontario, many farmers have relied on studies from other regions. To address this gap, the Christmas Tree Lab initiated the study "Indicators of Climate Change Impacts in Southern Ontario Christmas Tree Farms, aimed at identifying indicators of climatic changes to enhance resilience. This research involves a comprehensive examination of the experiences of Ontario's Christmas tree growers as they adapt to changing climatic conditions.

Through surveys and interviews, the study has collected detailed accounts of climatic observations and unique growing experiences from local farmers. These narratives are being utilized to create ecological calendars—tools based on seasonal changes that guide agricultural activities. By compiling these insights into regional datasets, the study aims to provide farmers with precise and actionable information. The presentation will highlight preliminary findings and areas for future research.

Preliminary findings have already informed a workshop with Ontario Christmas tree growers, where various climate adaptation and mitigation techniques were discussed. This research ultimately seeks to understand the specific impacts of climate change on Ontario's Christmas tree industry, offering farmers the tools and knowledge needed for effective adaptation and mitigation. Overall, this presentation aims to showcase the specific impacts of climate change on the Christmas tree industry in Ontario and highlight ways farmers are actively building tools for adaptation and mitigation.

Grower assessment survey to determine future research and extension objectives

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Michigan State University, United States

Michigan is the third largest Christmas tree producing state in the United States and has seen a surge in interest in tree production from new growers. To better inform future research and extension objectives, a grower needs survey was administered to Michigan Christmas tree growers in the Spring of 2024. The survey was conducted online with Qualtrics. Growers that had not responded to initial email survey request after one month had a reminder postcard mailed. The survey consisted of 52 questions in various categories, including pest management, irrigation management, nutrient management, and business management. Preliminary results (32 responses) indicate weed management (93%) and insect management (55%) were the growers' most significant pest management concerns. Grower preferences for receiving educational content varied greatly from in-person events (21%), online/virtual (15%), online documents (20%) to paper publications (20%). These results suggest that the majority of growers' are concerned with immediate issues related to weeds and pests, but variation in preferences for delivery of information, reflects changing and broadening demographics among growers. We will discuss the implications of the survey results to inform extension and research initiatives to support the industry.

Evergreen Growth: Crafting a Marketing Blueprint for Michigan's Christmas Tree Farms

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Hope College, Holland, MI, USA

A mid-sized Michigan Christmas tree grower approached Hope College's Economics and Business Department to collaborate with undergraduate students on the design of an applied marketing campaign to raise awareness and drive customers to their operation. During the development of a 6-8 week marketing campaign proposal for this grower, two larger issues were identified: 1) the impact of seasonality on customer relationships, and 2) the need for a more systematic approach to handling a Christmas tree grower's customer relationships, especially when considering the potential return on investment. Additionally, through discussions with individual growers and at Michigan Christmas Tree Association meetings, there is a strong trend towards growers using social media and other customer relationship management tools without much understanding of what–if any–returns growers get.

This research seeks to better understand the dynamics of what Michigan Christmas tree customers are looking for in order to provide a springboard for the development of a marketing toolkit for both choose and cut and retail operations. In September and October of 2024, we will conduct focus groups with potential Michigan customers to interrogate and understand their choices when considering the purchase of a Christmas tree. This primary data on Michigan consumers will provide us with key insights on core trends in what customers care about, and sellers understand consumer constraints and demands.

This exploratory research will form the basis of a state-wide customer survey in 2025. The goal of the survey is to identify if the trends that emerged from the 2024 focus groups are generalizable to all consumers in Michigan. Practically, this work will help growers make better, data-driven decisions around consumer needs and desires and develop a data-based toolkit of common marketing recommendations for the purpose of helping growers invest in successful marketing activities. Academically, this work will create opportunities to continue to look into more nuanced areas of marketing that are not broadly understood. This is principally seen in the unique nature of the Christmas tree industry in that it involves a highly seasonal offering with a low degree of differentiation, outside of a focus on the customer experience.

The Ecology of UK Christmas Trees. A 2022 Study

Colin Palmer
The British Christmas Tree Growers Association (BCTGA)

This study compared the influence of organic, non-intensive, and intensive tree management on the ecology of Christmas trees, based on the following categories:

1a. Soil health (14 plantations): Total soil populations of bacteria, protozoa and fungi were similar to adjacent grass rides. Populations of bacteria & mychorriza beneficial to nutrition were consistently low in the crop.

1b. Soil carbon (14 plantations): Soil carbon levels in the crop and grass headlands were broadly similar, recording good organic carbon levels irrespective of the number of rotations.

2. Habitat for birds (5 sites): Bird surveys identified populations in Worcestershire and Yorkshire plantations, supported by internet studies. Some 40 bird species were recorded, including thirteen endangered species, indicating the positive environmental credentials of Christmas trees.

3. Habitat for arthropods, insects & spiders. (11 sites)

The following was observed: Foliar: The dominant summer arthropods were *Collembola spp.*. No beneficial insects were recorded. Soil Surface: Trees: <40 ground beetles of 9 species captured in five overnight pitfall traps. Grassland: 3 - 4 captured, wheat stubble 80 captured. Air: <300 moths/site caught in overnight light traps comprising some 100 different species. Populations of all species were similar in organic and most minimal input plantations, but particularly low where intensively managed.

4. Habitat for mammals, amphibians and reptiles (39 sites)

This survey was undertaken by BCTGA members (not analysed by crop management type).

Small mammals including bats, field mice, voles & shrews: 6,685 sightings. (many field mice - 30 sites). Medium mammals including rabbits, red squirrel, hedgehog & weasel: 8,469 sightings. (many rabbits - 31 sites). Large mammals including deer, foxes & badgers: 6,956 sightings (many foxes - 32 sites). Reptiles & amphibians including snakes, lizards & toads: 2,324 sitings. (many frogs - 27 sites). Pine martin, polecat & endangered red squirrel were found on some 10% of the sites.

Conclusion

This study suggests that Christmas trees crop support excellent environmental credentials in a typical rural mosaic of farming, hedgerows and woodlands which are unlikely to be enjoyed by plastic alternatives.

Establishment of Fraser fir Christmas tree plantations in response to mulch and root dips

Bert Cregg and Riley Johnson

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In the Great Lakes region of the United States Christmas tree plantations are established byplanting seedlings or transplants. Reducing plant moisture stress after planting is crucial to successful establishment of these small conifers. A myriad of products have been marketed to Christmas tree producers with claims to improve transplant success by limiting transplant shock. Since 2021, we have conducted a series of field trials in collaboration with Michigan Christmas tree growers to evaluate the effect of root dips, mulching and other cultural practices on transplant survival and growth. Root dip products applied immediately prior to planting included: DieHard™ Root Dip (endo/ecto mycorrhizae + polymer), MycoApply® Injector Ecto (ectomycorrhizae), SoilMoist™ Fines, and Roots® Terra-Sorb® Fine Planting Gel (polymer). Cultural treatments that were applied following planting included: foliar antitranspirant spray (Wilt-Pruf® [25% di-1-p-menthane]), wood chip mulch, shade blocks (20.3 cm x 30.5 cm mesh screen), controlled release fertilizer, and biochar. Root dips did not affect tree survival or growth in any of the trials. Mulch and shade blocks increased shoot growth at several farms. Improved survival of trees under mulch was associated with improved soil moisture. Mulch did not affect foliar nitrogen (N) concentration, indicating that mulch did not 'tie-up' N. The application of Wilt-Pruf reduced transpiration but also reduced photosynthetic rate, resulting in a net decrease in shoot growth. Fertilization at planting significantly reduced survival on two of four sites. Overall, the results suggest that cultural treatments, especially mulch, are more likely to improve plantation establishment than root dips.

Establishing a link between normalized difference vegetation index (NDVI) and balsam fir nutrition using uncrewed aerial vehicles and multispectral sensing

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Balsam fir trees are a specialty agricultural species that are largely used as Christmas trees. Soil or tissue sampling is seldom performed to assess balsam fir nutrition needs, which can contribute to over or under fertilization and subsequent environmental challenges. Remote sensing to determine the normalized difference vegetation index (NDVI) has had strong relationships with nutrition in other plants. This research aimed to determine whether there is a relationship between NDVI and nutrition in balsam fir. A random sample of 45 trees was selected in autumn of 2021 and then another 70 trees selected in spring of 2022. Soil and needle tissue samples were analyzed for N, P, K, Ca, Mg, S, Fe, Zn, Mn, B, and Cu. An uncrewed aerial vehicle equipped with a multispectral camera was flown over the orchard to determine the NDVI for each tree. Nutrition and NDVI were analyzed for correlations through all sampled trees. Separate correlation analyses were repeated for mature trees (greater than 5 years old) and young trees (less than 5 years old). Soil nutrients N, P, K had a significant relationship with NDVI in autumn sampling. Only N was correlated consistently in both autumn and spring, with R2 of 37% and 33% respectively. Relationships were much stronger when only mature trees were considered, increasing to 60% and 51% respectively. NDVI was found to offer predictive power for tissue N that can be useful to producers to help optimize fertilizer input. However, further work is needed to refine these relationships.

Weed Control and Tolerance of Fraser x Balsam Fir Hybrid to Topramezone Herbicide

JS Aulakh

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Field experiments were conducted to determine the effectiveness of postemergence (POST) applied topramezone for weed control and the safety of Fraser x balsam fir hybrid (*Abies fraseri x balsamea*). The bare-rooted Fraser x balsam fir hybrid seedlings (3+1) were transplanted in the spring of 2017 at a commercial Christmas tree farm in Enfield, CT. Topramezone herbicide was applied at 0, 98, 196, or 392 g ai ha^{-1} over-the-top (OTT) of trees in the spring of 2020 and 2021. A methylated seed oil surfactant was added (1% v/v) to all topramezone treatments. Treatments were applied approximately 5 weeks after bud-break. A compressed CO_2 backpack sprayer equipped with a single TeeJet 8002 nozzle delivering 187 L ha^{-1} at 207 kPa and 3.5 kph was used. Results indicated that topramezone was highly safe to Fraser x balsam fir hybrid. The highest rate of 392 g ai ha^{-1} caused temporary chlorotic injury only in 2020. The chlorotic injury was rated 8.2, 3.3, and 1.7% by 2, 4, and 8 weeks after treatment (WAT), respectively. By 4 WAT, Canada horseweed [*Conyza canadensis* (L.) Cronq], Carolina horsenettle (*Solanum carolinense* L.), large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and yellow foxtail [*Setaria pumila* (Poir.) Roem. & Schult.] were controlled 60 to 90%. By 12 WAT, Canada horseweed, large crabgrass, and yellow foxtail were controlled >70% whereas the Carolina horsenettle control varied from 35 to 54%, depending upon the topramezone rate. These results suggest that topramezone is a highly safe POST herbicide on tested Christmas tree species and can provide moderate control or suppression of some of the annual and perennial weed species tested in this study.

Control of *Neonectria* canker on fir (*Abies*)

Senior adviser Iben Margrete Thomsen, *University of Copenhagen; Venche Talgø, NIBIO*

Until 2011, fir canker caused by *Neonectria neomacrospora* was not recognized as a problem in the Christmas tree and greenery production in Denmark, although symptoms had been observed sporadically for at least ten years. This changed when an epidemic of *Neonectria* damage occurred in Denmark from 2011 to 2013, shortly after the symptoms and the fungus were reported from Norway. *Abies lasiocarpa* is among the most susceptible species, but in Denmark the main damage was seen in *A. procera* and *A. nordmanniana*, probably due to them being the most commonly used fir species.

The main factors in the disease development at the time were thought to be a combination of **1)** wet years (especially summer and autumns) before and during the epidemic, **2)** the presence of many abandoned (and thus dense) stands of Nordmann fir Christmas trees, and **3)** heavy *Dreyfusia nordmanniana* aphid infestation in 2012. Observations from 2011 to 2021 have shown that contaminated trees within 100 meters of a stand will contribute to high disease pressure. In addition, felling infected trees in and around a stand and leaving them on the ground will cause a huge build-up of inoculum and should be avoided at all costs.

Control of *N. neomacrospora* with fungicides is not feasible in Denmark. However, use of copper oxide (Nordox 75WG) during bud break is recommended in Norwegian *A. lasiocarpa* Christmas trees. Strict removal of infected trees within and around Christmas tree and greenery stands has proven to be sufficient in Denmark. In 2013 and subsequent years, Danish growers made a huge effort to get rid of infected trees and stands, both their own and neighboring stands often owned by farmers no longer actively managing the trees. This has reduced the amount of disease to manageable levels, but extreme amounts of rain in recent years should make growers vigilant, in order to spot the initial symptoms of *Neonectria* fir canker, mainly groups of dying shoots in spring and bark necroses.

Deciphering the mechanism of *Phytophthora* root rot resistance in *Abies* species

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Phytophthora root rot (PRR) is the biggest threat impacting Fraser fir (*Abies fraseri*) Christmas tree production in the southeastern United States. The primary causal agent is the invasive oomycete *Phytophthora cinnamomi*. Fraser fir is 100% susceptible to this disease and infection results in complete mortality. The pathogen is soilborne and spreads through the movement of flagellated zoospores that can swim through water. Once present in soil the pathogen has been documented to persist for decades. Attempts to manage the disease in field settings have relied on chemical management practices that have largely been ineffective. The development of disease-resistant germplasm is recognized as the ideal method to control this devastating pathogen. However, the development of resistant germplasm relies on a thorough understanding of the molecular, biochemical, physical, and genetic mechanisms that govern the interaction between *P. cinnamomi* and *Abies* spp. The Asian species momi (*A. firma*) and Trojan (*A nordmanniana* subsp. *equi-trojani*) fir harbour natural genetic resistance against PRR disease. These two exotic fir species are being used in comparative studies to help better understand host-pathogen interactions in this difficult-to-study system. We have performed two separate artificial stem inoculation experiments to attempt and understand both susceptibility of Fraser and resistance of momi and Trojan against the *P. cinnamomi* pathogen, using clonal grafts of all three fir species and a highly aggressive isolate of the *P. cinnamomi* (isolate 23ss04) pathogen. Necrotic bark tissues were collected at three time points during the infection process. Lesion lengths on the inner bark were measured 10 days post-infection; longer lesions were observed in Fraser fir when compared to momi and Trojan firs. Transcriptome assembly of both the hosts and pathogen is underway using RNA sequencing of bark samples. We plan differential expression (DE) analyses of RNASeq data with the goal to identify putative mechanisms involved in PRR-fir interactions. I also developed an in-house genome assembly and transcriptome for the *P. cinnamomi* pathogen. This resource will be critical to separating *P. cinnamomi* transcripts from infected bark samples across all three species. We aim to identify pathogenicity-associated genes and other important molecular markers involved in the disease process.

Climate-Induced Stress and Root Diseases in PNW Christmas Tree Plantations

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The mild, moist climate in western Washington and Oregon has helped enable growers in the Pacific Northwest (PNW) to lead the nation in Christmas tree production. Historically, the impact of drought stress during the growing season on this largely non-irrigated crop was limited to seedling survival. Large established trees with well-developed root systems were seldom impacted by drought. That is no longer the case. In recent years climate-induced drought stress has affected all age classes of trees. In addition, climate-related stress is not limited to high temperatures and drought. For example, western Washington and Oregon received record precipitation from mid-September through November 2021, followed by a protracted period of cool, wet weather during spring 2022, and record hot, dry conditions again during the summer in 2022. The increasing frequency of extreme temperatures and extended drought during the growing season, coupled with increases in seasonal precipitation has resulted in significant mortality or damage to Christmas trees.

Following increased fall and spring precipitation in 2021/22, unprecedented levels of *Phytophthora* root rot was observed in several noble fir plantations, including the mortality of more than 30,000 2- to 3-yr-old noble fir trees at one site. The mortality of 14,000 Fraser fir trees at another site appears to have been associated with the extensive development of *Armillaria* root disease, which is known to be aggressive on drought stressed trees, in 2022 and 2023. Increased occurrence of high temperatures has also resulted in significant increases in direct heat damage to the foliage (sunburn) on large, harvestable size trees. While the historic, multiple-day "heat dome" in June 2021 resulted in sunburn on Christmas trees and numerous other agricultural crops and forests in the PNW, the foliage on an estimated 4-5,000 harvestable size drought-stressed noble fir was severely damaged in August 2023 following one day when the temperature reached 40.6°C.

Research is underway to obtain a better understanding of the abiotic and biotic factors that are associated with increased tree mortality. Our goal is to provide growers with management recommendations that will reduce sunburn on foliage and the impact of root diseases that are more aggressive on stressed plants, and recommendations for alternative species that are more tolerant to root diseases, drought, and heat stress.

Accelerated climate change and increased spread of oomycete root rot pathogens in southern Appalachia impact Christmas tree based rural bioeconomies

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The production of Fraser fir (*Abies fraseri*) Christmas trees in the southern Appalachian Mountains of western North Carolina are facing significant mortality events due to increased spread of Phytophthora root rot which causes 100% mortality of infected trees. The disease is caused by several members of the genus Phytophthora of which *P. cinnamomi* is the most widespread causal agent of Fraser fir mortality. However, several other species have been isolated from infected roots as the number of Phytophthora species present on Christmas tree farms has grown over the last 20+ years. The gradual increase in oomycete diversity is likely driven by several factors including an increased dependence on out-of-state seedling production and the cascading impacts of accelerated climate change. We conducted a survey of Fraser fir Christmas tree farms in the summer of 2023 in the southern Appalachian Mountains to determine the current distribution and diversity of pathogenic Phytophthora species. In total, 332 trees were sampled from 89 sites in 17 counties across North Carolina, Virginia, and Tennessee. We isolated eight species of Phytophthora from 137 trees in 15 counties. Phytophthora species isolated from symptomatic Fraser fir included *P. cinnamomi*, *P. cryptogea*, *P. psuedocryptogea*, *P. kelmanii*, *P. europaea*, *P. plurivora*, and *P. cactorum*. Four of these species - *P. psuedocryptogea*, *P. kelmanii*, *P. plurivora*, and *P. cactorum* - have not previously been reported on Fraser fir in the Southern Appalachians. Additionally, we also isolated the oomycete pathogen *Elongisporangium undulatum* from symptomatic Fraser fir roots. *E. undulatum* has been shown to cause a root-rot disease in conifer species grown on European Christmas tree plantations. Ongoing work aims to evaluate the phylogenetic relationships amongst these isolates using multiple loci through molecular analyses. Confirmation of pathogenicity of these isolates is ongoing and will be performed through greenhouse inoculation trials to evaluate these newly detected species and determine their pathogenicity on Fraser fir Christmas trees.

Controlling Clopyralid Resistant Common Ragweed in Christmas Tree Production by Alternative Integrated Weed Management Strategy

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Common Ragweed (*Ambrosia artemisiifolia* L.) is an extremely competitive broadleaved summer annual weed found in Christmas tree production systems within Michigan. Common ragweed has had reported resistance to glyphosate, PSII inhibitors, PPO inhibitors, and ALS herbicides. There have been reports from Michigan Christmas tree growers of common ragweed resistance to clopyralid, a synthetic auxin herbicide, in Montcalm County Michigan. The objective of this study was to test alternative postemergence herbicide combinations and organic mulch on clopyralid-resistant common ragweed for weed control efficacy. Greenhouse experiments were conducted in 2021 and 2022 at the Horticulture Teaching and Research Center, Michigan State University. Two stages of common ragweed were used stage 1 (6-9 leaves) and stage 2 (12-14 leaves). Weed control treatments that were applied included clopyralid, glyphosate, oxyfluorfen, oxyfluorfen + glyphosate, clopyralid + oxyfluorfen, clopyralid + glyphosate, mulch only, mulch + oxyfluorfen + glyphosate, mulch + clopyralid + oxyfluorfen, mulch + clopyralid + glyphosate, and clopyralid + oxyfluorfen + glyphosate, and untreated control. Data collection included bi-weekly visual estimation of weed control until 8 weeks after treatment (WAT) using a scale of 0% meaning no control to 100% meaning complete death. Weed fresh weights at 8 WAT were also recorded. The experiment was a complete randomized block design with four replications per treatment. Results showed that for common ragweed stage 1 in 2021 and 2022 as well as stage 2 in 2022 at all evaluation dates mulch + clopyralid + oxyfluorfen provided the highest level of weed control. For stage 1 in 2022 this treatment combination provided 100% control from 2 WAT and always showed greater than or equal weed control to all other treatments. Based on fresh weight, the greatest plant growth occurred with glyphosate treatment in 2021 and clopyralid and mulch alone in 2022. Likely due to common ragweed resistance to these herbicides.

Poster presentation

The genome sequence of a highly aggressive *Phytophthora cinnamomi* strain that threatens endangered Fraser fir (*Abies fraseri*)

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Fraser fir (*Abies fraseri*) is endemic to the southeastern US and is considered to be the most elite Christmas tree in the country. North Carolina produces ~26% of all real Christmas trees in the US; however, the ~$400 million North Carolina Christmas tree industry is threatened by the combined effects of accelerated climate change and spread of a devastating disease. The disease, Phytophthora root rot (PRR), is primarily caused by the oomycete pathogen *Phytophthora cinnamomi*. The pathogen is difficult to control due to a robust asexual life cycle and hemibiotrophic mode of nutrition. The most effective way to manage this pest in the field is through deployment of genetically resistant germplasm. However, development of disease resistant conifer germplasm is very slow and requires many years of intense genetic improvement. To develop novel management strategies, my research project aims to develop genomic resources in this relatively obscure pathosystem. The first step in this process was to assemble the whole genome sequence of a highly virulent strain of the pathogen - *P. cinnamomi* isolate 23ss04. DNA sequencing was performed on an Oxford Nanopore Technology (ONT) MinION combined with an Illumina MiSeq sequencing device to obtain long- and short-reads, respectively. Raw reads were filtered and trimmed, then assembled using four *de-novo* assemblers. The four assemblies were subsequently merged to generate a single draft assembly. The draft assembly was polished using short reads and scaffolded. Our *de novo* genome assembly pipeline resulted in a final assembly consisting of 196 scaffolds and a genome size of 115.4 Mb. The N50 of the final assembly was 1.4 Mbps. BUSCO (Benchmarking Universal Single-Copy Orthologs) analysis showed 100 % completeness. Genome annotation is ongoing and will be conducted using publicly available databases and in-house RNA-seq datasets. The ultimate goal is to develop genomic resources to identify key pathogenicity-associated genes that could be used to facilitate downstream genetic management strategies.

Delphinella abietis is a great challenge in the organic Christmas tree production in Norway

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Delphinella shoot blight, caused by the fungus *Delphinella abietis,* is a severe foliar disease on fir (*Abies* spp.) in Europe (Talgø et al. 2016) and North America (Chastagner et al. 2017), and particularly on subalpine fir (*A. lasiocarpa*). It destroys current year needles and in severe cases entire shoots. The fungus produces numerous fruiting bodies containing ascospores that may easily spread by wind over distance in moist weather. In Norway, this pathogen has primarily been a problem in humid coastal regions of western Norway but following several seasons of mild and wet weather over the recent decades, it has also become problematic in inland regions of southeastern Norway. The older and denser the plantations become, the more humid the microclimate is, thus stimulating infections of *D. abietis* and development of shoot blight. In the autumn of 2022, this pathogen led to sanitation of hundreds of trees in an organic plantation of subalpine fir Christmas trees in northwestern Norway. Most trees had reached marketing size and were not saleable. However, also conventional growers may fail to control this pathogen if the current year shoots are not well protected by fungicides during bud break and shoot elongation in wet seasons (Talgø et al. 2016). Although, the organic field was situated in an open, well aerated area and was managed by pruning off lower branches and grazing by sheep, this was not sufficient to avoid infection under wet conditions and high disease pressure. Susceptibility among subalpine fir provenances may vary (Talgø et al. 2016, Chastagner et al. 2017), and growers in Norway have experienced that Fraser fir (*A. fraseri*) has high resistance to *D. abietis* (Talgø et al. 2021). Thus, in organic Christmas tree production, growing more resistant subalpine fir provenances, Fraser fir instead of subalpine fir, and even spruce (*Picea* spp.) instead of fir should be considered. Good effect by copper oxide has been proven against D. abietis (Talgø et al. 2020), however, it is not approved everywhere in organic production.

Chastagner, G.A., Riley, K., Coats, K.P., Eikemo, H. & Talgø, V. 2017. Delphinella Shoot Blight and Grovesiella Canker on *Abies lasiocarpa* in Western USA. Scandinavian Journal of Forest Research 32:432-437.
Talgø, V., Pettersson, M., Fløistad, I.S. & Stensvand, A. 2021. Tiltak mot edelgranskotsjuke [Managment of Delphinella shoot blight]. Den grønne gren 8:20-23.
Talgø, V., Skage, J.-O., Steffenrem, A., Eikemo, H., Brurberg, M.B. & Johnskås, R. 2016. Delphinella shoot blight on *Abies lasiocarpa* provenances in Norway. Forests 7, 7. 17 pp.
Talgø, V, Stensvand, A., Pettersson, M. & Fløistad, I.S. 2020. Management of diseases in Norwegian Christmas tree plantations. Scandinavian Journal of Forest Research 35:433-444.

Grazing to control fungal diseases in Norwegian Christmas trees

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From a disease point of view there are several good reasons for keeping the vegetation (grass and weed) low in Christmas tree fields. It improves the air circulation and thereby allows the foliage on the trees to dry quicker after irrigation, precipitation, fog, or dew. A dryer foliage will reduce infection of fungal spore on needles, young (not yet lignified) bark or through wounds caused by e.g., pruning, hailstorms, or strong winds. Some weed species are host plants for rust fungi affecting spruce (*Picea* spp.) and fir (*Abies* spp.) Christmas trees, e.g., willow herbs (*Epilobium* spp.) and the perennial fireweed (*Chamerion angustifolium*) are alternate hosts for fir-fireweed rust (*Pucciniastrum epilobii*), and goat willow (*Salix caprea*) is alternate host for fir-willow rust (*Melampsora abietis capreaum*). In Norway, several growers prefer grazing by sheep over chemical or mechanical management of weed in Christmas tree plantations. Also, cattle are used, but they cause more physical damage in the plantations. Trees may also get damaged by sheep, but if the following issues are taken into consideration the problems are likely minimized; (1) good knowledge of animal husbandry (e.g., give access to minerals/salt licks), (2) use specific sheep breeds (Shropshire, Leicester, Dorset and Suffolk are recommended), (3) keep up to five sheep plus their lambs per hectare, (4) monitor the weed situation regularly to enable movement of the sheep in time (sheep eat herbs, grass and broadleaved tree saplings before they start feeding on conifers, although, fir is preferred over spruce), (5) exclude individuals that for some reason prefer to graze on conifers, (6) keep an open space where the sheep can gather to relax and ruminate, (7) avoid stressing them by splitting the herd, and finally, (8) do not practice grazing the first couple of years after establishing the plantation.

Sæbø, A. & Langmoen. 2014. Lønnsomme juletrær. https://www.statsforvalteren.no/siteassets/fm-rogaland/bilder-fmro/landbruk/skogbruk/dokumenter/lonnsomme-juletrar-122014-publisert-versjon-2b-small.pdf

Top dieback on spruce in young forest stands and Christmas tree fields

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In 2021, we received reports of top dieback on Norway spruce (*Picea abies*) in young forest stands and Christmas tree fields in southeastern Norway (Innlandet county). On August 10, we investigated the problem in two forest stands and a Christmas tree field. The symptoms varied from chlorotic top and side shoots to completely dead (necrotic) tops. No physical wounds were observed. On some of the necrotic shoots, red fruiting bodies occurred after incubation in the laboratory. Isolations were carried out on PDA from small pieces excised from the leading edge between healthy and dead tissue. Several fungi were obtained, however, *Neonectria fuckeliana* was the only fungus found from all three locations. On July 13 in 2022, we revisited one of the forests stands plus a Christmas tree field in Akershus county. Only necrotic shoots from the previous year were observed, i.e. no newly infected trees were seen. However, the dieback on several trees in the forest stand had by then extended downwards the stem, occasionally all the way to the base where numerous fruiting bodies from *N. fuckeliana* were present. The same was observed in the Christmas trees in Akershus county. Although, not as aggressive as the close relative *N. neomacrospora* on fir (*Abies* spp.), the dieback on spruce indicates that *N. fuckeliana* is capable of killing young shoots and finally the entire trees. This dieback in spruce Christmas trees has also earlier been associated with *N. fuckeliana* both in Norway and Sweden (Pettersson et al. 2016). More research is required to understand the conditions required for the sudden emergence of top dieback in the spruce fields.

Pettersson, M., Frampton, J., Rönnberg, J. & Talgø, V. 2016. Neonectria Canker Found on Spruce and Fir in Swedish Christmas Tree Plantations. Plant Health Progress17:202-205 (http://dx.doi.org/10.1094/PHP-BR-16-0017). 4 pp.

Mock UAV pesticide application trial shows very variable coverage in Western North Carolina Christmas tree field

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Pesticide and herbicide application in Christmas tree fields in Western North Carolina (USA) has remained functionally unchanged for decades; conventional trailer-mounted mistblowers, high pressure pumps, or back-pack applicators are normal modes of application. Amid concerns regarding applicator health risk, the rising cost of labor, and environmental concerns, researchers and stakeholders are increasingly searching for more creative and autonomous options to lower pesticide and herbicide use as well as applicator exposure. However, autonomous application methods have failed to gain hold in the Western North Carolina Christmas tree industry, as Christmas tree fields in this region are too steep and muddy for traditional autonomous terrestrial robots. In addition, UAVs (unmanned aerial vehicles) were historically limited by low maximum payloads, thus American UAV operators have traditionally offered only identification and plant growth data to growers. However, current models of UAVs have much higher maximum payloads and extended battery life. Multiple companies are now offering pesticide and herbicide UAV application services to Christmas tree farmers. Little is known, however, regarding best UAV parameters in Western North Carolina Christmas tree fields.

In March 2024, North Carolina State Extension agents conducted a preliminary trial in a Western North Carolina Christmas field to examine coverage differences between various parameters offered by a XAG p100 liquid application. Agents tested 3 rates (in liters per hectare) and 3 sizes of droplets against the industry standard of application by high pressure sprayer mounted upon a truck. Results showed significantly higher coverage by the high-pressure sprayer, and very variable coverage by the various XAG p100 treatments. We propose to delve deeper into the efficacy of UAV applications compared to industry standards to create better recommendations for the industry in 2025.

Effect of methyl jasmonate (MeJA) on Fraser fir defense responses

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Fraser fir is native to the southern Appalachian Mountains and the most preferred Christmas tree in the US. Fraser fir is described as the "perfect" Christmas tree due to its pleasant aroma and elite post-harvest needle retention. However, Fraser fir faces significant biotic challenges including multiple piercing-sucking insect pests. The most concerning of these for NC Christmas tree growers is the elongate hemlock scale (EHS; *Fiorinia externa*). EHS is an invasive piercing-sucking insect introduced to the US from Japan in 1908. EHS feeds on the underside of needles causing a mottled appearance to foliage. The aesthetic value is diminished while salability is impacted as many states prohibit the importation of EHS infested plant materials. Chemical control measures and integrated pest management (IPM) practices are not very effective against EHS. However, planting insect resilient trees is recognized as the most effective management strategy. Conifer resilience against insects integrates multiple overlapping defense strategies. Generally, conifer and plant defenses against insect pests can be mediated through signaling cascades involving phytohormones such as jasmonic acid (JA) and salicylic acid (SA). Exogenous application of JA/SA has been shown to impact conifer defenses in several systems, but no information is available for Fraser fir. We evaluated the effect of MeJA (an analogue of JA) on defense responses in three Fraser fir genotypes. Clonal grafts of each genotype were treated with MeJA or a negative control treatment. Current year needles were collected from all treatment x genotype combinations 8 days post treatment for analysis using bright field microscopy. Anatomical differences were observed between both genotypes and treatment groups. Most notably, morphology of polyphenolic (PP) cells differed between treatment groups. ImageJ analysis of needles revealed significant differences in the abundances of phenolic bodies between treatments and resin duct area among genotypes. Most notably, the quality, type and total number of PP cells significantly differed between treatments and genotypes respectively.

Second cycle breeding and testing strategy for Fraser fir (*Abies fraseri*) and the NC State Christmas Tree Genetics Program

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Fraser fir (*Abies fraseri*) is the most popular Christmas tree species in the U.S. Fraser fir is adapted to cool, moist environments and geographically constrained to high elevation montane ecosystems. When grown as Christmas trees, Fraser fir is generally planted well below its natural climatic niche which adds stress to the tree, decreases productivity, and increases its sensitivity to pests and pathogens. To develop Fraser fir better adapted for use in the production of Christmas trees, the College of Natural Resources in North Carolina State University initiated a Fraser fir breeding program in the late 1970's. Two separate breeding populations have been established over the course of a 40+ year timeframe. The first breeding population was established using progeny from a subset of founder trees originating from four of the six natural provenances. Elite selections were identified for fast growth and quality as a Christmas tree. The second breeding population was initiated in 1994 as part of an intensive range-wide collection of founder trees to capture the depth and breadth of diversity for Fraser fir. Results from the first generation progeny tests found that on average the genetically improved Fraser fir families grew one foot taller and had $40/tree higher choose-and-cut value than unimproved seed sources following seven years of growth in the field. Despite the success of the first generation, the next generation of Fraser fir genetic improvement faces significant challenges: 20-30 years per breeding cycle cannot keep pace with the cascading effects of a warming climate. Therefore, to accelerate genetic improvement for the next generation we plan to implement a rolling front breeding strategy combined with molecular breeding that utilizes genotyping tools to improve genetic pedigrees. Also, we aim to further reduce costs and speed up breeding with pollen polymixes in conjunction with diallel crosses to combine elite-unrelated individuals from both breeding populations. Ultimately, we aim to limit inbreeding and maximize genetic gain. Additionally, we plan to implement a similar strategy for exotic Christmas tree species including Turkish (*A. nordmanniana* subsp. *bornmuelleriana*) and Trojan fir (*A. nordmanniana* subsp.*equi-trojani*) to rapidly develop the next generation of climate-resilient Christmas trees.

Impacts of nursery culture on transplant quality and subsequent out-planting performance in *Abies* Christmas tree plantations

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Planting stock quality is an important factor for the initial survival and growth of conifer stock planted for Christmas trees. In particular, seedling nutrient content has been linked to improved survival and growth of conifer planting stock following out-planting. In fall 2022, we collaborated with a commercial conifer nursery in Michigan (Northern Pines Nursery, Manton, MI) to examine the effect of late-season nitrogen (N) fertilization in the nursery beds (i.e., nutrient loading) on subsequent tree performance after lifting and out-planting. In fall 2022 we applied 0, 28, 56, or 84 kg of N per hectare to 2 + 2 transplant beds of Fraser fir (*Abies fraseri*) and Canaan fir (*Abies balsamea* var. *phernolepis*). Seedling cold hardiness was assessed 6 weeks after fertilization treatments and again in early spring before lifting. In spring 2023 the transplants were lifted and assessed for stem caliper, height, root/shoot ratio and needle nutrient concentration. Subsequently the trees were out-planted into a Christmas tree plantation in northern Michigan. We assessed survival and shoot growth after the first growing season. Fertilization treatment in the nursery did not affect shoot or needle cold hardiness on either sample date. Tree survival following out-planting was excellent (95% or greater) for both species and was not affected by fertilization. Fertilizing nursery stock in the transplant bed increased needle N concentration at lifting. First-year shoot growth rate for both species increased with increased N concentration. The results suggest that nutrient loading through late-season N fertilization can improve out-planting success without impacting planting stock cold hardiness.

Crossing the hydrophobic layers of conifer needles: how to improve foliar fertilization practices in Nordmann fir

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Mineral deficiencies severely impact the growth of Nordmann fir. Magnesium (Mg) and calcium (Ca) deficiencies are particularly relevant for the marketability of Christmas trees, as they lead to significant discoloration and premature needle abscission. These deficiency symptoms are indicative of a deficiency that appeared during the previous growth season, and an addition of Mg/Ca fertilizer to the soil failed to fully restore the tree's mineral status.

Foliar fertilization can provide the required elements directly to where they are needed, overcoming the limitations of conventional soil application. However, this is not a trivial task since the epidermal cells of Nordmann fir needles have thick cell wall and hydrophobic cuticle, which prevent efficient application and absorption of ordinary water-based nutrient solutions.

We are currently developing lipid-based foliar fertilizers that are more compatible with conifer needles than current water-based nutrient solutions. Our strategy involves usings a liposome system, where an aqueous solution containing the required nutrient is encapsulated in phospholipid spheres. This lipid coat acts as a detergent, greatly improving adhesion and spreading on the needle surface and facilitating penetration of the nutrients into the plant tissue.

We label our liposomes with fluorescent markers to monitor their behaviour on the needle surface and to identify the transport pathways inside the plant tissue. Additionally, we use Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Laser Ablation ICP-MS to quantify the amount of element taken up by the plant and to provide detailed information on nutrient distribution in the needles.

Our initial results suggest that foliar fertilization with nutrient-filled liposomes has the potential to restore Ca and Mg deficiencies in Nordmann fir, thereby improving their growth and ensuring their marketability as Christmas trees. Since liposomes are fully biodegradable, this is a sustainable strategy that can reduce the amount of fertilizer needed, thereby reducing the risk of soil and groundwater contamination, while effectively restoring mineral deficiencies in a fast and targeted manner.

Precision growing of Christmas trees (PRECITREE) – a new project

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PRECITREE will develop high-tech precision cultivation of Christmas trees, where each individual tree is assigned fertilizers and insecticides according to individual needs. In traditional Christmas tree production, these are usually applied uniformly over the entire growing area.

The project will

1) Use drone-based measurements of tree growth and insect damage.

2) Use tree growth as an indicator of soil quality.

3) Generate knowledge about Christmas trees' fertilizer needs.

4) Develop models for insect control.

5) Use statistical data modelling to produce card material for individual fertilization and insect control.

6) Implement the above in the form of software and equipment for mounting on machines and tools.

The project combines cultivation experience (Danish Christmas Tree Association) with the competences of two research institutions specialized in Christmas tree biology and cultivation (IGN), and high-tech agricultural engineering (PLEN), respectively. This will be coupled with the latest technology within machine applications (Thorsen Teknik) and Christmas tree equipment (Jutek). The equipment is tested and demonstrated with growers and in collaboration with forestry contractors, so that the concept can be spread to the entire industry.

PRECITREE is an interdisciplinary project which will benefit the cultivation economy, but also the water environment, groundwater and biodiversity - because of substantially less use of insecticides and fertilisers. Increased sustainability in Danish Christmas tree production will be central to maintaining and developing export markets. The project is financially supported by The Green Development and Demonstration Program [Grønt Udviklings- og Demonstrations program (GUDP)—Grant number: 34009-24-2274].