camcore

Global partners for the future of our forests

2017 Annual Report

NC STATE UNIVERSITY

2017 CAMCORE ANNUAL REPORT

International Tree Breeding and Gene Conservation

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EXECUTIVE SUMMARY

1. In 2017, Camcore membership expanded into new parts of the world. New members Miro Forestry Ghana and Miro Forestry Sierra Leone are our first members in West Africa, and are interested in *Eucalyptus pellita*, *Corymbia*, *Gmelina*, *Acacia*, and possibly teak. Both companies are relatively new greenfield operations growing timber for the domestic market in both countries. In addition, in 2017 Camcore added Sinar Mas Forestry (SMF) in Indonesia as a member. SMF grows tropical eucalpyts, primarily *E. pellita*, and *Acacia*, producing pulp and paper for Asian markets.

2. The third year of harvesting cones for the *P. patula* x *P. tecunumannii* hybrid breeding program was completed in 2017. Cones were harvested from a total of 167 unique full-sib hybrid families. Progress continues on the *P. tecunumanii* x *P. greggii* hybrid breeding program, with the second year of crossing completed with 52 unique full-sib hybrid families.

3. In 2016, seed was distributed from the *Eucalyptus* hybrid breeding effort, and in 2017, members from Chile, Colombia and South Africa planted early seedling selection blocks for initial screening of genotypes to move into clonal testing.

4. The Camcore global eucalypt NIR model was expanded with the addition of *E. grandis* samples from Martha Salas' M.S. research project. This will make our already good NIR models even more useful and robust. Martha completed her M.S. thesis on the genetic control of growth and wood properties in a population of *E. grandis* clones.

5. A project to transfer the global NIR models from the Camcore NIR spectrometer to a different NIR scanner owned by Mondi Forests was sucessful, and demonstrates that model development work by Camcore or members can be easily shared with other members.

6. Research demonstrated a very strong correlation between NIR chemical predicitons based on drill shavings from standing trees and breast -height wedges.

7. Wood samples were taken from a set of nine *Eucalyptus* and *Corymbia* species in trials in Uruguay and assessed for wood chemistry, timber stiffness as measured with acoustic velocity, and density as measured with the Resistograph. The species *E. smithii*, *C. citriodora* and *C. maculata* were shown to have very good properties for most important traits.

8. A set of 12 *Eucalyptus* species was evaluated for tolerance to *Austropuccinia psidii* in an artificial screening study conducted in Uruguay in collaboration with INIA. *E. benthamii*, *E. badjensis*, *E. longiostrata*, and *E. brassiana* were the most tolerant species in this study.

9. Andy Whittier completed his M.S. thesis research on nutrient deficiency symptoms in teak seedlings. Nitrogen, copper and potassium deficiencies are visible relatively quickly, while deficiencies of magnesium and molybdenum appear very slowly. A photographic guide will be prepared and distributed in 2018. Useful NIR models were developed to predict nitrogen, phosphorus, potassium and boron content in foliage samples. Models with the desktop NIR using dried foliage were very good, and models using live green foliage with a handheld NIR model were satisfactory.

10. The relationship between Resistograph and density was examined in a *P. taeda* population using a number of clones. Ring-by-ring density was measured with X-ray densitometry and was compared with ring-by-ring resistance. There was a strong linear relationship, with $R^2 = 0.83$.

11. Camcore staff taught courses in R statistical software programming and genetic analysis in Argentina, Venezuela, Chile and South Africa, and a three-day tree improvement shortcourse in Colombia with 40 students in attendance from a number of universities and forestry companies.

12. Camcore USA conservation work continues to attract new grant funding totaling $173,581 and much positive publicity. In 2017, we completed seed collections for five species (*Fraxinus quadrangulata*, *F. texensis*, *Abies fraseri*, *Picea rubens*, and *Tsuga caroliniana*). Initial trends from our hemlock seedling restoration study in western NC indicate that eastern hemlock benefits greatly from growing in full sunlight in canopy gaps.

RESUMEN EJECUTIVO (Español)

1. En el 2017 la membresía de Camcore se expandió a nuevas partes del mundo. Los nuevos miembros Miro Forestry Ghana y Miro Forestry Sierra Leona son nuestros primeros miembros en Africa Occidental y están interesados en *Eucalyptus pellita*, *Corymbia*, *Gmelina*, *Acacia*, y posiblemente teca. Ambas compañías son proyectos relativamente nuevos en sus operaciones (greenfield operations) produciendo madera para el mercado doméstico en ambos países. Adicionalmente, en el 2017 Sinar Mas Forestry se afilió como nuevo miembro de Camcore en Indonesia. Sinar Mas Forestry planta eucaliptos tropicales, principalmente *E. pellita*, y *Acacia*, produciendo pulpa y papel para los mercados asiáticos.

2. En el 2017 se completó el tercer año de cosecha de conos del programa de híbridos de *P. patula* x *P. tecunumanii* y se cosecharon conos de un total de 167 familias únicas de hermanos completos. Sigue avanzando el programa con el híbrido de *P. tecunumanii* x *P. greggii*, completando el segundo año de cruzamientos con 52 familias únicas de hermanos completos.

3. En el 2016 se distribuyó la semilla producida con cruzamientos de híbridos de eucaliptos y en el 2017, miembros de Chile, Colombia, y Sudáfrica plantaron bloques de selección de plántulas para el evaluación temprana de genotipos a ser llevados a ensayos clonales.

4. El modelo global NIR de eucaliptos de Camcore se expandió con la adición de las muestras de *E. grandis* del proyecto de investigación de Martha Salas. Esto hará que nuestro buen modelo NIR sea más útil y robusto. Martha Salas completó su tesis de maestría en ciencias en el control genético del crecimiento y las propiedades de la madera en una población de clones de *E. grandis*.

5. Un proyecto para transferir los modelos NIR globales del espectrómetro de Camcore a una máquina NIR propiedad de Mondi fue exitoso, y demuestra que el trabajo de desarrollo de modelos por parte de Camcore o sus miembros puede ser fácilmente compartido con otros miembros.

6. Investigaciones demostraron una alta correlación entre las predicciones NIR de la composición química de la madera basadas en virutas extraídas con taladro de árboles en pie y cuñas tomadas a la altura del pecho.

7. En ensayos en Uruguay se tomaron muestras de madera de un conjunto de especies de *Eucalyptus* y *Corymbia* y se evaluaron por su composición química, su rigidez medida con velocidad acústica, y su densidad medida con el resistrógrafo. Las especies *Eucalyptus smithii*, *Corymbia citriodora*, y *C. maculata* mostraron muy buenas propiedades para las características mas importantes.

8. Un conjunto de 12 especies de *Eucalyptus* fue evaluado por tolerancia al *Austropuccinia psidii* en un estudio de detección artificial conducido en Uruguay en colaboración con el INIA. *Eucalyptus benthamii*, *E. badjensis*, *E. longirostrata*, y *E. brassiana* fueron las especies más tolerante en el estudio.

9. Andy Whittier completó su tesis de maestría en ciencias en deficiencias nutricionales de plántulas de teca. Las deficiencias de nitrógeno, cobre y potasio son visibles relativamente rápido, mientras que las deficiencias de magnesio, y molibdeno aparecen muy lentamente. Una guía fotográfica será preparada y distribuida en el 2018. Se desarrollaron modelos NIR muy útiles para predecir el contenido de nitrógeno, fósforo, potasio y boro en muestras foliares. Los modelos con el NIR de escritorio para hojas secas fueron muy buenos, y los modelos que usaron follaje verde vivo con el NIR portátil fueron satisfactorios.

10. La relación entre el resistógrafo y la densidad de la madera en una población de *P. taeda* fue examinada usando varios clones. La densidad anillo por anillo fue medida con el densitómetro de rayos X y fue comparada con la resistencia anillo por anillo. Hubo una relación lineal fuerte con un $R^2 = 0.83$.

11. El personal de Camcore enseñó cursos en el lenguaje de programación estadística R y análisis genético en Argentina, Venezuela, Chile y Sudáfrica y un curso corto de tres días en mejoramiento genético de árboles en Colombia con 40 estudiantes de varias universidades y compañías forestales.

12. El trabajo de conservación en los Estados Unidos continúa atrayendo más fondos por valor total de $173,581 dólares y mucha publicidad positiva. En el 2017, completamos colecciones de semillas de cinco especies (*Fraxinus quadrangulata*, *F. texensis*, *Abies fraseri*, *Picea rubens*, y *Tsuga caroliniana*). Tendencias iniciales de nuestro estudio de restauración de plántulas de hemlock en el occidente de Carolina del Norte indican que el eastern hemlock se beneficia grandemente al crecer a plena exposición solar en los claros del dosel.

RESUMO EXECUTIVO (Português)

1. Em 2017, a associação Camcore se expandiu para novas partes do mundo. Os novos membros Miro Forestry Gana e Miro Forestry Sierra Leone são nossos primeiros membros na África Ocidental e estão interessados em *Eucalyptus pellita, Corymbia, Gmelina, Acacia* e, possivelmente, teca. Ambas as empresas são projetos relativamente novos em suas operações (operações greenfield) produzindo madeira para o mercado interno em ambos os países. Além disso, em 2017, Sinar Mas Forestry se juntou como novo membro da Camcore na Indonésia. Sinar Mas Forestry planta eucaliptos tropicais, principalmente *E. pellita* e *Acacia*, produzindo polpa e papel para mercados asiáticos.

2. Em 2017, o terceiro ano de colheita de cones do programa de híbridos de *P. patula* x *P. tecunumanii* foi concluído e os cones foram colhidos de um total de 167 famílias únicas de irmãos completos. O programa continua com o híbrido de *P. tecunumanii* x *P. greggii*, completando o segundo ano de cruzamentos com 52 famílias únicas de irmãos completos

3. Em 2016, a semente produzida com cruzamentos de híbridos de eucalipto foi distribuída e, em 2017, membros do Chile, Colômbia e África do Sul plantaram blocos de seleção de mudas para a avaliação precoce de genótipos a serem levados a ensaios clonais.

4. O modelo NIR global do eucalipto Camcore expandiu se com a adição de amostras de *E. grandis* do projeto de pesquisa de Martha Salas. Isso tornará nosso modelo NIR bom mais útil e robusto. Martha completou sua tese de mestrado no controle genético do crescimento e propriedades da madeira em uma população de clones *E. grandis.*

5. Um projeto para transferir os modelos NIR globais do espectrômetro Camcore para uma máquina NIR de propriedade da Mondi foi bem sucedido e demonstra que o trabalho de desenvolvimento do modelo da Camcore ou seus membros pode ser facilmente compartilhado com outros membros.

6. As investigações mostraram uma alta correlação entre as previsões NIR da composição química da madeira com base em pastilhas extraídas com broca de árvores em pé e cunhas colhidas na altura do peito.

7. Em ensaios no Uruguai, amostras de madeira foram retiradas de um conjunto de espécies de *Eucalyptus* e *Corymbia* e avaliaram sua composição química, sua rigidez medida com velocidade acústica e sua densidade medida com o resistômetro. A espécie *Eucalyptus smithii, Corymbia citriodora* e *C. maculata* apresentaram propriedades muito boas para as características mais importantes.

8. Um conjunto de 12 espécies de eucalipto foi avaliado quanto à tolerância a *Austropuccinia psidii* em um estudo de detecção artificial conduzido no Uruguai em colaboração com o INIA. *Eucalyptus benthamii, E. badjensis, E. longirostrata* e *E. brassiana* foram as espécies mais tolerantes no estudo.

9. Andy Whittier completou sua tese de mestrado em deficiências nutricionais de mudas de teca. As deficiências de nitrogênio, cobre e potássio são visíveis relativamente rapidamente, enquanto as deficiências de magnésio e molibdênio aparecem muito lentamente. Um guia fotográfico será preparado e distribuído em 2018. Modelos NIR muito úteis foram desenvolvidos para prever o conteúdo de nitrogênio, fósforo, potássio e boro em amostras foliares. Os modelos com o NIR de mesa para folhas secas foram muito bons e os modelos que usavam folhagem verde viva com o NIR portátil foram satisfatórios.

10. A relação entre o resistografista e a densidade da madeira em uma população de *P. taeda* foi examinada com vários clones. A densidade anelar por anel foi medida com o densitômetro de raios-X e comparada com a resistência anel por anel. Houve uma forte relação linear com $R^2 = 0,83$.

11. A equipe da Camcore ensinou cursos na linguagem de programação estatística R e análise genética na Argentina, Venezuela, Chile e África do Sul e um breve curso de três dias de aprimoramento genético de árvores em Colômbia com 40 estudantes de várias universidades e empresas florestais.

12. O trabalho de conservação nos Estados Unidos continua a atrair mais fundos totalizando US $ 173.581 e muita publicidade positiva. Em 2017, concluímos coleções de sementes de cinco espécies (*Fraxinus quadrangulata, F. texensis, Abies fraseri, Picea rubens* e *Tsuga caroliniana*). As primeiras tendências do nosso estudo sobre a restauração de mudas de cicuta no oeste da Carolina do Norte indicam que a cicuta do leste beneficia grandemente ao crescer em plena exposição solar nos claros do dossel.

MUHTASARI WA TAARIFA KUU (Kiswahili)

1. Camcore ilipanua uanachama katika sehemu mpya za dunia Mwaka wa 2017. Wanachama wapya Miro Forestry kutoka Ghana na Miro Forestry kutoka Sierra Leone ni wanachama wetu wa kwanza katika Afrika Magharibi, wanavutiwa na *Eucalyptus pellita, Corymbia, Gmelina, Acacia*, na mvule. Makampuni hayo yote ni mageni kwenye shughuli za green field za kupanda miti kwa soko la ndani katika nchi zote mbili. Aidha, mwaka wa 2017 Camcore imeongeza Sinar Mas Forestry (SMF) nchini Indonesia kuwa mwanachama. SMF inakuza eucalpyts ya kitropiki, hasa *E. pellita*, na *Acacia*, huzalisha massa na karatasi kwa masoko ya Asia.

2. Mwaka wa tatu wa mpango wa uzalishaji wa mseto wa *P. patula x P. tecunumanni* ulikamilishwa mwaka 2017, na mbegu mseto zimevunwa kutoka familia mia themanini na sita (167) ya uzazi kamili. Mpango wa uzalishaji wa *P. tecunumanii x P. greggii* unaendelea, na mwaka wa pili wa uzalishaji wa mseto kukamilika kwa familia hamsini na mbili (52) za kipekee.

3. Mnamo mwaka wa 2016, mbegu za uzalishaji wa mseto wa *Eucalyptus* zilisambazwa, na mwaka wa 2017, wanachama kutoka Chile, Colombia, na Afrika Kusini walipanda mapema vitalu vya uteuzi wa miche kwa uchunguzi wa awali wa genotypes halafu uchunguzi wa clone uanze.

4. Mfano wa Camcore NIR wa *Eucalyptus* ulimwenguni ulipanuliwa kwa kuongezwa kwa sampuli za *E. grandis* kutoka kwa mradi wa utafiti wa Martha Salas M.S. Hii itafanya mifano yetu mizuri ya NIR iwe bora zaidi na imara. Martha Salas alikamilisha utafiti wake wa M.S. (thesis). katika udhibiti wa maumbile ya ukuaji kwenye idadi kubwa ya clone za *E. grandis*.

5. Mradi wa kuhamisha mifano za kimataifa za NIR kutokana na spectrometer ya Camcore hadi skana tofauti ya NIR inayomilikiwa na Mondi Forests ulifaulu na hiyo inathibitisha kuwa mfano wa Camcore ua wanachama wake unaweza sambazwa kwa wanachama wengine

6. Utafiti ulionyesha uwiano mkubwa katika utabiri wa kemikali ya NIR kulingana na uchongagji wa miti na matawi ya miti katika kimo cha wastani

7. Sampuli za mbao zilichukuliwa kutoka kwa seti ya aina tisa za *Eucalyptus* na *Corymbia* kwenye majaribio nchini Uruguay na kutathmini kemia ya kuni, ugumu wa mbao, velocity, na wiani kama ilivyopimwa na resistograph. Aina *E. smithii, C. citriodora* na *C. maculata* zimeonyesha mtindo muhimu zaidi.

8. Mkusanyiko wa aina kumi na mbili (12) za *Eucalyptus* imetathminiwa kwa uvumilivu kulinganisha na *Austropuccinia psidii* katika utafiti wa uchunguzi uliofanywa nchini Uruguay kwa ushirikiano na INIA. *E. benthamii, E. badjensis, E. longiostrata*, na *E. brassiana* ni aina zenye kuvumilia zaidi katika utafiti huu.

9. Andy Whittier alikamilisha utafiti wake wa M.S (thesis) kuhusu dalili za upungufu wa virutubisho katika miche ya Mvule. Ukosefu wa nitrojeni, shaba na potasiamu huonekana kwa haraka, wakati upungufu wa magnesiamu na molybdenum huonekana polepole sana. Picha itatayarishwa na kusambazwa mwaka wa 2018. Mfano muhimu wa NIR umeandaliwa kutabiri nitrojeni, fosforasi, potasiamu na boroni maudhui kutoka kwenye sampuli za majani. Mfano wa NIR ulikuwa wa kuridhisha. Mifano ya meza kutumia majani yaliokaushwa ilikuwa bora na mifano ya majani mabichi yaliyoshikilwa kwenye NIR ya mkono iliridhisha.

10. Uhusiano kati ya upinzani na wiani ulifuatiwa kwenye *P. taeda* kwa kutumia clones nyingi. Uzito wa pete-kwa-pete ulipimwa na densitometri ya X-ray na ikilinganishwa na upinzani wa pete-kwa-pete. Kulikuwa na uhusiano mzuri, ukiwa $R^2 = 0.83$.

11. Wafanyi kazi wa Camcore walifunza kozi ya programu R ya takwimu za uchambuzi wa maumbile huko Argentina na Afrika Kusini, na kozi fupi ya siku tatu ya kuboresha miti huko Colombia kwa wanafunzi arobaini (40) waliotoka vyuo vikuu na makampuni ya misitu

12. Kazi nzuri ya uhifadhi ya Camcore kanda ya USA inaendelea kuvutia ufadhili mpya kufikia takriban dola 173,581 na pia utangazaji mzuri. Mnamo mwaka wa 2017 tulimaliza ukusanyaji wa mbegi za aina 5 ya miti *(Fraxinus quadrangulata, F. texensis, Abies fraseri, Picea rubens*, na *Tsuga caroliniana)*. Mwelekeo wa awali wa urejesho wa miche wa hemlock huko western NC unaonyesha kuwa eneo la mashariki la hemlock linafaidi sana kukua kwenye jua kati ya nafasi zilizofunikwa.

RINGKASAN EKSEKUTIF (Bahasa Indonesia)

1. Pada tahun 2017, keanggotaan Camcore di seluruh dunia memasuki babak baru. Miro Forestry Ghana dan Miro Forestry Sierra Leone merupakan anggota pertama yang berasal dari Afrika Barat yang berminat dalam pengembangan *Eucalyptus pellita*, *Corymbia*, *Gmelina*, *Acacia* dan juga Jati. Kedua perusahaan tersebut merupakan perusahaan yang relatif baru dalam penanaman jenis kayu untuk kebutuhan pasar domestik di negaranya. Selain itu, pada tahun 2017, Camcore juga menambahkan Sinar Mas Forestry yang terletak di Indonesia sebagai salah satu anggotanya. SMF mengembangkan jenis *Eucalyptus* tropis, terutama *E. pellita* dan *Acacia* untuk memproduksi bubur kertas dan kertas bagi pangsa pasar di Asia.

2. Persilangan tanaman jenis *Pinus patula* x *P. tecunumanii* dalam program persilangan hibrid telah selesai pada tahun 2017 sebagai tahun ketiga program tersebut, dan buah *Pinus* sudah dipanen sebanyak 167 famili full-sib hibrid yang unik. Program hybridisasi ini kemudian dilanjutkan pada persilangan antara *P. tecunumanii* x *P. greggii*, dimana telah memasuki tahun kedua program persilangan dengan menggunakan 52 famili full-sib hybrid dengan ciri khas tertentu.

3. Pada tahun 2016, benih sudah didistribusikan melalui program *Eucalyptus* hybrid, dan pada tahun 2017, Chile, Colombia, dan Afrika Selatan membangun blok pertanaman sebagai awal seleksi genotip untuk beralih ke pengujian klon.

4. Model NIR *Eucalyptus* Camcore secara global telah diperluas dengan penambahan sampel *E. grandis* dari proyek penelitian Martha Salas, M.S. Proyek ini akan membuat model NIR yang sudah bagus menjadi lebih berguna dan kokoh. Martha Salas menyelesaikan program Masternya dengan tesis tentang pengendalian genetik pertumbuhan dan sifat kayu pada populasi klon *E. grandis*.

5. Sebuah proyek untuk mentransfer model global NIR dari spektrometer NIR Camcore ke pemindai NIR yang berbeda yang dimiliki oleh Mondi Forest telah dinyatakan berhasil, dan menunjukkan bahwa pengembangan model oleh Camcore atau anggota-anggotanya dapat dengan mudah dibagikan kepada anggota lainnya.

6. Penelitian menunjukkan korelasi yang sangat kuat antara prediksi kimia NIR berdasarkan serbuk bor dari tegakan pohon dan pola setinggi dada.

7. Dalam percobaan di Uruguay, beberapa sampel kayu diambil dari sekumpulan yang terdiri dari sembilan spesies *Eucalyptus* dan *Corymbia* dan diteliti sifat kimia kayunya, kekakuan kayu diukur dengan kecepatan akustik, dan densitas diukur dengan resistograf. Spesies *E. smithii*, *C. citriodora* dan *C. maculata* terbukti memiliki sifat yang sangat baik pada parameter utama.

8. Satu set dari 12 spesies *Eucalyptus* dievaluasi mengenai toleransinya terhadap *Austropuccinia psidii* dalam studi seleksi buatan yang dilakukan di Uruguay dalam rangka kerjasama dengan INIA. *E. benthamii*, *E. badjensis*, *E. longiostrata*, dan *E. brassiana* adalah spesies yang paling toleran dalam penelitian ini.

9. Andy Whittier menyelesaikan program pasca sarjana dengan tesis tentang gejala kekurangan nutrisi pada bibit Jati. Kekurangan Nitrogen, Tembaga dan Kalium terlihat relatif cepat, sementara defisiensi Magnesium dan Molibdenum tampak sangat lambat. Panduan fotografi akan disiapkan dan didistribusikan pada tahun 2018. Model NIR telah dikembangkan untuk memprediksi kandungan Nitrogen, Fosfor, Potassium dan Boron dari sampel daun. Beberapa model dengan tampilan menggunakan daun kering memberikan hasil yang sangat bagus, dan model NIR genggam dengan menggunakan daun hijau segar memberikan hasil yang memuaskan.

10. Hubungan antara Resistograph dan densitas diuji pada populasi *P. taeda* dengan menggunakan sejumlah klon. Kerapatan antar lingkaran tahun diukur dengan densitometri sinar-X dan dibandingkan dengan jarak antar lingkaran tahun. Ada hubungan linier yang kuat antara $R^2 = 0{,}83$.

11. Staf Camcore mengajarkan mata kuliah program perangkat lunak statistik R dan analisa genetika di Argentina dan Afrika Selatan, serta mengadakan pelatihan singkat selama tiga hari di Kolombia dengan jumlah peserta yang hadir sebanyak 40 siswa dari beberapa universitas dan perusahaan kehutanan.

12. Konservasi Camcore USA terus bekerja untuk memperoleh dana hibah baru sebesar $173.581 dan banyak publikasi yang positif. Pada tahun 2017, Camcore menyelesaikan koleksi benih untuk lima spesies (*Fraxinus quadrangulata*, *F. texensis*, *Abies fraseri*, *Picea rubens*, dan *Tsuga caroliniana*). Kecenderungan awal dari penelitian restorasi bibit hemlock di NC barat menunjukkan bahwa hemlock timur memberikan keuntungan besar jika mendapatkan sinar matahari penuh di beberapa celah antar kanopi.

Message From the Director

Camcore completed its 37th year in 2017, an interesting year of both change and continuity.

For most of our history, Camcore membership has been concentrated in South America and southern and eastern Africa. In 2017, Camcore gained its first member organizations in West Africa: Miro Forestry Ghana and Miro Forestry Sierra Leone. The history of forestry in these countries is similar to ones we have heard many times before in other parts of the world. Over the past century Ghana has lost 85% of its forest cover due to agricultural conversion and excessive logging without replanting. Sierra Leone has a similar story, with the loss of forest exacerbated in recent years by a civil war from 1991 to 2002. These countries now have growing economies, with a strong internal demand for wood products, and an increased understanding of the value of plantation forestry to meet these needs. Camcore's genetic resources of tropical eucalypts, teak and gmelina are well suited for commercial forestry in West Africa.

Worldwide, fast-growing industrial plantations make up only 1.4% of total forest area, but produce 21% of the total world wood harvest.

Also in 2017, we gained a new member in Indonesia, Sinar Mas Forestry (SMF), one of the largest forestry companies in the world. SMF has traditionally focused on *Acacia* plantations, but the company plans to expand its production of tropical eucalypts in the future. In addition to SMF, at the end of 2017 the Advisory Board approved another large Indonesian company, the APRIL Group, to become a member beginning in 2018. The inclusion of an array of eucalypt species into our portfolio over the past 20 years has positioned Camcore to attract a broader array of forestry companies into membership.

In 2017, we made substantial progress in a number of ongoing breeding and research projects. The final harvest of seed for the *P. patula* x *P. tecunumanii* breeding project was completed, and propagation and test establishment will begin in 2018. The second year of crossing for the *P. tecunumanii* x *P. greggii* breeding project was completed. In the eucalypt hybrid breeding project, seedling-to-clone selection blocks were established by a number of members, and propagation for clonal tests should begin in 2018. We improved our NIR models for eucalypts, and learned more about the Resistograph to measure density. In the first results from our *Eucalyptus* disease screening project, we learned something about the tolerance of various eucalpyt species to *Austropuccinia psidii*. We added more data to our initiative to characterize all of our eucalypt species for important wood properties. Camcore graduate students Martha Salas and Andy Whittier completed M.S. degrees, and Camcore staff contributed to the training of new tree breeders around the world, teaching both university classes and shortcourses in tree breeding and data analysis.

We live in an ever-changing world. Many Camcore member countries are facing political and social challenges. The economic future is uncertain, with new technolgies creating new products, new opportunities, and new competitors. Uncertainty about future climate means that forestry organizations must have alternative species options available, species that can handle a range of possible limiting factors (e.g., increased drought, increased frost events, new pests). Accomplishment of any worthwhile goal requires many small steps; faithful, day-by-day, consistent progress. As tree breeders, we continue to establish genetic tests and identify well-adapted species and superior genotypes, knowing that, in the long run, we will make important and valuable genetic gains. As foresters, we continue to plant trees, year by year, knowing that they will grow, and trusting that the wood we grow will be used for valuable products and needed energy. According to data from FAO and FSC, fast-growing industrial plantations (the kinds of plantations that Camcore members establish) make up only 1.4% of total world forest area, but they produce 21% of the total world wood harvest. What we do is important. It is a wonderful bonus that our jobs as foresters and tree breeders are also interesting and enjoyable. I look forward to working with all of you in 2018.

Gary Hodge, Director

2017 Camcore Membership

Active & Associate Members

Argentina
- Arauco Argentina SA 1999
- Bosques del Plata, SA 2004

Brazil
- ArborGen do Brasil (Associate) 2013
- Klabin, SA 1987
- WestRock Brazil 1993

Chile
- Arauco Bioforest 1991
- CMPC Forestal Mininco 1991

China
- Guangdong Academy of Forestry (Associate) 2013

Colombia
- Tekia, SA 2010
- Forestal Monterrey Colombia SAS 1983
- Smurfit Kappa Colombia, SA 1980

Ghana
- Miro Forestry Ghana 2017

Guatemala
- Grupo DeGuate (Associate) 2006

Indonesia
- Sinar Mas Forestry 2017

Kenya
- Kenya Partnership 2005
  Kenya Forest Research Institute
  Tree Biotechnology Programme Trust

Mexico
- Proteak Uno SA de CV 2011
- Uumbal Agroforestal 2012

Mozambique
- Florestas de Niassa Limitada 2010
- Green Resources AS - Moçambique 2012

Republic of South Africa
- MTO|group Ltd 2006
- Merensky Pty Ltd 2004
- Mondi South Africa 1988
- PG Bison Holdings Pty Ltd 2006
- SAFCOL 1983
- Sappi Forests 1988
- York Timbers 2010

Sierra Leone
- Miro Forestry Sierra Leone 2017

Tanzania
- Green Resources AS - Tanzania 2013

United States of America
- USDA Forest Service (Associate) 2006

Uruguay
- Montes del Plata - EuFores SA 2006
- Weyerhaeuser Company 1980

Venezuela
- Masisa Terranova de Venezuela, SA 2000
- Smurfit Kappa Venezuela, SA 1986

Honorary Members

Belize, Ministry of Agriculture, Forestry, Fisheries, the Environment, Sustainable Development, and Immigration

El Salvador
- Centro Nacional de Tecnología Agropecuaria (CENTA)

Guatemala
- Instituto Nacional de Bosques (INAB)

Honduras
- Universidad ESNACIFOR

Mexico
- Instituto de Genética Forestal, Universidad Veracruzana
- Instituto Nacional de Investigaciones Forestales y Agropecuarias (INIFAP)

Nicaragua
- Instituto Nacional Forestal (INAFOR)

The 2017 Annual Meeting in Sweden

The forestry industry has a prominent role in Sweden and is visible in the national economy and the lives of private citizens. Forests occupy 70% of the land and 80% of these are managed. This gives the country well under 1% of the world's productive forests, yet the country produces from 5 to 8% of the world's wood in several important product categories and for some of these, ranks third in global exports. These achievements are even more impressive considering rotation ages are 100 years or more and mean annual increments average only 3 to 8 m^3/h/year, depending on species and region. This success has roots in the 1903 National Forest Act that instituted strict guidelines for harvesting and regeneration. Governmental policies have been modified over time as social objectives, environmental conditions, and biological knowledge have evolved. With the goal of achieving "an acceptable rate of return" on investment, rather than the maximum, Swedish forest companies are able to provide benefits to their owners and the entire country.

Camcore chose Sweden for the 2017 annual meeting because the forestry industry has been a leader in several areas of research. Tree breeding has some different challenges given the long rotation ages. Camcore members typically work with many species, but in Sweden research is highly focused on two dominant species (*Pinus sylvestris* and *Picea abies,* with *Betula* 3rd but less important). Sweden was also attractive because Camcore and NC State University have long-standing relationships with several Swedish academic institutions and have had an interchange of students and researchers.

The Camcore group convened in Stockholm for the welcome dinner and the first technical session. After a couple of days, we headed north by bus to Sundsvall and were hosted by SCA (Svenska Cellulosa AB) and given tours of their seed processing and nursery facilities at NorrPlant. This nursery produced almost 80 million seedlings in 2016. We also visited the Bollsta sawmill, one of SCA's five in Sweden, that has a capacity of 560,000 m^3/yr. Working with pine, the mill's main products are edge-glued panels, glulam, solid flooring and window and door frames. These and

The Camcore group at the Dag Lindgren Lektionssal. Dag is in center of the back row.

other products are exported to over 30 countries. The company exhibits high-efficiency use of by-products: chips are used for pulp, sawdust and shavings for heating pellets, and bark for biofuel.

Continuing north, the group landed in Örnskoldsvik. Don't even try [œɳɧœldsˈviːk], just pronounce it "eu-vik", like the locals! The schedule allowed for some sightseeing: after a ferry ride to the quaint island of Trysunda, we did some hiking in the high-coast region. Some hiked in the Skuleshogens National Park and others at the nearby mountain Skuleberget. Both provided beautiful panoramas of the coastal area and contact with unmanaged forests. The second half of the trip was based in Umeå (Ew-may-o) where we had several technical sessions and outings to a variety of forestry sites. We first visited Sävar, a research station of Skogforsk, the Swedish "forest service", where we were met by Station Chief Bengt Andersson. After a couple of informative presentations, we saw nursery facilities and their custom-designed seed processing facilities. The station extracts and tests seeds for the forestry industry. It applies a variety of treatments to "invigorate" the seeds for higher germination and to prepare seeds for long-term storage. One of the most interesting and sophisticated processes used is "water uptake sorting". Seeds are submerged in a large tank of flowing water and are sorted by size and density, which helps predict viability. Each category can be tested

Harvesting at a testing site of Vimek. These trees are 60 to 70 years old.

for germination and seedling vigor. The group moved outdoors to the Dag Lindgren Lektionssal, a demonstration planting to show the value of breeding and selection using blocks of trees from various levels of improvement. We were fortunate to have been guided by Dag himself, a world-renowned tree breeder and namesake of the plot. SweTree Technologies in Umeå hosted our next visit. This organization is owned by a number of companies and is dedicated to research in biotechnology related to several aspects of forestry, including developing gene technology, clonal production methods, plant nutrition and the creation of new materials. We visited various lab facilities and field trials that demonstrated many new and promising technologies. On the road again, we traveled to Vindeln to visit Vimek, a manufacturer of specialized harvesting equipment. The smaller-scale tractors and harvesters they build are especially suited to navigating dense plantations and handling small-diameter stems without damaging the site. Our most northerly stop was in Bygdsiljum to visit a Martinsons sawmill. This company has a long history of producing sawn wood in Sweden and today uses 1 million m^3 of pine and spruce logs. It began producing glulam in 1960 and more recently, has been specializing in cross-laminated timber (CLT). Using CLT, entire walls of structures can be prefabricated at the mill, complete with holes drilled for wiring and cut outs for doors and windows. These units increase the speed of construction and have been used in multi-floor buildings and wide-span bridges. Apartment buildings with seven floors have been built and plans for over 10 stories have already been made.

The trip to Sweden gave our group members exposure to different weather, tree species, and a different relationship of forestry with the people. Over half of the forests are owned by private citizens, so the Swedish public has a very high level of interest, understanding, and engagement in forest management. It was a pleasure to travel in a country where the forestry profession is respected by the general population and the challenge of balancing timber production with environmental concerns and quality of life seems to be a national dialogue rather than a confrontation.

As usual, we want to thank all the companies mentioned above for hosting our visits. In addition, we want to the thank the Nicholson Fund at NCSU for providing additional funding toward the meeting. Finally, very special thanks go to Bengt Andersson, Dag Lindgren, Harry Wu, Ola Lindroos, and Daniel Grans for all of their help in organizing speakers, field visits, and logistical arrangements, making our visit to Sweden an interesting and memorable experience.

Trysunda, a popular tourist and vacation town, seen from the ferry.

Part of the cross-laminated-timber (CLT) production line at Martinsons sawmill in Bygdsiljum.

Developments in Camcore

As always, Camcore staff spent much of the year making visits to members to discuss breeding strategies and to assist with ongoing research projects. Below is a brief summary of these visits and other developments.

Argentina

Gary Hodge and Juan José Acosta visited **Arauco Argentina** in April. We visited clonal tests and commercial plantations of willow (*Salix nigra*, *S. matsudana* x *S. alba*) and poplar (*Populus deltoides* x *P. nigra*), and some Camcore eucalypt studies located in the Delta region where the company has approximately 30,000 ha. There is potential for a substantial bioenergy market in Argentina, as well as options to use willow for particleboard and medium density fiberboard.

Gary and Juan José visited **Bosques del Plata** in April. The hybrid *P. greggii* x *P. tecunumanii* HE from the second series is showing great commercial potential. At 3 years, its volume is equal to that of highly improved *P. taeda*, with better branch diameter and crown architecture. Pure species *P. greggii* is also showing good potential as an alternative to *P. taeda*. In a Camcore 2nd generation study, we observed that some families have mean tree volume similar to the best control lots. It is also important to note that the company can produce *P. greggii* seedlings in half the time it takes to produce *P. taeda*. We have identified selection candidates for this species to move forward in the breeding cycle.

Ricardo Austin of Arauco Argentina with a 6-year-old *E. smithii* in a eucalypt benchmark study at Oasis Farm, in the Delta region of Argentina.

Brazil

In August, Juan José Acosta visited **Klabin.** The company recently bought a Resistograph to measure tree density in the breeding program. Juan José showed Fabricio Biernaski and his team how to use the software associated with the instrument to classify and export the data. In their brand new Technology Center, Juan José had productive discussions with Mario Ladeira and Fabricio about Klabin's pine breeding program. The company is defining work priorities for *P. maximinoi* and *P. tecunumanii*; special emphasis should be given to reviewing all selection candidates. Selected trees will be grafted and planted in an isolated breeding area. Juan José also explained how to use our Camcore NIR pipeline and run NIR models to predict lignin and cellulose.

Camcore visited **WestRock** in September. During Juan José's technical visit, the group discussed the use of the IML Resistograph in their breeding program and the techniques for processing data. Juan José also showed Ricardo Paím and his team how to use the R environment to calculate

Klabin's new technology center was opened in 2017.

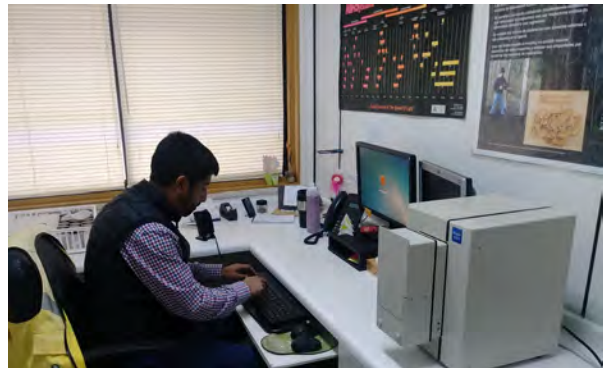
Gisela Andrejow and Waldemar Assis da Veiga of WestRock in a 2-year-old *E. benthamii* progeny study at la Formiga farm.

genetic parameters and breeding values for their trials. In 2015, WestRock established two Camcore progeny tests of *E. benthamii*. We noted that this species is performing very well in comparison to the control lots in these trials; however, attention should be paid to its form, especially forking and stem straightness.

Willi Woodbridge visited **ArborGen** in August to take samples for a wood research project. Specifically, Willi sampled trees in three 9½-year-old *P. taeda* clonal trials with the Resistograph and took increment cores for X-ray densitometry (see article in this Annual Report).

Chile

Juan José Acosta visited **Bioforest-Arauco** in December. During the trip, he met with Jaime Zapata, Ricardo Durán and Sofia Valenzuela (Universidad de Concepción) to talk about the development of the "SNP chip" for *P. radiata* and the involvement of the company. He worked with Mauricio Ramírez to explain how to run the R programs developed by Camcore to predict wood characteristics using near infrared spectroscopy. He also showed Mauricio and Simon Sandoval Camcore's methods to analyze Resistograph data. Juan José finished his visit by teaching a two-day R course to the Bioforest staff.



Mauricio Ramírez of Arauco Bioforest working with Bioforest's NIR spectrometer.

In December, Juan José also visited **CMPC** in Los Angeles. CMPC is thinking about buying an IML Resistograph for both operational and research use. Juan José gave the CMPC group a presentation about our experience with this tool and showed them the methods we use to analyze the data. Juan José also met with Rebeca Sanhueza and her team to show them our global NIR models for pines and eucalypts, and how to use the R pipeline.

Veronica Emhart, Berta Rothen, Luis Soto, Edgardo Velilla, Alex Medina (CMPC) and Juan José Acosta (Camcore) discuss Resistograph data analysis.

Colombia

Bill Dvorak and Juan José Acosta visited **Smurfit Kappa Colombia** (SKC) in March. During our visit, we inspected a provenance-progeny test of *Pinus oocarpa* located at La Cascada Farm and toured the pine conservation park in Chupillauta. Nhora Isaza and her crew have done an excellent job making grafts and establishing the trees for a number of provenances and families of *P. tecunumanii* and *P. maximinoi*. We also visited the Rancho Grande forest nursery in Restrepo and

The Smurfit Kappa Colombia gene conservation park for *P. tecunumanii* conservation in Chupillauta, near the city of Popayán, Cauca. Left to right: Juan José Acosta, Nhora Isaza, Bill Dvorak, Andrés Orozco, and Ovidio Orrego.

reviewed the design for a cutting experiment that will help refine the protocol for vegetative propagation of *P. maximinoi* and *P. tecunumanii*. We had a meeting with SKC's research group to discuss their strategic plan for the next 10 years. We also shared the results of the disease assessment study done in 2nd generation *P. tecunumanii* trials, and with the management group, we reviewed the utilization of *P. maximinoi* at SKC.

Gary Hodge visited **Tekia** in March. Due to challenges in acquiring land in Colombia, Tekia decided to scale back their teak plantation project and terminate Camcore membership. Tekia leaves as a member in good standing. Gary visited to discuss making selections in Tekia's Camcore teak trials, and arrange some logistics to transfer those selections to other Camcore members. We wish the Tekia team success in the future.

Gary also visited **Forestal Monterrey Colombia** (FMCo). Much of the visit focused on FMCo's *Pachira quinata* (red ceiba) breeding and testing program. Red ceiba is a high-quality hardwood species adapted to the hot and droughty conditions around Zambrano. The soils in this region are shrink-swell clays, and FMCo is doing some interesting research comparing cuttings and seedlings of *Gmelina* and red ceiba, as well as looking at the effects of alternative site prep, planting, and pruning regimes on survival, growth, and quality. Later in the year, Romeo Jump also visited FMCo to take Resistograph readings on *Gmelina* clonal trials to add density information to their clonal rankings.

Ghana

Gary Hodge and Juan Lopez visited **Miro Forestry Ghana** (MFGH). MFGH has 12,000 hectares under lease in Ghana, of which some 8,000 ha are plantable. To date, the company has planted about 4,500 ha with a mix of species, including *Acacia mangium*, *Gmelina arborea*, teak, and *E. pellita* and *E. grandis* x *urophylla* (GU) hybrids. Going forward, MFGH will plant mostly eucalypts, with a product objective of poles, sawtimber and veneer for the domestic market, and possibly a limited area of teak plantations for export purposes. MFGH has made preliminary selections of 54 GU clones and 74 *E. pellita* clones in their young plantations. A top priority is to establish clonal trials to improve the genetic quality of their production population. Camcore has shipped seed of 1st generation unimproved material of *E. pellita*, *E. urophylla*, and *E. camaldulensis* to MFGH, and four provenance-progeny trials were planted in 2017: two of *E. urophylla*, one of *E. pellita*, and one of *E. camaldulensis*. In 2018, we plan to provide improved genetic material of *Gmelina arborea* and *Tectona grandis* from Camcore breeding efforts in Latin America. Juan Lopez gave advice on fertilization and container type and size to improve the seedling quality in the nursery.

Halidu Gazali of Miro Forestry Ghana with a very nice teak seedling ready for planting.

Guatemala

Juan Lopez visited Guatemala in July 2017. Juan, Elmer Gutiérrez and Josué Cotzojay went to Finca Valle Verde of **Grupo DeGuate** in Retalhuleu to plan a fertilizer application trial and a seed collection for a Camcore teak progeny trial where a genetic thinning had recently been done. Seed collection by tree in this trial will allow Camcore to keep this important genetic material; more than 60 families from different sources are being tested in the study. Camcore staff also visited the seedling seed orchard of *P. tecunumanii* established by Grupo DeGuate in La Lagunilla farm in Jalapa, an excellent orchard where Guatemala will have access to improved seeds of the species. Juan also gave three lectures on tree breeding at INAB, the National Institute of Forests in Guatemala.

Elmer Guttiérez, Juan José Morales, Josué Cotzojay, and Randy Cuellar in the *P. tecunumanii* seedling seed orchard in Lagunilla, Jalapa, Guatemala.

Indonesia

Gary Hodge and Juan Lopez visited new Camcore member **Sinar Mas Forestry** (SMF) in June. SMF holds a lease on some 2 million hectares of land on the islands of Sumatra and Kalimantan as government concessions for plantation forestry. Currently, the main species for SMF are *Acacia crassicarpa* and *Eucalyptus pellita*. In the future, there is the possibility that hybrids of *E. pellita* as well as *Acacia* hybrids might play an important role for the company. In 2017, Camcore sent to SMF a number of seedlots of *E. pellita* for provenance-progeny testing. In addition, we sent some of the best 1st generation (unimproved) provenances and families of *E. urophylla*. In 2018, we plan to send 2nd generation seedlots of *E. urophylla* and *E. grandis*. In the short term, a high priority for the company will be to expand the genetic base of material being used to establish eucalypt plantations. Camcore will assist SMF to accelerate its clonal testing program and analyze data from current clonal trials already established. SMF currently plants *A. crassicarpa* as seedlings on about 66% of its landbase. Camcore will assist the company to develop strategies to identify top-performing full-sib families to be multiplied through the use of tissue culture in the R&D lab and hedges and rooted cuttings in the operational nurseries. SMF has a large and strong research team, and we hope to develop collaborative research projects in the areas of disease resistance screening and wood properties in the future.

Marius du Plessis at the PT Bukit Batu Hutani Alam nursery (Sinar Mas Forestry). The nursery produces about 10 million plants per year, mostly *Acacia crassicarpa*.

Kenya

The Kenya Partnership is a joint Camcore membership held by **Kenya Forest Research Institute** (KEFRI) and the **Tree Biotechnology Programme Trust** (TBPT). In 2017, KEFRI sent in age 5 measurement data for two hybrid pine trials and one trial each of *P. maximinoi* and *P. tecunumanii*. Both of these species have great potential in Kenya, as does the *P. patula* x *P. tecunumanii* hybrid. In 2018, Camcore will send *P. tecunumanii* pollen from Colombia and/or South Africa to KEFRI to begin making their own hybrid crosses. Kenya will participate in the second phase of the Camcore eucalypt hybrid program, with TBPT making crosses using *E. urophylla* as female parents.

Mexico

Juan Lopez visited **Proteak** in April. Camcore continues to help the company with selecting the best *Eucalyptus urophylla* and *E. pellita* families and individuals from its progeny trials. The Medium Density Fiberboard (MDF) plant is currently fed with *E. urophylla* from company plantations. Tests with *E. pellita* demonstrate the high potential of the species for wood panel production in the MDF plant. Camcore sent a list of *E. pellita* selection candidates based on the results of a multisite analysis. Juan made several recommendations for measuring wood properties in standing *Eucalyptus* and teak trees using Camcore protocols. The research team at Proteak is very enthusiastic about participating in the second phase of the Camcore *Eucalyptus* hybrid program.

Juan Lopez also visited **Uumbal** in April. Uumbal continues to make progress in its tree breeding program with several species of pine. Camcore has been providing Uumbal genetic material of species with commercial potential on company land. In the Xicotepec region, Uumbal has the opportunity to plant trees with coffee growers. Juan Lopez recommended exploring different types of agreements with third parties to expand tree planting in this area where *P. maximinoi*, *P. caribaea*, *P. oocarpa*, *P. elliottii* x *P. caribaea*, and *P. tecunumanii* grow well in coffee plantations. Juan also provided some tips to improve the outcome of grafting in *P. caribaea*. Camcore is working to help Uumbal with genetic analyses to select the best clones of the *P. elliottii* x *P. caribaea* hybrid.

Juan Lopez (Camcore), José Roberto Ricardez (Tecnotabla), Marynor Ortega, and Secundino Torres (Proteak) visit the Tecnotabla-Proteak MDF plant.

Sergio Hernandez, Carlos Gioia, Juan Quintero, and Rosa Aparicio standing by a row of control *P. elliottii* in a *P. oocarpa* progeny trial in Uumbal, Mexico.

Sierra Leone

Gary Hodge and Juan Lopez visited new member **Miro Forestry Sierra Leone** (MFSL). MFSL began operations in 2012, so it is a relatively new greenfield project. Project Manager George Catterick and Research Officer Christi Sagariya have made good progress in establishing a number of different species trials. MFSL has 21,000 hectares under lease, and there are a number of species being considered for commercial planting, including *Acacia mangium*, *Gmelina arborea*, and various eucalypt options, including *E. pellita*, *E. camaldulensis*, *E. grandis* x *E. urophylla* hybrids, and *Corymbia citriodora*. The product objectives are sawtimber, poles, and veneer, all targeted for the domestic market. MFSL has also identified some outstanding putative hybrids of *C. torelliana* x *C. citriodora* in a *C. torelliana* plantation block. MFSL is working hard to establish their first clonal trials of *E. pellita* and the *C. torelliana* x *C. citriodora* hybrids, and has begun developing a seed production area of *C. citriodora*. As with Miro Forestry Ghana, Camcore has shipped seed of 1st generation unimproved material of *E. pellita*, *E. urophylla*, and *E. camaldulensis* to MFSL. MFSL will participate in the second phase of the eucalypt hybrid breeding program, probably working on a *Corymbia* hybrid. Juan Lopez gave recommendations to improve the infrastructure of the rooting facilities to increase the rooting percentage of *Eucalyptus* species.

Christi Sagariya, Miro Forestry Sierra Leone, in a beautiful stand of *C. citriodora*. MFSL is developing a seed production area from this material.

South Africa

Juan Lopez visited **MTO** in the lowveld area where the company plants several eucalypt species for pole production. Camcore has been helping MTO for many years with its tree breeding program for pines in the Cape, but the area with eucalypt plantations is a relatively new acquisition of MTO. Camcore will provide MTO with improved and unimproved genetic material of *E. urophylla*, *E. grandis* and other species for its genetic improvement program. The trials of pure species will be the base of the program to increase diversity in *E. grandis* x *E. urophylla*, the main taxon in commercial plantations. Camcore is also helping MTO with data analysis for old clonal trials of eucalypts that were recently acquired with the land.

Christel Malek of MTO in an 18-month-old plantation of GU hybrids in the new MTO project in lowveld of Mpumalanga.

Camcore continues to help **SAFCOL** with a number of the company's tree breeding programs for several pine species. Juan Lopez made the technical visit to SAFCOL in May to follow up on Camcore activities. Multisite analyses of *P. maximinoi* and *P. tecunumanii* progeny trials in South Africa provided a list of candidate trees for selection. *Pinus maximinoi* is one of the main commercial species for SAFCOL, while *P. tecunumanii* is used for crosses with *P. patula*. Camcore is also assisting the company with genetic analysis of the *P. patula* x *P. tecunumanii* hybrid studies in order to select trees for commercial deployment. SAFCOL is propagating a number of families of *P. patula* x *P. oocarpa* in the nursery for the establishment of progeny trials by several South African companies. This material was provided by Smurfit Kappa Colombia who made the crosses with Camcore selections in Colombia.

Camcore continues helping **PG Bison** with the development of both its pine and eucalypt breeding programs. Data analysis was done for two five-year-old 2nd generation studies of *P. patula* with selections from Camcore trials in South Africa. New selections from these trials should be part of the elite population that the company will use for commercial plantations. The establishment and measurement of new pine hybrid trials will help PG Bison find alternative taxa to replace *P. radiata* plantations affected by *Fusarium circinatum* in the southern Western Cape. PG Bison is part of the *P. patula* x *P. tecunumanii* breeding program and will participate in the full-sib trial program in 2018. The company is also looking for eucalypt species adapted to the north of the Eastern Cape. Four Camcore trials of eucalypts have been planted in the last five years and we are helping the company to begin making selections.

York is taking part in several cooperative Camcore projects that will help the company make quick and lower-cost progress in its tree breeding program. One is the South African member project with *P. patula* x *P. tecunumanii* in which full-sib families of the hybrid will be used to establish progeny trials. York is also taking part in the Camcore eucalypt hybrid program, and will establish several clonal trials with many hybrid crosses York is also participating in wood sampling of Camcore pine hybrids. Wood properties will be measured in a pine hybrid trial at Klipkraal in 2018

Charlie Clarke, John Crawford-Brunt, Leonard Mabaso, Lizette deWaal in a 15-month-old pine hybrid trial at Hendriksdal. The vigorous trees in the picture are a 5x5 plot of *P. greggii* x *P. oocarpa*.

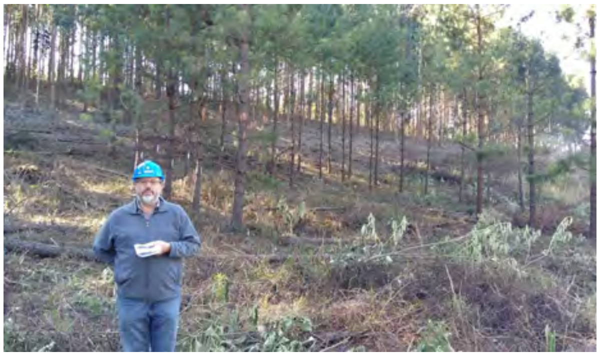
that was visited by Juan Lopez and the York research team during Juan's visit in May. Eucalypt and pine seeds are being sent to York every year to test alternative species and increase their genetic base.

Merensky continues to make an important contribution to the Camcore eucalypt testing and hybrid program. Merensky has 14 active provenance-progeny trials of *Corymbia* and *Eucalyptus*, and Sonia Du Buisson gave an engaging report on a number of Camcore species at the Regional Meeting. Merensky has excellent advanced-generation commercial clones of *E. grandis* and *E. grandis* hybrids, and these are hard to beat, but *Corymbia maculata* and *C. citriodora* show good potential. *Corymbia torelliana* had poorer volume growth and showed sensitivity to wind breakage at a young age, but this species is important for its rooting potential. Somewhat surprisingly, *E. pellita* has not grown well at Tzaneen through age 5 years. In Merensky's mixed species trials, some *C. citriodora* provenances have shown very good potential, along with *E. benthamii*. As part of the Eucalypt Hybrid Project, Merensky established seedling-to-clone selection blocks of *E. grandis* x *E. benthamii* and *E. grandis* x *E. pellita*, and completed the initial selections and thinning. The South African members are collaborating on the propagation and testing of all seven eucalypt hybrids, and in 2017, Charles Kempthorne took over the coordination of this work.

Five-year-old *Corymbia citriodora* shows excellent potential in Merensky's Camcore species trials at Tzaneen, South Africa (photo by Sonia Du Buisson).

Gary Hodge and Juan José Acosta visited **Sappi Forests** in July. We discussed a number of topics related to Sappi's internal breeding programs, including the *E. dunnii* clonal testing and wood sampling strategies, and the potential to apply molecular breeding techniques with this species. Sappi finished up the third year of crossing for the *P. patula* x *P. tecunumanii* breeding project, and their hard work on this project is much appreciated. Sappi has also developed the worlds first F2 *P. patula* x *P. tecunumanii* seed orchard, by converting a small hybrid clonal trial that had poor survival into a seedling seed orchard. Based on data from sister trials, the top 30 out of 100 clones were kept in the orchard. The clones were offspring from five *P. patula* mothers crossed with a *P. tecunumanii* pollen mix. Some seed has already been collected, so this will give us an early indication of the value of F2 seed for breeding or plantation use.

Gary and Juan José also visited **Mondi Forests** in July. We spent time discussing subtropical eucalypt breeding strategies (mostly GU hybrids), and the cool-temperate eucalypt breeding program, which emphasizes *E. dunnii* and *E. grandis* x *E. nitens* (GN) hybrids. Mondi continues to make good progress in the commercial production of *P.*



André Nel of Sappi in the world's first F2 seed orchard for *P. patula* x *P. tecunumanii* at De Magtenburg, South Africa.

patula x *P. tecunumanii* seed. Mondi also hosted the Camcore African Regional Meeting and the shortcourse in R software for genetic analyses (see articles in this annual report). Mondi continues to improve their production of eucalypt and pine cuttings in their greenhouse at Mountain Home through innovative research on the effects of temperature, time of day, and handling of cuttings.

An outstanding clone of *E. dunnii* in one of Mondi's cool-temperate *Eucalyptus* clonal trials. From back to front: Gert van den Berg, Kitt Payn, Noku Maplanka, Ben Pienaar, and Francois van Deventer.

Uruguay

Gary Hodge visited **Lumin** (formerly Weyerhaeuser) in December. Weyerhaeuser Company completed the sale of its Uruguay landholdings in September to a consortium led by the Timberland Investment Group of BTG Pactual. With the sale, there were no major changes in the management structure in Uruguay, and Lumin has indicated that they will continue with Camcore membership going forward. Lumin's primary product objective is plywood, and they plant both pines and eucalypts. *Pinus greggii* has shown great potential in Uruguay, and the *P. tecunumanii* x *P. greggii* hybrid should also do well. In the area of eucalypt tree improvement, the most important objective is reducing splitting to increase recovery in the veneer mill, but it is also important to expand the company's species portfolio to reduce disease risk and increase frost tolerance. Camcore's *E. benthamii*, *E. dorrigoensis*, and *E. grandis* genetic resources will all be very useful for Lumin.

Gary also visited **Montes del Plata** (MDP). MDP produces *Eucalyptus* pulp, primarily with *E. grandis* and *E. grandis* hybrids, but has been planting primarily *E. dunnii* for a number of years, so the furnish to the mill will be increasingly *E. dunnii* in the future. MDP has worked very hard to develop potted breeding orchards of *E. dunnii*, *E. grandis*, and *E. globulus*, and a number of the selected clones are beginning to produce flowers. MDP has also made 20 selections of *E. dorrigoensis* from Camcore trials, as well as 28 selections of *E. benthamii* from plantations. MDP is very interested in Phase II of the Camcore eucalypt hybrid program. The desire for future *E. dunnii* hybrids is for improved rooting, improved frost tolerance, water logging tolerance, and reduced content of calcium in the wood.

Venezuela

In February, Juan Luis Lopez and Juan José Acosta visited Venezuela. Despite the economic challenges and political uncertainties in the country, both **Smurfit Kappa Venezuela (SKV)** and **Masisa** are committed to continue working with Camcore for the long term. At **SKV,** Camcore selections of *E. urophylla* are being tested in 2nd generation and clonal tests on different sites. A pulping study developed with the pulp mill personnel and the forest research team is showing interesting results that will help to increase fiber productivity. Using our NIR models, pulp yield predictions can easily be included as selection criteria along with volume growth and wood density. Juan Lopez and Juan Acosta gave recommendations to the Smurfit research team to continue with the *Eucalyptus* hybrid program with the seedlings and hedges they have grown in the nursery.

During the last five years, the **Masisa** research group has established eight Camcore provenance - progeny tests of an array of species including *E. urophylla*, *E. pellita*, *E. brassiana* and *E. camaldulensis*. This is a very important addition to the company's breeding program. Masisa is expanding its genetic base with species that will bring more productivity and better wood properties, and can be used as hybrid partners. During our field trip, we observed that unimproved families of *E. urophylla* can produce up to 9 m^3/ha/year, showing the species' potential as an alternative to *Pinus caribaea* plantations.

Álvaro Gonzalez (SKV) and JJ Acosta (Camcore) discuss plans for the hybrid seedlings produced by the Camcore eucalypt hybrid program.

Masisa's personnel and Juan Lopez (Camcore) in a 5-year-old provenance - progeny trial of *E. urophylla* in Guayamure.

Africa Regional Technical Meeting

The 2017 Camcore Africa Regional Meeting was hosted by Mondi Forests in Howick, KwaZulu-Natal, South Africa in August. The meeting was well attended, with 23 participants. In a full-day indoor session, a number of important collaborative projects were discussed, including the *P. patula* x *P. tecunumanii* hybrid project, the eucalypt hybrid testing program, 2nd generation *P. maximinoi* and *P. tecunumanii* selections, and sentinel plantation establishment for disease monitoring. A second day of field visits took us to view an *E. dunnii* provenance - progeny test, a pine hybrid trial, 2nd generation tests of *P. maximinoi* and *P. tecunumanii*, and a *P. elliottii* seed source benchmark trial. These regional meetings have been an important catalyst to strengthen the collaboration among the southern African Camcore members. Many thanks to Mondi for hosting in 2017!

Participants in the Southern Africa Regional Meeting visiting the Mondi Research Center and Nursery at Mountain Home.

Camcore Pine Hybrid Projects

Camcore members advanced in the tree breeding work with pine and *Eucalyptus* hybrids. In pines, three projects are in progress: the management and assessment of pine hybrid trials planted by members since 2007; the *P. patula* x *P. tecunumanii* crossing effort by Sappi at the Shaw research station in Howick, South Africa; and the *P. tecunumanii* x *P. greggii* crossing effort by Smurfit Kappa in Colombia.

Bulk hybrid testing

Camcore members have planted over 90 pine hybrid trials in Africa and Latin America from 2007 to 2017. Seventeen of these have been evaluated for volume growth at eight years of age, 20 more at five years, and the rest are younger than five years. Wood properties (MOE, chemical composition, and density) for juvenile wood have been measured in eleven trials, eight at age seven or eight years and three at age five. Results for volume show that *P. patula* x *P. tecunumanii* (low and high elevation), *P. patula* x *P. oocarpa*, *P. greggii* x *P. tecunumanii* high elevation, *P. elliottii* x *P. caribaea*, and *P. caribaea* x *P. tecunumanii* low elevation are the hybrids with the most commercial potential. These results were summarized in last year's Camcore Annual Report. Four more trials will be sampled for wood properties in 2018, two in Brazil and two in South Africa.

Pinus patula x *P. tecunumanii* in Africa

This cooperative crossing project was initiated by the seven members in South Africa and Green Resources Mozambique in 2013 and additional seed collections were made in 2017. The objective is to collect seeds of 250 to 300 full-sib families for the establishment of progeny tests by the participating members. A big effort was made by the Sappi research team to make the crosses, monitor the cones, and collect the seeds. Part of the crosses made in 2013 and 2014 were lost to two hailstorms in those years but crosses made in 2015 were successful. A summary of hybrid seed collections in Sappi's *P. patula* clonal seed orchard at Lions River in Howick, KwaZulu-Natal are shown in Table 1.

Sappi will distribute the seeds to nurseries of several members in South Africa for vegetative propagation in 2018. Rooted cuttings will be produced for the establishment of progeny trials. The parents have been identified with genetic markers so that hybridity and identity of the top performing families in the trials can be verified later.

Pinus tecunumanii x *P. greggii* in Latin America

The agreement among Camcore members to start the tree breeding project with *P. tecunumanii* x *P. greggii* was made in 2015 at the annual meeting in Texas. Two members in Argentina, two in Brazil, one in Uruguay, one in Colombia, and one in Mexico chose to participate. Smurfit Kappa Colombia is making the crosses in its *P. tecunumanii* clonal seed orchards on different sites using pollen from 50 Camcore selections located in Brazil and Colombia. The purpose of this effort is to produce seeds of 250 to 300 full-sib families for the establishment of the hybrid progeny trials. A summary of the progress in 2016 and 2017 is shown in Table 2. No cones have been harvested yet, but the first collections from 2016 crosses will be made in 2018. Crosses and seed collections will continue over the next two years.

Table 1. Production of seeds of 167 full-sib families of *P. patula* x *P. tecunumanii* (high elevation and low elevation) in Sappi's *P. patula* clonal seed orchard at Lions River in Howick, KwaZulu-Natal.

Year	Maternal genotypes	Paternal genotypes	Crosses	Crosses with cones	No. of cones	No. of seeds
2013	21	25	54	44	658	12,728
2014	29	53	109	35	116	2,245
2015	33	69	135	88	973	14,022
TOTAL	43 unique	95 unique	298 unique	167 unique	1,747	28,995

Table 2. Number of crosses made and cone production of *P. tecunumanii* (high elevation and low elevation) x *P. greggii* var. *australis* in Smurfit Kappa Colombia *P. tecunumanii* clonal seed orchards.

Year	Crosses made	Maternal genotypes	Paternal genotypes	Crosses with cones	Live cones
2016	1,038	25	13	37	442
2017	1,745	24	13	35	1,156
TOTAL	2,783	34 unique	13 unique	52 unique	1,598

Left: Pollination of a *P. tecunumanii* cone in the Smurfit Kappa Colombia seed orchard with *P. greggii* pollen from Brazil.

Right: Developing cone with hybrid *P. tecunumanii* x *P. greggii* seed.

New Genetic Resources of *E. grandis*

In 2016, Camcore expanded our genetic resources with collections of improved and unimproved families of *E. grandis* (see 2016 Annual Report). Specifically, we received 130 advanced-generation families donated by Smurfit Kappa Colombia, and Mondi, Sappi Forests, and SAFCOL from South Africa. In addition, we acquired important provenance-progeny seed collections from 84 families representing 8 provenances. These seed collections represented a very large portion of the native range of *E. grandis*, from around 17° to 26° S latitude.

In 2017, we added 3 additional provenance-progeny collections from Australia to the Camcore genetic base. One of the provenances is from central coastal Queensland and fills a bit of a gap in our coverage of the northern end of the *E. grandis* native range. Two of the provenances are from New South Wales, and represent the southernmost provenance-progeny collections in the Camcore genetic base.

These seed purchases were made in conjunction with the Forest Molecular Genetics Programme (FMG) at the University of Pretoria. FMG is using these families along with many of the Camcore provenance-progeny collections from 2017 as part of the Genetic Diversity Atlas project.

Table 3. Location details for *E. grandis* provenance-progeny and seed orchard bulk seed acquisitions.

Provenance	State	Type	Latitude	Elev (m)	Fams
Eungella	Queensland	provenance-progeny	21° 12' S	845	7
Cherry Tree	New South Wales	provenance-progeny	28° 54' S	480	8
Bulahdelah	New South Wales	provenance-progeny	32° 20' S	13	10

Camcore *Eucalyptus* Hybrid Project

From the first phase of the *Eucalyptus* Hybrid Project, clonal trial trials will be ready to be established in 2018. This work began back in 2011 and to date has included controlled crosses, seed collection and germination, and screening block plantings. In 2018, we will start a second phase of the *Eucalyptus* hybrid program with many members participating in making crosses to produce seed for clonal trial establishment.

In 2011, several Camcore members with eucalypt plantations decided to pursue a project with hybrids using their own genetic material. The objective was to produce an array of eucalypt hybrids to be jointly tested by participating members. The plan was to have at least 20 full-sib families per cross, and to test the best individuals as clones. The expected benefit is the generation of a large amount of potentially valuable genetic material while sharing the costs and workload. Pollen collection and crosses were assigned to the members, and seeds of different hybrid crosses were produced and distributed to members in South America and South Africa. The members germinated part of the seed and planted the seedlings in blocks to screen the poor performers at age 18 months to two years. The status of the screening block plantings at the end of 2017 is shown in Table 4. More blocks will be planted in 2018. After eliminating slow growers and trees with poor form from the block plantings, the remaining trees will be tested in clonal trials. In 2018, the block plantings will be cut and sprouts will be collected for vegetative propagation in the nursery. Some members will establish clonal trials on multiple sites using rooted cuttings.

While this initial effort in *Eucalyptus* hybrids advances for some of the Camcore members, a second phase will be implemented in 2018. New hybrid crosses and additional members will be added to the project. So far, fourteen members have confirmed their interest in taking part in the second phase, offering pollen and committing to making crosses. New hybrid combinations such as *E. dunnii* x *E. benthamii*, *E. dunnii* x *E. badjensis*, *E. nitens* x *E. dunnii*, *E. urophylla* x *E. pellita*, *E. pellita* x *E. brassiana*, and others will be attempted. In addition, more seed of several crosses from the first phase will be produced in the second phase. This is another exciting program for Camcore members with great commercial potential

Table 4. Status of screening block plantings of *Eucalyptus* hybrid crosses in Chile and South Africa as of December 2017.

Member	Country	Seedlings (p = planted, s = surviving)	Hybrid planted in screening blocks	Age (years)
CMPC	Chile	102 (s)	*grandis* x *benthamii*	1.3
		238 (s)	*grandis* x *dunnii*	1.3
Sappi	S. Africa	234 (p)	*grandis* x *smithii*	1.6
Mondi	S. Africa	203 (s)	*grandis* x *globulus*	1.6
Merensky	S. Africa	1,139 (s)	*grandis* x *pellita*	1.6
		585 (p)	*grandis* x *benthamii*	1.7
SAFCOL	S. Africa	432 (s)	*grandis* x *dunnii*	1.6
		42 (s)	*grandis* x *brassiana*	1.6
York	S. Africa	21 (s)	*grandis* x *nitens*	1.5
SKC	Colombia	553 (p)	*grandis* x *pellita*	0.3
		5 (p)	*grandis* x *brassiana*	0.3
		190 (p)	*grandis* x *globulus*	0.3
		652 (p)	*urophylla* x *pellita*	0.3

Gert Van den Berg of Mondi in front of the 18-month-old seedling-to-clone selection block of *E. grandis* x *E. globulus*.

Genetics of Wood Properties in *E. dorrigoensis*

Eucalyptus dorrigoensis is a cold-tolerant, fast-growing species and is closely related to *E. benthamii*. The species has a very small natural distribution and a narrow genetic base in breeding programs around the world. Our population contains 4 provenances and 36 families: Sandy Hill (14), Tyringham via Dorrigo (5), Clouds CK Armidale (9) and Paddy Land SF (8), all collected in Eastern Australia. Our members have established 17 first-generation studies in the southern hemisphere: 4 in Brazil, 5 in Chile, 4 in South Africa and 4 in Uruguay. Genetic analyses for standardized tree volume were summarized in our 2016 Annual Report. Here we report on genetic parameter estimates for some important wood properties for one trial of *E. dorrigoensis* planted in Uruguay.

Materials and Methods

In late 2016, wood trait measurements were taken in a provenance-progeny test of *E. dorrigoensis* established in October 2011 by Weyerhaeuser (now Lumin) in Uruguay. This test has 22 families from the 4 provenances and is located near Tacuarembó at an elevation of 140 m.a.s.l. with mean annual rainfall of 1425 mm. We measured resistance using the IML Resistograph, modulus of elasticity (MOE) using the TreeSonic, and collected wood shavings to predict percentages of lignin and glucose with our global NIR model. Mixed model analysis was used to estimate variance components and genetic parameters including narrow-sense heritability (h^2), and additive genetic standard deviation (σ_A), and to predict family and individual-tree genetic values (BLUPs).

Results

Single-site heritability estimates are shown in Table 5. The 5-year-volume heritability was $h^2 = 0.17$, fairly typical for forest tree growth traits. For the wood traits, the heritability estimates ranged from $h^2 = 0.14$ (glucose content) to $h^2 = 0.55$ (lignin content). The global NIR model used to make the lignin and glucose predictions did not contain any *E. dorrigoensis* samples in the calibration, nevertheless, we expect the predictions to be useful to give us a good estimate of these genetic parameters (see article on Global Eucalypt NIR models in this report). For resistance, estimated heritability was $h^2 = 0.16$, somewhat lower than typically found for density in forest trees. For MOE, estimated heritability was $h^2 = 0.38$.

Even with somewhat lower-than-expected heritability estimates for the wood traits, the data clearly indicate opportunity to make genetic gain. For example, the estimated additive genetic standard deviation for lignin content was $\sigma_A = 0.90\%$. Assuming a normal distribution of genetic values, this implies a range of roughly ± 2.0% in lignin content in the *E. dorrigoensis* population. Similarly for glucose, we would expect to see a range of around ± 1.0%. These ranges of genetic values would be economically important for a pulping breeding objective. For the solid wood traits, there is probably also useful genetic variation, although interpretation is more difficult. For example, resistance units must be converted to density, and this relationship will vary by site and species (although always linearly related to wood density). The data also suggest that glucose and lignin are strongly and favorably correlated (i.e., more glucose equals less lignin), and that glucose is favorably correlated with resistance and MOE (i.e., high glucose equals stronger timber). It also appears that volume is unrelated to any of the wood traits.

This is our first study to characterize the genetic control of wood traits for *E. dorrigoensis*. The species has shown good growth in a range of environments, and the current results suggest that there is genetic variation for wood properties that can be captured in a breeding program. We believe that *E. dorrigoensis* has good commercial potential, and should continue to be emphasized in our breeding and testing efforts.

Table 5. Genetic parameters for *E. dorrigoensis* volume, Resistograph resistance, modulus of elasticity (MOE), lignin and glucose content. Parameter estimates from a single test site in Uruguay.

Trait	Units	h^2	σ_A
Volume	%	0.17	18.1
Resistance		0.16	97.4
MOE	GPa	0.38	0.81
Lignin	%	0.55	0.90
Glucose	%	0.14	0.58

Wood Properties of Eucalypt Species

Camcore has been working with eucalypt species for over 20 years. We started breeding and testing in 1996 with the collection of seed and establishment of provenance and progeny tests of *Eucalyptus urophylla*. To date, Camcore has sent more than 500 trials to members around the world including tropical, subtropical and temperate *Eucalyptus* and *Corymbia* species. This material will help diversify our members' genetic resources that will be used to identify species with commercial potential, increase options for selecting disease-, drought- and frost-resistant trees, and can be used in hybrid crosses. In 2016, the technical committee initiated a research project to evaluate wood properties of trees in our recent *Eucalyptus* and *Corymbia* studies. The objective was to evaluate the variation of wood properties in trees at least 5 years old in order to characterize the different species and compare them to commercial lots.

Materials and Methods

The first eucalypt wood samples came from two Camcore tests established by Weyerhaeuser Uruguay (now Lumin) in 2011. One test is from the South African benchmark series, the other from the temperate species series. The tests are located adjacent to one another on the same farm; environmental conditions are presented in Table 6. From both sites, we randomly selected 25 trees per species (only 20 trees for *E. grandis* from test 2 due to availability). A total of nine species were sampled (with two species sampled on both sites) in April 2017. For each selected tree, field measurements and wood samples were taken at breast height to assess three wood traits:

Table 6. Details of the 6-year-old eucalypt species trials in Uruguay.

Site Description	
Planted	October, 2011
State	Cerro Largo
County	Cerro Largo
Farm	Quebrachal 2
Latitude	32,61° S
Longitude	54,45° W
Elevation (m.a.s.l.)	200
Rainfall (mm)	1426.6
1. South African Benchmark	
Species	Samples
E. benthamii - Sappi	25
E. dunnii - Sappi	25
E. macarthurii - Sappi	25
E. saligna - Merensky	25
E. smithii - Sappi	25
E. grandis - Weyerhaeuser	25
2. Temperate Species	
Species	Samples
C. citriodora - Camcore	25
C. maculata - Camcore	25
E. badjensis - Camcore	25
E. benthamii - Camcore	25
E. grandis - Weyerhaeuser	20

- *Density*: The IML Resistograph was used to measure a density profile. The IML Resistograph system records the drilling resistance of a thin needle that is inserted into the wood under constant drive. While drilling, the required energy is measured; this resistance is directly proportional to the density of the wood at multiple points along the diameter.
- *Modulus of elasticity* (MOE): In its simplest form, MOE measures wood stiffness, and is a good overall indicator of strength. We estimated MOE using the TreeSonic. This tool measures the propagation time of a stress wave in the stem of a standing tree. Using this time and the distance between sensors, wave velocity is calculated, which correlates very well with MOE and wood strength.
- *Chemical traits* (NIR predictions): hand drills were used to extract wood shavings from under the bark to just short of the pith. Oven-dried shavings were shipped to North Carolina State University where they were ground into woodmeal and scanned with a FOSS 6500 NIR spectrometer. Spectral data from each sample were used in Camcore's global *Eucalyptus* NIR model (see article in this Annual Report) to predict percentages of lignin, glucose, Xylose and S/(S+G).

Statistical analyses used the following protocol. First, we fit a generalized linear model (GLM) for each trait (resistance, MOE, NIR-predicted variables). Second, the significance of each model was evaluated, and if observed variation between species was significant, pairwise comparisons (differences) were made between the least square means (LS means) for the different species. Third, trait distributions were plotted using box-and-whisker plots, and confidence intervals (CI 95%) for the mean response of each trait were calculated and plotted. All analyses were conducted using the R environment.

Results and Discussion

Figure 1 presents box-and-whisker plots representing the phenotypic variation in some of the important wood property traits. In general, all of the species had roughly similar amounts of phenotypic variation for a given trait. One exception might be *C. citriodora*, which had higher than average variation for glucose, resistance and MOE. Table 7 presents LS means for four chemical traits and two solid wood traits. For both sites and all traits, there was significant variation associated with species (all P-values were less than 0.001), which indicates that there are statistical differences

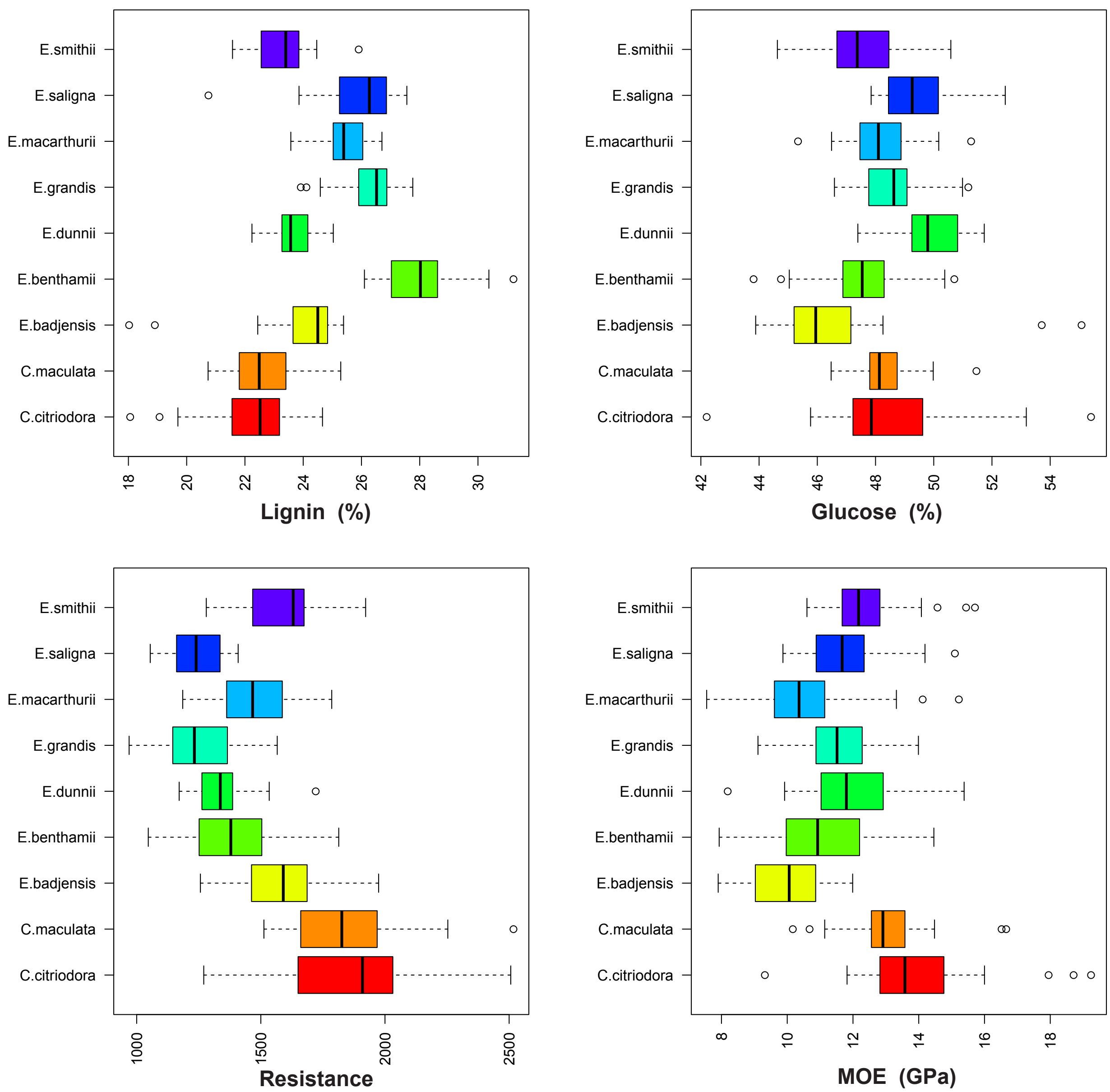


Figure 1. Box-plots of wood property values (lignin and glucose content, Resistograph resistance (directly related to wood density), and modulus of elasticity (MOE) observed in 6-year-old trials in Urugauy.

between species means. Interestingly, the two *Corymbia* species included in this analysis displayed the highest values for resistance and modulus of elasticity. LS means for the *Eucalyptus* species were intermediate to small, *E. grandis* being the species with the lowest value for Resistance and *E. badjensis* the species with the lowest value for MOE (Table 7).

Wood chemical traits are very important for some of our members, because they are related to the amount of chemicals required in the pulping process, their yield, and the amount of byproduct energy produced. For lignin, the most interesting species are *C. maculata* and *C. citriodora* with the two lowest lignin values. Species with intermediate to low lignin percentages include *E. smithii*, *E. dunnii* and *E. badjensis,* and *E. smithii* and *E. dunnii* also have good S/(S+G) ratios. For glucose, the more attractive species are *E. dunnii* and *E. saligna*. However, it is very interesting to note that the *Corymbia* species have similar percentages to *E. grandis* with intermediate values.

Using Table 7, a quick comparison of species can be made by scanning across the rows. For a given trait, green cells represent the top 3 species, yellow the 3 intermediate ones, and pink the 3 species in the bottom. All traits are ranked from highest to lowest value, with the exception of lignin, where low lignin is considered desirable for pulping. From Table 7, *C. maculata*, *C. citriodora* and *E. smithii* stand out as interesting species since they are ranked at the top or intermediate in value for most traits. For the *Corymbia* species, these results are very promising, and we should focus on testing these species more extensively. Noteworthy is the fact that the commercial species *E. grandis* and *E. dunnii* are top-ranked for glucose, however their observed values for the other traits are intermediate to low.

This is our first subset of *Eucalyptus* and *Corymbia* trials in which we comparatively characterize wood properties. The results are preliminary and should be seen as an indication of the potential that some species can bring to our breeding programs as alternative species or as hybrid partners. During the next few years, we expect to increase the number of sites significantly so we can draw better conclusions. We are sampling more species trials in Chile and South Africa in 2018.

Table 7. Summary of Least-squares means by species for important wood properties as measured in 6-year-old trials in Uruguay.
Cell highlights indicate rank out of the nine species studied, with green = ranks 1 to 3, yellow = ranks 4 to 6, and pink = ranks 7 to 9. Values followed by different letters are significantly different.

Rank out of 9
Ranks 1 to 3
Ranks 4 to 6
Ranks 7 to 9

Species	Resistance		MOE (GPa)		Lignin (%)		S/(S+G) (%)		Glucose (%)		Xylose (%)	
E. smithii	1597.4	b	12.2	bc	23.3	ab	80.5	a	47.6	cde	13.5	cd
E. saligna	1265.5	d	11.5	cde	25.8	dc	75.6	d	49.4	ab	11.7	ef
E. macarthurii	1503.3	bc	10.4	de	25.4	c	78.4	b	48.2	bcd	12.7	de
E. grandis	1249.2	a	11.5	cd	26.3	d	73.4	f	48.6	bc	12.1	ef
E. dunnii	1357.5	cd	11.7	cd	23.7	b	78.5	b	50.0	a	14.2	bc
E. benthamii	1389.0	c	11.0	de	28.0	e	74.9	d	47.6	de	11.6	ef
E. badjensis	1569.7	b	10.2	e	23.8	b	77.4	bc	46.8	e	14.4	bc
C. maculata	1813.3	a	13.3	ab	22.6	a	76.1	cd	48.4	cd	15.5	a
C. citriodora	1865.6	a	14.3	a	22.1	a	76.2	cd	48.5	cd	14.9	ab

Eucalyptus Disease Screening: *Austropuccinia psidii* Results from Uruguay

Introduction

Insect and disease outbreaks that threaten forest health continue to be an issue of much concern to the global forestry community. For Camcore, this concern is particularly acute for pest and pathogen threats to *Eucalyptus*. The rapid growth and expansion of our eucalypt breeding program has coincided with the global rise and spread of numerous insects and pathogens that pose a significant threat to eucalypt plantation sustainability and productivity. As a first step towards addressing this issue, at the 2014 annual meeting in Guatemala the Camcore Technical Committee approved a research project to begin screening Camcore eucalypt breeding material for susceptibility to several pathogens of concern to our members. This project involves multiple *Eucalyptus* species and pathogens, with partners in both Uruguay (Weyerhaeuser and INIA) and Colombia (Smurfit Kappa Colombia) conducting the screening studies. Readers are referred to the 2015 and 2016 Camcore Annual Reports for details on the full scope of the project. Here we report screening results for the myrtle rust pathogen, *Austropuccinia* (formerly *Puccinia*) *psidii*, from trials conducted in Uruguay.

Materials and Methods

Bulk seed lots of 12 *Eucalyptus* species (Table 8) were sent from Camcore in Raleigh, NC to Weyerhaeuser in Uruguay. From this seed Weyerhaeuser produced five-month-old seedlings at their nursery in Tacuarembó. The target number was 100 seedlings per species, but due to issues with *Botrytis cinerea* in the nursery the actual number of healthy seedlings available for screening varied (Table 8). Weyerhaeuser also provided resistant and susceptible commercial clones as controls for a total of 14 genotypes tested. Seedlings were arranged into 14 greenhouse tubette trays with one tray per species/clone. The 13 trays that contained the pure species and resistant clone also contained 10 seedlings of the susceptible clone as a positive control. Seedlings were transported to INIA's laboratory in Tacuarembó where the screening trial was conducted.

The *A. psidii* inoculum used for artificial inoculation was cultivated on and multiplied from urediniospores grown on *Syzygium jambos*. Spores were suspended in water with 0.02% Tween 20 at a concentration of 2.0 x 104 urediniospores/ml. A manual hand sprayer was used to apply the inoculum to the four apical leaf pairs on each seedling. Following inoculation, seedlings were incubated for 24 hours in complete darkness at 25°C and approximately 100% RH. Following incubation, seedlings were maintained in a growth chamber at 20°C and a 12:12 photoperiod for 20 days.

After 20 days, seedlings were evaluated for their level of susceptibility to *A. psidii* based on the visual scale in Figure 2. The scale has four degrees of susceptibility based on the degree of foliar necrosis visible on each leaf, ranging from resistant (S0) to highly susceptible (S3). This scale is a modification of that first developed by Junghans et al. 2003 (Fitopatologia Brasileria 28:184-188).

Results and Discussion

There was some level of rust symptom development in all 14 eucalypt genotypes tested (Table 8; Figure 3). *Eucalyptus benthamii* was the most resistant species with 91% of seedlings ranked in the S0 susceptibility class. *Eucalyptus badjensis*, *E. brassiana*, *E. camaldulensis*, and *E. longirostrata* all demonstrated low susceptibility with over 80% of seedlings ranked in the S0 and S1 susceptibility classes. Most of the remaining

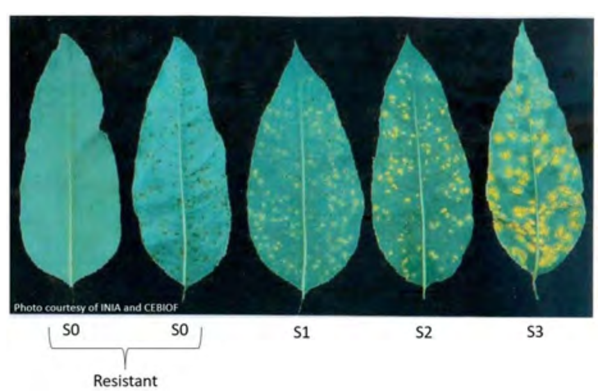


Figure 2. Visual scale (S0 = resistant to S3 = highly susceptible) of foliar symptoms used to score eucalypt foliage into susceptibility classes.

Table 8. Results of screening several eucalypt species for tolerance to *Austropuccinia psidii*. Percentage of seedlings of each eucalypt species assigned to each susceptibility class.

Species	Number tested	S0 (%)	S1 (%)	S2 (%)	S3 (%)
E. badjensis	95	68	26	6	0
E. benthamii	97	91	7	2	0
E. brassiana	63	71	15	8	6
E. camaldulensis	32	63	19	12	6
E. dorrigoensis	29	48	18	31	3
E. dunnii	100	25	18	38	19
E. globulus	83	41	26	12	21
E. grandis	64	39	34	22	5
E. longirostrata	93	65	30	4	1
E. nitens	80	30	49	14	7
E. pellita	20	30	15	10	45
E. urophylla	94	39	34	12	15
Resistant clone	100	8	46	32	14
Susceptible clone	100	0	6	47	47

species ranked with low to moderate levels of susceptibility with seedlings distributed across the S0, S1 and S2 susceptibility classes. *Eucalyptus pellita* demonstrated moderate to high susceptibility with more than half the seedlings scored into the S2 and S3 susceptibility classes. As expected, the susceptible clone was the genotype that demonstrated the highest level of rust susceptibility. Interestingly, the resistant clone ranked as the third most susceptible genotype in the trial. Based on a survey of the available literature, this is the first trial to evaluate the myrtle rust susceptibility of *E. badjensis*, *E. dorrigoensis*, and *E. longirostrata*, and largely confirmed species rankings based on earlier studies for *E. brassiana*, *E. camaldulensis*, *E. dunnii*, *E. globulus*, *E. nitens*, and *E. urophylla* (Zauza et al. 2010. Australian Plant Pathology 39:406-411).

Overall, the results of this screening trial are encouraging with the average susceptibility ranking of eight of the 12 species tested falling between the resistant (S0) and low susceptibility (S1) classes (Figure 3). Of particular interest to Camcore is the apparent resistance of *E. benthamii* and the low susceptibility of *E. dorrigoensis* to infection by *A. psidii*. These traits expand the potential usefulness of these species that have already demonstrated excellent potential for growth and cold hardiness in Camcore trials. Both species appear to have higher resistance to *A. psidii* than *E. dunnii*, suggesting they may be suitable alternative species for planting in high-rust-incidence areas or as hybrid partners for increasing rust resistance.

Other studies that have evaluated eucalypt susceptibility to myrtle rust have routinely ranked commercial sources of *E. pellita* as highly resistant to *A. psidii* (e.g. Guimaraes et al. 2010. Crop Breeding and Applied Biotechnology 10:124-131; Santos et al. 2014. Crop Breeding and Applied Biotechnology 14:244-250). In the current screening trial, *E. pellita* was the most susceptible of the pure species tested (Figure 3), with a little more than half of the seedlings categorized as moderately to highly susceptible (Table 8). This result was unexpected, but should be interpreted with caution. Camcore's *E. pellita* seed sources originate from provenances in the Papua province of eastern Indonesia, while most other commercial sources originate from Australia and Papua New Guinea. This seed source difference may partly explain why Camcore *E. pellita* appears to have higher levels of susceptibility to myrtle rust. In addition, it is important to note that there were only 20 *E. pellita* seedlings included in the trial due to poor seed germination and *B. cinerea* problems in the nursery. Low sample size and seedling health issues are likely to have influenced the screening results as well, and further studies are needed before we can make a final conclusion about the *A. psidii* susceptibility of Camcore *E. pellita*.

Camcore plans to continue working to better understand the relative resistance and susceptibility of our eucalypt breeding material to the myrtle rust pathogen. A second screening study will be conducted in 2018 at Smurfit Kappa Colombia, evaluating the same 12 species we studied in Uruguay with the addition of *E. smithii* material provided by Sappi. SKC will also lead the effort to screen for other pathogens of concern to Camcore members.

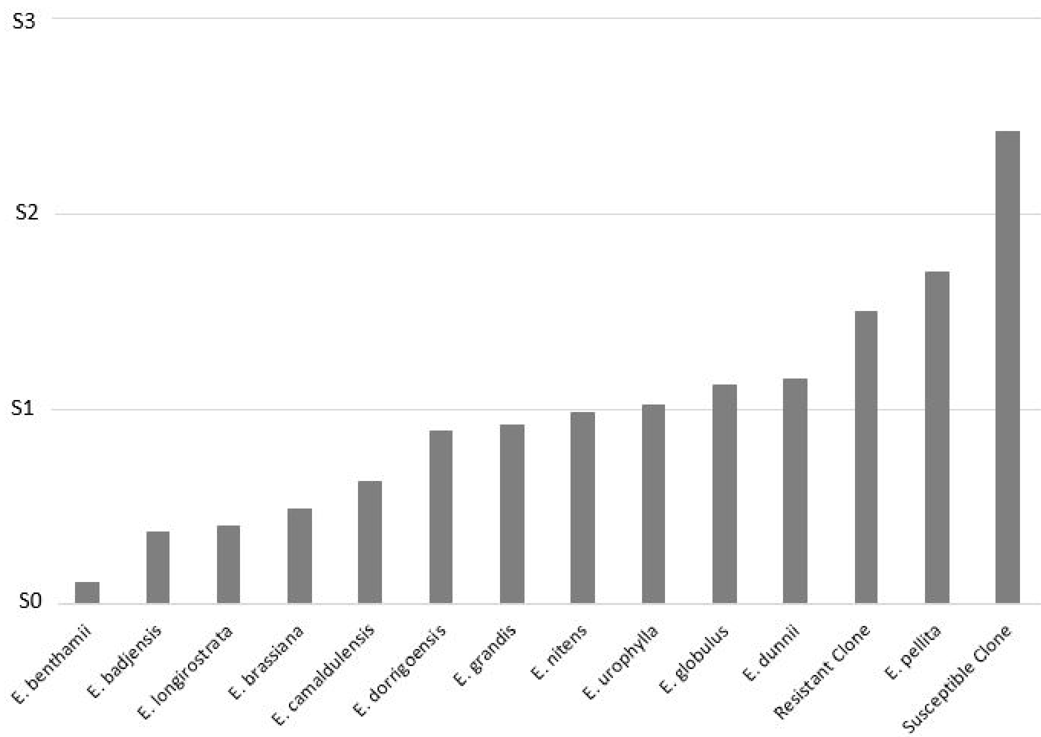


Figure 3. The mean susceptibility score for each eucalypt species and clone tested for tolerance to *Austropuccinia psidii*.

Eastern Hemlock Target-tree Release Study

Previous research by Camcore and our USFS colleagues (see Brantley et al. 2017 listed in the publications section of this annual report) indicates that increasing the amount of ambient light to the crowns of potted eastern hemlock seedlings causes a sharp decrease in population density of the hemlock woolly adelgid, the primary threat to hemlocks in the eastern United States. The data suggest that silvicultural tools such as thinning and selective harvests, combined with chemical and biological controls, may be appropriate for adelgid management in infested forests. In 2017, Camcore and our colleagues Albert “Bud” Mayfield and Tara Keyser with the USFS Southern Research Station received $74,105 in funding from the USFS Special Technology Development grant program and Forest Health Protection to initiate a field study to begin evaluating such adelgid management strategies. Using this funding, a target-tree release study was recently established to evaluate how increasing the amount of ambient light available to the crowns of eastern hemlocks in intermediate forest canopy positions affects hemlock woolly adelgid infestation density and the subsequent health of the tree. Ambient light around the crowns of individual trees is increased by creating gaps of two sizes (small versus large) using two methods (felling versus girdling), and adelgid density and tree health responses are compared to unreleased control trees. In 2017, 80 plots representing 16 replicates of 5 treatments (2 gap sizes x 2 gap methods, plus control) were successfully established and cut on state-managed and National Forest sites in MD, NC, TN, and VA. Installation of additional replicates in TN and GA, and measurements of tree health, HWA densities, gap dimensions and competing vegetative response on all plots will be completed in 2018. This project involves federal, state, and university collaborators, and established field plots span an area from western Maryland to northern Georgia.

Teak Seedling Nutrient Disorder Symptomology and NIR Models to Predict Foliar Nutrient Content

Over the last several years, Camcore has seen increased interest among members in growing teak, and has responded with the initiation of provenance-progeny trials as well as other research projects with the species. One of these was to quantify teak seedling responses to different nutrient disorders. The ability to accurately diagnose nutrient issues in teak seedlings will greatly benefit nursery managers working with this highly-valued plantation species. The teak nutrient studies described below were conducted by Andy Whittier of Camcore as part of his Masters of Science program.

Preliminary studies looked at the feasibility of growing teak seedlings in both sand- and liquid-culture hydroponic systems in a temperate greenhouse. These early studies showed that teak responded well to both hydroponic systems and did best when grown in a standard Hoagland nutrient solution at a pH of 5.8. Subsequent larger-scale foliar symptomology and NIR predictive foliar model studies were conducted utilizing the sand-culture hydroponic setup.

Foliar Symptom Studies

In order to describe and photograph foliar nutrient disorder symptoms, 252 teak seedlings from Venezuelan and Colombian sources were grown hydroponically at NCSU. These seedlings received either a control full-strength Hoagland nutrient solution or one of 12 treatments in which one nutrient of interest was removed. A fourteenth treatment utilized the standard Hoagland with ten times the amount of boron in order to observe seedling response to boron toxicity. Seedlings were monitored daily with high-quality photographs taken of each treatment upon the appearance of symptoms. Control seedlings were photographed at the same time for comparisons. In addition to photographs, plants from each treatment were destructively harvested at the onset of symptoms in order to analyze and report foliar nutrient levels when symptoms first appeared. Control plants were again sampled at the same date in order to provide reference values.

Nutrient deficiencies appeared at different dates, with N-related symptoms apparent after 14 days while molybdenum deficiency symptoms took 54 days to be observed (Figure 4). Differences in mean foliar nutrient levels between each of the respective nutrient treatments and the control plants were statistically significant for all but magnesium and iron (Table 9). Magnesium and iron deficiencies also produced some of the least obvious foliar symptoms of all nutrients investigated. Unique symptoms for all treatments were photographed. Foliar nutrient levels and photographs of symptoms will be utilized in the creation of a diagnostic guide depicting teak seedling foliar response to each of the 13 nutrient disorders investigated (e.g., see Figure 5). This guide will be distributed to Camcore members working with teak in order to help nursery managers more effectively manage teak seedling production.

Predictive NIR Nutrient Models

In addition to following visual nutrient disorder symptoms and foliar nutrient levels, a sister study was conducted in order to determine the feasibility of using NIR technology to develop predictive foliar nutrient models. The ability to use NIR technology as a means of detecting nutrient issues before the onset of visual symptoms would allow growers to remediate issues earlier and more

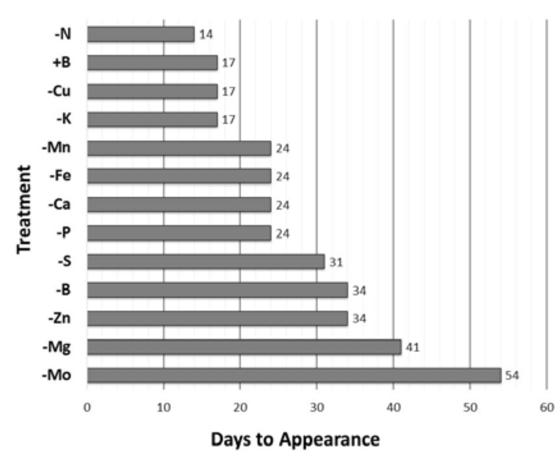


Figure 4. Mean days to the appearance of nutrient disorder symptoms on foliage.

effectively. In developing predictive NIR models, a portable handheld microPhazir scanner was used to scan leaves nondestructively. Following handheld scanning, the four most recently matured leaves were harvested, dried, ground, and analyzed in a laboratory desktop spectrometer (Foss NIRS 6500) equipped with a spinning sample module. The different scanners were used in order to evaluate the precision of each system. The benefits in ease of use of the handheld scanner, nondestructive nature of scanning, portability, and lower cost need to be weighed against the reduced precision when compared to models developed with the laboratory scanner.

For the development of predictive NIR foliar nutrient models, 280 teak seedlings were grown in a sand-culture hydroponic system. Seedlings were split into groups of 20 plants and were assigned one of 14 treatments. Treatment 1 consisted of a full strength Hoagland nutrient solution while treatment 2 was pure tap water with no added nutrients. Treatments 3 through 6 used the Hoagland solution with nitrogen altered to 25%, 50%, 75%, and 125% levels. Treatments 7 through 10 followed the same four levels with phosphorus being altered; treatments 10 through 14 altered potassium at the same rates. Five plants from each treatment were sampled once every three weeks for a period of three months. After handheld and desktop scanning, foliage was sent to the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) for nutrient level analysis. NIR scans were then correlated with foliar level data using the Camcore R-NIR data pipeline in order to develop predictive foliar nutrient models for each of the 13 nutrients investigated.

Predictive models for N, P, K, and B developed with the Foss 6500 laboratory scanner data ranged from excellent, with an R^2_{cv} of 0.96 for N, to good, with B

Table 9. Mean tissue nutrient concentrations at onset of observable disorder symptoms in hydroponically-grown teak seedlings. Molybdenum concentrations were not available.

Treatment	Days To Appearance	Nutrient Content			
		Element	Control	Treatment	Stat. Signif.
-N	14	N (%)	4.25	0.98	**
-P	24	P (%)	0.81	0.10	**
-K	17	K (%)	3.99	1.36	*
-Ca	24	Ca (%)	2.00	0.47	*
-Mg	41	Mg (%)	0.60	0.09	
-S	31	S (%)	0.23	0.10	**
-Fe	24	Fe (ppm)	42.00	34.20	
-Mn	24	Mn (ppm)	129.50	13.90	*
-Zn	34	Zn (ppm)	21.05	11.85	*
-Cu	17	Cu (ppm)	3.50	2.66	**
-B	34	B (ppm)	33.40	2.82	**
+B	17	B (ppm)	27.40	294.50	*

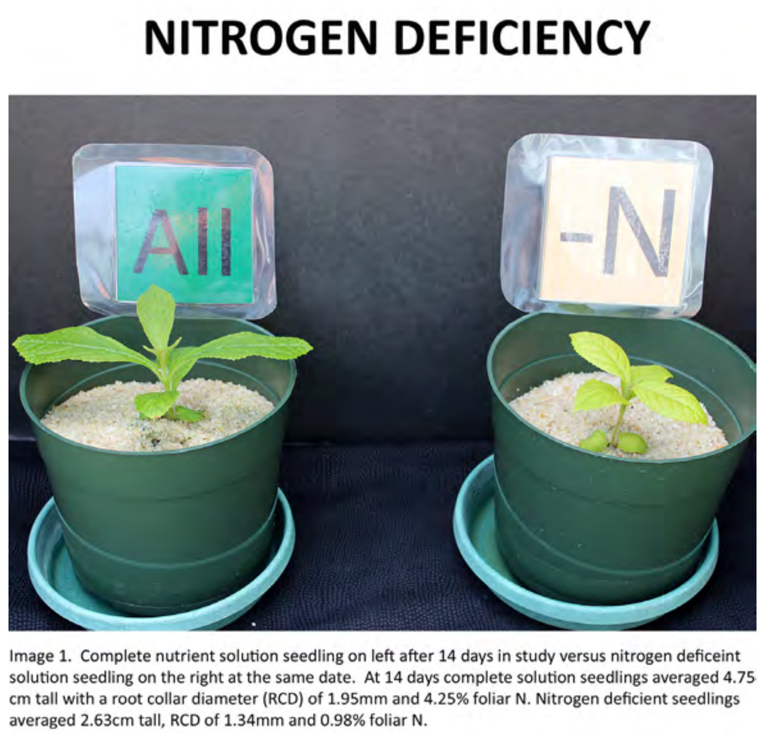


Figure 5. Example of the type information and photographs to be provided in the teak nutrient disorder symptom guide.

Table 10. Fit statistics for foliar nutrient level NIR calibration models for the Foss 6500.

Trait	Reference Value			Foss 6500 NIR Model						
	Mean	StDev	Range	Transformation	Factors	R^2_c	SEC	R^2_{cv}	SECV	RPD_{cv}
Nitrogen (%)	3.3	0.9	4.8	SNV	10	0.97	0.15	0.96	0.18	5.00
Phosphorus (%)	0.5	0.2	0.8	NIR	15	0.94	0.07	0.90	0.09	2.17
Potassium (%)	3.2	0.7	3.6	DT_SG7	9	0.94	0.19	0.83	0.30	2.33
Boron (ppm)	30.9	9.9	54.9	DT_SG7	9	0.90	3.57	0.72	5.78	1.71

Table 11. Fit statistics for foliar nutrient level NIR calibration models for the handheld microPhazir.

Trait	Reference Value			microPhazir						
	Mean	StDev	Range	Transformation	Factors	R^2_c	SEC	R^2_{cv}	SECV	RPD_{cv}
Nitrogen (%)	3.3	0.9	4.8	NIR	13	0.93	0.25	0.82	0.40	2.25
Phosphorus (%)	0.5	0.2	0.8	SG7	6	0.80	0.13	0.68	0.16	1.25
Potassium (%)	3.2	0.7	3.6	SG5	6	0.85	0.29	0.75	0.37	1.89
Boron (ppm)	30.9	9.9	54.9	SG7	5	0.62	6.86	0.43	8.35	1.19

having an R^2_{cv} of 0.72 (Table 10). Models for Mg with the Foss 6500 were fair with an R^2_{cv} of 0.51. Predictive models for the remaining eight nutrients analyzed by NCDA&CS were poor. The low R^2_{cv} for models of micronutrients is not surprising since plant levels of these nutrients were low and likely difficult to detect with NIR spectra.

Models developed using the handheld microPhazir followed the same trend as the Foss 6500 but were consistently less precise. Nitrogen models had a high R^2_{cv} of 0.82 while B had an R^2_{cv} of 0.43 (Table 11). Similar to the Foss 6500 models, the predictive nutrient models for the remaining eight nutrients developed with the handheld scanner were poor and provided no utility. While the models produced with the handheld scanner had lower levels of precision, one needs to weigh this disadvantage against the many benefits of the microPhazir. Is lower model precision acceptable given the reduction in labor and cost, and the non-destructive nature of sampling? In addition, the microPhazir offers a signficant time advantage over the desktop scanning, which requires 2 to 7 days to prepare the dried and ground sample material.

Summary and Outlook

Teak seedling nutrient-disorder studies produced two major outcomes that will be useful to teak growers throughout the world.

First, high-quality photographs, coupled with foliar nutrient levels at the onset of symptoms, will be used in the creation of a diagnostic photo guide of 12 nutrient deficiencies and one toxicity. This guide will include reference photos and foliar nutrient levels of control seedlings taken throughout the study. The guide will be developed in 2018 and distributed to interested teak growers.

Second, NIR models for N, P, K, Mg, and B foliar levels developed using a laboratory-grade Foss 6500 scanner ranged from fair to excellent. Models for N, P, K, and B developed using the handheld microPhazir scanner also ranged from fair to excellent but were consistently less accurate than models developed with the Foss 6500. The development of predictive models using laboratory and handheld scanners could be of use to nursery managers to monitor plant nutrient status.

X-ray Densitometry and Resistograph Profiles to Measure Rings in Pine Trees

Wood density is an important property of interest for both solid wood and pulp production, so this trait is also of interest to tree breeders. Often wood density is measured gravimetrically, using the water displacement method with core or wedge samples. The use of the IML Resistograph to estimate density has the advantages of being fast and non-destructive. Cores, wedges, and Resistograph profiles taken at breast height are often used to estimate a single density value for an entire tree. Many studies have shown variation in density within a single tree along the radius and up the stem, but a single sample at breast height is generally accepted as a good indicator of whole-tree density. The goal in tree breeding programs is usually to rank trees, not obtain absolute values, so density estimates, regardless of the method or accuracy, are expected to be very useful.

In some cases, there is a desire for higher resolution descriptions of density. This is particularly true in pines where annual rings are distinct due to the presence of early and late wood. Differences in whole-tree wood traits between trees, families, or species may be due to ratios of early to late wood. Transition from juvenile to mature wood is important for quality issues and occurs at the ring level. Also, changes in rates of diameter growth over time can be quantified with individual ring measurements, avoiding the complications of bark thickness and the use of circumference to estimate diameter. Camcore has used X-ray densitometry of solid wood strips to measure ring growth and late to early wood ratios. The method is expensive and time consuming, but produces reliable, high-resolution results. The Resistograph also produces profiles in which rings are clearly discernable. Although the resolution is not as high and the profiles are affected by friction from drilling, the method is very fast and requires no solid wood samples. The IML software actually does include a function to mark rings but it is rather simplistic and difficult to use. Nevertheless, we decided to sample a set of trees with both methods to compare results for density estimates at the ring level. ArborGen do Brasil offered to provide trees, personnel and funding to conduct this study. ArborGen had the objective to analyze tree growth and wood quality at the ring level for some of their commercial clones of *Pinus taeda*. This study was designed in a way to meet the following objectives for both ArborGen and Camcore:

- Compare wood density of 5 commercial clones and 2 controls from ArborGen's *P. taeda* breeding program.
- Look at differences in ring growth and density among these 7 genotypes.
- Compare X-ray densitometer and Resistograph methods for estimating whole-profile and ring-level wood density
- Explore ways to refine protocols to convert resistance readings to density estimates, including adjustments for needle friction.

Methods

Trees were chosen from three trials planted by ArborGen in late 2007 in the states of Paraná and Santa Catarina, Brazil. Sampling was done in April 2017 making the trials about 9.5 years old. Trees were planted in single-tree plots with 8 reps at 2 x 2.5 m spacing. Five trees of each clone were sampled on each site. Due to greater within-family variation for the controls, 10 trees were sampled for these genotypes. For each tree, a single Resistograph drilling was made near breast height, away from any visible branches or defects. The entry and exit holes were marked with red paint. Soon after, an increment core was taken 2 to 3 cm above

The ArborGen team with Willi Woodbridge (left) happy to finish sampling at the Rio Negro site.

Figure 6. Care was taken to align extracted cores (upper hole) with Resistograph readings (small lower hole in the red paint). Both samples are bark to bark.

Figure 7. Picture of whole core (above) and the 2-mm thick planklet sawn from half of that core.

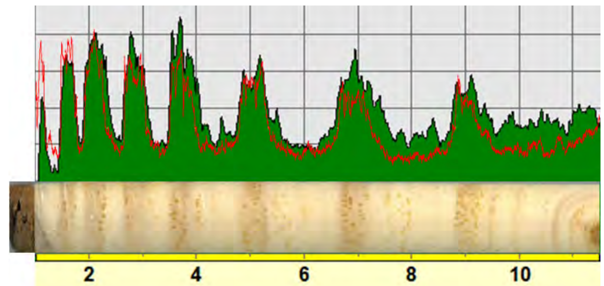


Figure 8. Alignment of rings and density profiles in A-1025, a 9.5-year- old *P. taeda* tree (9 annual rings are visible). The red line is from X-ray scanning, the green graph from the Resistograph. The image of the increment core shows the bark visible on the left, which was the entry side of the sample. The yellow scale indicates lengths in cm.

the Resistograph hole (Figure 6). In both samples, great care was taken to make sure that 1) the Resistograph hole bisected the circumference, 2) the increment core was well aligned with the Resistograph reading, and 3) the increment contained or was very close to the pith (Figure 7). For some trees, multiple Resistograph readings were taken to meet condition 1. Careful "aim" in drilling was used to meet condition 2 and in 40 trees, a second core was taken to meet condition 3. In asymmetric trees, it was not possible to meet all conditions. Cores were dried and shipped to Raleigh, where they were split in half, providing two replicates for each tree. Each half core was measured for specific gravity with the gravimetric method. Cores were then processed to make 2-mm thick planklets and scanned with the X-ray densitometer (Figures 7 and 8). Both Resistograph and X-ray scans gave point by point data. The X-ray data can be converted to density at each point but for Resistograph data, our current methods only yield whole-tree densities. For this reason, the growth and density values presented here will be based on the X-ray data. We hope to be able to make point-by-point conversions for Resistograph data after more mathematical testing with the data from this study.

Results for ring growth and density

Previous to this study, trees were measured for height and dbh (outside bark) at age 7 years. These values, and calculated volume, are shown in Table 12. The 7 genotypes were ranked and grouped into high growth (shaded dark green), intermediate (light green) and slower growth (orange) tiers. Average densities for these genotypes are also shown and a similar ranking and shading scheme was applied. Density values are the means of both core halves averaged for 15 trees (30 for controls). The shading scheme clearly shows that genotypes fall into a variety of groups and that fast growth is not clearly correlated to high or low density. For example, Clone 4 is ranked 3rd in volume and 1st in density. Clone 3, however is top ranked for volume but last for density. Note that volume was measured at age 7 and density at 9.5. Figure 9 shows ring-by-ring growth measured with the X-ray scanner. The same color scheme was applied. There are some slight differences in rankings between this graph and Table 12 because this diameter was measured at age 9.5, using inside bark, on a subset of the trees that were measured at age 7 with outside bark. For example, clone 2 is ranked 4th for dbh at age 7 but seems to track slightly higher than clone 4, ranked 3rd. Figure 10 shows the changes in density over 9 annual rings. The shape of these curves is typical for pine trees. Density increases in later rings. The higher value of ring 1 compared to ring 2 is often seen and is due mostly to scans hitting narrow rings of denser wood tangentially rather than passing perfectly through the pith. A drop in density seen from ring 8 to 9 occurs because ring 9 is not complete. Sampling occurred in the middle of the season before all the latewood was formed. The density values in these graph range from .300 to .550 and seem to be higher than the values reported in the table. This is because the ring-by-ring densities are measured with the X-ray densitometer while the values in the table are from direct gravimetric measurements. Both methods have limitations in measuring whole-tree densities accurately due to geometric issues of representing a disk or an entire stem with a straight cylinder through the diameter (an increment core). Despite these inaccuracies, for tree breeders, the relative ranking of densities should be valid.

Table 12. Values and rankings for DBH, Volume and Density of 5 clones and 2 controls. Densities are means of 2 core halves averaged over 15 trees (30 for controls).

Clone	DBH	Rank	Volume	Rank	Density	Rank
Clone 1	23.0	1	0.230	2	0.375	5
Clone 2	20.4	4	0.193	4	0.353	6
Clone 3	22.9	2	0.246	1	0.347	7
Clone 4	22.6	3	0.229	3	0.422	1
Clone 5	20.5	5	0.188	5	0.404	2
Control 1	19.5	6	0.159	6	0.385	4
Control 2	17.9	7	0.133	7	0.387	3
Average	20.1		0.177		0.383	

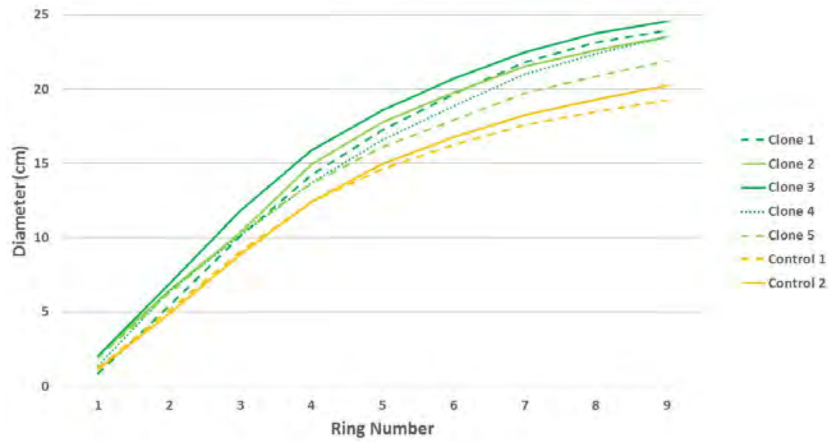


Figure 9. Growth in diameter of 7 genotypes of *P. taeda* trees through age 9. Dark green lines are the fastest growing families (based on age 7 volume), light green are intermediate, and orange are the slowest growers.

Resistance-Density Relationship

Once the ring means for density and for resistance were determined, we investigated the relationship between resistance and density. We decided to limit the data to rings 2 through 8, thinking that ring 1 values might be more variable than other data due to the proximity to the pith. There were also a number of options regarding the unit of observation that could be used to examine this relationship:

- whole-core values, n = 139
- half-core values, n = 278
- mean of two half-cores, n = 139
- ring values for each half-core, n = 2418
- ring averages, two half-cores, n = 1209

All analyses gave similar results, so for the purposes of this report, we will focus on only two approaches: whole-core values, and ring averages across two half-cores. For both types of observations, we used SAS Proc Mixed to examine various linear regression models to predict density from resistance (e.g., linear and quadratic terms, different intercepts and slopes for each of the three sites).

There was a strong linear relationship between resistance and density for both the whole-core dataset and the ring-average dataset (Figures 11 and 12). For a simple linear regressions, the fit $R^2 = 0.827$ for ring-average values, and $R^2 = 0.802$ for

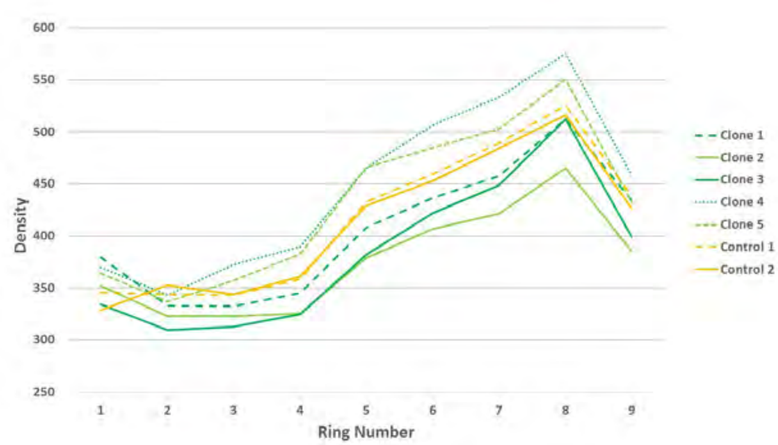


Figure 10. Change in density of rings over 9 years. Dark green lines are the fastest growing genotypes (based on age 7 volume), light green are intermediate, and orange are the slowest growers.

the whole-core values. The inclusion of a quadratic term in the linear model did not result in statistically significant improvement. The inclusion of site-specific intercept and slope coefficients did result in statistically significant improvement, but the practical improvement was negligible. For example, for the ring average dataset, with the inclusion of site-specific intercept and slope, the R^2 increased from 0.827 to 0.829, and the root mean square error decreased from 31.66 to 31.56. Similarly, for the whole-core dataset, the more complex model increased R^2 from 0.802 to 0.817, and decreased root mean square error from 13.46 to 13.17.

The intercept and slope coefficients for the two datasets are quite similar, but not "identical". This is at least partially due to the fact that the two datasets cover different ranges of resistance and density. For example, the values in the ring-average dataset range roughly from 300 to 600 kg/m^3, while the values in the whole-core dataset range from 320 to 480 kg/m^3.

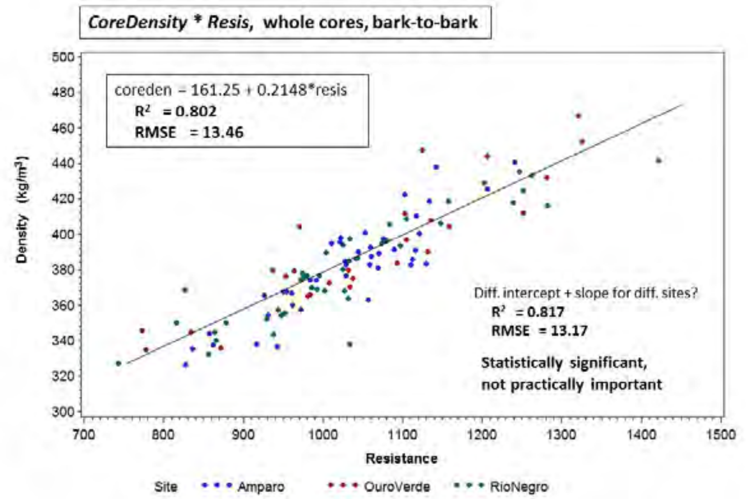


Figure 11. Scatter plot of mean resistance versus mean density for bark-to-bark cores of *P. taeda* sampled across three sites in Brazil. Points represent averages for the entire bark-to-bark increment core (rings 2 to 8) from a sample tree.

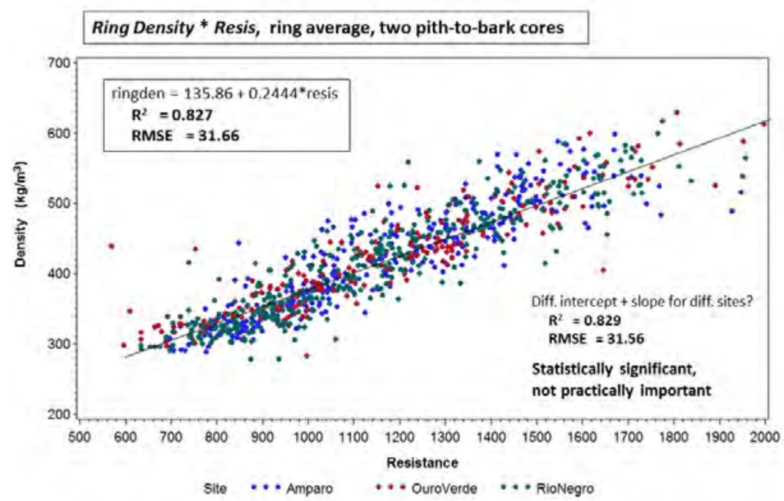


Figure 12. Scatter plot of mean resistance versus mean density by ring for *P. taeda* sampled across three sites in Brazil. Points represent averages for a given ring from two pith-to-bark increment cores (i.e., two sides of a bark-to-bark core) from a sample tree.

Summary and Implications

The results from this study indicate that for a given species, the IML Resistograph will give very reliable results for ranking genotypes for density. There is a a strong linear relationship with density, which suggests that the resistance values can be used directly for ranking. Of course it is important to clean or adjust the resistance data so that only the resistance values for wood are being used, and not values that represent bark or air.

It is possible to calibrate the density-resistance relationship for a given site, but this does not seem to be practically important for samples taken from the same species within the same region and season. There is a possibility that a seasonal effect exists; this remains a topic for research. In addition, we still think there is the likelihood of different density-resistance regressions for different pine species (see Annual Report 2016).

If breeders and researchers are interested in converting resistance to density, we still believe that it is appropriate to sample a small number of cores, say 5 to 10 cores, per species per site. With X-ray analysis, this would give samples of 40 to 80 rings/species/site. Another approach would be to stratify the core sampling based on the resistance measurements. For example, using Figure 11 as a case study, the breeder could sample 5 trees at the lower end of the range from resistance = 750 to 850, and 5 trees at the upper end from resistance 1200 to 1400, and develop a quite good regression line. But if breeders are only interested in ranking genotypes, then resistance measurements could be used directly, and all genetic parameters and BLUPs calculated in the resistance scale.

Expanded Global Eucalypt NIR Models: + *E. grandis*

Introduction

NIR spectroscopy offers tree breeders a fast and inexpensive method to assess wood properties for thousands of trees in a breeding population. In the 2015 Annual Report, we presented results for global NIR models that predict a number of important wood chemical properties for eucalpyt species. The model was based on samples of three datasets: *E. urophylla*, *E. dunnii*, and a third dataset of primarily *E. globulus* with a limited number of *E. nitens* samples. Here we report on the expansion of that model with a number of wood samples from another very important species, *E. grandis*. The 2015 Annual Report provides additional details, and a full report of the global NIR models has been submitted for publication.

Materials and Methods

Four sets of samples were used in this study: 1795 *E. urophylla*, 400 *E. dunnii* from Uruguay, 480 *E. globulus* and *E. nitens* from Chile (408 and 72 samples, respectively), and 1226 *E. grandis* from Colombia. All wood samples were ground into woodmeal using a Wiley mill. The samples were dried at 50˚C for 24 hours, then removed from the oven and allowed to come to room temperature. They were than scanned in a Foss 6500 NIR spectrometer using a spinning sample module. Reflectance readings were taken for NIR wavelengths from 1100 to 2500 nm, at 2-nm intervals.

In each case, the samples sent for wetlab analysis were pre-selected from a larger set of samples based on principal component analysis (PCA) of spectra, and on pulp yield and chemical predictions from prior NIR models. The samples for wetlab chemistry were selected to ensure good representation of the variation for preliminary predicted chemical traits, and for variation of the first two principal components of the spectral dataset.

Final wetlab chemistry was done for 186 samples: 50 samples of *E. urophylla*, 50 samples of *E. dunnii* from Uruguay, 50 samples of *E. globulus* and *E. nitens* from Chile (41 and 9 samples, respectively), and 36 samples of *E. grandis* from Colombia. Wetlab chemistry was done by Shawn Mansfield at the University of British Columbia. The chemistry was done on the same 4-gram woodmeal samples that had been scanned with NIR. The traits measured were: glucose, xylose, mannose, arabinose, galactose, and total sugar content; soluble lignin, insoluble lignin, and total lignin content, S/G ratio, and S/(S+G) percent, where S = syringyl lignin and G = guayacyl lignin. In this report, we will focus on only four important wood chemical traits: glucose, xylose, insoluble lignin, and S/(S+G).

NIR model development

NIR models were developed using the Camcore NIR R-pipeline. The pipeline examines models built with the raw spectra plus 13 different transformations of the spectra. The pipeline also identifies and deletes outliers, and conducts leave-one-out cross-validation. Both single-species NIR models and multiple-species models were investigated. The best models were selected by examining standard error of cross-validation (SECV), model fit measured by R^2_{CV}, and the number of factors. To examine how well these models might extrapolate to other species not included in the original model, we used models developed with three of the species datasets to predict wetlab chemical values for the fourth species.

Results and Discussion

Single-Species NIR Models

For all four datasets, it was possible to develop good single-species NIR models for all four chemical traits. In general, the models for the two lignin traits were slightly better than the models for the two sugar traits. For example, for acid-insoluble ligin, R^2_{CV} ranged from 0.64 to 0.96 across the four datasets. For glucose, the R^2_{CV} ranged from 0.60 to 0.90 across the four datasets. The best single-species models were obtained with the *E. globulus* - *E. nitens* dataset, with R^2_{CV} ranging from 0.90 to 0.96 for the four traits. The worst single-species models were obtained for *E. dunnii*, with R^2_{CV} ranging from 0.56 to 0.69 for the four traits, although even these models would still be useful for ranking genotypes in a breeding program. Notably, for the *E. dunnii* predictions, the SECVs for all traits were very similar to the SECVs observed in the other species datasets. This suggests that the lower R^2_{CV} values observed for *E.*

dunnii are primarily due to the smaller range in variation observed in this species. For example, for insoluble lignin content, the range from lowest to highest among *E. dunnii* samples was only 4.4%. For the other species, the range was 10.5%, 13.0%, and 15.2% for *E. grandis*, *E. globulus*-*E. nitens*, and *E. urophylla*, respectively.

Combined-Species Model

Very good to excellent models were obtained for insoluble lignin, S/(S+G), and xylose, with R^2_{CV} ranging from 0.89 to 0.96, and the model for glucose was good, with R^2_{CV} = 0.74 (Table 13, Figure 13). Standard errors of cross-validation (SECV) for the global models were similar to but slightly larger than the average SECV in the four single-species models. For example, for insoluble lignin, the average single-species SECV was ± 0.83%, while the global SECV was ± 0.91%. Similarly, for glucose, the average single-species SECV was ± 1.49%, while the global SECV was ± 1.68%. An exception to this trend was for the trait S/(S+G), where average single-species SECV was ± 1.378%, while the global SECV was ± 1.334%.

Model Extrapolation to "New" Species

To get some indication of how well the global model might extrapolate to predict species not included in the calibration data set, we used different three-species models to predict the fourth species. For example, a model built with *E. urophylla*, *E. dunnii*, and *E. globulus* + *E. nitens* could be used to predict values for *E. grandis*.

Across sixteen scenarios examined (four traits x four species), there was a wide range in the quality of the extrapolation predictions from very good to poor. Comparing the four traits, the best extrapolations were found for acid-insoluble lignin and S/(S+G), and the poorest extrapolations were for glucose. Comparing the species, the best extrapolations were found for *E. globulus* + *E. nitens*, with good to excellent predictions for all four traits. For this dataset, across the four traits, the single-species R^2_{CV} ranged from 0.90 to 0.96, and the extrapolation R^2_P ranged from 0.85 to 0.93. The next best extrapolations were for the *E. grandis* dataset, followed by the *E. urophylla* dataset. In comparison, the *E. dunnii* extrapolations for insoluble lignin, xylose , and glucose were disappointing (R^2_P = 0.40, 0.41, and 0.17, respectively, substantially less than the corresponding R^2_{CV}). However, the *E. dunnii* extrapolation predictions for S/(S+G) were good, with R^2_P = 0.64 that was actually higher than the single-species R^2_{CV} = 0.56.

For four for the sixteen species-trait scenarios, the extrapolation predictions equaled or exceeded the quality of the single-species cross-validations, with R^2_P greater than cross-validation R^2_{CV} (Table 13).

- E. *urophylla* - insoluble lignin
- *E. grandis* - insoluble lignin
- *E. grandis* - S/(S+G)
- *E. dunnii* - S/(S+G)

For another five of the species-trait scenarios, the extrapolation predictions were excellent relative to the single-species cross-validations. For the *E. globulus*-*E. nitens* dataset, extrapolations for all four traits had R^2_P only slightly less than R^2_{CV} (Table 13), and for the *E. grandis* – xylose scenario, R^2_P = 0.67 compared to R^2_{CV} = 0.68 for the single-species cross-validation.

For the *E. urophylla* – xylose scenario, R^2_P = 0.68 from the extrapolation was not as good as the single-species R^2_{CV} = 0.83, but it was easily high enough to be useful in a breeding program.

For the remaining 6 out of 16 trait-species scenarios, the extrapolation fit statistics were clearly worse than the single-species cross-validation, with average R^2_P = 0.42, while R^2_{CV} = 0.71.

Improvement of Global Models

We wanted to examine the impact of incorporating a small number of wetlab observations from the “new” species into the calibration model to improve predictions for the new species. Four species-trait extrapolation scenarios were chosen:

- *E. urophylla*, glucose
- *E. urophylla*, S/(S+G)
- *E. dunnii*, glucose
- *E. dunnii*, insoluble lignin

These four scenarios represent cases where the prediction fit statistics were significantly worse than the single-species cross-validation fit statistics (Table 13). The two *E. urophylla* scenarios represent cases where there is a wide range of variation in the wetlab values for the trait to be predicted, while the two *E. dunnii* scenarios represent cases where there is a more narrow range of variation in the wetlab values (for both traits, the smallest range of all four species). The process will be il-

Table 13. Summary statistics for NIR models for wood chemistry traits with a combined-species dataset.

E. urophylla, *E. dunnii*, *E. globulus*, *E. nitens*, *E. grandis*								
	Wetlab		**NIR Model**					
Variable	Mean	St. Dev.	Transformation	Factors	R^2_C	SEC	R^2_{CV}	SECV
Acid-insoluble lignin	24.1	4.6	SNV + SG5	6	0.97	0.751	0.96	0.905
S/(S+G)	78.4	6.3	MSC + SG7	11	0.98	0.909	0.95	1.334
Glucose	46.7	3.3	MSC + SG7	9	0.84	1.312	0.74	1.680
Xylose	12.8	2.3	SNV + SG7	9	0.94	0.580	0.89	0.754

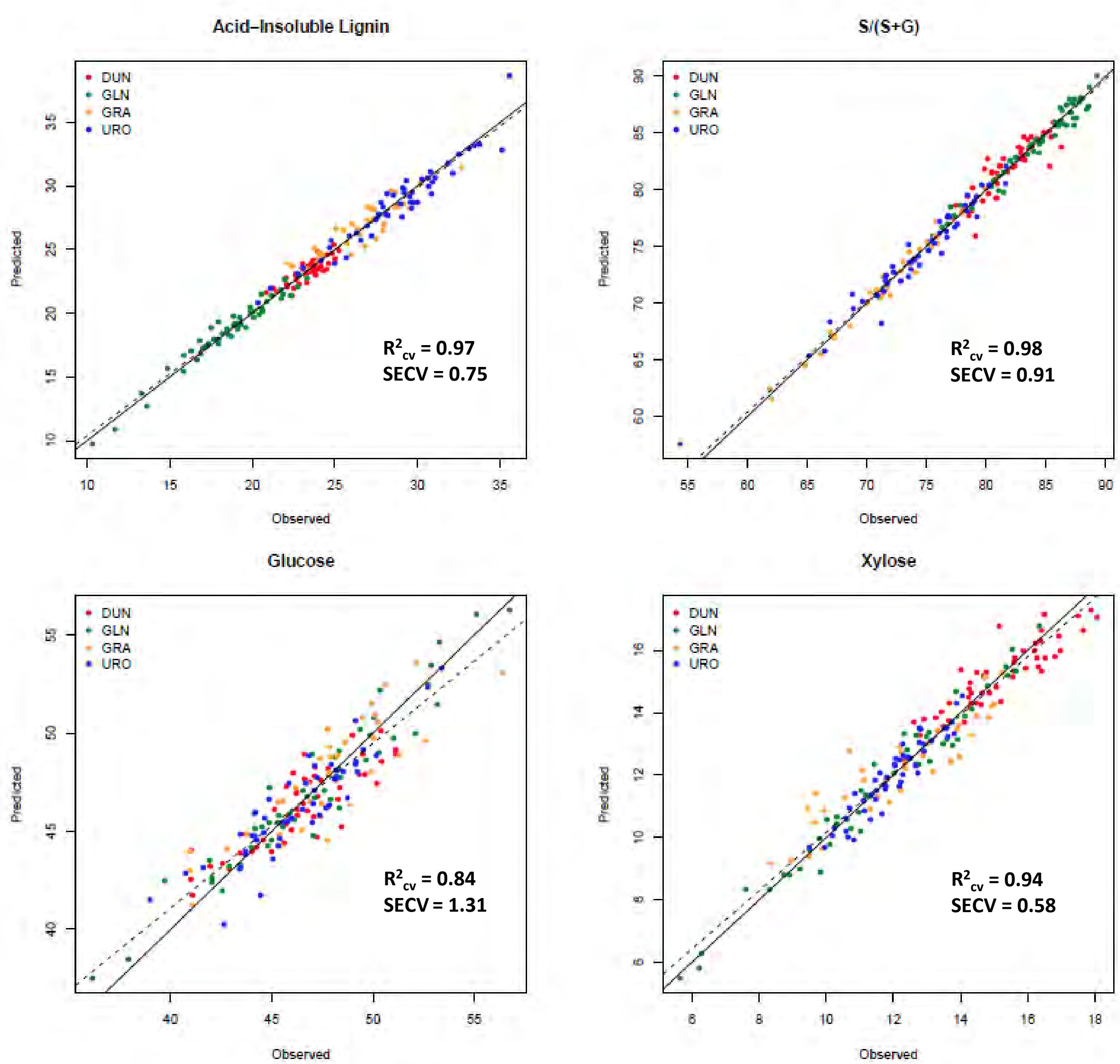


Figure 13. Observed lab values and predicted values for acid-insoluble lignin, S/(S+G), glucose and xylose content. Predictions from multiple-species mulitiple-site NIR models (DUN = *E. dunnii*, GLN = *E. globulus* + *E. nitens*, GRA = *E. grandis*, URO = *E. urophylla*).

lustrated for the scenario for *E. dunnii* and the trait glucose. The *E. dunnii* dataset contained 50 wetlab observations, and these were divided randomly into five sets of 10 observations. One set of 10 *E. dunnii* observations was incorporated into the global calibration model containing 50 *E. urophylla* + 36 *E. grandis* + 50 *E. globulus* and *E. nitens* observations. The calibration model was fit as described above, and used to predict the remaining 40 *E. dunnii* glucose observations. This was repeated five times for each of the five sets of 10 observations, and average R^2_P and SEP were calculated. This same process was repeated for the other three species-trait scenarios.

The inclusion of 10 samples of a "new" species into a global calibration made a significant improvement in the prediction fit statistics. For *E. urophylla* S/(S+G), single-species R^2_{CV} = 0.87 and the extrapolation prediction R^2_P = 0.45. With 10 observations from *E. urophylla* included in the calibration, the mean R^2_P for the remaining *E. urophylla* observations was R^2_P = 0.82, with a substantial reduction in SEP. For *E. urophylla* glucose, single-species R^2_{CV} = 0.78 and the extrapolation prediction R^2_P = 0.58. Adding 10 observations from *E. urophylla* to the calibration improved the R^2_P to 0.71. Similarly, for *E. dunnii* insoluble lignin, single-species R^2_{CV} = 0.78, R^2_P = 0.58, and the improved R^2_P was 0.52. For the most challenging species-trait scenario, *E. dunnii* - glucose, the single-species R^2_{CV} was 0.60, and the extrapolation was very poor, R^2_P = 0.17. Adding 10 observations of *E. dunnii* into the calibration improved the R^2_P to 0.40, which is still only moderate, but much closer to the upper baseline of the single-species R^2_{CV} of 0.60.

Conclusions and Outlook

The current Camcore global model for eucalpyts should be very suitable to predict wood chemistry for any of the species currently included in the calibration model (*E. urophylla*, *E. dunnii*, *E. globulus*, *E. nitens*, and *E. grandis*). For any species not included in the model, breeders could use the NIR models with the expectation that the predictions will be accurate enough to rank candidates in a breeding program. As opportunities develop to include additional species in the model, we will do so incrementally with a small number of samples from each new species. For example, if a project arises to study wood chemistry of *E. benthamii*, we would use the current model (*urophylla* + *dunnii* + *globulus* + *nitens* + *grandis*), and expand the calibration dataset with wetlab data on 10 to 15 *E. benthamii* samples.

Table 14. Single-species NIR models compared to extrapolation predictions from multi-species models.

Single-species cross-validation statistics (R^2_{CV} and SECV) are compared to extrapolation prediction statistics ((R^2_P and SEP). Multi-species models are calibrated with three unrelated species datasets and used to predict the fourth species. Species abbreviations are URO = *E. urophylla*, DUN = *E. dunnii*, GLN = *E. globulus* + *E. nitens*, GRA = *E. grandis*.

E. urophylla	Single-species		DUN-GLN-GRA	
Variable	R^2_{CV}	SECV	R^2_P	SEP
Insoluble Lignin (%)	0.87	1.17	0.90	1.08
S/(S+G) (%)	0.87	1.75	0.45	3.98
Glucose (%)	0.78	1.28	0.58	3.04
Xylose (%)	0.83	0.45	0.68	0.78
E. dunnii	Single-species		URO-GLN-GRA	
Variable	R^2_{CV}	SECV	R^2_P	SEP
Insoluble Lignin (%)	0.64	0.58	0.40	0.83
S/(S+G) (%)	0.56	1.60	0.64	1.66
Glucose (%)	0.60	1.60	0.17	3.24
Xylose (%)	0.69	0.80	0.41	1.22
E. globulus **+** *E. nitens*	Single-species		URO-DUN-GRA	
Variable	R^2_{CV}	SECV	R^2_P	SEP
Insoluble Lignin (%)	0.96	0.53	0.93	0.80
S/(S+G) (%)	0.92	1.05	0.90	1.18
Glucose (%)	0.90	1.30	0.85	2.67
Xylose (%)	0.96	0.52	0.93	1.01
E. grandis	Single-species		URO-DUN-GLN	
Variable	R^2_{CV}	SECV	R^2_P	SEP
Insoluble Lignin (%)	0.78	1.04	0.80	1.04
S/(S+G) (%)	0.93	1.12	0.97	0.81
Glucose (%)	0.69	1.79	0.51	2.35
Xylose (%)	0.68	1.07	0.67	1.13

Acknowledgements

Thanks to Smurfit Kappa Colombia, Smurfit Kappa Venezuela, Weyerhaeuser Company, CMPC Forestal Mininco, Sappi Forests, Mondi Forests, and Arauco Argentina for collection of wood samples used in this project, and to Juan Pedro Posse and Martha Salas for all their hard work in the field and the lab.

Transfer of Camcore Eucalypt NIR Models

Camcore has very good NIR models to predict wood properties of eucalypts. Our models are based on samples from multiple species and multiple sites, so these "global" models should be useful for analyzing genetic parameters and ranking genotypes regardless of species, geographic source, age of the material, etc. For some Camcore members, it will make sense to send samples to our lab in Raleigh NC to screen using our Foss 6500 NIR spectrometer. However, some Camcore members with large research teams and many thousands of samples to analyze may prefer to do NIR screening in-house. In these cases, it would be useful to be able to transfer the NIR models developed by Camcore to other NIR machines.

In the 2014 Annual Report, we presented results of a project to transfer our pine NIR models to member machines. The project was very successful, and demonstrated a simple and cost-effective method to transfer NIR models from one lab and NIR spectrometer to another. In 2017, a similar approach was used to transfer our global eucalypt models to a Bruker NIR spectrometer owned by long-time member Mondi Forests, South Africa.

Project Summary

Mondi had developed internal NIR models for a number of eucalypt species, but not including *E. dunnii.* The Camcore models were calibrated with a number of species, including *E. dunnii.* The Mondi research team screened 1380 *E. dunnii* samples, and used their current models to predict lignin and cellulose. They then pre-selected 200 samples from the tails of the distribution, and sent those woodmeal samples to Raleigh. In addition, samples of *E. grandis, E. grandis* x *E. urophylla,* and *E. grandis* x *E. nitens* (n = 40, 60, and 60 samples, respectively) were sent to Raleigh.

The woodmeal samples were then processed in our lab according to standard protocols, and scanned with the Foss 6500. Predictions were made for all sugar and lignin content variables, and these predictions were then used as "pseudo-wet-lab" values. Mondi spectra from the Bruker spectrometer were then used to build NIR models.

Very good NIR models were produced for the *E. dunnii* dataset and for the *E. grandis* + hybrid dataset (e.g., see Figure 14). For *E. dunnii*, for the traits of glucose content, lignin content, and S/G ratio, calibration R^2 was 0.91, 0.96, and 0.86, respectively. Similarly, for *E. grandis* + hybrids, calibration R^2 was 0.92, 0.97, and 0.88, for glucose, lignin, and S/G, respectively. Mondi breeders then used the newly-developed NIR models for *E. dunnii* to predict chemical traits for a provenance - progeny test population and to estimate genetic parameters. All three traits had very high levels of genetic control, with narrow-sense heritability estimates of h^2 = 0.56, 0.48, and 0.79 for glucose, lignin, and S/G, respectively.

Implications and Outlook

The use of Camcore NIR predictions as "wetlab" values makes for a fast and cost-effective method to transfer NIR models from our lab to any other spectrometer. This approach can be used to transfer our models to very precise (and expensive) laboratory machines, or to less powerful (and less expensive) portable NIR machines. This means that we can leverage our research and share data and results among the whole Camcore community, speeding model development and reducing costs.

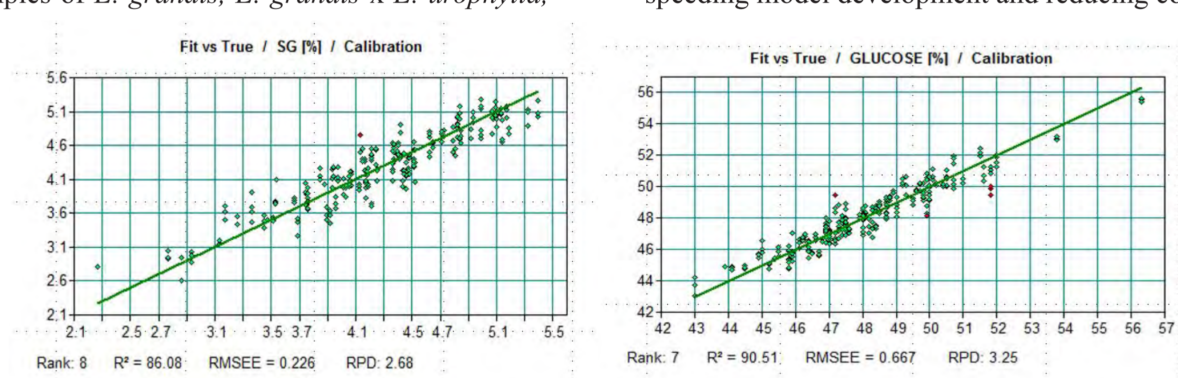


Figure 14. NIR models for *E. dunnii* developed by Mondi Forests using a Bruker NIR spectrometer and Camcore global eucalypt NIR model predictions as pseudo-wetlab values.

Comparison of NIR Results for Shavings vs. Wedges in *Eucalyptus* species

Introduction

Non-destructive testing (NDT) methods for wood characterization are key to success in breeding programs, because they don't permanently alter the structure of the trees, and companies can save both money and time during evaluation and research. Comparisons between destructive and NDT methods are of special interest since they allow breeders to evaluate the degree of accuracy of the data obtained using NDT.

Materials and Methods

In 2016, we conducted a study to compare wood properties of four eucalypt species in Uruguay. Approximately 120 trees (18 years old) were sampled in a field trial owned by Weyerhaeuser (now Lumin). We measured wood resistance using the IML Resistograph, modulus of elasticity (MOE) using TreeSonic, and predicted wood chemical traits using our NIR global models on wood shavings extracted at breast height. Results for this project were presented in our 2016 Annual Report. In 2017, Weyerhaeuser's research team felled the trees, and wedges were extracted and sent to NC State where they were ground into woodmeal for NIR scanning. With this new set of samples, we wanted to compare the NIR predictions from wedges (treated here as our destructive method) against the NIR predictions obtained from the shavings (NDT method) from the same trees. We analyzed the distribution of the predicted variables under the two sampling techniques, created comparison plots and ranked the trees to compare consistency in ranking for the top performing individuals.

Results and Discussion

We used our Camcore R pipeline to estimate the following four wood chemical traits: insoluble lignin, glucose, S/(S+G) and xylose. For each trait, we selected the model that best fit the data based on cross-validation statistics obtained for our Global Eucalypt NIR models (earlier in this report). Figure 15 illustrates the distribution of the predicted traits under the two sample types. Red box-plots correspond to the NIR prediction of shavings whereas the blue box-plots correspond to wedges. Note that both dispersion and distribution patterns of the traits are very similar for the two sampling techniques; there is also a clear differentiation between species. However, mean NIR predicted values are different for shavings and wedges, thus, we compared consistency across prediction by evaluating how the top performing individuals rank (Table 15).

For simplicity, we are presenting the rankings of the 10 best trees according to their predicted lignin and xylose. Lignin values were sorted

Table 15. Ranking of the best 10 trees out of 120 according to their NIR predictions based on shavings and wedges.

Lignin				Xylose			
SHAVINGS		WEDGES		SHAVINGS		WEDGES	
Tree_ID	%	Tree_ID	%	Tree_ID	%	Tree_ID	%
WYE065	19.52	WYE067	22.11	WYE081	14.32	WYE081	14.92
WYE008	20.55	WYE008	22.42	WYE113	14.02	WYE113	14.53
WYE009	20.57	WYE009	22.61	WYE024	13.76	WYE109	14.40
WYE067	20.98	WYE069	22.72	WYE047	13.75	WYE026	14.35
WYE026	21.43	WYE066	22.76	WYE025	13.72	WYE024	14.32
WYE109	21.43	WYE065	22.80	WYE122	13.67	WYE046	14.29
WYE021	21.50	WYE024	22.83	WYE007	12.94	WYE068	14.20
WYE066	21.72	WYE085	23.16	WYE026	12.88	WYE069	14.01
WYE085	21.73	WYE109	23.26	WYE018	12.75	WYE064	13.99
WYE087	22.03	WYE025	23.32	WYE036	12.69	WYE108	13.96

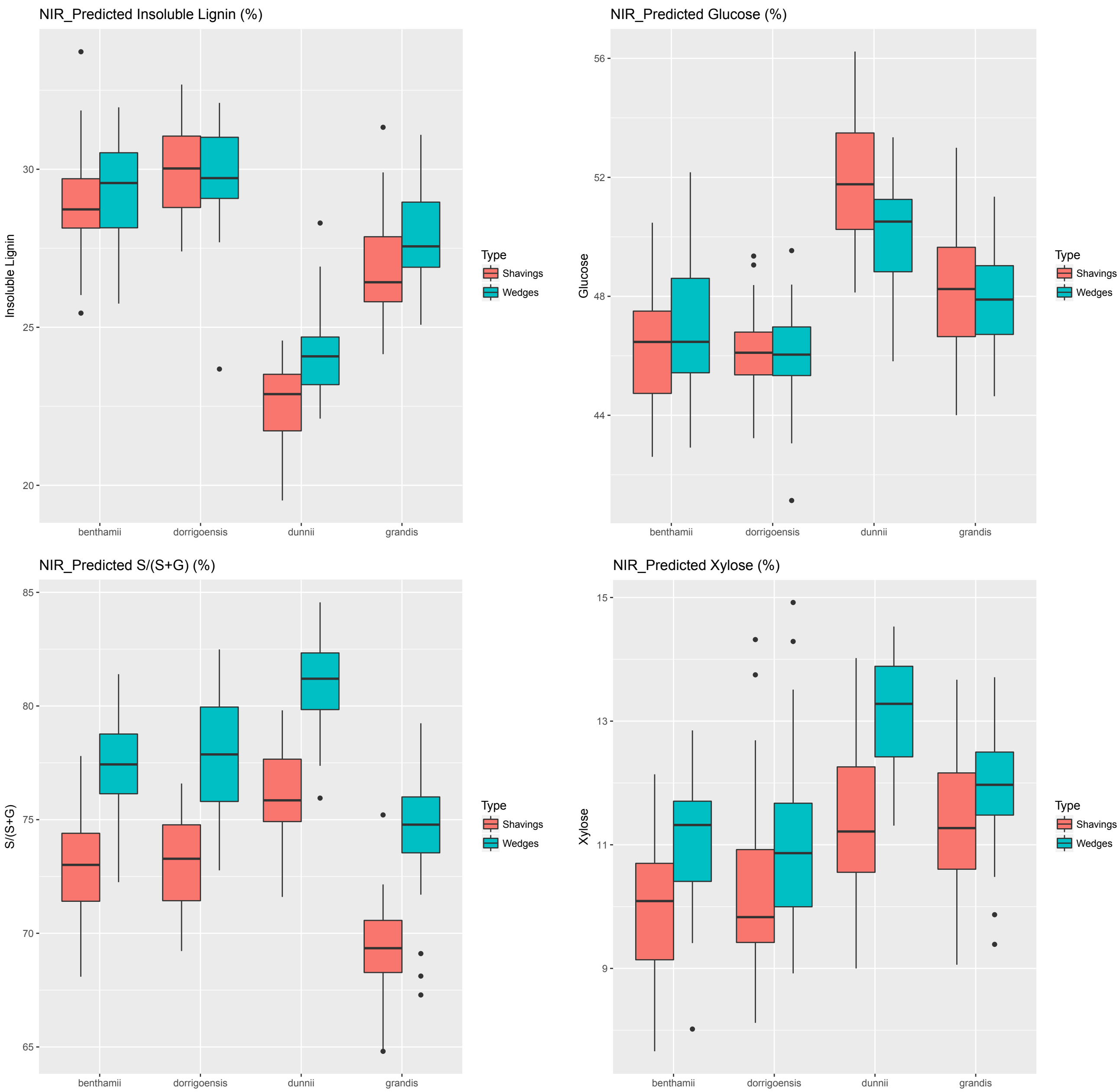


Figure 15. Box plots for NIR-predicted variables under two sample types.
Top left to right: Insoluble lignin, Glucose. Bottom left to right: S/(S+G) and Xylose.

from smallest to largest based on their shaving predictions. Seven out of ten trees were represented in both rankings (green cells). Interestingly, note that 80% of the best 5 trees under the shavings rank (green cells with white letters) are present in both rankings. Similarly, we ranked the trees from largest to smallest for xylose and we identified 4 out the 10 top trees for shavings in the top 10 for wedges. Consistency across rankings was proportional to the model strength. The coefficient of determination (R^2_{CV}) was higher for the lignin model (0.959) than xylose model (0.895).

Summary

This study allowed us to evaluate the consistency of NIR predictions from NDT (shavings) and destructive methods (wedges) in four *Eucalyptus* species. Although there are some differences between wood wedge and wood shavings predictions, the observed rank is fairly consistent for the top (or bottom) individuals. Collecting wood shavings is an efficient sampling technique (easy, economical and non-destructive) that yields similar results to collecting wedges.

Sterile Transfer of Genetic Material: Pine Scion Research

Camcore is continuing to develop the pine scion sterilization protocol and other sterile propagation projects used for sharing plant material. The main objective is to establish an efficient method for demonstrating that shipped material is clean, and consequently, to avoid lengthy plant quarantines. After the preliminary study on *Pinus taeda* scions in 2016, we have completed three different experiments as part of the project on the sterilization of pine scion. Two assessments were performed in July and September at the Forest Health Protection Laboratory (FHPL) at Smurfit Kappa Colombia (SKC), and one performed in August at the NCSU Molecular Tree Breeding Laboratory in Raleigh (MTBL).

Gildardo Montenegro of SKC sampling *P. tecunumanii* scions at a trial in Restrepo, Valle del Cauca

Experiment A, Colombia

The first experiment was conducted in July 2017 at the FHPL. A set of 120 *Pinus tecunumanii* scions and 120 *P. maximinoi* scions were collected in SKC genetic trials. Scions were wrapped in damp paper towels and placed in plastic bags to prevent dehydration. On the day of collection, the scions were placed in a refrigerator at approximately 7 °C for one day.

Half of the scions of each species were stripped of needles and the other half had the needles trimmed, leaving the needle sheath attached to the stem. Trimming, compared to stripping, prevented direct contact of chemical treatments with the wounds left by stripping. For both stripped and trimmed stems, scions were divided into groups of six and subjected to one of ten treatments (including a control). The chemicals used were Liquinox (lab soap), ethanol (C_2H_6O) at two concentrations, hydrogen peroxide (H_2O_2), and bleach ($NaClO$). Treatments were applied under aseptic conditions. After chemical treatments, the scions were placed in culture tubes (25 x 150 mm polycarbonate) that had been filled with 15 ml of Murashige and Skoog culture medium, supplemented with 30 g/l of sucrose and solidified with 4 g/l of Gelzan. Tubes were maintained in a room at a temperature between 23 to 27 °C under a 24-hour light regime provided by cool white fluorescent tubes. Contamination was scored every week based on visual inspections of areas of the medium where contamination was likely to occur.

Results

By day 28 all explants were contaminated. During the evaluation, it was evident that stripped scions were slower to develop contamination than the trimmed ones.

Experiment B, North Carolina

Thirty scions of *P. taeda* were collected from trees in a 14-year-old plantation in the Schenck Forest at NC State University. Sampling procedures from experiment A were followed. All scions were stripped of needles, placed in a Pyrex bottle, and subjected to a 1% Liquinox wash for 10 minutes and a 5-minute rinse using sterilized water. After washing, scions were divided into groups of six and subjected to one of four treatments in aseptic conditions at the MTBL. A fifth group served as a control. The four treatments included submersion in bleach and two were treated with ethanol. In addition, either a sonicator bath or a vacuum pump was used. In theory, the sonicator's ultrasonic vibrations agitate the solution and allow better penetration of the cleaning chemicals into hard-to-reach places. The vacuum pump is used to remove air from a sealed container, and the idea was to test whether this would remove air bubbles attached to the scions, allowing the chemicals to reach more surfaces for better cleaning.

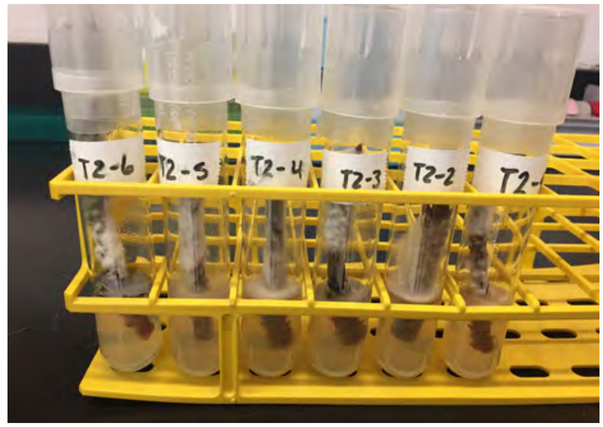
After chemical and mechanical treatments, the scions were placed in culture tubes (25 x 150 mm polycarbonate) that had been filled with 15 ml of Murashige and Skoog culture medium, solidified with 4 g/l of agar. No sucrose was added. Tubes were maintained on a lab counter at room temperature under a 24-hour light regime provided by cool white fluorescent tubes. Contamination was scored every week based on visual inspections of areas of the medium where contamination was likely to occur.

Results

Contamination was present by the first week on the controls but not the other treatments. However, physical deterioration from desiccation was evident on most of the explants treated with the vacuum pump. By the second week, several tubes from all the treatments were showing contamination, and the damaged explants in the vacuum pump treatments were becoming necrotic. By day 21, all of the tubes were contaminated.

Experiment C, Colombia

The third experiment was conducted in September at SKC's FHPL. Forty-eight *P. maximinoi* scions were collected from trees in SKC genetic trials, wrapped in damp paper towels and placed in plastic bags to prevent dehydration. The scions were stored at room temperature for 4 days before treatments. Another 48 scions of the same species



Contaminated explants of *P. taeda* at day 21 of Experiment B.

were collected, wrapped in damp paper towels in plastic bags and left overnight in a refrigerator at approximately 7 °C. These two treatments will be referred to as "No Cold" and "Cold" storage regimes. The rationale for the No Cold regime is to allow time for fungal spores to germinate as the resulting mycelium might be easier to kill than intact spores. Scions were stripped of needles and washed using a 1% liquinox solution followed by a triple rinse with sterilized water. The scions were divided into groups of three and subjected to one of eight treatments. Seven treatments consisted of submersion in one or two chemicals and the eighth was a control. The chemicals used were 70% ethanol (C_2H_6O), 5.25% or 2.5% bleach (NaClO), and the systemic fungicides Mertect (Thiabendazole 500 gr/l), Cabrio (Metiram 550 g/kg + Pyraclostrobin 50 g/kg) and Rally (Myclobutanil 400 g/kg). Treatments were applied under sterile conditions. Each group of three scions was placed inside a

Table 16. Chemical and fungicide treatments, concentrations, and duration of submersions (minutes) applied to groups of three pine scions in Experiment C.

Treatment	C_2H_6O		NaCLO		Mertect		Cabrio		Rally	
	% v/v	min	% v/v	min	mL/L	min	g/L	min	g/L	min
C1			2.50	30						
C2			5.25	30						
C3	70	2	5.25	30						
C4			5.25	30	2.5	3				
C5					2.5	3				
C6							7	3		
C7									4	3
C8	Control									

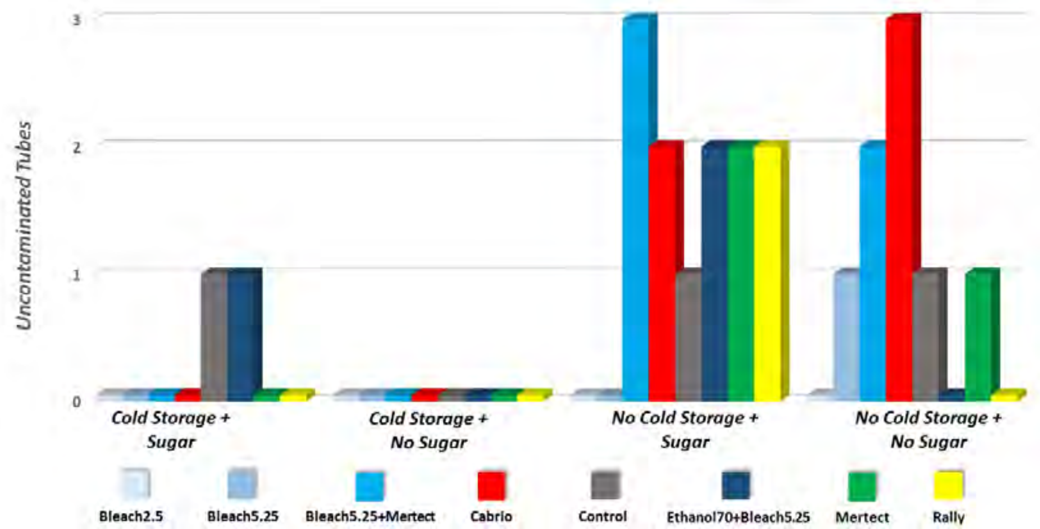


Figure 16. Efficacy of sterilization treatments in four regimes: number of uncontaminated pine explants in culture tubes at 28 days. Each combination of 4 regimes and 8 chemical treatments had 3 explants.

round Pyrex bottle or plastic tray and the chemicals were poured over the scions. The scions were gently agitated inside the containers for the specified time. Scions were rinsed three times for 5 minutes with sterilized water after each treatment involving bleach. Details of the chemical treatments are presented in Table 16.

After chemical and fungicidal treatments, the scions were placed in culture tubes. All tubes contained 15 ml of Murashige and Skoog culture medium, solidified with 4 g/l of agar. Half of the tubes were supplemented with 5% sucrose ("Sugar" regime) and the other half were not ("No Sugar"). Sucrose was added to increase contaminant development so that the treatments could be evaluated; however, sugar is not necessary for the explants to survive. Tubes were maintained between 23 to 27 °C under a 24-hour light regime provided by cool white fluorescent tubes. The experiment consisted of 96 explants: 3 replications of 8 chemical treatments under four regime combinations: Cold + Sugar, Cold + No Sugar, No Cold + Sugar, No Cold + No Sugar.

Results

Contamination was scored every week based on visual inspections of five different areas in the tube where contamination was likely to occur. At each of these areas, a score of 0, 1, or 2 was given for no, possible, and certain contamination, respectively. At day 28, contaminated and uncontaminated tubes were counted and these final values are shown in Figure 16. Successful sterilization was evident with two treatment - regime combinations: Bleach 5.25 + Mertect under the No Cold + Sugar regime, and Cabrio fungicide under No Cold + No Sugar regime. It is important to note that in the uncontaminated treated tubes and untreated controls, the explants showed signs of yellowing or shriveling by day 28. This reminds us that explants may have suffered from chemical treatments and/or deterioration over time.

Uncontaminated scion after being pulled from the tube at day 28 of Experiment C.

Outlook

Knowing the conditions and chemical treatments required to produce sterile, ready-to-graft explants that are permissable by plant protection agencies in member countries is important to Camcore. These techniques will be the key to efficient transfer of scion of the best parents that will eventually be identified in our pine hybrid breeding projects. Results from these preliminary experiments will help define the protocols for the sterile transfer of pine scions and of other types of genetic material (seedlings, rooted cuttings, etc.).

The work described here is just the first phase of what will be a long-term effort in this area. In 2018, we plan to expand this research to investigate sterilization of greenhouse-grown cuttings of eucalypts and pines. We also plan to begin an import "experiment", requesting permission from phytosanitary agencies in various countries to import live vegetative material (cuttings, scions, or plants) of eucalypts and pines. The idea is to learn what are the requirements, or to begin talking with the agencies in order to begin the process of developing procedures.

Pine SNP Chip Development

Camcore continues to work toward developing a SNP chip for tropical and subtropical pines by participating in grant-funded work whose objectives are to discover, annotate, and validate SNPs from millions of potential loci using an existing large-scale *Pinus taeda* genomics project. This work is led by Fikret Isik (NC State University), Jill Wegrzyn (University of Connecticut), Andrew J. Ecker (Virginia Commonwealth University), Richard A. Sniezko (USDA Forest Service) and Juan José Acosta (Camcore). Good progress was made in 2017, including the creation of the Conifer SNP Consortium (CSC) that will facilitate the inclusion of additional pine species for development of SNP chips. As a group, we will have a higher volume of genotyping samples, and will be able to negotiate better genotyping prices. The consortium is composed of six groups: Loblolly pine (NC State University), Tropical pines (University of Pretoria and Camcore, NCSU), Radiata pine (Scion, NZ), Norway spruce (Swedish University of Agricultural Sciences), Douglas-fir and western white pine (Oregon State University), and B4EST- European project-H2020 (19 European partners from 9 European countries, 6 forest tree species: *Picea abies*, *Pinus sylvestris*, *Pinus pinaster*, *Pinus pinea*, *Populus sp*, and *Fraxinus excelsior*).

To date, our work with tropical pines has involved the following steps:

1) We have conducted a pilot study for which we sent 4 libraries (40 samples) for exome capture to discover polymorphic sites in *P. greggii*, *P. oocarpa*, *P. patula* and *P. tecunumanii*.

2) Data has been analyzed and over 40,000 high-quality SNPs have been identified for each species. Data analysis was conducted by Dr. Jill Wegrzyn's lab at the University of Connecticut. We thank her and her student Madison Caballero for all their hard work.

3) In a second phase of this project, we sent additional species for sequencing: *P. maximinoi*, *P. caribaea*, *P. greggii*, *P. oocarpa* and *P. tecunumanii*. We created libraries covering the distribution range for each species.

We expect the sequence data in the summer of 2018. Data analysis will be conducted by Colin Jackson (graduate student at Camcore) under Jill's guidance. Camcore and FMG will then design a SNP chip for screening and will select the best SNPs for the commercial arrays. It is our expectation to have a work plan and a genotyping cost structure by the end of 2018. We are talking to genotyping centers to get a favorable price for the CSC members. Non-consortium organizations may be charged a higher price per sample if they decide to use the SNP arrays developed by the consortium.

Camcore Seed Collections 2017

We continued making seed collections in natural stands of Central American countries in 2017. In Guatemala, we collected seeds from 21 trees of *Pinus maximinoi* and *P. tecunumanii* in San Jerónimo and from 20 trees of *P. oocarpa* in El Castaño (Table 17). In Honduras, we collected seeds from 81 selected trees of *P. tecunumanii* and *P. maximinoi* from five different provenances: Culmí, La Esperanza, Las Trancas, Dulce Nombre de Copán, and Marcala. This genetic material will be distributed to Camore members for the establishment of new genetic trials and conservation banks. In 2017, we renewed agreements with the National Institute of Forests in Guatemala (INAB) and the National Institute of Forests in Nicaragua (INAFOR) to maintain our close collaboration to conserve the natural stands of native species. With population growth, the number of challenges for conservation increases. Agriculture and cattle, resin extraction, consumption for fuelwood, illegal logging, and squatters are some of the main causes of dwindling forest tree populations. In addition, the frequency of forest fires and pest infestations increases when the natural stands are managed poorly or not managed at all. As it is our practice, we report the conservation status of natural stands following the standards defined by the International Union for Conservation of Nature (IUCN).

Josué Cotzojay (Camcore) prepares to climb a *P. tecunumanii* tree for seed collection at La Esperanza provenance in Honduras.

Some of the remaining trees in the *P. maximinoi* stand at Dulce Nombre de Copán, Honduras. The small plants underneath the trees are coffee plants. This provenance was classified as "Endangered", according to IUCN standards.

Table 17. Summary of seed collections completed in Central America in 2017.

Country	Species	Provenance	Conservation Status	Latitude	Longitude	Trees
Guatemala	*P. tecunumanii*	San Jerónimo	Critically endangered	15º 03’ N	90º 18’ W	15
Guatemala	*P. maximinoi*	San Jerónimo	Critically endangered	15º 03’ N	90º 18’ W	6
Guatemala	*P. oocarpa*	El Castaño	Vulnerable	15º 01’ N	90º 09’ W	20
Honduras	*P. tecunumanii*	Culmí	Vulnerable	15º 06’ N	85º 33’ W	18
Honduras	*P. tecunumanii*	La Esperanza	Vulnerable	14º 16’ N	88º 13’ W	17
Honduras	*P. tecunumanii*	Las Trancas	Endangered	14º 07’ N	87º 49’ W	10
Honduras	*P. maximinoi*	Dulce Nombre de Copán	Endangered	14º 50’ N	88º 51’ W	18
Honduras	*P. maximinoi*	Marcala	Vulnerable	14º 10’ N	88º 01’ W	18

Camcore Domestic Conservation Program Update

Endangered tree species threatened by insects, pathogens, catastrophic wildfire, poor forest management, habitat fragmentation, and climate change continues to be a topic of much concern in the United States. The USDA Forest Service (USFS) and other government agencies continue to recognize genetic resource conservation as key to preserving the sustainability of the nation's forests, and Camcore remains an important collaborator in these efforts. Since 2003, Camcore has taken the lead in designing gene conservation strategies for some of the most at-risk species, implementing seed collections and supporting research on population genetics, seed technology, and nursery protocols, and conducting pivotal field studies on species restoration. This has been accomplished with nearly $1.3 million in grant funding from the USFS, has produced 15 peer-reviewed journal publications, 36 technical and conference papers, and 90 oral and poster presentations at scientific conferences, and trained four graduate students. Most importantly, these efforts have conserved nearly 10 million tree seeds representing 10 threatened species. These accomplishments would not have been possible without the continued support of our colleagues with the USFS (Barbara Crane with the Southern Region National Forest System; Rusty Rhea, Don Duerr, and Gary Mann with Forest Health Protection; Albert "Bud" Mayfield, Frank Koch, Dana Nelson, and Bryan Mudder with the Southern Research Station), Kevin Potter with NC State University, and our friends across the Camcore membership.

The Camcore Domestic Conservation Program enjoyed another successful year in 2017. Camcore Research Forester Andy Whittier planned and carried out all of our 2017 domestic seed collections (Table 18). Overall, he completed seed collections for five species representing 24 provenances and 159 mother trees. North Carolina Cooperative Extension Agent Thomas Glasgow conducted additional seed collections on behalf of Camcore, sending seed from 4 mother trees of Carolina ash, 1 mother tree of pumpkin ash, and 1 mother tree of green ash from the Brice's Creek provenance in Craven County, NC. These ash species are among the most threatened tree species in the United States, and continued seed collections from these will be a major focus of the domestic program in 2018.

Red spruce cones ready for collection at Waterrock Knob. Spruce cones often produce copious amounts of resin.

Field mapping and data collection continued in the Carolina hemlock conservation assessment study. This project is nearing completion and is yielding much useful information. As of the end of 2017, of the 137 possible population occurrences Camcore has identified, 75 have been visited, censused, and mapped. Sixty-four were found to contain naturally occurring Carolina hemlock populations, six contain planted Carolina hemlock, and five had no Carolina hemlock. Populations range in size from two trees to as many as 1,500 trees with an average population size of 134. Tree health ranges from poor (< 10% of trees surviving) to excellent (> 90% of trees surviving), with no discernible trends in population health relative to geography, elevation, or latitude. Sites that had previously received imidacloprid treatments for hemlock woolly adelgid infestation are in better health than those receiving no treatment or releases of biological control agents. Within chemically treated sites, tree health declines with increased distance from trails and roads. Recent wildfires have heavily impacted Carolina hemlock, most notably the population at Table Rock and Pinnacles in South Carolina and Dobson Knob and Shortoff Mountain in North Carolina. An estimated fifty percent of Carolina hemlocks in these populations were killed by the fires.

We also continue to follow and collect data from our hemlock seedling restoration study in western North Carolina. This study is testing the effects of canopy structure (gap versus thinned), deer exclusion, fertilization, and competition control on the establishment, survival, health, and growth of eastern hemlock seedlings planted into Southern Appalachian forests where the species has been heavily impacted by the hemlock woolly adelgid. In 2017, we collected a third year of data on tree survival and growth and competing vegetation. A thorough data analysis and manuscript will be prepared in 2018. Initial trends indicate that eastern hemlock benefits from both fertilization and competition control, but that these effects are small relative to the positive effect that growing in full sun under a canopy gap has on hemlock height and diameter growth.

2017 was another good funding year for the domestic conservation program. We received new grant funds totaling $173,581. This includes a grant from the USFS to evaluate target-tree release strategies for improving the health and sustainability of eastern hemlock in the Southern Appalachian Mountains (see box on page 28 in this Report), as well as funding from the Town of Cary, NC to conduct research that will help the town better understand and manage the relic stand of eastern hemlock they manage at the Hemlock Bluffs Nature Preserve. Preserve Manager Mark Johns played a key role in helping Camcore to secure this funding and will help conduct the research on site.

Table 18. Summary of seed collections completed by the Camcore Domestic Conservation Program in 2016.

Country	Species	Provenance	Latitude	Longitude	Elev (m)	Trees (#)
USA	*Tsuga caroliniana*	C.H. Campground	35.8053	-82.2546	823	7
USA	*Tsuga caroliniana*	Kitsuma Peak	35.6205	-82.2605	933	9
USA	*Tsuga caroliniana*	Cliff Ridge	36.1028	-82.4508	671	7
USA	*Tsuga caroliniana*	Shortoff Mtn	35.8308	-81.9026	833	10
USA	*Tsuga caroliniana*	Hawksbill Mtn	35.9131	-81.8866	1185	10
USA	*Tsuga caroliniana*	Shope Creek	35.6501	-82.4300	1110	8
USA	*Tsuga caroliniana*	Chattooga River	34.8172	-83.3049	330	1
USA	*Tsuga caroliniana*	UMRS	36.4006	-81.3182	929	17
USA	*Tsuga canadensis*	C.H. Campground	35.8053	-82.2546	823	10
USA	*Tsuga canadensis*	Cliff Ridge	36.0908	-82.4582	620	5
USA	*Tsuga canadensis*	Hawksbill Mtn.	35.9129	-81.8859	481	1
USA	*Tsuga canadensis*	Chattooga River	34.8000	-83.3000	344	5
USA	*Tsuga canadensis*	BRP Balsam	35.4101	-83.0451	1562	9
USA	*Tsuga canadensis*	BRP Mt. Mitchell	35.7070	-82.2714	1495	7
USA	*Tsuga canadensis*	BRP Mt. Pisgah	35.3208	-82.8398	1482	10
USA	*Abies fraseri*	Waterrock Knob	35.4623	-83.1222	1613	4
USA	*Abies fraseri*	Mt. Hardy	35.3020	-82.9347	1644	3
USA	*Picea rubens*	Waterrock Knob	35.4503	-83.1169	1505	8
USA	*Picea rubens*	Plott Balsam	35.5084	-83.1756	1509	1
USA	*Picea rubens*	BRP Mt. Mitchell	35.7173	-82.2793	1546	10
USA	*Picea rubens*	BRP Richland	35.3794	-83.0226	1677	10
USA	*Picea rubens*	BRP Mt. Pisgah	35.3167	-82.8550	1593	5
USA	*Fraxinus quadrangulata*	Julian Savanna	38.1695	-84.9272	646	1
USA	*Fraxinus quadrangulata*	Griffith Woods	38.3264	-84.3587	771	1
USA	*Fraxinus caroliniana*	Brice's Creek	35.0158	-77.0295	2	4
USA	*Fraxinus profunda*	Brice's Creek	35.0158	-77.0295	2	1
USA	*Fraxinus pennsylvanica*	Brice's Creek	35.0158	-77.0295	2	1

We were also able to spread the word in 2017 about our domestic conservation efforts through publications, presentations, and publicity. Four peer-reviewed journal articles were published on an array of topics that included strategies and challenges for gene conservation, silvicultural options for eastern hemlock restoration, and population genetics of Carolina hemlock (see box below). Program Manager Robert Jetton gave oral presentations at the East Texas Forest Entomology Seminar, The Southern Forest Insect Work Conference, and the HWA Program Managers Meeting, and Andy Whittier spoke at both the Mountain Research Station Field Day and the High Elevation Forest Restoration Workshop. Our work on gene conservation, population genetics, and silvicultural restoration received positive publicity this year, with feature articles appearing in the USFS Compass Live Weekly newsletter, the USFS Southern Forest Health Research and Management newsletter, the USFS Chief's Desk newsletter, and the New Bern Sun Journal newspaper. Finally, our hemlock gene conservation efforts and the tree climbing prowess of Andy Whittier were featured prominently in the video "The Hemlock Woolly Adelgid Problem" produced by Untamed Science (https://www.youtube.com/watch?v=jE4T1HBeQlo).

Carolina hemlock seedlings growing in the Camcore greenhouse at the Mountain Research Station in Brevard NC, to be used for restoration silviculture research and to establish seed orchards.

Carolina Hemlock Population Genetics

This year Camcore and our NCSU and USFS colleagues published our long-awaited results on the population genetics of Carolina hemlock in Tree Genetics and Genomes (see Potter et al. 2017 listed in the publication section of this annual report). This research was part of the M.S. research of former Camcore graduate student Lia Campbell, and involved important contributions from Dana Nelson and Sedley Josserand with the USFS Southern Institute of Forest Genetics and Kevin Potter with NCSU who was lead author on the paper. For the study, 439 Carolina hemlock individuals representing 29 populations were sampled, the most extensive rangewide sampling of the species for genetic analysis to date. The individuals were screened across 12 polymorphic microsatellite loci and resulting data analyzed to calculate genetic diversity and structure parameters. Given that Carolina hemlock is a rare conifer species that exists in a small number of isolated populations within the limited geographic range of the Southern Appalachian Mountains, the results of this study were largely as expected. The species has a low level of genetic diversity (H_O = 0.141) and the isolated populations are highly inbred (F_{IS} = 0.713). However, we also found that Carolina hemlock has a surprisingly high level of population differentiation (F_{ST} = 0.473) with little gene flow (N_m = 0.740), levels unprecedented for a North American conifer with wind-dispersed pollen and seed. The results indicate that the species is below the threshold level of gene flow necessary to avoid genetic drift and resulting reductions in population fitness associated with disturbance, such as what the species is already experiencing due to infestations by the exotic hemlock woolly adelgid. This highlights the importance of Camcore's ongoing gene conservation efforts for Carolina hemlock, and the data will help us refine our seed collection efforts to better capture the representative diversity and adaptability of the species.

Tree Breeding Course in Colombia

Camcore, Smurfit Kappa Colombia (SKC) and the Universidad Nacional de Colombia (UNAL) in Medellin organized the first "Curso teórico-práctico de mejoramiento genético forestal" (Theoretical and applied forest tree breeding course), which was held in the city of Cali, Colombia in March 2017. There were 27 students representing 16 Colombian forestry organizations, including private companies, government agencies and universities. The course was taught by national and international instructors who donated their time and knowledge: Gary Hodge, Bill Dvorak, Juan Lopez and Juan José Acosta (Camcore), Maria Claudia Díez and Jaime Muñoz (UNAL - Medellin and Palmira), Byron Urrego, Carlos Rodas and Nhora Isaza (Smurfit Kappa Colombia), Camilo Ramírez (Tekia), Miguel Rodríguez (Forestal Monterrey Colombia) and Diego Guzmán (Núcleos de Madera). The course provided full scholarships for three students of the Universidad del Cauca in Popayán and partial scholarships for two students of the UNAL in Medellín. We want to express our gratitude to the organizing committee: Maria Claudia Díez (UNAL-Medellín), Nhora Isaza (SKC) and Juan José Acosta (Camcore NC State). We also want to thank SKC's Forestry Division for the economic support and for hosting the visit to the company's facilities in Restrepo, Valle del Cauca.

Carlos Mario Jiménez of SKC explaining the commercial production of *E. grandis* clones in the Restrepo nursery as part of the applied breeding course in Colombia.

The closing ceremony and reception for the applied tree breeding shortcourse In Colombia.

R Shortcourses

In 2017, we continued offering R training sessions to our members. R is a free software environment for statistical computing and graphics that is rapidly increasing in popularity for research and business. Two types of courses were presented to our members: an introduction to R software, and the use of R for quantitative genetics analysis.

The first course is an introductory R class with the goals of learning the basis of good programming in R, understanding how R works, and knowing how to use R as a daily tool. Students in this course learn how to manage and work with R objects (variables, vectors, matrices, and databases), how to use logical operations to analyze data, and methods to get help and load packages. Special emphasis is given to using R for graphical applications. In 2017, this course was taught by Juan José Acosta as part of the Camcore technical visit to Masisa in Venezuela (February), Bosques del Plata and Arauco in Argentina (April) and Bioforest in Chile (December).

The second course focuses on quantitative genetics analysis using R. The course started with basic quantitative genetics theory applied to provenance and progeny tests, and was followed by R programming lessons on data quality control, mixed models for estimation of genetic parameters for single or combined sites, estimation of BLUPs and selection techniques. This course was taught by Gary Hodge and Juan José Acosta from July 31 to August 1 and was hosted by Mondi (South Africa). Staff from Mondi, SAFCOL, Merensky, Sappi, and the Institute for Commercial Forestry Research in Pietermaritzburg attended the class.

Changes in Camcore

André van der Hoef left Miro Forestry and moved to Indonesia to work with Sinar Mas Forestry as a tree breeder, where he will be in charge of research trials in the field. André has always been a great Camcore supporter while working at other companies, and we look forward to working with him in Indonesia.

Eloy Ignacio Sánchez left Uumbal in 2017 to look for new challenges in international forestry. We wish Eloy much success in his new professional endeavors.

Eric Cantor left Masisa Venezuela and took the position of Forestry Director in Uumbal Mexico in 2017. Eric moved to Mexico with his family to tackle new challenges in this position. **Nora Barrios**, Eric's wife, who was working as nursery manager in Masisa Venezuela, also left the company. Best wishes to Eric and his family.

Gerardo Balza, member of the research team of Smurfit Kappa Venezuela left the company to look for new professional opportunities in the Dominican Republic. We wish the best to Gerardo in his new challenges.

Tracy Maritz, *Eucalyptus* tree breeder with Sappi, decided to leave the company in 2017 to pursue other interests. Tracy, who worked with sugar cane before coming to forestry, did a great job working for several years for Sappi. We wish Tracy a fulfilling life with her family.

Francois van Deventer, research forester with Mondi, left the company to pursue new challenges in Indonesia. He is now working as a tree breeder for APRIL. APRIL will join as a new member of Camcore in 2018.

Gert Van den Berg, who had been working as a tree breeder in Mondi for several years, left the company to work for Sappi as the Principal Research Officer for Hardwood Hybrid Breeding. We wish success to Gert in his new position at Sappi.

Mmoledi Mphahlele was promoted to the position of Tree Breeder for the Mondi Cold Tolerant Eucalypt program. Mmoledi continues his PhD work at the University of Pretoria on potential applications of genomic selection in *E. grandis.*

Sphelele Mbanjwa was promoted to the position of Tree Breeder for the Mondi Subtropical Eucalypt program. We look forward to working closely with Sphelele in the years ahead.

Jorge Martínez-Haedo, previously working on forest protection research in Weyerhaeuser Uruguay, left the company in the second half of 2017 to work with the Uruguayan Forestry Society as the Coordinator of the Forest Health Committee. Jorge worked closely with Robert Jetton in Camcore on a research project measuring the impact of *Thaumastocoris peregrinus* on *Eucalyptus* plantations. We wish Jorge success in his new professional life.

Christi Sagariya joined Miro Forestry Sierra Leone as a tree breeder early in 2017. Prior to joining Miro, Christi worked in India for more than 10 years in both government and private sectors in tree breeding with *Casuarina, Eucalyptus*, *Tectona* and *Leucaena*.

Menason Essakku joined Miro Forestry in the second semester of 2017 and took the position of Tree Breeding Manager for Ghana. Menason came to Miro Forestry from the Tamil Nadu Forest Department in India, where he was working as a technical officer helping farmers to grow good quality seedlings and practice good agroforestry.

Miguel Rodríguez, who was the Forestry Director of Monterrey Forestal for many years, decided to retire at the end of 2017. Miguel was always a great supporter of Camcore and a great leader and he will continue to be part of the Camcore family. We expect to see him at the annual meeting in Colombia in 2018. We wish Miguel the best in his new life.

Willie Brink is the new manager of research at MTO. Willie has been working in forest planning with the company for several years. Willie took on the responsibilities of Philip Cox, who went to work as operations manager at APRIL, Indonesia. Our best wishes to Willie and Philip with their new responsibilities at both companies.

Ilse Botman left PG Bison to take the position of Technical Services Manager with SAFCOL. Ilse will be based in Nelspruit. We wish Ilse the best in her new position.

Graduate Programs and Training

Andy Whitter, Research Forester with Camcore's Domestic Conservation Program, completed his M.S. degree with a thesis entitled "Nutrient Disorder Foliar Symptoms, Foliar Nutrient Levels and Predictive Near-infrared Spectroscopy Nutrient Models of Teak (*Tectona grandis* L.f.)." Andy will continue to be based in Asheville, NC, continuing his work on Camcore's USA gene conservation projects, as well as contributing to other Camcore research projects.

Martha Salas, Research Geneticist with Smurfit Kappa Colombia, completed her M.S. degree with a thesis entitled "Clonal genetic variation of *Eucalyptus grandis* W. Hill ex Maiden in Colombia". Martha returned to Smurfit Kappa Colombia, where she will lead the tree breeding programs for the company.

Juan Pedro Posse, Research Manager with Lumin Uruguay, continues working on the final stages of his PhD dissertation on the genetic control of wood properties in *Eucalyptus dunnii*. Juan Pedro plans to complete the PhD dissertation and graduate in 2018.

Colin Jackson began an M.S. program in the fall of 2017. Colin completed his B.S. in forestry at Oklahoma State University, and worked as a research intern in tree breeding with Weyerhaeuser. Colin is being jointly funded by Camcore and the NC State *P. taeda* Tree Improvement Program to work with molecular genetic data related to the pine SNP chip.

Luis Ibarra began an M.S. program in the fall of 2017, being funded by the Camcore graduate student stipend, and supported by Arauco Bioforest in Chile. Luis has worked in tree breeding for Bioforest for a number of years, and the long-term plan is for Luis to pursue a PhD in quantitative genetics and breeding.

Publications and Papers

Publications

Acosta J.J. , Fahrenkrog A.M., Neves, L.G., Resende, M.F.R., Dervinis, C., Holliday, J.A.. Kirst, M. Exome re-sequencing reveals parallel evolutionary history, genomic diversity, and targets of selection in the conifers *Pinus taeda* and *Pinus elliottii*. Genome Biology and Evolution. Submitted

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The 2017 Camcore Advisory Board

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Nhora Isaza (Smurfit Kappa Colombia) teaches aspiring tree breeders at the *Pinus tecunumanii* and *P. maximinoi* potted breeding facility at SKC's La Estrella nursery. This was the first course in Theoretical and Applied Tree Breeding taught in Colombia, which was organized by Camcore and SKC. Students representing government agencies, forest industry, and three universities were in attendance.

Front Cover: Enoch Totimeh and Menason Essakku of Miro Forestry Ghana in the a newly established *E. pellita* progeny test. Miro Forestry Ghana and Miro Forestry Sierra Leone are the first two Camcore members in West Africa.