camcore

Global partners for the future of our forests

2018 Annual Report

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International Tree Breeding and Gene Conservation

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EXECUTIVE SUMMARY

1. In 2018, Camcore gained a new member, APRIL Indonesia, the 2nd in that country. APRIL grows tropical eucalypts and acacia to produce pulp and paper for Asian markets. This increases our presence in southeast Asia, and may open possibilities for other members in the future. In 2017, Weyerhaeuser Company sold their lands in Uruguay to BTG Pactual, and the company was renamed Lumin. In 2018, Lumin formally joined Camcore.

2. We completed an analysis of 43 pine hybrid tests with 5-year growth data. In addition, we have wood properties data from twelve 8-year-old tests in various countries. In general, *Pinus patula* x *P. tecunumanii* and *P. greggii* x *P. tecunumanii* are doing very well in all tests, confirming our decision to focus on full-sib breeding of these varieties. Another hybrid with great promise in tropical environments is *P. caribaea* x *P. tecunumanii*.

3. The *P. patula* x *P. tecunumanii* hybrid breeding program produced seed of 126 full-sib hybrid families. The families will be divided into two sets for field testing. Vegetative propagation is now underway for a set of 66 families, and the first field tests will be established in the second half of 2019. Work on the *P. tecunumanii* x *P. greggii* hybrid breeding program continued in 2018, with 94 full-sib crosses attempted.

4. Camcore eucalypt hybrid breeding work continues. Phase 1 crosses have been established in seedling selection blocks, and pre-selections have been made in a number of countries. The first clonal tests from this phase will go into the ground in South Africa in 2019. Phase 2 crossing involves 16 members and will produce 25 hybrid varieties.

5. Seed collections of improved Camcore teak and gmelina have been made in Colombia. In addition, selections of the top genotypes have been propagated for clonal testing. We plan to ship family seed collections and rooted cuttings of both species to Miro Forestry in Ghana and Sierra Leone for conservation and establishment of progeny and clonal genetic tests.

6. Camcore graduate students Martha Salas and Juan Pedro Posse have completed research projects on the genetic control of wood properties in *Eucalyptus grandis* and *E. dunnii*, respectively. Wood chemistry and solid wood traits are under strong genetic control in both species. Regardless of the final product objective, tree breeders can add value to their companies by incorporating wood traits into their selection and breeding programs.

7. The *Eucalyptus* species wood characterization project now has data from Chile, Uruguay, and South Africa. Species were compared for wood resistance to penetration (related to density), modulus of elasticity (MOE, timber strength), and wood chemistry (glucose, xylose, lignin content and composition). In Chile, *E. globulus* has better wood properties than all other species tested. In Uruguay, some species offer better density and/or better MOE than *E. grandis* or *E. dunnii*. In South Africa, several species offer better density and/or better MOE than *E. grandis* or the GU hybrid.

8. A second screening project to compare tolerance of eucalypt species to the pathogen *Austropuccinia psidii* was completed in collaboration with Smurfit Kappa Colombia. The first screening project was done in Uruguay with INIA. *Eucalyptus brassiana*, *E. camaldulensis*, and *E. longirostrata* all performed very well in both screening studies. *Eucalyptus dunnii* and *E. grandis* performed relatively poorly in both studies, although their performance in Colombia was slightly better than in Uruguay.

9. Good progress was made toward the production of a tropical pine SNP chip for marker analysis and genomic selection. Bioinformatic data has been gathered on six species (*P. patula*, *P. maximinoi*, *P. tecunumanii*, *P. greggii*, *P. caribaea* and *P. oocarpa*), and in 2019 we will conduct a large experiment with ThermoFisher Scientific to screen some 420,000 candidate SNP markers in order to identify a set of 50,000 SNPs that will make up an operational chip.

10. Camcore worked with Prof. Brad Potts and Dr. Jakob Butler at the University of Tasmania on a literature review of lesser-known eucalypt species. The objective was to identify species with potential as pure species or hybrid partners to help address various environmental challenges. A set of 21 species was identified, and these will likely be the focus of our collection efforts over the next decade.

11. Our USA gene conservation efforts continue to receive good publicity and financial support. In 2018, seed collections of Table Mountain pine (*P. pungens*) and various ash species (*Fraxinus*) were completed, and explorations for pitch pine (*P. rigida*) collections were made. Although hemlock is considered a very shade-tolerant species, a surprising result from our research is the importance of increased sunlight for hemlock seedling survival and growth, and possibly for the recovery of older trees from hemlock woolly adelgid infestation.

RESUMEN EJECUTIVO (Español)

1. En el 2018 Camcore ganó un nuevo miembro en Indonesia, APRIL Indonesia. APRIL planta eucaliptos tropicales y acacias para producción de pulpa y papel para los mercados asiáticos. Esto incrementa nuestra presencia en el sureste asiático y podría abrir posibilidades para otros miembros en el futuro. En el 2017, Weyerhaeuser Company vendió sus tierras en Uruguay a BTG Pactual y la compañía fue llamada Lumin. En el 2018, Lumin se afilió formalmente a Camcore.
2. En Camcore completamos el análisis de 43 ensayos de híbridos de pino con datos de crecimiento a cinco años. Adicionalmente, tenemos datos de propiedades de la madera de doce ensayos de ocho años de edad en varios países. En general, *P. patula* x *P. tecunumanii* y *P. greggii* x *P. tecunumanii* mostraron buenos resultados en todos los ensayos, confirmando nuestra decisión de concentrarnos en cruzamientos de hermanos completos de estos dos híbridos. Otro híbrido promisorio en ambientes tropicales es el *P. caribaea* x *P. tecunumanii*.
3. El programa del híbrido de *P. patula* x *P. tecunumanii* produjo semillas de 126 familias de hermanos completos. Las familias serán divididas en dos grupos para ser evaluadas. Actualmente se desarrolla la propagación vegetativa para un grupo de 66 familias, y los primeros ensayos de campo se establecerán en la segunda mitad del 2019. El trabajo en el programa del híbrido de *P. tecunumanii* x *P. greggii* continuó en el 2018, con la realización de 94 cruces de hermanos completos.
4. El trabajo en el programa Camcore de cruzamientos de híbridos de eucalipto continúa. Los híbridos de la fase 1 han sido establecido en bloques de selección de plántulas, y ya se han realizado preselecciones en varios países. Los primeros ensayos clonales de esta fase serán plantados en Sudáfrica en el 2019. Los cruces de la fase 2 involucran a 16 miembros que producirán 25 híbridos diferentes.
5. En Colombia se realizaron colectas de semillas mejoradas de teca y Gmelina arborea. Adicionalmente, se han propagado selecciones de los mejores genotipos para ensayos clonales. Tenemos planes de enviar semillas y estacas enraizadas de ambas especies a Miro Forestry en Ghana y Sierra Leona para conservación y establecimiento de ensayos de progenie y de clones.
6. Los estudiantes de postgrado de Camcore Martha Salas y Juan Pedro Posse han completado sus proyectos de investigación en el control genético de propiedades de la madera en *E. grandis* y *E. dunnii*, respectivamente. La química de la madera y las propiedades de madera sólida están bajo fuerte control genético en ambas especies. Independientemente del producto final que se quiera, los mejoradores forestales pueden agregar valor para sus compañías al incorporar características de la madera dentro de los programas de selección y mejoramiento genético.
7. El Proyecto de caracterización de la madera de especies de *Eucalyptus* ahora cuenta con datos provenientes de Chile, Uruguay, y Sudáfrica. Las especies fueron comparadas en términos de Resistencia (densidad), módulo de elasticidad (MOE, rigidez de la madera), y química de la madera (contenido de glucosa y xilosa, y composición y contenido de lignina). En Chile, *E. globulus* tiene mejores propiedades de la madera que todas las otras especies ensayadas. En Uruguay, algunas especies ofrecen mejor densidad y/o mejor MOE que *E. grandis* o *E. dunnii*. En Sudáfrica, varias especies ofrecen mejor densidad y/o mejor MOE que el *E. grandis* o el híbrido GU.
8. Se completó una segunda evaluación de desempeño para comparar la tolerancia de las especies de eucaliptos al patógeno *Australopuccinia psidii* en colaboración con Smurfit Kappa Colombia. El primer proyecto se realizó con el INIA en Uruguay. *Eucalyptus brassiana*, *E. camaldulensis*, y *E. longirostrata* se desempeñaron muy bien en ambos estudios. *Eucalyptus dunnii* y *E. grandis* tuvieron un desempeño relativamente pobre en ambos estudios, aunque su desempeño en Colombia fue ligeramente superior que en Uruguay.
9. Se ha logrado buen avance en el Proyecto de producción de un SNP chip para pinos tropicales a ser utilizado en análisis de marcadores y selección genómica. Se ha generado información bioinformática para seis especies (*P. patula*, *P. maximinoi*, *P. tecunumanii*, *P. greggii*, *P. caribaea* y *P. oocarpa*), y en el 2019 haremos un experimento a gran escala con ThermoFisher Scientific para evaluar unos 420,000 marcadores SNPs candidatos, con el objetivo de identificar un grupo de 50,000 SNPs que conformarán el chip operacional.
10. Camcore trabajó con el profesor Brad Potts y el Dr. Jakob Butler en la Universidad de Tasmania en una revisión de literatura sobre especies de eucalipto poco conocidas. El objetivo fue identificar especies que tienen potencial como especies puras o como compañeros híbridos para ayudar a enfrentar varios desafíos ambientales. Se identificó un grupo de 21 especies, las cuales muy probablemente serán el objetivo de nuestras colectas en la próxima década.
11. Nuestros esfuerzos en la conservación de genes en los Estados Unidos continúan recibiendo buena publicidad y soporte financiero. En el 2018 se completaron colectas de semillas de *Pinus pungens* y varias especies de *Fraxinus,* y también se hicieron algunas exploraciones para la colecta de semillas de *P. rigida*. Aunque el hemlock es considerado una especie muy tolerante a la sombra, un resultado sorpresivo en nuestra investigación es la importancia del incremento de la luz solar en la sobrevivencia y el crecimiento de las plántulas para esta especie y posiblemente en la recuperación de árboles mayores atacados por el insecto *Adelges tsugae*.

RESUMO EXECUTIVO (Português)

1. Em 2018, a empresa April da Indonésia se tornou associada a Camcore. A empresa April, desenvolve e cultiva eucaliptos tropicais e acácia para a produção de celulose e papel para os mercados Asiáticos. Este novo associado aumenta nossa presença no Sudeste Asiático, como também pode abrir novas possibilidades para futuros novos membros. Em 2017, a Weyerhaeuser vendeu as suas propriedades florestais no Uruguai para o BTG Pactual e a nova empresa agora é chamada de Lumin. Em 2018, a empresa Lumin, se tornou uma associada da Camcore.
2. Finalizamos as análises de 43 testes de híbridos de Pinus com dados de 5 anos. Destes testes, já temos informações sobre a qualidade da madeira de testes com 8 anos de idade, provenientes de vários países. Em geral, *P. patula* x *P. tecunumanii* e *P. greggii* x *P. tecunumanii* estão se desenvolvendo muito bem em todos os testes, confirmando nossa decisão de focar no cruzamento controlado destas espécies. Outro híbrido com potencial em ambientes tropicais é *P. caribaea* x *P. tecunumanii*.
3. O programa de cruzamentos para a produção de híbridos de *P. patula* x *P. tecunumanii* produziu sementes de 126 famílias de irmãos completos. Estas famílias serão divididas em 2 grupos para testes de campo. A propagação vegetativa está sendo utilizada para a multiplicação de 66 famílias e os primeiros testes a campo serão estabelecidos no segundo semestre de 2019. O programa de cruzamentos de *P. tecunumanii* x *P. greggii* teve continuidade com 94 cruzamentos controlados efetuados em 2018.
4. O programa de cruzamentos para a produção de híbridos de eucaliptos está em andamento. FASE 1- os cruzamentos foram estabelecidos em campo em blocos e já foram efetuadas seleções em vários países. Os primeiros testes clonais da fase 1 serão estabelecidos na África do Sul em 2019. FASE 2- Dois cruzamentos envolvem 16 empresas associadas e produzirão 25 híbridos.
5. A Camcore colecionou sementes de teca e gmelina na Colombia. Seleções dos melhores genótipos tem sido propagados para testes clonais. Nós planejamos enviar coleções de sementes por famílias e material enraizado de ambas as espécies para as empresas Miro Forests em Ghana e Sierra Leone para conservação e estabelecimento de testes de progênies e testes clonais.
6. Juan Pedro Posse e Martha Salas, ambos estudantes de pós graduação da Camcore finalizaram os seus respectivos projetos de pesquisa sobre o controle genético das propriedades da madeira em *E. dunnii* e *E. grandis* respectivamente. Tanto as características químicas como variáveis físicas da maderia possuem controle genético nas duas espécies estudadas. Sem considerar o produto final, melhoristas podem agregar valor, incorporando características da madeira nos programas de melhoramento.
7. O projeto de caracterização da madeira de várias espécies de *Eucalyptus* têm fornecido dados provenientes do Chile, Uruguay e África do Sul. As espécies foram avaliadas para a densidade com (Resistógrafo), módulo de elasticidade (MOE) e química da madeira (glucose, xylose, conteúdo de lignina). No Chile, o *E. globulus* possui as melhores caraterísitcas da madeira quando comparado as outras espécies testadas. No Uruguay, algumas espécies demonstram possuir melhor densidade e/ou melhor MOE que *E. grandis* ou *E. dunnii*. Na África do Sul, várias espécies demonstram ter melhor densidade e/ou melhor MOE do que *E. grandis* ou o híbrido de GU.
8. Em colaboração com Smurfit Kappa da Colombia, foi concluído um segundo projeto com o objetivo de comparar a tolerância de espécies de *Eucalyptus* ao patógeno *Austropuccinia psidii*. O primeiro projeto foi conduzido no Uruguay com INIA. As espécies *Eucalyptus brassiana*, *E. camaldulensis*, e *E. longirostrata* apresentaram tolerância nos 2 estudos. *Eucalyptus dunnii* e *E. grandis* não apresentaram tolerância em ambos os testes, porém a sua perfomance na Colombia foi um pouco melhor quando comparado ao Uruguay.
9. Avançamos com a produção de SNP chip para pinus tropicais para análise de marcadores e seleção genômica. Dados de bioinformática foram compilados para 6 espécies (*P. patula*, *P. maximinoi*, P. *tecunumanii*, *P. greggii*, *P. caribaea* e *P. oocarpa*). Em 2019 conduziremos um grande teste com a empresa ThermoFisher Scientific para testar 420M marcadores SNP com o ojetivo de identificar um grupo de 50M SNPs que irá produzir um chip operacional.
10. Em cooperação com Prof. Brad Potts e o Dr. Jakob Butler da University of Tasmania foi executado uma revisão de literatura de espécies de eucalipto menos conhecidas. O objetivo foi identificar espécies com potencial de serem trabalhadas como espécies puras e para hibridação. Um grupo de 21 espécies foi identificado e este será o foco onde colocaremos esforços para efetuar coletas na próxima década.
11. Nossos esforços para conservação genética nos EUA continuam a receber grande publicidade e suporte financeiro. Em 2018, completamos várias coleções de sementes de *P. pungens* e *Fraxinus* como também incursões para coletas de *P. rigida*. Apesar da Tsuga ser considerada uma espécie muito tolerante a sombra, obtivemos um resultado surpreendente com a importância do aumento da luminosidade na sobrevivência e crescimento desta espécie, como também da importância da luz na recuperação de indivíduos adultos infestados pela colchonilha.

MUHTASARI WA TAARIFA KUU (Kiswahili)

1. Mwaka 2018, Camcore ilipata mwanachama wa pili Indonesia, APRIL Indonesia. APRIL inakuza eucalpyts na mshanga ya kitropiki kutengeneza massa ya kuni na karatasi kwa masoko ya Asia. Hii imeongeza uwepo wetu katika Asia ya kusini, na inaweza kufungua uwezekano kwa wanachama wengine katika siku zijazo. Mnamo 2017, Kampuni ya Weyerhaeuser iliuza ardhi zao nchini Uruguay kwa BTG Pactual, na kampuni hiyo ikaitwa Lumin., Lumin ilijiunga na Camcore mwaka 2018.

2. Tulikamilisha uchambuzi wa vipimo 43 vya pine za mseto na takwimu ya ukuaji wa miaka mitano. Kwa kuongezea, tuna takwimu ya mbao ya miti kutoka kwa vipimo kumi na viwili vya umri wa miaka minane katika nchi mbalimbali. Kwa ujumla, *Pinus patula* x *P. tecunumanii* na *P. greggii* x *P. tecunumanii* inafanya vizuri sana katika vipimo vyote, kuthibitisha uamuzi wetu wa kuzingatia uzazi kamili wa aina hizi. Mseto mwingine wenye ahadi kubwa katika mazingira ya kitropiki ni *P. caribaea* x *P. tecunumanii*.

3. Mpango wa uzazi wa mseto wa *P. patula* x *P. tecunumanii* ulizalisha mbegu za familia mia moja na ishirini na sita . Familia zitagawanywa katika seti mbili za kupima shamba. Uenezaji wa mimea unaendelea kwa seti za familia sitini na sita (66), na vipimo vya kwanza vya shamba vitaanzishwa katika nusu ya pili ya mwaka 2019. Mpango wa kuzalisha mseto *P. tecunumanii* x *P. greggii* uliendelea mwaka 2018, na michanganyiko kamili tisaini na nne kujaribiwa.

4. Kazi ya Camcore ya uzalishaji eucalypts mseto inaendelea. Michangnyiko ya awamu ya kwanza imeanzishwa katika vitalu vya uteuzi wa miche, na uchaguzi wa awali ulifanywa katika nchi kadhaa. Vipimo vya kwanza vya clone kutoka kwenye awamu hii vitapandwa Afrika Kusini mwaka 2019. Michanganyika ya kuvuka kwa Awamu ya 2 inahusisha wanachama kumi na sita na itazalisha aina 25 za mseto.

5. Mbegu zilizoboreshwa za teak ya Camcore na Gmelina zimefanyika nchini Colombia. Aidha, chaguo za genotype za juu zimesambazwa kwa kupima clone. Tuna mpango wa kusafirisha makusanyiko wa mbegu za familia na vipandikizi vya mizizi ya aina zote mbili hadi Misitu ya Miro nchini Ghana na Sierra Leone kwa ajili ya uhifadhi na kuanzishwa vizazi na vipimo na maumbile ya clone.

6. Wanafunzi wa chuo Martha Salas na Juan Pedro Posse wamekamilisha miradi ya utafiti juu ya udhibiti wa maumbile ya miti ya *E. grandis* na *E. dunnii*, kwa mtiririko huo. Kemia ya kuni na sifa imara za miti iko chini ya udhibiti wa maumbile yenye nguvu katika aina zote mbili. Bila kujali lengo la mwisho la bidhaa, wazalishajii wa miti wanaweza kuongeza thamani kwa makampuni yao kwa kuingiza sifa za mbao katika miradi zao za uteuzi na kuzalishana.

7. Mradi wa utambulisho wa kuni wa *Eucalyptus* sasa una takwimu kutoka Chile, Uruguay, na Afrika Kusini. Aina zilifananishwa na Urekebishaji (wiani), moduli ya elasticity (MOE, nguvu za mbao), na kemia ya kuni (glucose, xylose, maudhui ya lignin na muundo). Huko Chile, *E. globulus* ina sifa bora zaidi ya kuni kuliko aina zote zilizopimwa. Nchini Uruguay, aina fulani hutoa wiani bora na / au bora zaidi moduli ya elasticity ya *E. grandis* au *E. dunnii*. Afrika Kusini, aina kadhaa hutoa wiani bora na / au bora zaidi moduli ya elasticity ya *E. grandis* au mseto wa GU

8. Mradi wa uchunguzi wa pili wa kulinganisha uvumilivu wa aina za eucalypt kwa pathojeni *Austropuccinia psidii* ulikamilishwa kwa kushirikiana na Smurfit Kappa Colombia. Mradi wa uchunguzi wa kwanza ulifanyika nchini Uruguay na INIA. *Eucalyptus brassiana*, *E. camaldulensis*, na *E. longirostrata* zote zilifanya vizuri sana katika tafiti zote za uchunguzi. *Eucalyptus dunnii* na *E. grandis* zilifanya vibaya katika tafiti mbili, ingawa matokeo yao huko Colombia yalikuwa bora kidogo kuliko Uruguay

9. Mafanikio mazuri yalipatikana kwenye uzalishaji wa Pine Chip SNP ya kitropiki kwa uchambuzi wa alama na uteuzi wa genomic. Takwimu za bioinformatic zimekusanywa kwenye aina sita (*P. patula*, *P. maximinoi*, *P. tecunumanii*, *P. greggii*, *P. caribaea* na *P. oocarpa*), katika mwaka 2019 tutafanya jaribio kubwa la kisayansi na ThermoFisher kuonyesha baadhi ya alama husika 420,000 za SNP ili kutambua seti ya SNP 50,000 ambazo zinatengeneza chip ya operesheni..

10. Camcore ilifanya kazi na Prof. Brad Potts na Dk Jakob Butler katika Chuo Kikuu cha Tasmania kutathmini upya maandiko ya aina zisizo na umaarufu za eucalypt. Lengo lilikuwa kutambua aina safi au washirika wa mseto ili kusaidia kushughulikia changamoto mbalimbali za mazingira. Seti za aina 21 zilitambuliwa, na hizi zitamulikwa kwenye juhudi zetu za ukusanyaji kwenye miaka kumi ijayo.

11. Jitihada zetu za uhifadhi wa jeni huko USA zinaendelea kupata huduma nzuri na ufadhili wa kifedha. Mnamo mwaka wa 2018, mkusanyo wa mbegu kutoka Table Mountain pine (*P. pungens*) na aina mbalimbali za ash (*Fraxinus*) zilikamilishwa, na uchunguzi wa mkusanyiko wa pitch pine (*P. rigida*) ulifanyika. Ingawa hemlock inachukuliwa kama aina yenye uvumilivi kwenye kivuli, matokeo ya kushangaza kutoka kwa utafiti wetu ni umuhimu wa kuongezeka kwa miale ya jua kwa ajili ya kuishi kwa mimea ya hemlock , ukuaji, na uwezekano wa kufufua miti nzee kutoka kwa hemlock woolly adelgid infestation.

RINGKASAN EKSEKUTIF (Bahasa Indonesia)

1. Tahun 2018, Camcore memperoleh anggota kedua di Indonesia, yakni APRIL Indonesia. APRIL memproduksi tanaman tropis jenis Eucalyptus dan Akasia untuk industri bubur kertas dan kertas untuk pasar Asia. Hal tersebut menunjukkan eksistensi Camcore di Asia Tenggara dan memungkinkan terbukanya peluang untuk anggota lain di masa mendatang. Pada tahun 2017, Weyerhaeuser Company menjual arealnya di Uruguay kepada BTG Pactual dan mengganti nama perusahaannya menjadi Lumin. Tahun 2018, Lumin secara resmi bergabung dengan Camcore.

2. Camcore telah menyelesaikan uji analisis 43 pinus hibrida dengan data pertumbuhan umur 5 tahun. Selain itu, Camcore telah memiliki data properti kayu dari 12 uji yang berumur 8 tahun dari berbagai negara. Secara umum, *Pinus patula* x *P. tecunumanii* dan *P. greggii* x *P. tecunumanii* menunjukkan hasil yang sangat baik di setiap uji coba, meyakinkan keputusan kami untuk berfokus pada uji “full-sib” dari varietas ini. Jenis hibrid lain yang berpeluang besar di daerah tropis adalah *P. caribaea* x *P. tecunumanii*.

3. Program pemuliaan hibrida *P. patula* x *P. tecunumanii* menghasilkan benih dari 126 famili hibrid “full-sib”. Famili -famili tersebut akan dibagi menjadi 2 set untuk pengujian lapangan. Saat ini, satu set perbanyakan vegetatif yang terdiri dari 66 famili sedang dalam tahap uji coba dan uji lapangan pertama akan dilakukan pada semester kedua tahun 2019. Pengerjaan program pemuliaan hibrida *P. tecunumanii* x *P. greggii* dilanjutkan pada tahun 2018 dengan percobaan persilangan dengan 94 “full-sib”.

4. Proses pemuliaan hibrida Eukaliptus Camcore masih terus berlangsung. Persilangan tahap pertama telah dilakukan di blok seleksi pembibitan dan kegiatan praseleksi telah dilakukan di sejumlah negara. Uji klonal pertama dari tahap ini akan dilakukan di Afrika Selatan pada tahun 2019. Sedangkan persilangan tahap kedua melibatkan 16 anggota Camcore dan akan memproduksi 25 varietas hibrida.

5. Benih Jati dan Gmelina yang dikembangkan Camcore telah diproduksi di Kolombia. Sebagai informasi, beberapa seleksi genotipe-genotipe unggul telah diperbanyak untuk uji klonal. Camcore berencana untuk mengirimkan koleksi benih famili dan stek akar kedua spesies tersebut ke Miro Forests di Ghana dan Sierra Leone sebagai bentuk upaya konservasi dan pembangunan uji keturunan dan uji klonal genetik.

6. Mahasiswa pascasarjana Camcore, Martha Salas dan Juan Pedro Posse telah menyelesaikan riset penelitian tentang kontrol genetik sifat kayu *E. grandis* dan *E. dunnii*. Kimia kayu dan sifat kayu solid berada di bawah pengaruh kontrol genetik yang kuat pada kedua spesies. Terlepas dari tujuan produk akhir, “tree breeder” dapat menambah nilai bagi perusahaannya dengan memasukkan sifat-sifat kayu ke dalam program seleksi dan pemuliaan.

7. Proyek sifat karakteristik kayu jenis *Eucalyptus* saat ini memiliki data dari Chili, Uruguay dan Afrika Selatan. Spesies tersebut dibandingkan menggunakan Resistograph (kerapatan), modulus elastisitas (MOE, kekuatan kayu) dan kimia kayu (glukosa, xylosa, kadar lignin dan komposisi). Di Chili, *E. globulus* memiliki sifat kayu lebih baik dibandingkan spesies lainnya yang pernah diuji. Di Uruguay, beberapa spesies menunjukkan hasil uji kerapatan yang lebih baik dan atau MOE yang lebih baik dibandingkan spesies *E. grandis* atau *E. dunnii*. Di Afrika Selatan, beberapa spesies menunjukkan kerapatan yang lebih baik dan atau MOE dibandingkan *E. grandis* atau GU Hibrid.

8. Proyek seleksi tahap kedua untuk membandingkan toleransi Eukaliptus terhadap patogen *Austropuccinia psidii* telah diselesaikan melalui kerjasama dengan Smurfit Kappa Colombia. Proyek seleksi tahap pertama dilakukan di Uruguay bersama INIA. *Eucalyptus brassiana, E. camaldulensis*, dan *E. longirostrata* menunjukkan hasil yang sangat baik dalam kedua tahap seleksi tersebut. *Eucalyptus dunnii* dan *E. grandis* menunjukkan hasil yang relatif tidak bagus di kedua tahap seleksi meskipun hasil keduanya di Kolombia lebih baik dibandingkan Uruguay.

9. Kemajuan yang baik telah dihasilkan untuk produksi chip SNP (Single Nucleotide Polymorphism) jenis pinus tropis untuk analisa penanda dan seleksi genomik. Data bioinformatika telah diperoleh dari 6 spesies (*P. patula*, *P. maximinoi*, *P. tecunumanii*, *P. greggii*, *P. caribaea* dan *P. oocarpa*) dan pada tahun 2019, Camcore akan mengadakan experimen besar yang bekerjasama dengan Thermo Fisher Scientific untuk menyeleksi beberapa kandidat dari 420,000 kandidat penanda SNP untuk mengidentifikasi satu set yang terdiri dari 50,000 SNP yang akan membentuk chip operasional.

10. Camcore bekerjasama dengan Prof. Brad Potts dan Dr. Jakob Butler dari University of Tasmania dalam meninjau ulang jenis Eukaliptus yang kurang dikenal. Tujuan kolaborasi ini adalah untuk mengidentifikasi spesies yang berpotensi sebagai spesies murni atau “hybrid partners” untuk membantu mengatasi berbagai tantangan lingkungan. Satu set yang terdiri dari 21 spesies telah teridentifikasi dan kemungkinan spesies tersebut akan menjadi fokus dalam usaha pengoleksian Camcore selama 10 tahun ke depan.

11. Upaya konservasi gen di Amerika terus menerima publisitas yang baik dan dukungan finansial. Tahun 2018, koleksi benih *P. pungens* (dikenal dengan "Table Mountain Pine") dan beberapa jenis *Fraxinus* telah selesai dan eksplorasi untuk koleksi *P. rigida* (dikenal dengan "Pitch Pine") telah dilakukan. Meskipun jenis hemlock dianggap sebagai jenis yang sangat toleran terhadap naungan, hasil yang mengejutkan dari riset kami adalah pentingnya meningkatkan sinar matahari bagi kelangsungan hidup dan pertumbuhan semai hemlock dan memungkinkan adanya pemulihan pohon yang lebih tua dari serangan serangga Hemlock Woolly Adelgid (HWA).

Message From the Director

Camcore completed its 38th year in 2018. We began our work with subtropical pines, and around the world are perhaps still primarily known for our work with species like *P. tecunumanii, P. patula* and *P. maximinoi.* For these pine species, and many others, we are the world leaders in breeding and testing, and we have learned much about species adaptability, reproductive biology, nursery and silvicultural practices, wood properties and disease tolerance.

But in addition to our work with pines, for the past 20 years we have also worked extensively with eucalypt species. We now have family-level collections of 15 different *Eucalyptus* and *Corymbia* species that we can provide to our members. We recognize a need to expand our eucalypt genetic resources even more, so in 2018 we collaborated with the University of Tasmania to identify another 21 species that have commercial potential. Many of these species will be priorities of our collection work over the next decade. Since all Camcore genetic material belongs to all members, improvement of any species by any member benefits the whole group. Access to this suite of genetic diversity for pines and eucalypts provides all members with an incredible "insurance policy", reducing the risk posed by the explosion of new pest and disease threats around the world.

In every region where we have data, one or more pine hybrids are substantially superior to the pure species currently being used as the commercial plantation option.

Although we have an array of pure species of both pines and eucalypts, we believe inter-species hybrids are the future of plantation forestry in the tropics and subtropics. In 2018, we completed an analysis of 43 pine hybrid trials with 5-year growth data. In every region in Latin America and southern Africa where we have data, one or more pine hybrids are substantially superior to the pure species currently being used as the commercial plantation option. Many of the pine hybrids also have superior wood properties compared to the local commercial species, and we believe that hybrids will offer a broader tolerance to diseases. Our collaborative breeding project with *P. patula* x *P. tecunumanii* has produced full-sib families currently being propagated for testing. Crossing for a similar project with *P. tecunumanii* x *P. greggii* is ongoing.

With eucalypt hybrids, the first phase of our collaborative project has produced families from 10 different hybrid combinations, and clonal trials will be going out to the field beginning in 2019. Crossing for the second phase of the project is underway, and the current target is to produce 25 different hybrid combinations, many involving *E. grandis, E. pellita, E. dunnii, E. globulus*, as well as some *Corymbia* hybrids.

We are also excited about the development of new molecular tools with potential to help our breeding efforts. Our work in collaboration with the University of Pretoria to develop a tropical pine SNP chip is progressing, and we hope to have an affordable operational chip available in the second half of 2019. We envision, in the near future, applying genomic tools to make gains in real-life tree breeding programs. We are currently working with three members to help them develop genomic selection models to extract additional genetic gain from their pure-species production populations. We expect the SNP chip to be even more useful for improvement of hybrid populations, and we are planning research in this area.

Finally, although our history has been primarily in Latin America and Africa, we are now seeing our geographical footprint expand. In 2018, APRIL joined the program as a full member, giving us a second member in Indonesia. Our work with tropical eucalypt species like *E. urophylla* and *E. pellita*, as well as our work on hybrids promises to be of great interest to other organizations in southeast Asia.

Late in 2018, I received an email from a friend and colleague, someone who is familiar with Camcore, but not currently working for a Camcore member. He mentioned that he keeps up with our activities through local contacts, and always hears great things about our work. He closed with the statement **"I hear that Camcore is moving from strength to strength. It is good to know that forestry Research & Development can still flourish."** This is why all of us on the Camcore staff remain so enthusastic about the work we do. Our working model of collaboration, sharing knowledge and genetic material, and leveraging our research dollars has paid dividends over our 38-year history. It will continue to do so in the future. We look forward to many years of working toward our common goals with you.

Gary Hodge, Director

2018 Camcore Membership

Active & Associate Members

Argentina
- Arauco Argentina SA 1999
- Bosques del Plata, SA (Associate) 2004

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

Chile
- Arauco Bioforest 1991
- CMPC Forestal Mininco (Associate) 1991

China
- Guangdong Academy of Forestry (Associate) 2013

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

Ghana
- Miro Forestry Ghana 2017

Guatemala
- Grupo DeGuate (Associate) 2006

Indonesia
- APRIL Indonesia 2018
- Sinar Mas Forestry 2017

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

Mexico
- Proteak Uno SA de CV 2011
- Uumbal Agroforestal 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

United States of America
- USDA Forest Service (Associate) 2006
- Weyerhaeuser Company 1980

Uruguay
- Montes del Plata - EuFores SA 2006
- Lumin 2018

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

Honorary Members

Belize
- Ministry of Agriculture, Forestry, Fisheries and the Environment

El Salvador
- Centro Nacional de Tecnología Agropecuaria (CENTA)

Guatemala
- Instituto Nacional de Bosques (INAB)

Honduras
- Universidad ESNACIFOR

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

Nicaragua
- Instituto Nacional Forestal (INAFOR)

The 2018 Annual Meeting in Colombia

Smurfit Kappa Colombia (SKC) hosted the 2018 Camcore annual meeting from September 24 to October 5. It was a well-organized meeting with excellent field visits, technical sessions, Camcore committee meetings and great social events. Thirty-one people (not counting SKC staff) attended the meeting, representing 18 members from 11 countries.

The first day of the meeting, we were welcomed by SKC CEO, Alvaro José Henao, who gave on overview of the Smurfit Kappa Group's operations in Colombia and all over the world. We heard two more excellent presentations, one by Dr. Juan Esteban Carranza, Economist at Bank of the Republic of Colombia, on "The Colombian Manufacturing Sector in the 21st Century", and one by Nicolás Pombo, Forestry Manager at SKC, on "Forestry Division activities".

Later that morning we visited the SKC Experience Center, where the company provides a place for customers to get hands-on knowledge of how packaging influences every step of the supply chain. The Experience Center promotes innovation through "store visualizers" and "inspiration rooms". We also visited the forest tree seed laboratory to see the processing of cones and capsules from the initial harvesting to the final packing of seeds to be sent to the nursery. Juan Carlos Bastidas of SKC gave an interesting presentation showing results of pulping studies with *E. pellita*. That night, SKC sponsored the welcome dinner at the Hacienda Del Bosque Restaurant where everyone enjoyed a delicious meal.

The second day, the group traveled by bus south of Cali towards Popayán. We visited provenance-progeny trials of *E. pellita* and *E. urophylla* where we saw the potential of these two species for commercial plantations as pure species and as hybrid partners. Camcore selections have been made on these sites based on volume growth and wood density. We stopped at an interesting 13-year-old weed control study of *P. tecunumanii*, where results clearly indicate the large effect on survival, volume growth and diameter distribution of three different treatments: chemical control, mechanical control, and no weed control. Two more sites were visited, an operational stand of *P. tecunumanii* where we saw the effect on growth of different thinning intensities and another trial where the stand density index is used as a criterion for managing stand density. We also saw harvesting operations and had lunch in a conservation park that included beautiful 37-year-old *P. tecunumanii* trees.

The third day we stayed near Popayán to visit several research trials and a clonal seed orchard of *P. maximinoi*. Interesting results were shown in a variety of trials including a benchmark study of tropical eucalypts, a progeny test of full-sib families of low-elevation *P. tecunumanii*, a 2nd generation progeny test of *P. tecunumanii*, a study of phosphate fertilization at planting of *E. grandis*, and a test of hedge recycling of *P. tecunumanii*.

Juan Lopez of Camcore and Nicolás Pombo of SKC with an excellent clone from the 3rd generation of *E. grandis*.

A second technical session was held in the Monasterio Hotel in Popayán the next day. John Byron Urrego with SKC described the productivity of various pine species at different site elevations on the company land. Fabricio Biernaski with Klabin discussed his research on the influence of propagation method and container type on the initial growth of *P. maximinoi*. Lizette de Waal with York Timbers showed results of her project on the use of field and artificial freezing studies to assess frost tolerance in tropical pines. Finally, our guest Keith Jayawickrama, Director of the Northwest Tree Improvement Cooperative (Oregon State University), gave on overview of the work done with Douglas-fir and other species in the US Pacific Northwest.

SKC nursery personnel in Restrepo, Valle explained seedling production and research projects in the nursery, and the phytosanitary protection program housed in the Forest Health Protection Laboratory. In the afternoon, Martha Salas, tree breeder at SKC, talked about cone and seed production in a clonal seed orchard of *P. tecunumanii*. We also visited an 8-year-old Camcore pine hybrid study showing *P. greggii* x *P. tecunumanii* competing in volume growth with improved families of *P. maximinoi* and *P. tecunumanii*, and an 8-month-old eucalypt hybrid seedling selection block with four different hybrids that show good growth and potential for the establishment of clonal trials.

On October 1st, we visited a weed control study in eucalypts, and a comprehensive study on realized gains of *E. grandis*, and then traveled to El Cerrito, Valle, where we had a very nice lunch at El Hatico Natural Reserve. The owners of El Hatico farm and professionals from the sugar cane industry gave interesting presentations on sugar cane research and production in Valle, Colombia.

The next day, we stayed in Termales el Otoño Hotel, near the city of Manizales, where we had a day-long technical session. Martha Salas of SKC and Juan Pedro Posse of Lumin showed results from their studies on wood genetics of *E. grandis* in Colombia and *E. dunnii* in Uruguay, respectively. Mmoledi Mphahlele with Mondi showed results from genomic selection of *E. grandis* in South Africa. Andrew Whittier of Camcore presented his research on teak nutrition deficiency studies and NIR models at NC State University. Dr. Carlos Rodas with SKC also described the company's Forest Health Management Program.

The following day, we visited the harvesting training center of SKC, where foresters showed safety measures and technical knowledge used to train workers in tree harvesting. Dr. Guillermo Vasquez with the National University of Colombia in Medellín presented results of his study with SKC on the influence of land use on the hydrological response in headwaters of the Central Andes of Colombia. At the end of the day, we visited two studies in El Cedral farm: a 2nd generation progeny trial of *P. maximinoi* with amazing trees, and a study on *Dothistroma septosporum* incidence on various pine species.

The last day, we had a short technical session and the business meeting. Adriano Almeida gave an overview of forestry and research in the APRIL Group, a new member of Camcore. Juan Schapovalof with Arauco Argentina showed results the company has obtained with top pruning of pines in clonal seed orchards. Finally, Arnulf Kanzler and Jolanda Roux gave a presentation on Sappi's response to global warming and pest and disease threats that affect South African plantation sustainability.

We had an excellent farewell dinner the last night to close the meeting. Everyone returned home the following day, happy after a successful event and the opportunity to share professional knowledge and camaraderie within the Camcore group. We will see you next year in Portugal for the 2019 meeting!

Byron Urrego from SKC gives a presentation about pine productivity.

Meeting participants pause for a group picture in a pine research trial at La Suiza farm, Colombia.

Developments in Camcore

Camcore staff spend much of their time each year making visits to members to discuss Camcore projects, as well as internal company breeding and research activities. Below is a brief summary of these visits and other developments.

Argentina

Camcore continues to help **Arauco Argentina** with both their pine and eucalypt breeding programs. At all three pine hybrid trials established by the company, the *Pinus caribaea* x *P. tecunumanii* hybrid outperforms the local improved *P. taeda* by an impressive margin (over 30% more volume at age 8 years). Arauco manages their *P. taeda* breeding orchards with top pruning in order to reduce costs and improve safety for cross pollination. The company is now testing this approach on *P. tecunumanii* with good results. Grafted *P. tecunumanii* planted in 2015 received a top pruning in 2016, a second pruning in 2017, and produced pollen catkins in 2018. Camcore will visit Arauco in Argentina in early 2019, and will also organize a visit to the southeast USA to investigate *Populus* and *Salix* genetic resources.

Brazil

Camcore traveled to **Klabin** in May. The main objectives of our visit were to help plan Klabin's strategy for the development of genomic selection models for *P. taeda* and discuss their contribution to the Conifer SNP consortium. Klabin is involved in the development of two SNP chips: *P. taeda,* and tropical pines. The company wants to use those tools to develop Genomic Selection (GS) models to accelerate their breeding cycle. For Loblolly pine, they plan to build a model that would be used to assist the selection of the best CP Somatic Embryogenesis clones, so they will calibrate the model with an elite set of parents and offspring. Camcore is working with Fabricio's team to identify the trees based on their breeding values, and the company will start collecting samples for DNA extraction and genotyping in 2019. Juan José Acosta also followed up on Klabin's breeding program for *P. maximinoi*, *P. tecunumanii* and pine hybrids, and trained personnel from our two Brazilian members in the basics of R programming.

In October, Juan José Acosta from Camcore visited **WestRock**. He had productive discussions with WestRock's Management and Tree breeding teams about our proposal for GS to improve family forestry for *P. taeda*. Juan José gave a presentation about the development of the pine SNP chip (see article in this report) and explained the basic steps required for building a good genome-wide selection model. We then looked at WestRock's database to define a strategy for selecting the best families and the best trees within families to be phenotyped and genotyped. We plan to build GS models for growth, wood density, and chemical traits of wood such as cellulose and lignin. Juan José also participated in Gisela Andrejow's Ph.D. committee, and spent one day in Curitiba at her dissertation defense at the Universidad Federal do Paraná.

Gisela Andrejow, Mara Engel and Waldemar da Veiga (WestRock) standing by a row plot of 6 trees belonging to one of their best full-sib families on El Paredão Farm. This is one of the families for which Genomic Selection models will be built.

Klabin and WestRock once again helped take wood samples from Camcore trials to add to our knowledge of hybrid pines. Fabricio Biernaski and Klabin helped Willi Woodbridge take samples from 120 trees from 4 hybrids in an 8-year-old 2nd series hybrid pine trial in Monte Alegre. Waldemar da Veiga and WestRock worked with Willi to sample 210 trees from a trial in Zaniolo, also 8 years old and from the 2nd series of pine hybrids. Teams from both of these companies are experienced in this work and it was completed in a short time period.

Chile

Juan Lopez visited **Arauco Bioforest** in Chile in April to discuss several projects on which Camcore and the company are working. The establishment and management of provenance-progeny trials with *Eucalyptus* species was reviewed, as was the development of the *Eucalyptus* hybrid program, phases 1 and 2. A shipment of small quantities of pollen for hybrid crosses was scheduled and pollen of *P. maximinoi* and *P. tecunumanii* has been sent since the visit. Coordination of online meetings with other Camcore members to discuss controlled pollination techniques in pines were scheduled and held later in the year. Juan explained the use of an R program developed by Camcore to estimate wood resistance in standing trees, and provided results on wood properties for many species measured by Camcore. Since the visit, Bioforest has sown seeds of four eucalypt hybrids for the establishment of seedling selection blocks and clonal trials in the field. Camcore members are collecting pollen of *E. pellita* and *E. benthamii* to send to Bioforest to make crosses with *E. nitens* and *E. globulus* respectively. Arauco sent pollen of *E. globulus* to Raleigh, that will be shipped to Sinar Mas in Indonesia for crosses with *E. pellita*.

Iván Appel, José Ordóñez and the research team at Arauco-Bioforest worked with Romeo Jump to take wood samples from eucalypt species trials in Los Alamos and San Ambrosio in March. They

Romeo Jump supervises wood sampling of eucalypt trees in an Arauco trial in Chile.

sampled 350 trees of eight species. These results were presented at the annual meeting in Colombia.

Colombia

Gary Hodge and Juan José Acosta visited **Smurfit Kappa Colombia** in February. During our visit, we discussed strategic activities for tree breeding research at SKC for the next 10 years, and prioritized topics based on both importance (value to the company) and urgency (payback in the short to mid term). Two topics with very high importance and urgency were maximizing *P. maximinoi* deployment to plantations, and understanding the prioritization of *E. grandis* vs. *E. grandis* x *E. urophylla*. We also reviewed their seed production program and evaluated their orchards based on expected genetic gain, contamination and productivity. We are working with SKC and Carlos Rodas' group to conduct disease-screening studies in both laboratory and field tests to evaluate 12 eucalypt species for tolerance to four different diseases: *Austropuccinia* spp., *Botryosphaeria* spp., *Ceratocystis* spp., and *Chrysoporthe* spp.

Ghana and Sierra Leone

Gary Hodge and Juan José Acosta visited **Miro Forestry** in Ghana and Sierra Leone in 2018. The main goals of our visit were to discuss the overall R&D program for 2019 and to plan the establishment of a series of clonal tests for *E. pellita*, *E. urograndis* and *E. urophylla.* This series of studies will be replicated across many sites using a new and more efficient experimental design, so that the best clones can be deployed to Miro's operations. Several non-eucalypt species are being tested for commercial forest potential, primarily *Gmelina arborea*, *Acacia mangium* and *Tectona grandis*. We suggested establishing spacing studies with these species to evaluate the effect of planting density on tree form. We also suggested to use sand beds for clonal propagation in the nurseries in both countries to boost productivity and to use space more efficiently. We discussed several designs and we expect the company to build the first sand beds in Sierra Leone in 2019. Miro is planning to develop a forest health and protection program for its landholdings. Camcore is making

A Camcore *E. urophylla* progeny test at Miro Forestry in Ghana. This trial was featured on the front cover of the 2017 Annual Report.

suggestions for the first steps Miro should take to set up a robust, practical, and simple system to monitor its forest health.

Willi Woodbridge traveled to Miro in both Ghana and Sierra Leone to teach the week-long Data Management short course. Juan José Acosta also traveled to teach an R class to Miro staff. See more details about these classes later in this report.

Indonesia

Gary Hodge and Juan Lopez visited **Sinar Mas Forestry** (SMF) in June. SMF is working hard to increase seed-to-plant efficiency in their nurseries, with a goal of 80% for eucalypts and 60% for *Acacia crassicarpa*, while maintaining seedling quality at the present level. Our visit this year focused on the Palembang region. This region has some unique and challenging soils, in particular the marine clays, which make up about 75% of the landbase. The soils in this region tend to have high water tables, very low pH, and high salt concentration. The company is doing some very interesting work with some native tree species that may be candidates for commercial forestry on challenging sites in Pelambang. Species that have potential include *Melaleuca leucadendra* (Gelam), *Lophostemon* spp., *A. crassicarpa*, and *Casuarina equisetifolia*. In the near term, Camcore plans to help SMF develop NIR models to predict wood chemistry for *E. pellita*, and in the longer term, we plan to work together on *Melaleuca* and *Acacia* species and hybrids. We also conducted a special BLUP analysis of some *E. pellita* progeny test data to assist SMF with a marker-aided selection study. SMF has enthusiastically joined the eucalypt hybrid project, agreeing to make five different *E. pellita* hybrids.

Gary and Juan also visited **APRIL Indonesia** (Asia Pacific Resources International Holdings) in June. This was the first Camcore visit to this member, so our purpose was to become familiar with the company and to determine how we might best help the research and tree breeding teams. APRIL currently has about 460,000 ha of plantations distributed in four regions, with some 300,000 ha in the Kirinci region where they plant about 50% eucalypts and 50% acacia. They have a strong research and breeding team in place, and around 1000 genetic trials of eucalypts (mostly *E. pellita*) and acacia. APRIL is interested in expanding their genetic base for a number of species from the Camcore portolio, with *Corymbia*, *E. urophylla*, *E. grandis* and *E. pellita,* in order of priority. APRIL has an active wood research team, and we spent time discussing NIR modeling and opportunities to collaborate with Camcore. APRIL has also joined the *Eucalyptus* hybrid breeding project, making a commitment to complete three different *E. pellita* hybrids. We are very excited about having two members in Indonesia, as it creates possibilities to leverage our work and perhaps expand our membership in Indonesia and Malaysia. *Acacia* species make up a critical part the plantation base of both members (and other potential members in the region), so we are thinking about ways that we might expand our Camcore species portfolio.

André van der Hoef of Sinar Mas Forestry next to an outstanding clone of *E. pellita*. This is a 2-year-old trial on a very harsh marine clay soil found in the Palembang region of south Sumatra, Indonesia.

A four-tree row plot of an outstanding 3rd generation *E. pellita* clone in an APRIL clonal test (age 3 years) on Nagodang estate near Kirinci, Sumatra, Indonesia.

Kenya

The Kenya Partnership is a joint Camcore membership formed by **Kenya Forest Research Institute** (KEFRI) and the **Tree Biotechnology Programme Trust** (TBPT). The main objective of the technical visit to Kenya this year was to train KEFRI and TBPT staff in controlled pollination of pines and eucalypts. Juan Lopez with Camcore and Nhora Isaza, recently retired tree breeder from Smurfit Kappa Colombia, taught a short course on how to make hybrid crosses between species within each genus. Juan and Nhora gave theoretical presentations in the office and practical demonstrations in the lab and field at the Londiani Regional Research Centre. The students found the course very useful. They learned interesting concepts and techniques that can be used in their own research programs. During the visit, Juan and Nhora visited several Camcore trials with Ebby Chagala and her research team. Juan made recommendations on the crosses to be made in pines and eucalypts to continue advancing the tree breeding program in Kenya and to fulfill Kenya's commitment to the Camcore *Eucalyptus* hybrid program. KEFRI and TBPT are interested in receiving material of *Gmelina arborea* and *Tectona grandis* from Camcore in the near future that would be planted in 2nd generation progeny trials.

Mexico

In May, Juan José Acosta and Robert Jetton visited our two members in Mexico. The field tour with **Proteak**'s R&D group started with a visit to two provenance-progeny tests of *E. pellita* and *E. urophylla* for which Camcore had sent genetic values and selected trees had been identified and confirmed. We recommended to the tree breeding team to give high priority to the establishment of a clonal bank with the 99 selections of *E. pellita* and the 114 of *E. urophylla,* and then to establish as many clonal tests as possible to identify superior clones for future forestry operations. We visited a provenance-progeny test of *P. caribaea* that can be converted into a seedling seed orchard through genetic thinning. The material from thinnings could be used to study the variation of wood density, a very important trait for the production of MDF panels in the company's new mill. Juan José presented to the forestry management team the results of a multivariate analysis in which soil, foliage, and growth information was combined to determine the key factors that influence the productivity of teak on the company's landholdings.

Students from KEFRI, KFS, and TBPT at the Camcore controlled pollination workshop in Kenya.

Secundino Torres (Proteak), standing by a selected tree of *P. caribaea* in a Camcore provenance-progeny test located on the Beatriz Jaume farm.

A significant portion of our visit with **Uumbal** was spent discussing several problems with forest pests that are affecting the company's pine plantations. The main insects are: pine bark beetles, specifically *Ips calligraphus*, spider mites in the genus *Oligonychus*, and the pine tip moth *Rhyacionia frustrana*. Problems with *Ips* attacks are probably the most threatening to Uumbal, so during the visit we discussed several factors that may be causing stress in the plantations and may predispose the trees to attack. Some factors are high planting density, wounding of trees for resin extraction, and resin flow attracting the beetles. Robert Jetton gave important recommendations about management in the field and highlighted the good work the company is making by focusing on monitoring, early detection and rapid response, as well as the creation of a phytosanitary protection laboratory for pathogen and insect diagnostics. We also observed the operational process to extract resin in their plantations, and met with

Sergio Hernández, Robert Jetton, Guadalupe Pérez and Carlos Gioia in Uumbal's new phytosanitary protection lab.

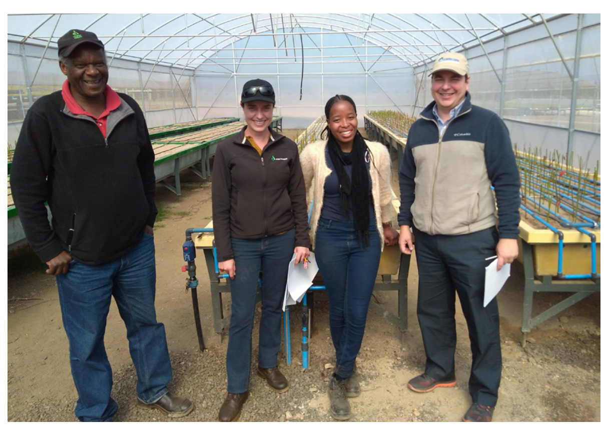
EricCantor and his team to discuss ideas about how this process can be improved. Camcore continues to help Uumbal with data analysis for its clonal population of *P. elliottii* x *P. caribaea*; during our visit we gave advice about how data should be processed.

South Africa

In July 2018, Juan José Acosta and Juan Lopez visited **Mondi** in South Africa. We had one meeting in the office and two days in the field visiting genetic trials. This was a great opportunity to discuss the Camcore *Eucalyptus* hybrid project, in which Mondi is participating by collecting pollen of *E. nitens* and *E. benthamii* and making crosses of *C. torelliana* x *C. maculata*. We visited some of the *Corymbia* trials in Mondi and discussed the potential of the species and their hybrids on dry sites. We also visited Mondi's nursery where the seeds of *P. patula* x *P. tecunumanii* produced in Sappi's *P. patula* CSO were sown a few days before our visit. Mondi will provide the rooted cuttings of the full-sib families to the South African members to establish the hybrid progeny trials. In one of the *P. tecunumanii* low-elevation trials visited in Zululand, the provenance from Los Planes in Honduras was better than other excellent provenances from Yucul and San Rafael del Norte in Nicaragua. Even though Mondi has made some selections of this provenance in the field, we will send recently collected seeds from Los Planes to Mondi and other Camcore members. Camcore continues to help Mondi with the wood properties processing and analysis. Juan José explained to Nicci Edwards the R code that easily performs the NIR data analyses, and taught her the new method developed by Camcore to quickly process the Resistograph data using R. We have plans to do more wood sampling of pine hybrids and eucalypt species at Mondi in 2019.

Kitt Payn and Nokukhanya Maplanka standing by a *P. tecunumanii* selection from Los Planes, Honduras in Montingy, Zululand.

Juan Lopez and Juan José Acosta visited **York Timbers** in South Africa at the end of July where they had office meetings and field visits with Lizette de Waal and Leonard Mabaso. Several projects on which Camcore and York are working together were discussed. Lizette presented York's breeding strategy and Camcore staff gave some input. Camcore gave an update on the status of the *P. patula* x *P. tecunumanii* program in South Africa, as well as the *Eucalyptus* hybrid program. Juan José Acosta explained the pine SNP chip sampling project in detail to Lizette and Eric Droomer, and listed the benefits to the company. Camcore gave recommendations on designing research trials conducted in the new nursery research tunnels for mother plants.



Leonard Mabaso, Lizette de Waal, and Fanele Mabaso of York Timbers and Juan José Acosta from Camcore visiting the new research tunnels for mother plants in York's nursery.

Juan Lopez and Juan José Acosta visited **Sappi** in July. We had many discussions with the tree breeding and tree biotechnology groups about the operational steps that Sappi is taking to develop its own genome-wide selection models for *E. dunnii* and the *E. grandis* x *E. nitens* hybrid. For the latter, Camcore is assisting Sappi with a complex quantitative analysis that involves a posteriori creation of incomplete blocks according to the spatial distribution in the field. The purpose of this analysis is to expand the number of varieties that can be included in their training models for prediction of rooting, growth traits and wood properties. During our field tour, we visited a frost-prone area that the company uses to screen new genetic material of eucalypts and pines. Sappi is working actively in both of our hybrid programs. In 2018 Sappi contributed pollen of *E. dunnii* which

Sappi's tree improvement and tree biotechnology groups on a frost screening area for eucalypts (left) and pines (right).

will be used for crosses with *E. pellita* by Sinar Mas (Indonesia), and they are making crosses between *E. dunnii* and *E. benthamii* with pollen provided by Mondi. Seeds of *P. patula* x *P. tecunumanii* have been sent to Mondi for vegetative propagation; this material will be distributed to all South African members for test establishment.

Juan José Acosta and Juan Lopez also met with **SAFCOL** in South Africa, visiting field trials, the conservation bank, and participating in office meetings. Camcore presented results from the analysis of SAFCOL progeny trials to the research team, including estimates of genetic parameters and predictions of genetic values for the company's *P. patula* and *P. tecunumanii* parents, and for full-sib families of the *P. patula* x *P. tecunumanii* hybrid. Juan José presented details on the status of the SNP chip project with Camcore and NC State University. Juan Lopez

Bongani Noludwe of PG Bison surveys a 7-year-old stand of *E. nitens* planted in the northern Eastern Cape of South Africa.

gave a brief update on the implementation of the *P. patula* x *P. tecunumanii* breeding project that uses seeds produced by Sappi and germinated in Mondi's nursery. SAFCOL continues to be very interested in expanding commercial plantings with *P. maximinoi*, and Camcore is helping the company to increase productivity of this species by making new selections in progeny trials. During the field trips, we visited pine hybrid trials, progeny trials, and a 16-year-old *P. patula* x *P. tecunumanii* study.

Gary Hodge visited **PG Bison** in August in the northern Eastern Cape. The main commercial species for the Ugie mill is *P. patula*, but other pine varieties have demonstrated sufficient potential to justify continuing breeding work. The *P. patula* x *P. tecunumanii* hybrid will likely have a role for the company. PGB is participating in the South Africa hybrid breeding project, and will be testing full-sib families as part of that work. PGB also has the opportunity to select some *P. tecunumanii* parents from a joint Merensky-PGB progeny test at Langeni. We visited an 8-year-old 2^{nd} generation progeny trial of *P. greggii* var. *greggii* (northern variety), and it appeared that the northern *P. greggii* was quite competitive with the commercial *P. patula* in terms of volume. This was a bit surprising, and with the test due to be measured early this year, we are interested in seeing the 8-year data. PGB also has the best genetic resources of any Camcore member for both *P. greggii* var. *australis* (southern variety) and *P. leiophylla.* We outlined plans to make additional seed collections of both of these species. Although pines are likely to continue to be of primary importance for the Ugie MDF mill, some eucalypt species are doing very well. *Eucalyptus benthamii* and *E. badjensis* are

Christel Malek (MTO) with a putative *P. taeda* x *P. oocarpa* hybrid in a 3-year-old test near Lottering in the southern Western Cape province of South Africa.

Cool temperate eucalypts have good growth potential in the Eastern Cape of South Africa. Left, a 3-year-old Camcore Temperate Eucalypt Benchmark species trial; right, a 3-year-old *P. patula* plantation at Mpur, Eastern Cape, on Merensky land.

showing good growth, but on this visit, the best performance we observed was in *E. nitens*.

Gary Hodge also visited **MTO** in August. The normal commercial species in the southern Cape is *P. radiata*, but in recent years there has been concern over low survival due to *Fusarium circinatum*. MTO has worked hard to sanitize their nursery with H_2O_2 treatments of irrigation water, and this seems to be working well. We visited a planting-stock trial comparing 1st, 2nd, and 3rd generation radiata seedlings, 2nd generation radiata cuttings, and *P. elliottii* 2nd generation seedlings. The *P. radiata* seedling survival was over 90%, much higher than in plantations established in the past few years. Nevertheless, the rapid growth of *P. maximinoi* and Florida-source *P. taeda* suggest that these species should have a place in the MTO portfolio. A 2nd generation *P. maximinoi* test planted on a typical *P. radiata* site had an average height of 6 meters at age 3 years. The form of the trees was good, but it appeared that pruning should perhaps be done earlier than with *P. radiata*. We also had a very interesting visit to a 3-year-old hybrid trial near Lottering. Most of the *P. radiata* was dead, but several hybrids showed promise, including *P. patula* x *P. tecunumanii*, and putative hybrids of *P. elliottii* x *P. maximinoi*, *P. greggii* x *P. tecunumanii*, and *P. taeda* x *P. oocarpa*.

Gary also visited **Merensky** at Weza. We visited a number of pine and eucalypt trials. One stop was a family cuttings trial with 34 *P. patula* x *P. tecunumanii* families that the company is using commercially. Merensky is currently planting only about 10% of its pine lands to the hybrid, but both growth and survival look very good. In the 10-year-old Camcore pine hybrid trial at Mpur, the top variety in terms of growth was *P. patula* x *P. tecunumanii* (low elevation). In second place was *P. patula* x *P. greggii* (south); this hybrid generally looks very nice, but it has not generated much interest in South Africa due to the relatively low level of *Fusarium* tolerance of *P. greggii*. We also visited a 3-year-old temperate eucalypt species trial (from the Camcore benchmark series), where the top performers were a *E. grandis* x *E. nitens* clone (a commercial control) and the *E. benthamii* seedlots. Although this part of the country has traditionally been planted to pines, the growth of this young eucalypt trial was very impressive compared to a neighboring planting of *P. patula* established at the same time.

Romeo Jump traveled to South Africa to lead two wood sampling trips. At **York**, he worked with Lizette de Waal and Leonard Mabaso to sample 540 trees from an 8-year-old pine hybrid trial in Klipkraal. Romeo recommended the use of the Resistograph for Jaco-Pierre van der Merwe's Ph.D. research project at York. At **SAFCOL**, he worked with Clement Thabethe and Philip van Nierkerk to sample another pine hybrid trial in Brooklands where they collected data and samples from a whopping 720 trees. This is the largest single-site wood sampling effort to date. Samples were processed in Raleigh and results are presented in this report. Thanks to York and SAFCOL for supporting this work.

In August, Andy Whittier and Willi Woodbridge were hosted by **Merensky** to conduct another wood sampling project. They worked in two *Eucalyptus* species trials in Prinsloorust and Cristinasrust and sampled 480 trees of 12 species, including some *Corymbia* and hybrid controls. For solid wood samples for specific gravity measurement, a subset of trees were felled and wedges cut from breast-high disks. All samples were processed in Raleigh and results are presented in this report. Thanks to Sonia du Buisson, her team, George Dowse and Ayabonga Chonco for helping with all aspects of this project.

Uruguay

Gary Hodge and Juan Lopez visited **Montes del Plata (MDP)** in Uruguay in June. One of the main projects on which MDP and Camcore are working together is the *Eucalyptus* hybrid program. Mónica Heberling, her research team, Gary and Juan visited the *E. dorrigoensis* progeny trial in La Rosada farm to make plans for collecting pollen to be used for crosses with *E. dunnii*. The synergy of all the Camcore members working together on this hybrid program should bring exceptional benefits. After the visit, Camcore made a statistical analysis of six clonal trials of *E. dunnii* at MDP, using yearly measurement data. The objectives of the analysis were to estimate genetic parameters for a clonal population, to estimate age-to-age genetic correlations, and to test the efficiency of making early selections in the species using DBH, height and volume. The optimal age for early selections was determined to be three years, when genetic gain per unit time is greatest. Camcore continues to help the company calculate the optimal number of clones to move from the initial clonal trials with single-tree plots to the expanded clonal trials with block plots. The development of an efficient strategy for the tree breeding program will help MDP obtain the largest genetic gain in the shortest time at the lowest possible cost.

A Camcore *E. dorrigoensis* progeny trial on La Rosada farm belonging to Montes del Plata. MDP will collect pollen here for hybrid crosses with *E. dunnii*.

E. grandis planting to be sampled for the splitting and veneer yield research project in the Lumin plywood plant.

Lumin in Uruguay was visited by Gary Hodge and Juan Lopez in the middle of June. Juan Pedro Posse took Gary and Juan to the plywood mill to plan for a wood study on *E. grandis* splitting. This study is looking for a relationship between wood chemical composition and splitting in the logs and yield in the mill. This is a continuation of Juan Pedro Posse's research for his Ph.D. studies. Lumin is actively working in the *Eucalyptus* hybrid project, making pollen collections of *E. dunnii* and *E. benthamii*, and making crosses of *E. grandis* x *E. dunnii*. Lumin also has a two-year-old progeny trial of *E. grandis* x *E. benthamii* from crosses made in the first phase of the program. Clones of the best families will be selected and tested in clonal trials. Camcore continues to help Lumin develop its tree breeding program, including testing, evaluating, and selecting families and trees of new species with commercial potential. This material is also a source of diversity that provides the company with options for alternative species, reducing the risk of catastrophic losses in commercial plantations. Lumin is also part of the Camcore *P. tecunumanii* x *P. greggii* hybrid project initiated in Colombia (see article on this project later in this report).

Venezuela

Due to the difficult political and social situation in Venezuela, we were not able to visit **Smurfit Kappa Venezuela** or **Masisa** in 2018. Both companies have been valuable Camcore members for many years, and have made important contributions to the program. We hope that 2019 will bring better things for the country.

Regional Meetings

South Africa

The 2018 Southern Africa Regional Meeting was held at Stellenbosch University in the Western Cape. In addition to our normal one-day technical meeting on Camcore matters, we had one additional day of indoor meetings to hear from university faculty and staff about the research being done in the Forestry and Wood Science department. We had 19 attendees representing all seven South African members. The Camcore session covered a number of important topics, including the *P. patula* x *P. tecunumanii* hybrid project, the tropical pine SNP chip, the *Eucalyptus* hybrid project, and reports on Camcore research.

The next day we heard some interesting presentations from Stellenbosch researchers. Dave Drew and Anton Kunneke both spoke about some new imaging technology, Terrestrial Laser Scanning, that has great potential for inventory and biometrics, and may offer some new possibilities for tree breeding research. Brand Wessels spoke about how stand density can affect within-tree patterns of wood density, MFA, and MOE. Ben du Toit spoke about work being done by the silviculture research group, including thinning strategies and carbon allocation and storage. Geoff Downes, a wood properties expert visiting from Australia, spoke about his work with the Resistograph and NIR to assess density and wood chemistry. Hannel Ham summarized her Ph.D. research on reproductive biology and hybridization of *P. radiata*. We closed the afternoon with a visit to the Deciduous Fruits, Vines and Wine breeding group, part of the South African Agricultural Research Council. We heard about fruit breeding from Taaibos Human, and were surprised to find that apples and pears have a longer breeding and selection process than forest trees! We also learned about honeybush tea genetics and breeding from an old friend and former tree breeder, Cecilia Bester. We finished the day with a visit with ARC wine grape breeders (and yeast breeders), where we *carefully* studied some of their work.

The following day, we closed out the meeting with a half day in the field looking at some dryland eucalypt species and genetics trials, and visiting the Paarl Arboretum, led by Deon Malherbe, long-time friend of Camcore. Many thanks to our hosts from Stellenbosch, in particular Ben du Toit, for coordinating arrangements on that side. Also, thanks to André Nel of Sappi for helping with planning and logistics.

Brazil

This year, WestRock in Brazil hosted the Camcore regional meeting for Latin America. There was good participation with representatives from Arauco Argentina, Arborgen, Klabin and WestRock in Brazil, Arauco Chile, and Smurfit Kappa Colombia. The first day, there was an indoor meeting where foresters from each company made presentations about their own research and tree breeding programs. Heuzer Guimaraes, Forestry Business Director of WestRock, started the day by welcoming the guests and expressing WestRock's pleasure to be hosting the meeting. Gary Hodge and Juan Lopez from Camcore US gave several talks, including the Resistograph wood density R program and the relationship between wood chemistry (predicted using NIR) and pulp yield models using Smurfit Kappa Venezuela data as an example. Juan gave a presentation showing the progress made on the pine and eucalypt hybrid programs in Camcore.

The second day, the research team of WestRock did a nice job showing some of their research trials in the field. We saw a 3-year-old *Eucalyptus* hybrid clonal trial in which the *E. dunnii* x *E. globulus* was superior in volume growth to *E. dunnii*, *E. saligna* and the hybrid *E. dunnii* x *E. saligna*. We also saw a 3-year-old *E. benthamii* progeny trial where there were no differences among seed sources. It was very interesting to visit a study where we learned about the growth model of a loblolly pine mass control operational trial. It was a great opportunity for everyone to share technical knowledge, and to learn from the tree breeding program of WestRock. Thanks very much to Heuzer Guimaraes, Ricardo Paím, and his research team.

Participants in the Southern Africa Regional Meeting hosted by Stellenbosch University.

Participants in the Latin America Regional Meeting hosted by WestRock in Brazil.

Pine Hybrid Testing: Results from 43 Trials

Introduction

In 2003, Camcore started our pine hybrid program. The goal is to test many pine hybrids to determine their commercial potential. These hybrids could offer additional benefits compared to pure species through the combination of traits from two parents and from hybrid vigor or heterosis. Some pine hybrids may be better adapted to specific environmental conditions. Compared to pure species, they may have a desirable combination of beneficial traits, including a higher tolerance to drought or frost, better disease resistance, good wood properties, or higher volume growth. To date, our members have planted more than 90 pine hybrid trials in Africa and Latin America, and almost half of them have growth data of at least 5 years of age. At the Annual Meeting in Guatemala in 2014, Camcore's technical committee decided to characterize the wood properties of pine hybrids in a subset of the tests, evaluating trees that are close to 8 years of age. In this article, we summarize all available growth data and wood research results for our pine hybrid studies and attempt to create an overall view that depicts the variation of growth and wood properties among pine hybrids and pure species controls.

Materials and Methods

Evaluations of total height in m (HT), diameter at breast height in cm (DBH) and tree quality were made by our members according to Camcore's protocols at ages 5 and 8 years. Data was merged and processed at NCSU and individual-tree volume (m^3) was estimated using HT and DBH.

The merged database for this study contains growth data from 43 studies. Pine hybrid trials are located in Argentina, Brazil, Colombia, Kenya, Mozambique and South Africa. Wood traits were measured in a subset of 12 tests (Table 1). In each test, we randomly selected about 30 trees per treatment (hybrid or control lot), and for each tree, field measurements and wood samples were taken at breast height to assess the following wood traits:

Cellulose and Lignin content

We used hand drills to collect wood shavings from just inside the bark to just short of the pith. Oven-dried wood shavings were shipped to NC State University, ground into woodmeal, and scanned on a FOSS 6500 NIR spectrophotometer. Spectra generated for each sample were used in Camcore's Global Pine NIR models to predict lignin and cellulose content.

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 stress wave propagation time in the bole of standing trees. With the time of travel and the distance between device sensors, fiber direction velocity is calculated. This correlates very well with MOE and wood strength.

Resistance

We used the IML Resistograph to record the resistance profile of the trees. The IML Resistograph system measures the drilling resistance of a thin needle-like drill that is inserted into the wood at breast height and rotated at a constant speed. While drilling from one side of the tree to the other, the required energy is measured and this resistance is directly proportional to the density of the wood. The resulting profile includes the resistance measured at multiple points (10 per mm) along the drilling path. This path is along the diameter of the tree so it is analogous to taking an increment core. Resistance profiles were adjusted for friction, and bark resistance was excluded from the data before calculation of a mean "core" resistance.

Foreman Dibakwana (left) and Lucky Mnisi (right) of York Timbers taking a sample of wood shavings from an 8-year-old pine hybrid tree.

Table 1. Trial information for Camcore bulk pine hybrid tests.

Country	Member	Test ID	Location	Elev. (m)	Precip. (mm)	Volume Data 5 yr	Volume Data Group	Wood Data 8 yr	Wood Data Group
Argentina	Arauco	9845H01B1	Los Motosierristas	195	1965	x	ArgBra	x	ArgBra
Argentina	Arauco	9845H01B2	Pto. Bossetti	235	1926	x			
Argentina	Arauco	9845H01B3	Pto. Libertad	252	1926	x			
Argentina	BDP	9848H01A1	Timbauva	127	1657	x		x	
Brazil	Klabin	9826H01C1	Monte Alegre	800	1368	x			
Brazil	Klabin	9826H01C2	Monte Alegre	800	1368	x			
Brazil	Klabin	9826H02C1	Monte Alegre	880	1600	x		x	
Brazil	Klabin	9826H02C2	Azulao	880	1700			x	
Brazil	WestRock	9827H01A1	São Miguel da Ros.	785	1556	x			
Brazil	WestRock	9827H01A2	Schafauser	790	1556	x		x	
Brazil	WestRock	9827H02A	Zaniolo R69 T20	790	1842			x	
Brazil	WestRock	9827H02B	Canivete - Talhão 21	785	1755	x			
Colombia	Smurfit Kappa	9802H01A1	Delicias	2140	3915	x	ColKen-Moz	x	Col-SA
Colombia	Smurfit Kappa	9802H01A2	Sinai	1735	1286	x			
Colombia	Smurfit Kappa	9802H01A3	Peñas Negras	2631	2130	x			
Colombia	Smurfit Kappa	9802H02A1	Campania	2350	3594	x			
Colombia	Smurfit Kappa	9802H02A2	La Suiza	1500	1278	x			
Colombia	Smurfit Kappa	9802H02A3	Los Chorros	2206	2118	x			
Kenya	Kenya	9850H02K1	Turbo	1859	1500	x			
Kenya	Kenya	9850H02K3	Kodera/Muguga	2070	981	x			
Mozambique	Green Resources	9859H01G	Chimbonila	1200	1403	x			
South Africa	MTO	9852H01B1	Witelbos, L16b	196	942	x	SA-Cape		
South Africa	MTO	9852H01B2	Kruisfontein, D13b	236	945	x		x	
South Africa	MTO	9852H02B2	Garcia A25c	435	644	x			
South Africa	SAFCOL	9810H01A2	Spitskop, A30	1610	1300	x	SA-Cool	x	
South Africa	SAFCOL	9810H01A4	Belfast, A30b	1880	950	x			
South Africa	SAFCOL	9810H02A3	Jessievale A22c	1755	1075	x			
South Africa	Mondi	9818H01C	Woolstone H13	1137	930	x		x	
South Africa	Mondi	9818H02C2	Ncalu (B02B)	1120	868	x			
South Africa	Mondi	9818H02C3	Mahehle (A12)	1145	957	x			
South Africa	Mondi	9818H02C4	Mistley (T010)	1134	1005	x			
South Africa	Merensky	9849H01D1	Mpur D15a	1450	881	x			
South Africa	Merensky	9849H01D2	Mhlahlane, G02a	1020	1239	x			
South Africa	Merensky	9849H02D	Weza G08d	1080	996	x			
South Africa	York Timbers	9863H02I4	Jessievale A59	1710	.	x			
South Africa	Sappi	9807H01E	Usutu C23	1294	1150	x	SA-Warm		
South Africa	Sappi	9807H02E1	Grootgeluk, B21c	1320	917	x			
South Africa	Sappi	9807H02E2	Nooitgedacht, H17d	1156	917	x			
South Africa	SAFCOL	9810H01A1	Wilgeboom C2b	970	1180	x			
South Africa	SAFCOL	9810H01A3	Spitskop, B31b	1300	1180	x			
South Africa	SAFCOL	9810H02A1	Brooklands G4	1160	950	x		x	
South Africa	SAFCOL	9810H02A2	Roburnia A24b	1345	1075	x			
South Africa	York Timbers	9863H02I1	Klipkraal R27	1280	1595	x		x	
South Africa	York Timbers	9863H02I2	Maggsleigh D14	1280	1199	x			
South Africa	York Timbers	9863H02I5	Goegeloof K08	1460	.	x			

Safcol foresters Eunice Sehlabela (left), Daniel Khumalo and Clement Thabethe (right) take Resistograph readings in an 8-year-old pine hybrid trial in Brooklands, Mpumalanga, South Africa.

Ronaldo Donizete dos Santos (right) and Adalberto Custodio da Silva of Klabin take TreeSonic readings in a pine hybrid trial in Monte Alegre, Paraná, Brazil.

Rodrigo de Lima (left) and Douglas Naizer of WestRock take an increment core in an 8-year-old pine hybrid trial in Zaniolo, Santa Catarina, Brazil.

Data Analysis

Statistical analysis for this project included fitting generalized linear models (GLM) for all traits: volume at 5 and 8 years, percentage cellulose and lignin, core resistance, and MOE. Significance of each modeled trait was evaluated, and if variation between treatments was observed, comparisons were made between their LSMEANS. Confidence intervals for the LSMEANS of each trait were also calculated and plotted. Data analysis was conducted in R version 3.5.0.

For modelling volume, we excluded the treatments that had a field survival less that 60 percent. Study sites were combined into five groups based on climate and/or hybrid overlap:

- Argentina and Brazil
- Colombia, Kenya and Mozambique
- Western Cape in South Africa (SA Cape)
- Cool sites in South Africa (SA Cool)
- Warm sites in South Africa (SA Warm)

Modeling for wood properties was done in two groups:

- Argentina and Brazil
- Colombia and South Africa

Results and Discussion

Volume

For volume at 5 and 8 years, we partitioned the total variation into blocks, treatments and error. The variation associated with treatments on all traits was statistically significant in all cases (all P-values were less than 0.001), which indicates that there are differences in mean volume between treatments.

In general, there are approximately twice as many trials with 5-year data than with age-8 data, so here we will focus on 5-year results which should be more robust. At age 5, the most promising hybrid combinations are CARxTEC, PATxTEC, and GRSxTEC, for the regions Argentina and Brazil, Colombia, Kenya and Mozambique, South Africa Cool, and South Africa Warm. The hybrids ELLxCAR and TAExELL perform well in the Western Cape in South Africa. In Figure 1, light-colored bars denote treatments that are present on only one site, thus these will have a wider 95 % confidence

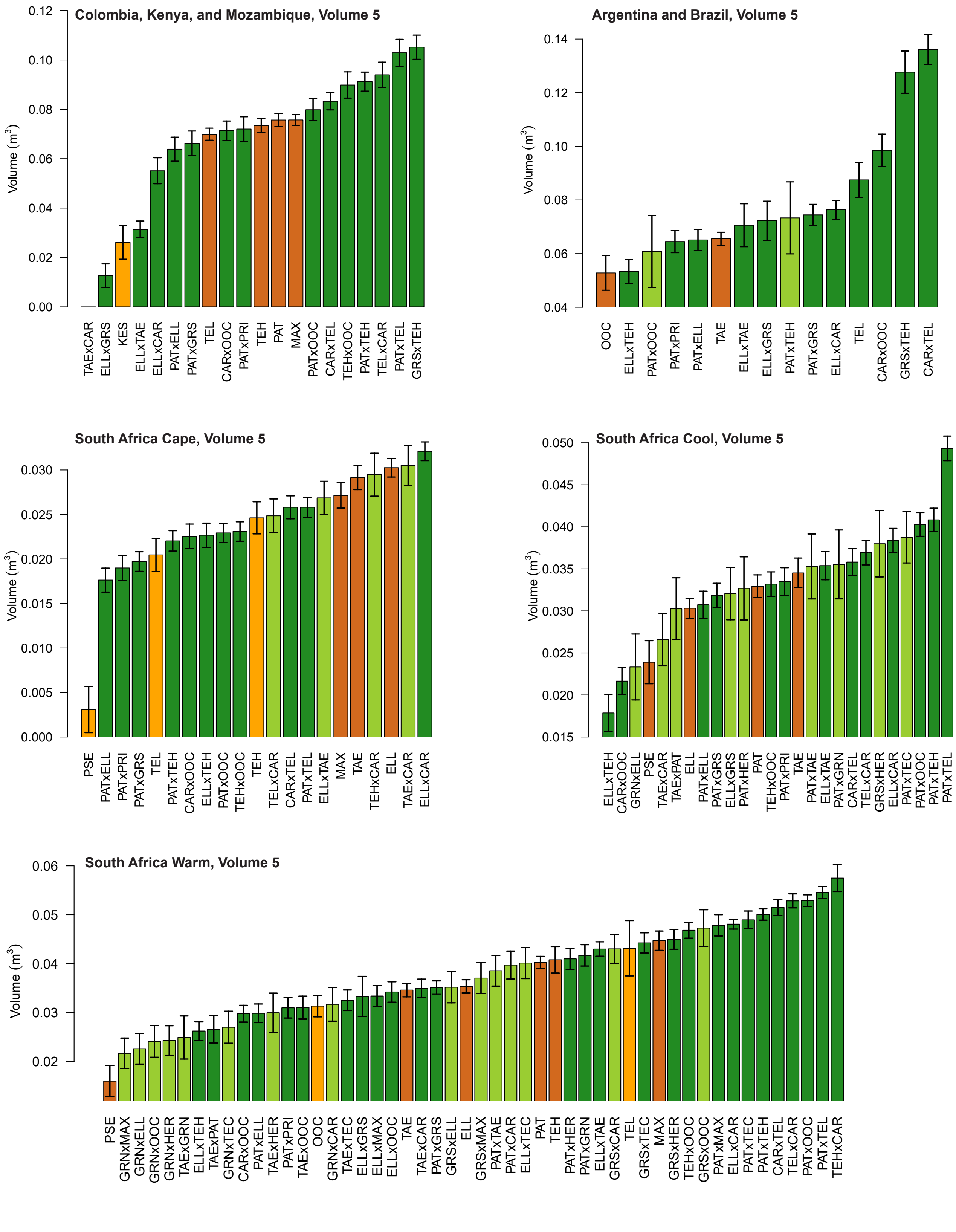


Figure 1. LSMEANS and 95 % confidence intervals for volume at 5 years in different regions. Light orange and light green bars indicate species / hybrids tested on only one site.

interval. Overlapping confidence limits for two or more treatments indicate no statistical differences between them. In general, hybrid rankings derived from 8-year data were similar to rankings observed at 5 years. Hybrid combinations between the species *P. caribaea*, *P. tecunumanii*, *P. oocarpa*, *P. patula*, *P. greggii* and *P. elliottii* produced hybrids with higher tree volumes.

Wood quality

Wood properties at age 8 were analyzed using the methods described for volume. Rankings for cellulose, lignin, resistance and MOE LSMEANS are shown in Table 2 where the best four hybrids for each trait are highlighted in blue. Interestingly, hybrids *P. patula* x *P. tecunumanii*, *P. patula* x *P. greggii*, and *P. greggii* x *P. tecunumanii* stand out for cellulose, lignin, resistance and MOE, whereas *P. tecunumanii* x *P. caribaea* ranked well only for resistance in Colombia and South Africa.

Among the pure species, good wood properties are observed in *P. patula*, *P. tecunumanii*, *P. taeda*, *P. oocarpa*, *P. pseudostrobus* and *P. radiata*. However, only *P. patula* and *P. tecunumanii* ranked well for growth at 5 years; *P. taeda* and *P. oocarpa* ranked intermediate, and *P. pseudostrobus* always ranked at the bottom in all South Africa trials. No growth data is presented for *P. radiata* because it was tested only by MTO and its survival in the trials was always under 60 percent.

Summary and Outlook

We have been devoting many resources to pine hybrid testing, and recently, to the establishment of a multinational breeding program for the specific hybrids *P. patula* x *P. tecunumanii*, and *P. tecunumanii* x *P. greggii*. The results in this report confirm that we are on the right track. As a group, we should also consider future work with other hybrids that are showing good potential, such as *P. patula* x *P. greggii* and *P. tecunumanii* x *P. caribaea*.

Table 2. Treatment rankings for wood traits at 8 years of age. The top four hybrids are highlighted in blue.

Argentina and Brazil				
Rank	**Cellulose**	**Lignin**	**Resistance**	**MOE**
1	PATxTEH	PATxTEH	OOC	PATxTEH
2	PATxOOC	PATxOOC	TAE	TEL
3	PATxGRS	PATxGRS	ELLxTAE	GRSxTEH
4	PATxELL	TEL	TEL	PATxOOC
5	TEL	PATxELL	PATxELL	ELLxCAR
6	PATxPRI	TAE	PATxTEH	CARxTEL
7	GRSxTEH	GRSxTEH	GRSxTEH	TAE
8	TAE	PATxPRI	PATxOOC	PATxELL
9	CARxTEL	ELLxTAE	ELLxTEH	ELLxGRS
10	ELLxTAE	OOC	ELLxGRS	ELLxTAE
11	ELLxCAR	CARxTEL	CARxOOC	OOC
12	ELLxTEH	ELLxGRS	ELLxCAR	PATxGRS
13	CARxOOC	CARxOOC	PATxGRS	ELLxTEH
14	ELLxGRS	ELLxTEH	CARxTEL	CARxOOC
15	OOC	ELLxCAR	PATxPRI	PATxPRI
Colombia and South Africa				
Rank	**Cellulose**	**Lignin**	**Resistance**	**MOE**
1	PSE	RAD	RAD	TEHxOOC
2	RAD	PSE	TAE	PATxTEH
3	PATxGRS	PATxGRE	ELLxTEH	PATxMAX
4	PATxGRE	PATxGRS	TAExCAR	PATxTEL
5	PAT	PATxTEH	TELxCAR	MAX
6	PATxTEH	PAT	TEHxOOC	PAT
7	PATxMAX	PATxMAX	MAX	PATxGRS
8	PATxTEC	PATxTEL	PATxOOC	PATxTEC
9	PATxPRI	PATxOOC	PATxTEH	PATxELL
10	PATxTEL	PATxELL	CARxTEL	PATxOOC
11	PATxELL	PATxPRI	ELLxTAE	PATxGRE
12	MAX	TEHxCAR	CARxOOC	ELLxTEH
13	PATxOOC	MAX	PATxGRS	PATxPRI
14	TEHxCAR	TEHxOOC	PATxMAX	TEHxCAR
15	ELLxTEH	PATxTEC	PATxTEC	TAE
16	TEHxOOC	ELLxTEH	TEHxCAR	TELxCAR
17	TAE	TAE	GRSxTEC	ELLxGRE
18	TAExCAR	TAExCAR	PSE	ELL
19	ELLxGRE	TELxCAR	PATxGRE	GRSxTEC
20	TELxCAR	ELLxGRE	PATxTEL	ELLxTAE
21	GRSxTEC	ELLxTAE	PATxPRI	RAD
22	ELLxTAE	CARxTEL	PATxELL	PSE
23	ELLxCAR	GRSxTEC	ELLxGRE	ELLxCAR
24	CARxOOC	CARxOOC	PAT	CARxTEL
25	CARxTEL	ELLxCAR	ELL	CARxOOC
26	ELL	ELL	ELLxCAR	TAExCAR

Camcore Pine Hybrid Projects

Results from Camcore bulk pine hybrid trials have consistently shown excellent growth and wood properties of both *Pinus patula* x *P. tecunumanii* and *P. greggii* x *P. tecunumanii* hybrids. In 2019, we made significant progress in the full-sib breeding projects underway for these two hybrids in southern Africa and Latin America.

P. patula x *P. tecunumanii* in Africa

The seeds of *P. patula* x *P. tecunumanii* collected in Sappi's *P. patula* clonal seed orchard in Lions River, Howick, were sent to Mondi's nursery for propagation. Two batches of seeds were sown, the first in July and a second in October. Results of germination and seedling production are shown in Table 3.

Twenty-two families of *P. patula* x *P. tecunumanii* HE had more than 13 (and up to 93) genotypes growing in the nursery and 10 other families had fewer than 13 seedlings per family. This group of 10 families will be combined in the nursery as one bulk treatment in the progeny trials. Three more bulk seed lots will be created from hybrid seeds received from Smurfit Kappa Colombia.

Eighteen families of *P. patula* x *P. tecunumanii* LE had more than 12 (and up to 90) genotypes per family and another 15 families had 10 or fewer seedlings per family. Four bulks will be made out of these 15 families. As with the hybrid with *P. tecunumanii* HE, these bulks will be included as treatments in the progeny trials. In the bulk seed lots, the identity of exceptional trees in the trials can be determined with genetic markers.

Based on current and expected propagation, two trials per company will be planted with the following schedule: PG Bison and MTO in April 2020, Sappi and Merensky in November 2020, Mondi in November 2021, and York and Safcol in November 2022.

Seeds of 50 families of the *P. patula* x *P. tecunumanii* hybrid were sent to Smurfit Kappa Colombia in exchange for seeds of *P. patula* x *P. oocarpa* and *P. patula* x *P. tecunumanii,* previously provided by the company.

P. tecunumanii x *P. greggii* in Latin America

Smurfit Kappa Colombia continues to make crosses in their clonal seed orchards of *P. tecunumanii* with *P. greggii* pollen received from Brazil and collected from Camcore selections in Colombia. Great progress was made in 2018 as can be seen in Table 4.

Pollen from the *P. tecunumanii* mother trees in Colombia has been collected by Smurfit Kappa and will be sent to Raleigh for distribution to Klabin and WestRock in Brazil, where hybrids of the reciprocal crosses will be made on *P. greggii* seed orchards at both companies. This activity will serve as a backup for hybrid seed production by family in case seed production and germination in Colombia is poor. Smurfit Kappa Colombia will continue making crosses and collecting cones in 2019.

Table 3. Summary germination of *P. patula* x *P. tecunumanii* full-sib seed in Mondi's nursery.

Hybrid	1st sowing	2nd sowing	Seedlings
P. patula x *P. tecunumanii HE*	575	335	910
P. patula x *P. tecunumanii LE*	340	261	601
Total	915	596	1,511

Table 4. Number of crosses of *P. tecunumanii* (high and low elevation) x *P. greggii* var. *australis* made and cones and seeds produced in Smurfit Kappa Colombia's clonal seed orchards.

Year	Crosses	Mothers	Fathers	Crosses w/ cones	Live cones	Seeds
2016	1,038	25	13	37	405	9,304
2017	4,747	55	32	147	2,798	17,707
2018	1,336	37	31	94	928	

Camcore *Eucalyptus* Hybrid Project

Camcore members are actively working on the development of the *Eucalyptus* hybrid program phases 1 and 2. In phase 1, the South African members selected and felled trees in the hybrid seedling selection blocks at 18 months of age, did some DNA fingerprinting, collected coppice cuttings from selections, bulked up the material into hedges, and took wood samples for density measurements. In 2019, the South African companies will produce cuttings for tests and will plant the first clonal trials with hybrids of *E. grandis* x *E. globulus*, *E. grandis* x *E. benthamii*, and *E. grandis* x *E. dunnii*. A small number of clones of *E. grandis* x *E. smithii* and *E. grandis* x *E. brassiana* will also be tested.

Smurfit Kappa Colombia established selection blocks with four hybrid crosses and made a first thinning at 8 months, eliminating trees with poor form or growth. From their hybrid selection blocks, Smurfit Kappa Colombia selected 350 trees of *E. grandis* x *E. pellita*, 350 *E. urophylla* x *E. pellita*, 77 *E. grandis* x *E. globulus* and 4 trees of *E. grandis* x *E. brassiana*. These selections were made after the thinning, and will be used for the establishment of clone x site interaction trials, with the exception of the last hybrid, which shows poor form and growth and a low level of adaptation. Other members in Latin America (Arauco in Chile, and Klabin and WestRock in Brazil) will sow seeds of several hybrids in 2019 for the establishment of selection blocks and/or genetic tests.

Some hybrid seeds (*Corymbia torelliana* x *C. citriodora*, *E. urograndis* x *E. dunnii* and *E. urophylla* x *E. dunnii*) contributed by Klabin will be shipped to several members in 2019.

Camcore members continue to develop phase 2 of the *Eucalyptus* hybrid program and adjustments to the plan for hybrid crosses have been made based on pollen availability. Pollen collections by members were initiated in 2018, and so far, we have received pollen from the following members: Sappi, pollen of *E. dunnii*; Arauco Chile, *E. globulus* and Smurfit Kappa Colombia, *E. grandis*. This pollen will be shipped to Sinar Mas, APRIL and Proteak at the beginning of 2019 for their crosses. Some companies are collecting pollen that they will use for crosses with their own selected female trees, including APRIL in Indonesia, Arauco Chile, Montes Del Plata and Lumin in Uruguay, Klabin and WestRock in Brazil, Smurfit Kappa in Colombia, Miro Forestry in Sierra Leone and Ghana, and East Africa in Kenya. These companies are collecting pollen of the following species: *E. urograndis*, *E. badjensis*, *E. dorrigoensis*, *E. dunnii*, *E. benthamii*, *E. urophylla*, *C. citriodora* and *E. camaldulensis*. Crosses being made by 16 members should produce seeds of 25 hybrids that will go to clonal field trials. Crosses will be made in 2019 with more in 2020 and 2021, based on pollen availability.

Seven-month-old hybrid seedling selection blocks established by SKC in Restrepo, Valle, Colombia. This is the same planting shown on the front cover but 6 months later.

Christi Sagariya of Miro Sierra Leone and his team built five towers to access flowers for controlled pollination of *Corymbia* trees.

Camcore Teak Update

Camcore has established several teak progeny trials in different countries. Current Camcore members with trials are Proteak in Mexico and Grupo DeGuate in Guatemala. Some previous members also have important trials with genetic material that belongs to the program.

Juan Lopez visited TEKIA in February 2018 to coordinate the propagation of clones selected in one of the progeny trials. TEKIA planted the progeny trial in Carmen de Bolívar, Colombia with 48 families from 13 sources in October 2011. Based on 5-year measurements, Camcore identified 166 candidates, of which 94 were selected in the field. At the end of the year, TEKIA had 1 to 3 mother plants of 28 of the selected clones and of 4 additional clones from other good families. Camcore is working with TEKIA to get access to this material in 2019 once the company has several mother plants from each of the 32 clones. The plants will be used by Camcore to establish a teak clonal bank that will produce plants for clonal trials for members. Camcore has another progeny trial in Guatemala with 63 families from sources similar to those in the TEKIA trial in Colombia. This trial was thinned at five years of age, and the best three trees from each six-tree family plot were left standing. With the wider tree spacing in this trial, flowers are more abundant and many fruits are produced through open pollination. In 2018, we made a seed collection of 277 trees from 63 families from 16 sources. We have the seeds in Raleigh and they will be distributed to Camcore members in 2019 for the establishment of progeny trials.

Mother plants of teak propagated from Camcore selected trees in TEKIA's progeny trial in Carmen de Bolívar, Colombia.

Camcore Gmelina Update

After many years of work by Camcore in *Gmelina arborea* tree improvement, fifty clones have been selected in 1st generation progeny tests, and these have been propagated through rooted cuttings. A clonal seed orchard and several clonal trials have been established with this material by Forestal Monterrey on the Caribbean coast of Colombia.

Camcore members in several countries are interested in obtaining ramets of these clones to be tested under local conditions. The clonal seed orchard has started to produce open-pollinated seed and these were collected in 2018. Juan Lopez visited Forestal Monterrey in Colombia early in the year to coordinate seed collections, clone propagation and conservation of *Gmelina* genetic material. The foresters at Forestal Monterrey collected as many fruits as possible and 30 of the 50 clones produced enough seed to establish genetic trials. Some of these seeds will be sent to Miro Forestry in Ghana and Sierra Leone and to KEFRI in Kenya.

One of the five clonal trials established by Forestal Monterrey was chosen to produce plants. Two trees from each of the 50 clones were cut to produce stump sprouts that were collected and used to the nursery for vegetative propagation. Enough rooted cuttings were produced to use for clonal trials in West Africa and a clonal bank at Smurfit Kappa Colombia; these should be shipped in the first months of 2019. In the mid term, Camcore is planning to distribute in vitro material of *Gmelina* and *Tectona grandis* to its members, and is working with a lab in Bogotá to develop tissue culture protocols for this purpose.

More seeds of *Gmelina* from the clonal seed orchard will be collected in 2019 and Camcore will propagate more plants of the 50 clones to be distributed to other members.

Forestal Monterrey agreed to establish a new, temporary conservation bank of all the genetic material of the species. The bank will be moved to another company in the future.

Rooted cuttings of the 50 *Gmelina arborea* clones at Forestal Monterrey, Colombia.

Genetic Variation in a *E. grandis* Clonal Population for Growth and Wood Properties

Martha Salas of Smurfit Kappa Colombia recently completed her M.S. at NC State University. Here we summarize some of the important results of her work. Her full thesis can be accessed through the NC State University library or from the Camcore web page. Martha was supported by the Camcore graduate student stipend, and has returned to lead the tree breeding program at Smurfit Kappa Colombia.

Introduction

Smurfit Kappa Colombia (SKC) is a vertically integrated forest products company producing kraft pulp and paper from both pines and eucalypts. SKC began a tree improvement program of *Eucalyptus grandis* in 1987 with the aim of developing genetically superior seeds and clones for deployment to commercial plantations. To date, the company has completed three generations of improvement, and is currently executing the strategy for the 4th generation. Traditionally, operational clones have been selected using an index of volume and wood density. From an industrial perspective, the breeding objective should consider the amount and cost of pulp; hence this research was aimed at understanding the genetic variation in wood chemical traits as well. The objectives of this study were to 1) examine the genetic control and genotype x environment interaction for growth, wood density, and wood chemical traits of the 3rd generation elite clonal population of *E. grandis* planted in Colombia, and 2) evaluate the impact of growth and wood properties on the cost of production of bleached kraft pulp, using a simulation model that integrates forestry and mill production. The specific wood chemical traits examined in this study are NIR predictions for sugars (glucose, xylose, galactose, arabinose, and mannose), lignin (total, soluble, and insoluble), S/G lignin ratio, also analyzed as S/(S+G), and pulp yield.

Materials and Methods

This study was based on measurements of tree growth and wood traits taken from a series of clonal trials of *E. grandis*, known as the Elite Population, from the 3rd generation of improvement at SKC. There were 374 clones derived from 21 parents crossed to produce 40 full-sib families. The clones were established on 12 sites (farms) representing the range of the soils and climate in which *E. grandis* is planted operationally by the company. The experimental design was an alpha lattice with 5 to 9 trees per incomplete block and 10 replications per site. Each test contained from 315 to 374 clones, and all clones were assessed for volume and density across the 12 sites. Using a selection index based on volume and density at 3 years of age, the best 77 clones were selected for wood chemistry analysis. The best 77 clones were derived from 20 parents and represent 31 controlled pollination families. A set of 3 clonal control lots of *E. grandis* and 3 of *E. urograndis* were included in the population of study, for a total of 83 clones. A subset of three of the 12 clonal trials was selected for wood sampling, with one test in each of the company's North, Central and South Zones. In total, 1222 trees were selected for the wood sample subpopulation, representing 83 clones on three farms with approximately five ramets per clone per site (Table 5).

Traits Measured

Growth traits were measured in all 12 studies: height and diameter at breast height (DBH) at 3 and 6 years. Tree volume was calculated using a company-developed equation. An NIR-predicted wood density at 6 years was estimated, using a model developed for this study. For NIR prediction, wood density was first measured on a subset of 365 wedge samples in NCSU labs, and then woodmeal from the wedges was scanned in order to calibrate an NIR model. The NIR model was satisfactory, with a cross-validation $R^2 = 0.66$, and a standard error of cross-validation (SECV) of ± 0.021. This model was then used to predict age-6 density for 1222 *E. grandis* samples.

Wood chemical traits were also predicted with NIR models. Global NIR models for *E. urophylla*, *E. dunnii*, *E. globulus*, and *E. nitens* wood chemistry developed by Camcore (see 2016 Annual Report) were expanded and recalibrated to include wetlab chemistry results from a subset of 36 samples of *E. grandis* from the wood sample subpopulation. The previously developed global NIR models were first used to obtain initial

Table 5. General information for the *E. grandis* clonal trials selected for wood chemistry sampling.

Farm	Zone	Latitude (N)	Longitude (W)	Elevation (m.a.s.l)	Rainfall (mm)	Date Planted	No. of Clones
Tesalia	North	4° 48'	75° 36'	1969	2712	7/9/2007	374
Mota	South	2° 32'	76° 38'	1731	2221	6/2/2007	372
Alpes	Center	4° 00'	76° 27'	1614	1428	6/29/2007	374

predictions of chemical traits for all samples, and subsequently, 36 out of 1222 were selected for wetlab chemistry performed at the University of British Columbia with the same 4-gram woodmeal samples used for desktop NIR scanning.

Recalibrated global NIR models (2017 Annual Report, Hodge et al. 2018, JNIRS 26:117-132) were then used to predict the following traits for the 1222 samples: glucose, xylose, galactose, arabinose, mannose, total lignin, insoluble lignin, soluble lignin, S/G ratio, and syringyl percentage, as S/(S+G). In addition, NIR predictions were made for pulp yield using a previously developed model based on 99 *E. grandis* samples with pulping data collected in 2009.

Genetic Parameter Estimation

A standard multiple-site linear model was used to analyze all variables, with the model including test and replication as fixed effects, and clone, clone x test (farm), and error as random effects. Statistical analyses were carried out using R and the *nmle* and *lme4* packages. Variance component analyses and predictions of clonal genetic value (clonal BLUPs) were made using R (R Core Team 2016) and the *nmle* and *lme4* packages in R (Pinheiro et al. 2018; Bates et al. 2015). Clonal heritability (or broad-sense heritability, H^2) and Type B clonal genetic correlation (r_{Bg}) estimates were calculated as:

$$H^2 = \sigma^2_C / (\sigma^2_C + \sigma^2_{CxF} + \sigma^2_e)$$

where:

H^2 = broad-sense heritability
σ^2_C = clonal genetic variance
σ^2_{CxF} = clone x farm interaction variation
σ^2_e = within-site error variance attributed to microsite variation in farm and measurement error

$$r_{Bg} = \sigma^2_C / (\sigma^2_C + \sigma^2_{CxF})$$

where:

r_{Bg} = Type B genetic correlation
σ^2_C = clonal genetic variance
σ^2_{CxF} = clone x farm interaction variation

Type B correlations over multiple sites range between zero and one; an $r_{Bg} \approx 1$ indicates a near-perfect correlation between performance in different environments, or in other words, an absence of genotype (or provenance) x environment interaction

Finally, genetic correlations among growth traits and wood density at ages 3 and 6, and among growth traits, wood density, and wood chemical traits at 6 years were estimated using ASREML. For each correlation of interest, a paired-trait analysis was conducted using the same multiple-site linear model discussed above. The clonal genetic correlation and the associated standard error were estimated directly by the program.

Results and Discussion

Growth Traits

In the full population of 374 clones, mean volume growth across the 12 trials was 0.358 m^3 per tree at age 6 years (Table 6). For the wood subpopulation (representing approximately the top 25% of the population), the mean volume growth was substantially higher at 0.491 m^3 per tree. The result of this selection pressure based primarily on growth meant that both heritability and Type B genetic correlation for volume growth were higher in the full population than in the wood subpopulation (H^2 = 0.33 vs 0.24, and r_{Bg} = 0.74 vs 0.64, respectively),Table 7.

Wood Traits

Summary statistics of wood chemical traits for the wood sample subpopulation are presented in Table 7. Mean glucose content was 48.0%, xylose was 12.1%, and mean mannose, galactose and arabinose were all less than 1.3%. Insoluble lignin was 26.9% of the total chemical composition, mean soluble lignin was 3.7%, and mean S/G ratio was 2.8. Mean S/(S+G) was 72.1%. Both S/G and S/(S+G) express the relationship between easy-to-extract syringyl lignin, and hard-to-extract guaiacyl lignin. Although S/G is a familiar variable in the wood science literature, S/(S+G) turns out to be a better variable for NIR modeling (and may be easier to interpret).

In general, wood chemical traits exhibited moderate to high levels of genetic control ranging from $H^2 = 0.17$ (galactose) to $H^2 = 0.68$ (S/(S+G)). Lignin-related traits had higher clonal heritability ($H^2 = 0.46$ to 0.68) than sugars ($H^2 = 0.17$ to 0.39). Pulp yield was under a high level of genetic control ($H^2 = 0.46$). Type B genetic correlations were generally high, indicating low genotype x environment interaction ($r_{Bg} = 0.77$ to 0.98). Again, lignin-related traits exhibited lower genotype x environment interaction ($r_{Bg} = 0.85$ to 0.98) than sugar traits ($r_{Bg} = 0.77$ to 0.91).

The clonal genetic standard deviation (σ_C) was 1.2% for glucose, 0.8% for insoluble lignin, 0.4 for S/G ratio, and 1% for pulp yield. These values represent the potential increase of the means if selection for these wood chemical traits is applied to the subpopulation. These estimates can be interpreted as the feasible potential gain without sacrificing gains in other traits like volume.

Genetic Correlations Among Traits

Strong age – age correlations between 3 and 6 years were found for all growth traits, e.g., $r_g = 0.85$ for volume, $r_g = 0.85$ for DBH, and $r_g = 0.78$ for height. This confirms that genetic selection can be effectively applied at 3 years to reduce the time required for breeding cycles.

Correlations between growth traits and wood density at rotation age were moderately negative ($r_g = -0.35$ to -0.43). Previous studies of *Eucalyptus* report unfavorable correlations similar to the ones found in this study, e.g., $r_g = -0.36$ between DBH and density of *E. nitens* at 9 years (Hamilton et al. 2009, *Tree Genetics and Genomes*). However, other studies of *E. grandis* clones have found close to zero correlation between wood density and growth traits, e.g., $r_g = -0.08$ between wood density and MAI at 6 years (Osorio et al.

Table 6. Genetic parameter estimates for volume growth in the full population (374 clones) and the subpopulation selected for wood sampling (top 80 clones selected primarily for volume growth).

Population	Volume (m^3)	H^2	r_{Bg}	σ_C
Full (374 clones)	0.358	0.33 (± 0.03)	0.74 (± 0.03)	35.4
Wood subset (80 clones)	0.491	0.24 (± 0.05)	0.64 (± 0.10)	21.9

Table 7. Genetic parameter estimates for chemical wood properties in the wood sample subpopulation, using NIR predictions. H^2 = clonal (broad-sense) heritability, r_{Bg} = clonal Type B genetic correlation, σ_C = clonal genetic standard deviation.

Variable	Mean	H^2	r_{Bg}	σ_C
Density (g/cm³)	0.425	0.39 (± 0.07)	0.89 (± 0.06)	0.017
Glucose (%)	48.0	0.39 (± 0.07)	0.91 (± 0.06)	1.2
Xylose (%)	12.1	0.27 (± 0.05)	0.87 (± 0.10)	0.5
Galactose (%)	0.6	0.17 (± 0.04)	0.77 (± 0.14)	0.1
Arabinose (%)	0.2	0.35 (± 0.07)	0.79 (± 0.08)	0.0
Mannose (%)	1.3	0.19 (± 0.04)	0.81 (± 0.13)	0.1
Total Lignin (%)	30.8	0.47 (± 0.09)	0.85 (± 0.05)	0.7
Insoluble Lignin (%)	26.9	0.52 (± 0.09)	0.88 (± 0.05)	0.8
Soluble Lignin (%)	3.7	0.64 (± 0.11)	0.98 (± 0.02)	0.2
S/(S+G) (%)	72.1	0.68 (± 0.11)	0.95 (± 0.02)	2.0
S/G	2.8	0.63 (± 0.11)	0.95 (± 0.03)	0.4
Pulp Yield (%)	50.2	0.46 (± 0.08)	0.87 (± 0.05)	1.0

2003, *Theoretical and Applied Genetics*). The discrepancy between our results and those from Osorio et al. might be attributed to the fact that they studied the 2nd, (not the 3rd) generation of clones.

Correlations between growth traits and wood chemical traits were generally low to moderate, with absolute value $|r_g| \leq 0.50$ in almost all cases. There was a slight positive correlation between growth traits and pulp yield (r_g = 0.35 to 0.50), which is a favorable correlation. In addition, correlations between growth traits and lignin were favorable for pulp production, i.e. growth correlated negatively with lignin.

Some wood chemical traits were correlated to wedge wood density at a moderate level; for example, density and glucose (r_g = 0.25), and density and pulp yield (r_g = -0.23). These results suggest that at some higher value, wood density interferes with pulp yield, making it difficult to find trees with both high density and high pulp yield. Wood density was significantly correlated with galactose (r_g = 0.60) and mannose (r_g = -0.34).

The most relevant wood chemical traits for pulp production showed strong correlations. Glucose was strongly correlated with almost all the chemical traits either positively or negatively ($|r_g|$ = 0.61 to 0.83). This finding makes sense since glucose is the primary component of wood and as it increases, the other traits must decrease and vice versa. Glucose was negatively correlated with most of the traits except with pulp yield (r_g = 0.83) and galactose (r_g = 0.65). Pulp yield was negatively associated with xylose (r_g = -0.48), arabinose (r_g = -0.81), total lignin (r_g = -0.82), and insoluble lignin (r_g = -0.72). Insoluble lignin showed negative correlation with S/G (r_g = -0.70) and S/(S+G) (r_g = -0.62), indicating that as lignin increases, it also becomes harder to extract during pulping.

Impact on the Mill

A straightforward model simulation developed at the Forest Biomaterials Department at NC State University was used to evaluate the effect of growth and wood properties of the *E. grandis* clones on the cost of pulp production. The model includes cost factors from both forestry and mill operations, and was used to rank all 80 clones on the basis of cost of production per ton of pulp. Results indicate that favorable wood chemical traits can justify the selection of a clone that may not have the highest volume production. For example, two clones ranked #20 and #21 by dry matter growth rate (both 22.5 green tons/ha/year) improve to #6 and #8 when ranked by total cost per ton of pulp. These two clones exhibit some of the highest pulp yields (PY = 50% and 49.8%, ranked #4 and #11). Both clones also have very low insoluble lignin (both 25.8%, ranked #3 and #4), and high S/G ratios (S/G = 3.3, ranked #3 and #4). Pulping these clones would require less recovery and bleaching chemicals, thereby reducing costs.

Impact on Selection Strategy

From this study, it is clear that assessing wood properties, including both density and chemical traits, can produce significant value for an integrated pulp and paper company. The large amount of genetic variation for volume growth, even in this advanced-generation population of *E. grandis*, indicates that growth will continue to be the primary trait in most tree breeding programs, but wood traits should not be neglected. However, it seems likely that wood traits should be assessed only on the better growing genotypes, e.g., the top 15 to 20% based on growth.

Martha Salas of SKC marking a disk from a 9-year-old, 3rd generation *E. grandis tree* in a clonal trial at Motas Farm, Cauca, Colombia.

Genetic Variation of *E. dunnii* Wood Properties

Juan Pedro Posse of Lumin (Uruguay) has nearly completed his Ph.D. at NC State University. This article summarizes some of the important results of his research on the genetic control of wood properties. When completed, his full thesis can be accessed through the NC State University library or from the Camcore web page. Juan Pedro was supported by the Camcore graduate student stipend, and has returned to manage research and the tree breeding program at Lumin.

Introduction

Lumin is a vertically integrated forest products company producing pine and eucalypt plywood. Currently, the most important eucalypt species planted in the country are *E. globulus* var. *globulus* (for pulp), and *E. grandis* (for pulp and timber). While these two species are generally well adapted to the ecological conditions of Uruguay, neither is optimal in conditions of low winter temperatures, poor drainage, or low site productivity. In recent years, *E. dunnii* has demonstrated good potential on a range of sites in the country. This study focused on examining the genetic variation in *E. dunnii* wood properties in a series of progeny tests with families from the full native range of the species. The specific wood chemical traits examined are NIR predictions for sugars (glucose, xylose, galactose, arabinose, and mannose), lignin (total, soluble, and insoluble), and S/G ratio, also analyzed as S/(S+G). In addition, acoustic velocity measurements (related to timber stiffness) and wood density measurements were taken. The objectives of the study were to 1) examine the level of genetic control and genotype x environment interaction for growth and wood properties, and 2) determine if basic wood properties or combinations of traits might be associated with splitting tendencies of logs following harvesting. The control of splitting is of critical importance in the production of veneer and plywood.

Materials and Methods

A collection of 351 open-pollinated (OP) families of *E. dunnii* from 12 provenances was planted in four progeny tests, along with four groups of commercial controls included in all trials: five OP commercial families of *E. dunnii* from Australia, a set of two commercial clones of *E. grandis*, an *E. grandis* seed orchard bulk lot from Mondi (South Africa), and a set of five *E. grandis* hybrid clones developed by Mondi. All of the Mondi material has been used extensively in commercial plantations in Uruguay since the early 2000s.

The tests were planted in two regions (East and North) in each of two planting seasons (Fall and Spring). Thus, there were four tests: East-Fall, East-Spring, North-Fall, and North-Spring; site details are presented in Table 8. Tests were planted at a 4 x 2-meter spacing, equivalent to 1250 trees per ha. Around age 3 years, the tests were pruned to about 2.5 m of height to facilitate access to the trial. Due to the large number of genetic entries, the 351 families were divided into six sets. At each test site, each of the six sets was planted with a Randomized Complete Block design with 25 replications of single-tree plots. Each set contained four to five provenances, with each provenance represented by 10 to 16 families. The six sets of families were the same for all four sites. In addition to the families of *E. dunnii* in each set, all 13 of the genetic controls were included in all replications of all sets. This was done to provide better linkage between the sets to make better comparisons among the families.

Growth Traits

Height (HT) and diameter (DBH) measurements were taken at ages 2, 4, and 6 years, and an index of volume (VOL, m^3) was calculated as 0.00003 x DBH^2 * HT. Taking age-6 height measurements was time consuming due to the height of the trees and the difficulty of seeing the tops of the crowns. To reduce costs, all trees were measured for DBH at age 6, but only 20% of the trees in each rep were measured for height with a hypsometer. Regression models to predict HT using DBH were developed for each site, and volume was calculated with measured DBH and predicted HT.

Table 8. General information for the *E. dunnii* provenance-progeny trials.

Test		Latitude	Longitude	Rainfall (mm)	Mean min temp.	Frosts / year	Frost-free days / year
Zone	Season						
East	Fall	32°16´52" S	54°17´20” W	1243	5.1 °C	11.1	126
East	Spring	32°49´35” S	54°59´29” W	1285	6.4 °C	11.1	126
North	Fall	31°13´28” S	55°51´10” W	1484	7.0 °C	5.2	194
North	Spring	31°45´14” S	55°51´55” W	1461	7.0 °C	5.2	194

Wood Sampling

Based on growth at age 2 years, 63 families (5 to 6 families per provenance from all 12 provenances) were selected for wood sampling at the North-Fall site. Of those 63 families, a subset of 20 families was selected and sampled at two additional sites, North-Spring and East-Fall, in order to examine genotype x environment interaction. In addition to the *E. dunnii* families, three of the 13 controls were sampled for wood properties on all three sites: the orchard bulk from Mondi, one *E. grandis* clone, and one *E. grandis* x *E. camaldulensis* clone.

Sampling was done at age 4 years using 15 random trees for every genetic entry in every test. Acoustic velocity measurements (referred to as time-of-flight or TOF) were taken in the standing trees using a Fakkop TreeSonic tool. Two measurements were taken on each tree on opposite sides of the bole. Increment cores were taken with a 12-mm increment borer. Increment core samples were divided at the pith, and one half used for density measurement and one half used for NIR scanning. Wood basic density was measured using the gravimetric method. A four-gram sample of woodmeal from one half of the increment core was scanned with a Foss 6500 NIR spectrometer.

Wood Chemistry and NIR Models

An NIR model specific for *E. dunnii* was developed in order to predict important wood chemistry traits. A set of 400 *E. dunnii* samples was scanned, and a pre-existing NIR model for *E. urophylla* (see 2012 Camcore Annual Report) was used to make preliminary predictions of wood chemical traits. Preliminary predictions were made for glucose and xylose content, Klason lignin content, and ratio of syringyl to guaiacyl lignin (S/G). Using these data, 50 *E. dunnii* samples were selected for laboratory wet chemistry. This set of 50 was selected in order to have a somewhat uniform distribution across the range of all four chemical traits and the first and second principal components of the transformed spectra. The set of 50 *E. dunnii* samples was sent to the University of British Columbia for wetlab chemistry assessment. Traits analyzed were glucose, xylose, galactose, mannose, arabinose, soluble lignin, insoluble lignin (Klason lignin), and S/G. Total lignin content was estimated by summing soluble and insoluble lignin. In addition, a subset of 122 *E. dunnii* representing 62 families and 12 provenances was selected for laboratory assessment of calcium (Ca) and phosphorus (P) content. Measurements were conducted by the Soil Testing Lab, NC Dept. of Agriculture and Consumer Services. For all chemical traits, NIR models for *E. dunnii* were developed using SAS PROC PLS on the transformed spectral data. Final NIR models were used to make predictions of all traits for the full set of 1570 samples, which were then used in the genetic analyses.

Genetic Parameter Estimation

A standard multiple-site linear model was used to analyze all variables. Preliminary analyses showed no statistically significant provenance variation for almost all growth and wood traits, and no commercially important provenance variation for any trait. The final linear model thus included test, set, and replication as fixed effects, and family and family x test interaction as random effects. Narrow-sense heritability (h^2) was estimated as:

$$h^2=\sigma^2_a / \sigma^2_{phen}$$

where σ^2_a = estimated additive variance, calculated as $\sigma^2_a = 3\sigma^2_f$, and σ^2_{phen} = phenotypic variance. Type B genetic correlations (r_{Bg}) were estimated as:

$$r_{Bg} = \sigma^2_f / (\sigma^2_f + \sigma^2_{fxe})$$

Type B correlations over multiple sites range between zero and one; an $r_{Bg} \approx 1$ indicates a near-perfect correlation between performance in different environments, or in other words, an absence of genotype (or provenance) x environment interaction. In order to examine patterns of genotype x environment interaction, paired-site analyses were done for all possible pairs of sites, and r_{Bg} estimated for each pair.

Genetic correlations among traits were estimated using ASREML (Gilmour et al. 2006). For each correlation of interest, a paired-trait analysis was conducted using the same multiple-site linear model discussed above. The genetic correlation and the associated standard error were estimated directly by the program.

Results and Discussion

NIR Models

Very good NIR models were obtained for 10 of 11 wood chemistry traits. For those 10 traits, R^2 ranged from 0.80 (for glucose) to 0.98 (for lignin, galactose and mannose). The glucose model, with only 3 factors, was quite good, with an $R^2 = 0.80$, and SECV = 1.6. The lignin model was excellent, with $R^2 = 0.98$ and SECV = 0.7, and similarly, the insoluble lignin model was very good, with $R^2 = 0.89$ and SECV = 0.8. The models to examine lignin composition were both good, but the fit was slightly better for the S/(S+G) model than for S/G (with $R^2 = 0.88$ versus $R^2 = 0.76$, respectively). An excellent NIR model was found for calcium content, with $R^2 = 0.96$, but the model for phosphorus content was the worst of the 11 chemical traits, with $R^2 = 0.45$. Mean Ca content in these 50 *E. dunnii* samples was 2007 mg/kg, while the P content was 216 mg/kg. The low P content may be associated with larger lab errors compared to those for Ca, and this would result in poorer fits to the NIR model.

Genetic Parameters for Wood Traits

Heritability estimates for the wood property traits range from moderate (e.g., $h^2 = 0.20$ for arabinose) to very high (e.g., $h^2 = 0.78$ for S/(S+G) (Table 9). Heritability for density was $h^2 = 0.45$, which corresponds well to typical values in the literature. The other "solid wood" trait in this study, TOF, also had a high heritability ($h^2 = 0.57$). It is interesting to note that the heritability estimate for total lignin was $h^2 = 0.21$, while the estimate for insoluble lignin (Klason lignin) was substantially higher, $h^2 = 0.35$. The NIR model for total lignin was slightly better than the model for Klason lignin ($R^2 = 0.98$ and $R^2 = 0.89$, respectively), so the lower heritability for total lignin may reflect a real difference in genetic control. For the two traits that partition syringyl and guaiacyl lignin, a higher heritability was found for S/(S+G) ($h^2 = 0.78$) than for S/G ratio ($h^2 = 0.57$). In this case, the higher heritability was associated with a better NIR model, $R^2 = 0.88$ for S/(S+G) versus $R^2 = 0.76$ for S/G.

Genotype x environment interaction (GxE) was low for all wood property traits (Table 9). With one exception, all of the wood property traits examined in this study have r_{Bg} between 0.84 to 1.00, where $r_{Bg} = 1$ indicates zero GxE across sites. The one exception is Ca (calcium content), with $r_{Bg} = 0.74$. The genetic standard deviation estimates in Table 9 (σ_a) are expressed in the units of measurement, and must be compared to the trait means in order to understand if the genetic variation that is present is economically important. One genetic standard deviation (σ_a) can be interpreted as a quick approximation of potential genetic gain for a trait. For example, the trait glucose content has $\sigma_a = 1.22\%$, which indicates that approximately 16% of the population will have glucose content greater than 1.22% above the population mean (assuming a normal distribution). Increased glucose content should roughly correspond to an increase in pulp yield, and a 1% increase in pulp yield is very important economically. Genetic variation for xylose also appears to be important ($\sigma_a = 0.70\%$). There is less genetic variation for Klason lignin content ($\sigma_a = 0.45\%$) than for glucose or xylose, but this will still have substantial economic impact. Breeders could also increase the amount of syringyl lignin relative to the more difficult-to-extract guaiacyl lignin. For S/G ratio, $\sigma_a = 0.35$, so if the population mean for the trait is moved up one genetic standard deviation, mean S/G ratio would improve from S/G = 3.98 to S/G = 3.98 + 0.35 = 4.33. For S/(S+G), $\sigma_a = 1.35\%$, and an increase of syringyl lignin percentage of 1.35% is roughly equivalent to an increase in S/G ratio of 0.35. This indicates that the two expressions of the trait are estimating similar amounts of genetic variation available to the breeder.

Table 9. Genetic parameter estimates for wood properties of *E. dunnii*. h^2 = heritability (narrow-sense), r_{Bg} = Type B genetic correlation, σ_a = clonal genetic standard deviation.

Variable	Mean	h^2	r_{Bg}	σ_a
Time-of-Flight (ms)	296.1	0.50 (± 0.14)	0.88 (± 0.18)	13.87
Density (kg/m³)	433	0.45 (± 0.12)	0.98 (± 0.21)	35.6
Glucose (%)	47.5	0.50 (± 0.14)	0.88 (± 0.18)	1.22
Xylose (%)	15.6	0.40 (± 0.11)	0.91 (± 0.21)	0.70
Galactose (%)	0.92	0.38 (± 0.11)	0.93 (± 0.24)	0.16
Arabinose (%)	0.34	0.20 (± 0.08)	0.95 (± 0.44)	0.02
Mannose (%)	1.44	0.43 (± 0.11)	1.00 (NA)	0.25
Total Lignin (%)	27.8	0.21 (± 0.08)	0.84 (± 0.36)	0.46
Insoluble (Klason) Lignin (%)	23.7	0.35 (± 0.11)	0.86 (± 0.24)	0.45
S/(S+G) (%)	81.2	0.78 (± 0.18)	0.98 (± 0.11)	1.35
S/G	3.98	0.57 (± 0.15)	0.97 (± 0.17)	0.35
Ca (mg/kg)	2007	0.30 (± 0.09)	0.74 (± 0.21)	404
P (mg/kg)	216	0.25 (± 0.09)	0.92 (± 0.35)	33.5

E. dunnii Growth: Age-Age Clonal Genetic Correlations

Eucalyptus dunnii occurs naturally in two small disjunct populations located in the southeastern corner of Queensland and the northeastern region of South Wales in Australia. Despite its narrow range, *E. dunnii* is a very important species for the establishment of commercial plantations for our members in Brazil, Uruguay and South Africa, due to its adaptability to drier and frost-prone sites and desirable wood properties for pulp. In this article, we analyze a series of six clonal tests established by Montes del Plata (MdP) in Uruguay. Field tests used a single-tree plot (STP) experimental design with 20 repetitions per site. Study sites are located in the center and northwestern regions of Uruguay and were established between April 2012 and October 2013 and growth measurements were taken yearly. For this analysis, two tests had annual measurements through age 4 years, two tests had annual measurements through age 5 years, and two tests had annual measurements through age 6 years. The objectives of this study were to estimate genetic parameters and age-age genetic correlations, and to test the efficiency of early selections for growth traits (DBH, HT and VOL).

Data Analysis

First, we calculated an individual-tree volume index using an equation developed for juvenile trees (Ladrach 1986. Smurfit Cartón de Colombia. Informe de Investigación No. 105.):

$$VOL=0.00003\times DBH^2\times HT$$

where: VOL = individual tree volume (m^3)
DBH = diameter at breast height (cm)
HT = tree total height (m)

For all growth traits, phenotypic coefficients of variation were calculated by replication and by site, and then standardized to have a mean of 100 and the appropriate standard deviation. The resulting standardized traits are denoted as stDBH, stHT and stVOL. Standardized traits were used to estimate variance components, genetic parameters and age-age genetic correlations. Variance components and genetic parameters were calculated using the statistical language R version 3.5.0. Age-age genetic correlations and clonal values (BLUPS) were estimated using ASREML 4.10.

Single-site analyses were conducted for all traits and for all ages to 1) ensure that genetic variation for the traits was observable and 2) evaluate the consistency of the data across sites and measurements. For the single-site analyses, the linear mixed model was:

$$y = B + t + \varepsilon$$

where: y = standardized traits stVOL, stDBH, stHT
B = replication effect
t = the clone effect
ε = the residual error of the model

All single-site analyses showed meaningful genetic variation, so all trials were used in combined-site analyses for any given measurement age. The combined-site linear model was as follows:

$$y = S + B(S) + t + txs + \varepsilon$$

where: y = standardized traits stVOL, stDBH, stHT
S = site effect
B = replication effect
t = the clone effect
txs= clone x environment effect
ε = the residual error of the model

The genetic parameters phenotypic variance (V_{phen}), broad-sense heritability (H^2), and clone-level type B genetic correlation (r_{Bg}) were estimated as follows:

$$V_{phen}= \sigma^2_{clone} + \sigma^2_{txs} + \sigma^2_{\varepsilon}$$

$$H^2= \sigma^2_{clone} / V_{phen}$$

$$r_{Bg} = \sigma^2_{clone} / (\sigma^2_{clone} + \sigma^2_{txs})$$

H^2 gives us an idea of the degree to which the trait is under genetic control in the clonal *E. dunnii* population, and r_{Bg} gives some idea of how consistently the clones perform across environments.

Multi-trait across-site models were used to estimate age-age genetic correlations between all standardized traits and standardized volume at age 6 (stVOL6).

Results

Summarized results are presented in Table 10. The broad-sense heritability estimates for growth traits ranged between 0.18 and 0.38. In general, lower H^2 values were observed at younger ages, and for all standardized growth traits, maximum H^2 was observed at age 6 years. The clonal-level type B genetic correlation estimates for this population were very high, meaning that only very small changes in clonal ranks occur across the study environments. This is encouraging since it indicates that selected superior clones in this population will perform well across a range of environments.

In addition to the genetic parameters, we also calculated efficiency of selection (Q) and changes in genetic gain (ΔGain), using stVOL6 as a benchmark (Table 10):

- Q is a measure of the efficiency of early and/or indirect selection relative to the efficiency of direct selection for volume at age 6 years. Q is a function of the genetic correlation between any given trait and stVOL6 ($r_{gx,gv6}$), and their clonal mean heritabilities.
- Δ Gain is a function of selection intensity (we assumed 5%), clonal mean heritabilities, their genetic correlation, and the clonal variation obtained for the reference trait (stVOL6).

To give practical meaning to both efficiency of selection and changes in genetic gain, we divided both Q and ΔGain values by t: the time it would take to observe the effect of a new clone in the company's operation. We assumed a value for t of 9 years which is the sum of 1) the age at which the selection is made, and 2) the time it takes to deploy the clone and grow it to rotation age.

Age-age genetic correlations between all growth traits and stVOL6 were very high, but note that the correlations between DBH and VOL are always higher than the correlations between HT and VOL. It is also important to note that the maximum values for Q/t and ΔGain/t are reached when the selections are made at 3 years of age (Table 10 and Figure 2), and that there is practically no difference between the gains obtained if the selection is made based on DBH in comparison with VOL.

In summary, in order to maximize resources for this population of *E. dunnii*, it is clear that the best age for making young clone selections on growth traits is 3 years. The marginal genetic gain made by selecting on volume compared to selecting on DBH is very small at all ages. Measuring height is typically much slower (and is therefore more costly) than measuring DBH. If wood quality is of importance, we suggest measuring wood properties at age 4 years for the top 20 to 25% of the clones and using the data to refine the selections.

Table 10. Selection efficiencies and genetic gains. The trait stVOL6 (in bold) is considered the target trait for selection.

Trait	H^2	r_{Bg}	H^2_{cmean}	$r_{gx,gv6}$	Q	$Q_{/t}$	Δ Gain	Δ Gain/t	r_{Bg}
stVOL2	0.217	0.818	0.939	0.789	0.772	0.070	54.086	4.917	0.818
stVOL3	0.292	0.855	0.955	0.936	0.924	0.077	64.717	5.393	0.855
stVOL4	0.323	0.877	0.962	0.979	0.970	0.075	67.965	5.228	0.877
stVOL5	0.306	0.912	0.967	0.996	0.989	0.071	69.308	4.951	0.912
stVOL6	**0.382**	**0.960**	**0.980**	**1.000**	**1.000**	**0.067**	**70.065**	**4.671**	**0.960**
stDBH2	0.213	0.847	0.944	0.818	0.803	0.073	56.255	5.114	0.847
stDBH3	0.305	0.871	0.959	0.925	0.915	0.076	64.140	5.345	0.871
stDBH4	0.340	0.895	0.966	0.965	0.958	0.074	67.113	5.163	0.895
stDBH5	0.304	0.913	0.967	0.976	0.970	0.069	67.944	4.853	0.913
stDBH6	0.358	0.959	0.979	0.991	0.990	0.066	69.350	4.623	0.959
stHT1	0.195	0.783	0.927	0.564	0.549	0.055	38.456	3.846	0.783
stHT2	0.182	0.845	0.938	0.651	0.636	0.058	44.593	4.054	0.845
stHT3	0.256	0.881	0.956	0.813	0.803	0.067	56.237	4.686	0.881
stHT4	0.303	0.875	0.960	0.856	0.847	0.065	59.330	4.564	0.875
stHT5	0.229	0.864	0.950	0.860	0.847	0.060	59.325	4.237	0.864
stHT6	0.275	0.950	0.971	0.919	0.914	0.061	64.068	4.271	0.950

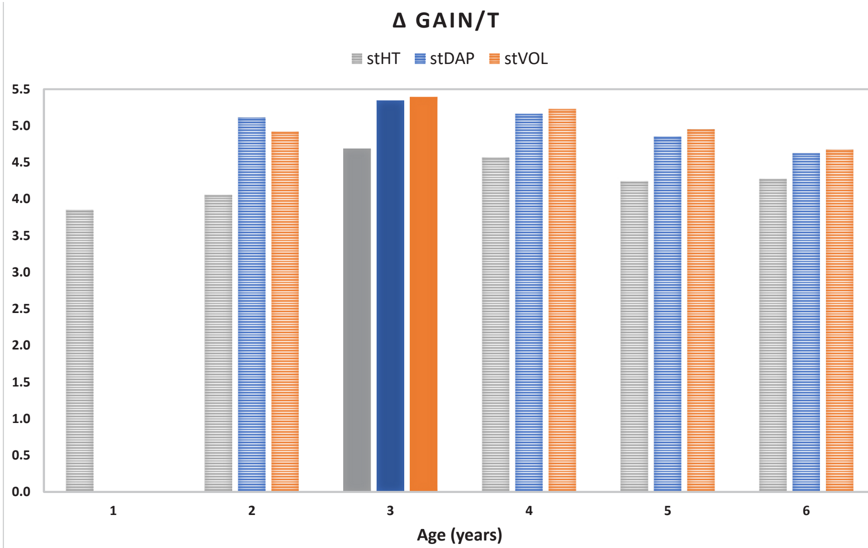


Figure 2. Percent genetic gain per unit time (selection age + 9 years) for different selection ages. Age 3 years (solid bars) is the optimum age for selection for growth.

Strategies for an Improvement Program with *E. benthamii* in Southern Brazil

Gisela Andrejow of WestRock recently completed her Ph.D. at the Federal University of Paraná. The full thesis can be obtained through the Federal University of Paraná library (www.portal.ufpr.br).

Introduction

Brazil is a major producer and exporter of forest-based products. Eucalypt plantations comprise 73% of the reforested area in Brazil, with plantings extending from the north to the south. WestRock Brazil is an integrated paper and packaging company located in the southern region of Brazil with one paper production unit and four corrugated cardboard conversion plants, and about 54,000 hectares of forests to meet its fiber demand. The main limitation to forestry in the southern region of Brazil is low temperatures. Tree breeders should identify cold-hardy species that also show rapid growth, high productivity, and good wood quality for diverse markets. The objectives of this study were to identify frost-resistant species of *Eucalyptus* for the cold regions in southern Brazil, and to analyze provenance-progeny tests to estimate genetic parameters that will help geneticists define breeding strategies.

Materials and Methods

We evaluated the adaptive potential of nine species of *Eucalyptus* for growth traits, survival and frost tolerance in species introduction studies. The purpose of this study is to select the best species for a tree breeding program. Two trials were established in the municipalities of Mafra and Três Barras in the state of Santa Catarina. Seeds for the species originated from natural populations in Australia and were from 129 open-pollinated families (Table 11). The experiments used a Randomized Complete Block design with four replications, where species were arranged in square plots of 16 plants with spacing of 2.0 x 3.0 m. Additionally, provenance and progeny tests of *E. benthamii* were established in three geographic areas; two in the municipalities of Mafra e Porto União in the North Plateau of Santa Catarina, and one in the municipality of São Mateus do Sul in southern Paraná. At each site, the experiment was established with randomized blocks, using 91 treatments (provenances and progenies), five replications, and five plants per plot. We evaluated frost damage at 1 year of age and individual tree volume (m^3/tree) at 3 years of age. Genetic parameters and genotype x environment interaction (GxE) were evaluated for individual-tree volume. We also estimated genetic gains for basic wood density, measuring the wood resistance using the Resistograph.

Results and discussion

In the species introduction studies, all species showed frost damage with percentage of trees affected ranging between 11.66% to 99.87%. The species that showed the highest frost tolerance on both sites was *E. macarthurii* (26% of the plants with no damage in Mafra and 82.92% in Três Barras), followed by *E. viminalis* and *E. benthamii*. However, survival at both sites was very high for all species tested, ranging from 100 to 88%, indicating that frost events did not strongly affect species survival in the first year. The average survival across species at age 5 years was 58% and 60% for Mafra and Três Barras, respectively. The most prominent species, with the highest survival rates in both locations, was *E. dorrigoensis*, followed by *E. saligna* and *E. benthamii*. Lower survival rates were observed for *E. badjensis*, *E. tereticornis* and *E. viminalis*, indicating their low adaptation to the frost prone environments (Table 11). Growth data at 3 years of age allow us to identify *E. benthamii* as the most productive species, mean DBH was 14.2 cm for Mafra and 14.7 cm for Três Barras, which is 15.3 and 20.8% above the study mean.

No frost damage was observed in the three provenance-progeny trials of *E. benthamii* during the first 3 years of evaluations, giving evidence of the adaptability of the species to cold, frost-prone environments. We calculated genetic parameters for both single-site and combined-site datasets. For single-site analysis, the estimated values for the family mean heritability (h^2_f) were moderate to high for Mafra and São Mateus do Sul (0.55 and 0.59, respectively) and low for Porto União (0.16). Genetic parameters obtained by combined estimations for volume and wood resistance at 3 years of age are presented in Table 12. For volume, we estimated the narrow-sense heritability to be 0.22 and the family mean heritability to be 0.64, which implies that there is genetic variability between the progenies and selection potential among the genotypes of *E. benthamii*. Interestingly, the magnitude of the genotype x environment interaction was very small indicating stability in the ranking for this trait. For the combined analysis, we were able to calculate the percentage of genetic gain. If we assume that selection is made across all sites, and that the best performing 184 individuals from 45 families are selected, the genetic gain for volume at age 3 is 42%. Genetic parameters for resistance (indirect, non-destructive estimation of basic wood density) also indicate that there is genetic variability between the progeny. We obtained high values for the narrow-sense heritabilities and very low levels of GxE. Those estimates were consistent with our findings for volume at 3 years, thus, we conclude that indirect evaluation of wood density using the Resistograph is a good method to estimate wood density in our breeding population. Finally, the results obtained here indicate the importance of genetic analysis in order to obtain practical results, define strategies, and guide decisions that will help develop genetic tree improvement programs for *E. benthamii*.

Table 11. Percent survival of various species at ages 1 and 5 years in trials on 2 sites.

Species	Fams	Mafra		Três Barras	
		Surv. 1 year	Surv. 5 years	Surv. 1 year	Surv. 5 years
E. amplifolia	5	98.75	66.25	100.00	77.81
E. badjensis	20	90.08	17.11	97.97	8.52
E. benthamii	20	95.23	76.64	97.50	77.42
E. dorrigoensis	14	95.87	80.69	99.67	89.06
E. macarthurii	28	93.00	62.33	94.59	51.95
E. nobilis	10	97.19	57.34	97.03	59.69
E. saligna	12	97.83	82.34	99.87	76.06
E. tereticornis	10	96.88	39.06	99.84	74.69
E. viminalis	10	89.74	42.63	88.13	28.59

Table 12. Genetic parameters for Volume and Resistance measured in this study.

Trait	h^2	h^2_f	r_{bg}
Volume	0.22	0.64	0.68
Resistance	0.51	0.85	0.89

Wood Properties of Eucalypt Species

Camcore has been studying eucalypts for over two decades and we have sent more than 500 genetic trials with tropical, subtropical and temperate *Eucalyptus* and *Corymbia* species to our members. This material adds diversity to our member's genetic bases and helps identify pure species or hybrids with commercial potential. Camcore's technical committee decided in 2016 to initiate a research project to evaluate wood of the species growing in our *Eucalyptus* and *Corymbia* trials that are 5 or more years old. The objectives are to evaluate the variation of wood properties among species, rank species based on desirable wood properties, and compare them against the commercial lots in the trials. Here we present results from studies located in Chile, South Africa and Uruguay.

Materials and Methods

During 2017, we sampled wood from two Camcore tests established in 2011 by Lumin, Uruguay, (97-11-04G2 and 97-11-07M3). In 2018, we measured four additional tests: two established in 2011 by Bioforest, Chile (92-21-01A and 97-21-07A3) and two in South Africa established by Merensky in 2012 (97-49-01J1 and 97-49-08J). We wanted to sample 30 trees per species, per site. However, due to mortality, small diameter or poor form, fewer trees were available for some species (Table 13). Also, for a few species, we sampled more than 30 trees, which indicates that several levels of improvement were present for some species , usually used as controls. Nine species were evaluated in Chile, 11 in Uruguay and 12 in South Africa. For each sampled tree, field measurements and wood samples were taken at breast height to evaluate three wood traits. We used the following sampling methods:

- Measurement of resistance in wood to penetration using a Resistograph. This value is genetically correlated with wood density.
- Estimation of Modulus of Elasticity (MOE) using the TreeSonic.
- NIR analysis of wood shavings collected with hand drills to predict percentages of lignin, glucose, xylose and S/(S+G).

We followed our standard field sampling strategy; a more detailed explanation of this protocol is given in the article "Pine Hybrid Testing: Results from 43 Trials" earlier in this report.

The Merensky research team members process wood cookies recently collected from a eucalyptus species trial.

For the statistical analysis, we built a generalized linear model (GLM) for each trait (resistance, MOE, and NIR-predicted variables) and evaluated the significance of the model. If variation between species was observed, comparisons of the species LSMEANS were made. We also created scatter-pie chart plots (Figures 3 to 5), in which each species (or hybrid) is located on a Cartesian grid of resistance (X-axis) and Modulus of Elasticity (Y-Axis). Additionally, each point is plotted as a pie chart that represents the proportions of Guaiacyl (Lignin_G), and Syringyl lignin (Lignin_S). The pie chart diameter is related to the % of glucose observed for each species. NIR prediction of wood traits, statistical analyses and creating graphs were conducted in the R environment.

Results and Discussion

For all countries and for all traits, the variation associated with species (or hybrids) was significant (P-values were less than 0.001). LSMEANS are presented in Table 13. For each country and for each trait, we used three colors to differentiate species rankings: dark green for the top third, light green for the middle third and yellow for the bottom third. For example, for glucose percentage in Chile, the best species are *E. globulus*, *E. globulus* var. *bicostata*, and *E. macarthurii*. The species in the middle third are *E. benthamii*, *E. dunnii* and *E. smithii*, whereas *E. badjensis*, *E. nitens* and *E. saligna* are in the bottom third.

Wood chemical traits are very important to many Camcore members because they affect the amount of chemicals required in the pulping process, their yield, and the amount of byproduct energy produced. By inspecting Table 13, we can identify interesting species for each country.

- In Chile, species like *E. globulus*, *E. globulus* var. *bicostata*, and *E. smithii* are always ranked in the top and middle thirds for all traits.
- In South Africa, interesting wood properties are observed for *C. citriodora* var. *variegata*, *C. henryi*, *E. drepanophylla* and *E. moluccana*; while *E. grandis*, *E. grandis* x *E. camaldulensis*, and *E. grandis* x *E. urophylla* presented intermediate values for all traits except resistance.
- In Uruguay, *C. maculata* and *C. citriodora* are always ranked in the top and middle thirds for all traits. *E. smithii*, *E. dunnii* and *E. saligna* ranked between the top and middle for all traits except glucose for *E. smithii*, and resistance for *E. dunnii* and *E. saligna*.

Table 13. Trial details and summary of results.

Country	Species	Trees	Glucose (%)	Xylose (%)	Lignin (%)	S_pct	MOE (Gpa)	Resis-tance
Chile Bioforest *(Los Alamos, planted 2011)*	*E. badjensis*	30	48.6	14.2	23.1	77.0	12.2	1583.9
	E. benthamii	60	49.5	11.8	26.0	74.3	11.5	1274.3
	E. dunni	18	49.8	14.5	23.1	76.1	10.9	1308.7
	E. globulus	60	50.3	14.2	20.6	81.5	15.0	1616.1
	E. globulus_bicostata	29	50.4	14.3	22.2	77.6	11.6	1700.4
	E. macarthurii	29	50.4	12.1	24.7	74.9	12.3	1500.4
	E. nitens	60	47.3	15.4	22.4	76.1	12.4	1524.8
	E. saligna	29	49.0	13.3	25.8	71.8	10.4	1321.5
	E. smithii	30	49.2	14.0	22.0	78.4	13.4	1567.0
South Africa Merensky *(Prinsloorust and Christinasrust, planted 2012)*	*C. citriodora_variegata*	30	49.7	14.7	20.9	79.1	14.9	1889.6
	C. henryi	15	51.2	12.7	21.7	77.6	15.0	1773.9
	E. benthamii	15	47.1	11.5	26.3	77.8	12.2	1412.0
	E. drepanophylla	15	49.5	13.8	23.5	77.1	17.1	2697.7
	E. grandis	90	49.9	11.5	24.4	74.8	14.5	1409.5
	E. grandis x E. camaldulensis	30	49.1	11.8	24.9	76.4	15.3	1479.3
	E. grandis x E. urophylla	120	49.4	11.5	25.4	75.4	14.9	1506.4
	E. longirostrata	45	46.8	12.1	25.4	80.5	16.1	1840.8
	E. major	30	49.1	10.8	27.4	75.1	14.7	1923.3
	E. moluccana	30	50.0	13.4	20.4	79.7	15.6	2612.1
	E. pellita	30	48.0	8.9	28.9	70.1	17.1	1637.7
	E. urophylla	30	48.6	11.7	26.1	73.9	14.0	1590.5
Uruguay Lumin *(Quebrachal 2, planted 2011)*	*C. citriodora*	24	48.9	14.7	22.0	76.4	14.5	1871.6
	C. maculata	25	48.7	15.3	22.6	76.2	13.5	1827.4
	E. badjensis	23	47.2	14.2	23.7	77.5	10.4	1576.6
	E. benthamii	50	47.6	11.6	28.0	74.9	11.0	1389.3
	E. dunnii	25	49.5	14.6	23.8	78.3	11.6	1355.7
	E. grandis	64	49.2	11.6	26.2	73.3	12.3	1324.3
	E. grandis x E. camaldulensis	20	49.6	11.2	27.9	73.8	11.0	1419.8
	E. grandis x E. urophylla	20	48.1	12.8	27.8	72.5	11.6	1359.3
	E. macarthurii	25	47.8	12.8	25.4	78.3	10.1	1491.1
	E. saligna	25	49.1	11.8	25.8	75.5	11.2	1248.2
	E. smithii	22	47.2	13.8	23.5	80.4	12.1	1594.9

Figure 3. Scatter-pie chart for Chile.

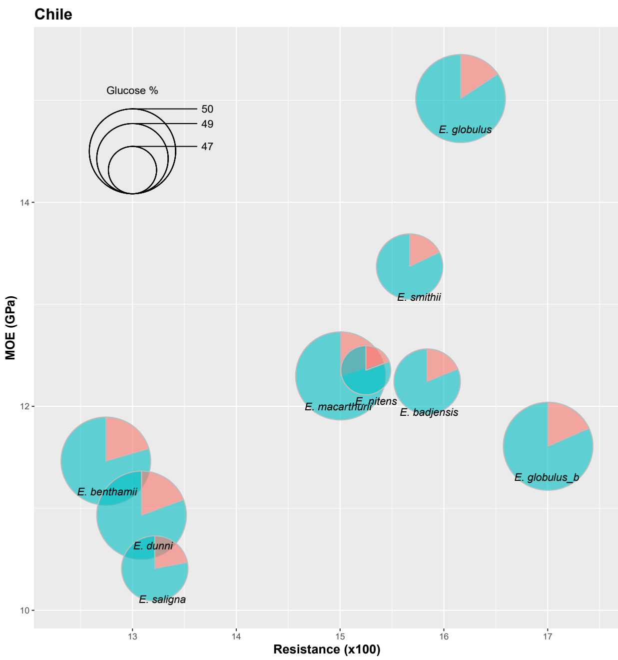


Figure 4. Scatter-pie chart for Uruguay.

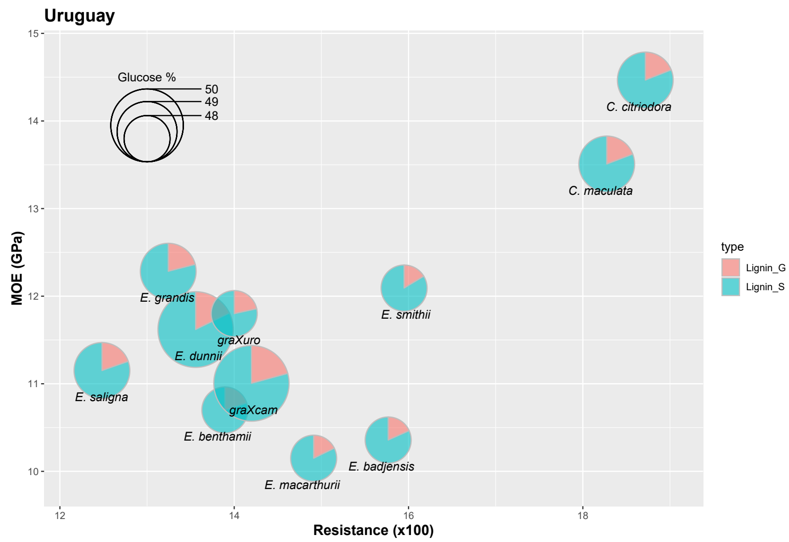
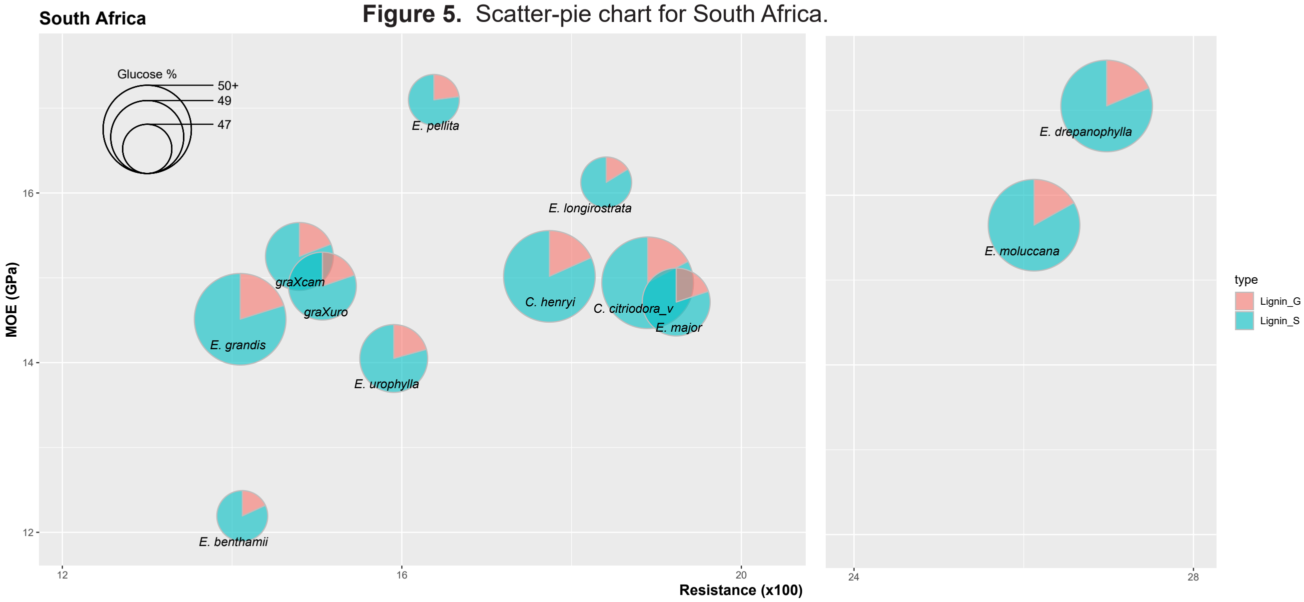


Figure 5. Scatter-pie chart for South Africa.



Graphs of the wood traits in the scatter-pie chart plots also allow us to identify desirable species in terms of their physical and chemical wood properties. In Chile, the species that exhibit the highest % glucose are *E. globulus*, *E. benthamii*, and *E. dunnii*, while *E. globulus* is the species with the highest values of density and MOE (Figure 3). In Uruguay, the two *Corymbia* species have the highest values for MOE and resistance but intermediate Glucose%. *E. dunnii* and *E. grandis* x *E. camaldulensis* have the best Glucose% with intermediate to low values of resistance and MOE (Figure 4). Finally, In South Africa, *E. drepanophylla* and *E. moluccana* have high MOE, resistance and Glucose%. *C. citriodora* var. *variegata*, *C. henryi*, and *E. grandis* also have very good Glucose%, but their MOE and resistance are intermediate (Figure 5).

With the addition of these four tests in 2018, we have a stronger database. As a group, we perhaps should expand our testing of *Corymbia* species, and use this descriptive analysis to identify the potential that some species can bring to breeding programs in pure or hybrid form. During the next few years, we will sample more sites including, for 2019, studies in Colombia, South Africa and Uruguay.

Myrtle Rust Screening Update

Introduction

As Camcore's *Eucalyptus* program has grown over the past decade, we have been working on a number of projects to better understand various threatening pests and pathogens. Past and current projects have focused on *Thaumastocoris peregrinus*, *Leptocybe invasa*, *Austropuccinia psidii*, *Botryosphaeria* sp., *Ceratocystis* sp., *Chrysoporthe* sp., *Teratosphaeria gauchesis*, and *T. destructans.* This article reports on one of these projects, *Eucalyptus* species-level screening for susceptibility to the myrtle rust pathogen *A. psidii*. We first reported on this screening study in the 2017 Camcore Annual Report with a focus on screening results from Uruguay where we had collaborated with INIA and Weyerhaeuser (now Lumin). Those results are presented again here, along with 2018 results from a companion study conducted in Colombia in collaboration with Carlos Rodas and the Forest Health Protection Laboratory at Smurfit Kappa.

Methods

The two screening studies were conducted in different countries by different lab groups and with slightly different experimental designs. However, they used a standardized method for inoculating and evaluating myrtle rust susceptibility. Both utilized aqueous suspensions of *A. psidii* urediniospores isolated from *Syzygium jambos* as the source of inoculum, and a 48-hour dark incubation followed by 12:12 daily photoperiod maintained for 20 days as symptoms developed. At the end of both experiments, seedlings were evaluated and scored for rust symptom development according to the scale developed by Junghans et al. 2003 (Fitopatologia Brasileria 28:184-188): S0-I = immune resistance, S0-HR = hypersensitive resistance, S1 = development of small-sized disease pustules, S2 = development of medium-sized pustules, and S3 = development of large-sized pustules. Both studies included 12 *Eucalyptus* species, one resistant control, and one susceptible control. *Eucalyptus dorrigoensis* was included in the Uruguay study but not the Colombia study, and *E. smithii* was included in the Colombia study but not the Uruguay study. The resistant and susceptible controls used were commercial clones of known myrtle rust susceptibility and were provided by Lumin and Smurfit Kappa.

Results and Discussion

The percentage of seedlings of each species scored in each rust severity class in both screening experiments are presented in Figure 6. Our analysis of this data is still preliminary, but there are some interesting trends worthy of comment. *Eucalyptus brassiana*, *E. camaldulensis*, and *E. longirostrata* all performed very well in both screening studies, with 60 to 80 percent of tested seedlings scored as resistant (S0-I and S0-HR rust severity classes). *Eucalyptus dunnii* and *E. grandis* performed relatively poorly in both studies, although their performance in Colombia was slightly better where 50 percent of seedlings of both species scored as susceptible (S1, S2, and S3 rust severity classes) while in Uruguay 60 (*E. grandis*) and 75 (*E. dunnii*) percent scored as susceptible.

These results also demonstrate the importance of producing test seedlings under climatic conditions to which they are best adapted. For

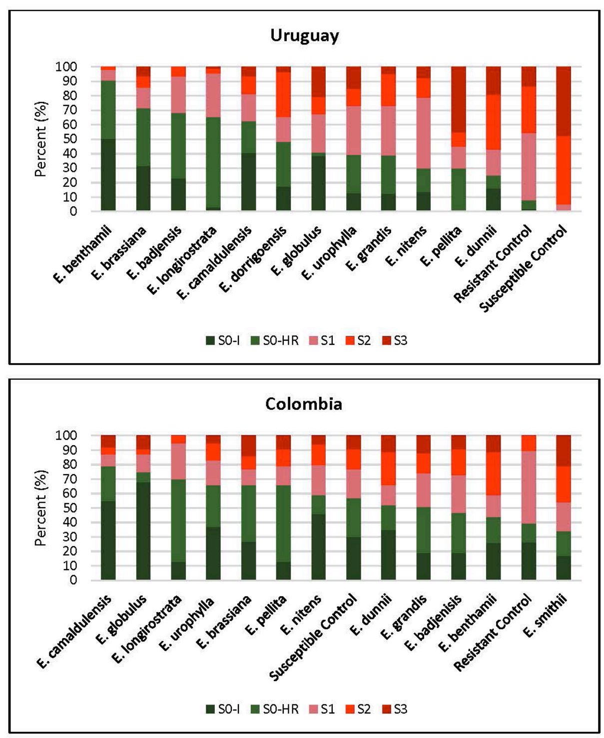


Figure 6. Percentage of seedlings in each rust severity class in the *Austropuccinia psidii* screening studies in Uruguay (top) and Colombia (bottom).

example, the more temperate species *E. badjensis* and *E. benthamii* performed better (70 to 90 percent of seedlings scored as resistant) in the more temperate climate of Uruguay compared to tropical Colombia (approximately 55% of seedlings scored as susceptible). Conversely, the more tropical species *E. pellita* and *E. urophylla* performed better (65 percent of seedlings scored as resistant) in tropical Colombia compared to more temperate Uruguay (60 to 70 percent of seedlings scored as susceptible).

The data also indicate that we need to take more care in selecting appropriate genotypes to serve as resistant and susceptible controls. In the Uruguay trial, the susceptible control performed as expected, ranking as the most susceptible genotype. However, in Colombia the susceptible control actually ranked as moderately resistant. In neither study did the resistant controls perform as expected, with both ranking among the most susceptible genotypes.

As mentioned above, this report is preliminary and not intended to present a complete account of these screening trials. We are currently in the processing of finalizing the data analysis and preparing a journal article for publication. When available this will be distributed to Camcore members for consideration.

Eucalyptus pellita Pulping Properties

Eucalyptus pellita is a species native to Northern Queensland and Southern New Guinea, tested in many countries, and planted commercially as a pure species on a large scale in Indonesia. Juan Carlos Bastidas with Smurfit Kappa Colombia (and a former graduate student with Camcore at NC State University) conducted an *E. pellita* pulping study and presented his results at the Camcore annual meeting.

As a plantation species, *E. pellita* has several advantages and disadvantages for the pulp and paper industry. Some of the well-known advantages are high productivity, high wood density, good resistance to diseases, easy hybridization, site adaptability, and high rooting capacity. The better-known disadvantages are high lignin content, low cellulose yield, high pulping shives, and difficult-to-treat pulp.

The objective of Bastidas' study was to compare the bleachable grade kraft pulping and papermaking properties of *E. pellita* wood from the Villanueva plantation to *E. grandis* wood taken from SKC's plantations. Villanueva is a municipality in the Department of Casanare, Colombia, where some small plantings of *E. pellita* grow in the piedmont at 300 meters elevation and 4º 38' North latitude. Forty-six logs of 9-year-old trees were provided by Refocosta for this study. All the tests were run in SKC's laboratory following international test standards and using suitable equipment. An M/K 2000-gram digester was used for cooking the chips with an H factor of 1000, a cooking temperature of 170ºC, a 4:1 liquid to wood ratio, and a 20 to 22% active alkali charge.

Results showed important differences between the two species in all the properties measured in the study. The mean wood density of *E. pellita* was 688 kg/m³ while the *E. grandis* was 450 kg/m³, a 53% difference. Percentage of extractives in the wood of *E. pellita* was 5.1% vs. 1.1% in *E. grandis*, five times more. In the pulping study, the *E. pellita* required 25% more chemical charge (greater chemical consumption) than *E. grandis* at different Kappa numbers leaving less residual alkali available in the process. Regarding the pulping properties, pulp yield was 6% lower for *E. pellita* than for *E. grandis* for Kappa numbers from approximately 16 to 45, a huge difference with significant effects on pulp productivity. The other two pulping properties, brightness and viscosity, were always higher for *E. grandis* than for *E. pellita* at several Kappa numbers. Finally, for the handsheet properties, *E. pellita* required more refining energy than *E. grandis,* and had lower sheet density at various Canadian Standard Freeness (CSF) values. *Eucalyptus pellita* had 25% less burst strength, 35% less tensile strength and 38% less tear strength than *E. grandis* at 400 CSF.

The specific results of this study are limited to only one provenance of *E. pellita* in Colombia, but are probably representative of the general differences between the two species.

Seed Maturation and Optimal Container Size for *P. maximinoi* Seedlings and Cuttings

Fabricio Biernaski recently completed his Ph.D. at the Federal University of Paraná. Some of his important results are summarized here. The full thesis can be obtained through the Federal University of Paraná library (www.portal.ufpr.br). The container study is published at http://www.conhecer.org.br/enciclop/2017b/agrar/influencia%20do%20metodo.pdf, and the cone study has been submitted to "Revista Scientia Forestalis".

Introduction

Pinus maximinoi is a subtropical pine with great potential as a commercial plantation species in the southern hemisphere. It has shown outstanding growth in southern Brazil, in the Andes region of Colombia, and in southern and eastern Africa. In addition, *P. maximinoi* has excellent wood quality, with a uniform density profile, excellent timber strength, and relatively low lignin content compared to other commercial species like *P. taeda* and *P. patula*. In Brazil, Klabin owns 226,000 ha of plantations of which 60% are pines. Current pine plantation establishment at Klabin is about 90% *P. taeda* and 10% *P. maximinoi*. *Pinus maximinoi* is highly graft incompatible, and this can make it difficult to establish clonal seed orchards, resulting in limitations on the amount of commercial seed available worldwide. Vegetative propagation of *P. maximinoi* is relatively easy, so seedlings can be multiplied with cuttings. Commercial production in nurseries, whether by seedlings or by cuttings, is typically done with containers. However, the extremely rapid growth of the plants has led to problems with root binding in the standard container size used for *P. taeda* (around 55 cm^3).

Cone Collection

The objective of this study was to determine the optimal collection time of *P. maximinoi* cones in order to maximize seed germination. This is important to maximize the effective seed yield from seed orchards. This study was done in a clonal seed orchard of *P. maximinoi* established in Telêmaco Borba, Paraná, Brazil in 1998. Cones were collected weekly from late October to late December 2014 from 4 clones and 3 ramets/clone. From each ramet, 5 cones were collected, and the specific gravity of the cones was measured using water displacement. Seed was extracted, and seed germination under a 16-hour photoperiod and 25°C environment was assessed.

There was a high percentage of empty seed (54%), which was nearly constant across all collection dates. Empty seeds in pines represent the abortion of embryos after fertilization, and could be due to self-fertilization. The clonal seed orchard is relatively small with wide spacing (117 trees at approximately 22 x 22 m); perhaps a bigger orchard and/or more dense spacing could produce a more dense pollen cloud and reduce the percentage of empty seed.

Considering just the full seeds, seed germination increased steadily throughout the experiment, and began to plateau at around 90% in the beginning of December (Figure 7). Not all germinated seeds produced plants, but plant production followed a pattern similar to seed germination, with a plateau in early December around a maximum of 65 to 70% (Figure 7). A very useful practical result of this study is that the optimal cone collection time corresponded to a cone specific gravity = 1.00. This means that an orchard manager can determine the proper time to collect *P. maximinoi* cones by checking whether they float in a bucket of water (which has specific gravity = 1.00).

Optimal Container Type and Size

The objective of this study was to determine optimal container type and size to produce healthy *P. maximinoi* plants for commercial plantations This study examined root development of cuttings and seedlings in three different sizes of containers (55, 95, and 115 cm^3). In addition, each size was tested with and without air-pruning slits in the sides of the container. Finally, a paper pot (55 cm^3) was tested for both seedlings and cuttings, for a total of 14 treatments. Both seedlings and cuttings were grown in the nursery for 250 days total (60 days in the greenhouse, 60 days in the shade house, and 130 days in the growth area) before planting in a field trial. The field test was planted in January 2015 in Telêmaco Borba, PR, with 4 replications, 14 treatments, and 6-x-6-tree block plots. At age 34 months, DBH and height were measured, and at 35

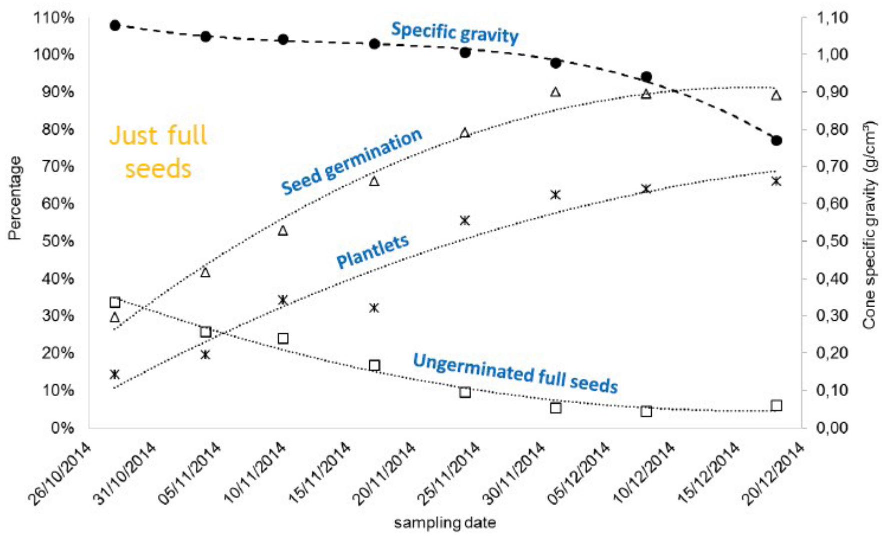
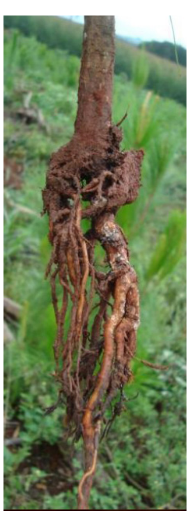


Figure 7. Seed germination, and plant production, and cone specific gravity for *P. maximinoi* cones collected at different dates in a seed orchard in Paraná, Brazil.

months, 3 trees per treatment were excavated for evaluation of root development

The largest container size (115 cm³) and the paper pot (55 cm³) treatments produced around 10% more volume growth at 34 months than the conventional 55 cm³ container size. In terms of root development, there were also important differences observed among container sizes. For normal plastic containers, larger sizes were generally associated with improved root direction, distribution and taproot formation (Figure 8). Interestingly, the paper pot containers, which were only 55 cm³, produced the best results for root direction and distribution. Typically, tree fall and wind throw associated with poor root formation begins to occur right around this age (35 months), so the patterns of root formation seen here will begin to have impacts on survival and stocking from age 3 years onward. Nursery managers should consider either large containers or paper pots for *P. maximinoi* commercial production.



A malformed root ball in a young *P. maximinoi* due to the use of small seedling containers.

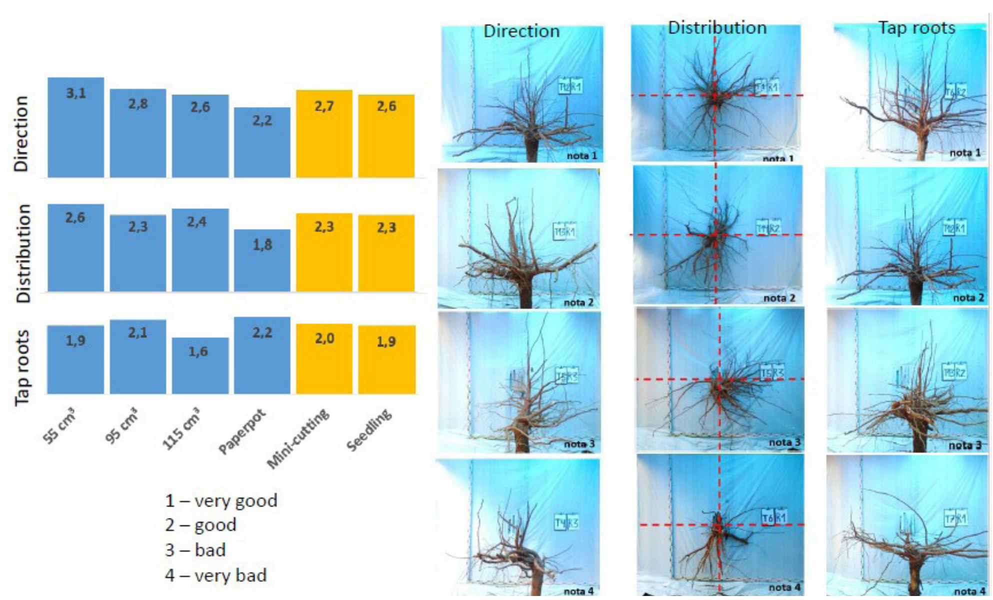


Figure 8. Root development (direction, distribution, and taproot) observed in 35-month-old *P. maximinoi* plantlets. Plantlets (cuttings and seedlings) were grown in the nursery in plastic containers of different sizes (55, 95, and 115 cm³), and in 55 cm³ paper pots. Traits were scored on a four-point scale, with 1 = very good and 4 = very poor.

Frost Tolerance and Artificial Frost-Screening Results for *Pinus oocarpa* and *P. patula x P. tecunumanii hybrids*

Lizette de Waal recently completed her M.Sc. at the University of Pretoria. The full thesis can be obtained through the University of Pretoria. The P. patula x P. tecunumanii manuscript is in preparation, and the P. oocarpa results have been published in Southern Forests.

Introduction

Pinus patula has been the primary commercial pine species planted in South Africa for over 100 years, but recently there has been growing interest in the potential of *P. patula* hybrids. This interest was initially driven by the rise in *Fusarium circinatum* that produces pitch canker disease and can lead to significant mortality of *P. patula* in both the nursery and the field. Two possible hybrids are *P. patula* x *P. tecunumanii* and *P. patula* x *P. oocarpa*. Both *P. tecunumanii* and *P. oocarpa* are highly tolerant to *F. circinatum*, and bring fast growth and some advantageous wood properties to the hybrid. However, both species are frost susceptible, so methods to identify frost tolerance in potential hybrid parents of both species is of great interest.

P. oocarpa

This study examined multiple provenances and families and three different approaches to assess frost tolerance: 1) scoring survival and frost damage in field plantings, 2) artificially freezing needles and assessing damage with the electrolyte leakage/conductivity method (EC), and 3) artificially freezing whole plants and assessing frost damage. Large differences among provenances were found (Figure 9). A key result of this study was that the EC method was in good agreement with the field assessment method for ranking different taxa and *P. oocarpa* provenances for frost susceptibility. In addition, as might be expected, higher latitude sources of *P. oocarpa* had less frost damage in the field, and less damage in artificial freezing of whole plants and of needles as measured with EC.

P. patula x P. tecunumanii

This study examined a large set of hybrid families of *P. patula* x *P. tecunumanii* (both low and high elevation), and compared two approaches of frost tolerance screening. The first was the same artificial freezing of needles and EC measurement and the second was "pseudo-field testing" for frost tolerance. The latter approach involved taking trays of seedlings (5 reps, 20 trees/family/rep) and exposing them to natural frost conditions at two field sites. The pseudo-field testing appeared to work well, and significant differences among hybrid families were found for frost damage score. There was a moderate correlation between the field frost tolerance and the artificial freezing EC measurements.

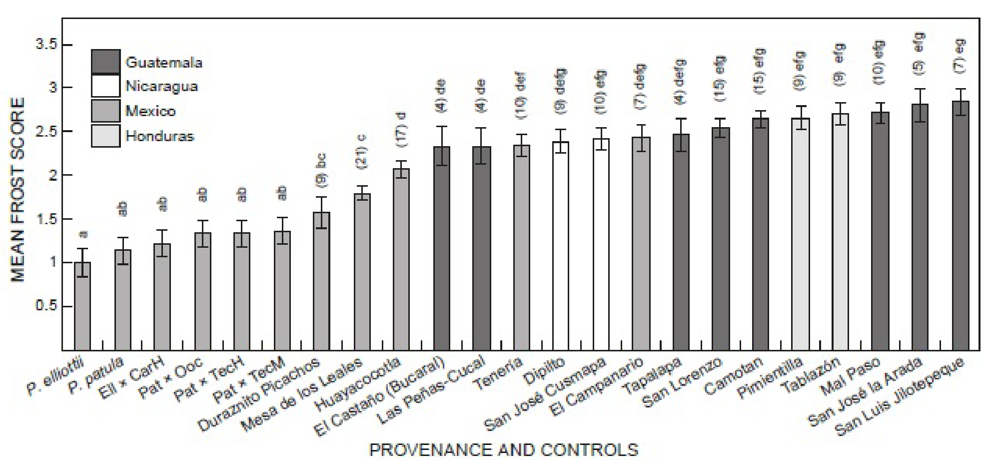
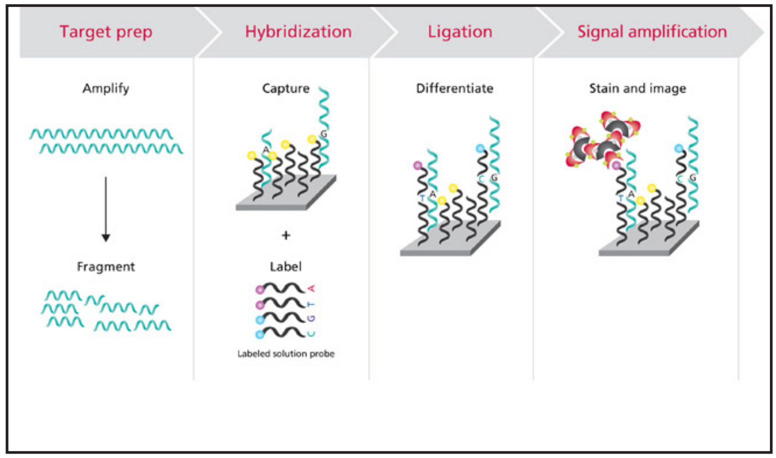


Figure 9. Mean frost score for *P. oocarpa* provenances and commercial controls in the artificial freezing study. Numbers in parentheses above the bars indicate the number of families representing each provenance. Treatments that do not share a common letter above the bars are significantly ($p < 0.05$) different. Error bars represent the standard error of the mean.

Tropical Pine SNP Chip: Update

The objective of this project is to discover, annotate and validate single nucleotide polymorphisms (SNPs) in tropical pines from millions of potential loci using next-generation sequencing. This study is part of the Conifer SNP Consortium (CSC) housed at NC State University (NCSU). Currently, SNP chips are being designed for three projects: tropical pines, led by Camcore at NCSU and Forest Molecular Genetics (FMG) at the University of Pretoria, *Pinus taeda,* led by the Tree Improvement Program at NCSU, and *P. radiata,* led by Scion in New Zealand. Members of the CSC will have access to and preferential pricing for any of the SNP chips that are created by the three groups. The genotyping provider for the consortium will be Thermo-Fisher Scientific (TF), a company based in California with offices around the world. The steps to develop the tropical pines SNP chip are described below.



Schematic of SNP chip development by TFS.
www.affymetrix.com/products_services/axiom_custom/axiom_mydesign.affx

Our group will provide DNA sequence data for high-confidence SNPs to TF. Thermo-Fisher will use these data to design and produce a high-density SNP screening chip with about 420,000 SNPs. Those 420,000 SNPs will be used to genotype 480 selected trees representing the diversity of the tropical pine species. With this data, we will select the most informative 50,000 SNPs to create an operational SNP chip, which will have different practical purposes such as: DNA fingerprinting, species discrimination, population genetics and/or genomic selection. For tropical pines, we will use the same population as the Genome Atlas project housed by FMG at the University of Pretoria. This population is comprised mainly of unimproved Camcore material provided by our members in South Africa. A Camcore graduate student at NCSU and a Post-doctoral fellow at FMG are currently working with next-generation sequencing information generated by exome-capture and RNA-seq to identify the SNP list that will be sent to TF.

The 50,000 SNP chip will be available exclusively to the CSC members at a genotyping cost of $20 per tree. Non-members will pay $44 per tree. The ideal commercial SNP chip for tropical pines should have about 5,000 SNPs unique to each of the following species: *P. patula*, *P. maximinoi*, *P. tecunumanii*, *P. greggii*, *P. caribaea* and *P. oocarpa* and 20,000 SNPs shared among all the species.

The development of the 50,000 SNP chip and the low genotyping cost of $20 per tree offered by TF, requires an upfront commitment to 1) pay $45,000 for the screening array and 2) commit as a group to genotyping 8,064 trees at a price of $20 per tree over a three-year period. Total cost of the project = $45,000 + $161,280 = $ 206,280. Camcore and FMG will cover the $45,000 of the screening array from member contributions and grant funding; these funds have already been allocated. The member companies will commit to genotyping the 8,064 samples over the next three years. This obligation to future genotyping is a requirement for the tropical SNP chip project to be completed; without this commitment, there will be no chip development, and definitely no genotyping at a cost of $20 per tree. To meet this obligation, if we assume that five Camcore members commit to this project; each member will have to submit 1,613 samples over three years or 538 samples per year, equivalent to $10,760 dollars per year. If more companies join the project, the cost per member will be lower.

Increasing the Robustness of the Global Eucalypt NIR Model

When someone hears the word "robust", ones initial thought might be of a flavorful coffee. But "robust" has a statistical meaning as well. A "robust statistic" is resistant to errors produced by deviations from theoretical assumptions, e.g., the normality of underlying distributions. This means that if the assumptions are only approximately met, the robust estimator will still have a reasonable efficiency and an acceptably small bias. If we expand this idea to a statistical prediction model, a "robust model" might be one that will give good predictions even for samples that might be somewhat different than the population of samples that was used to calibrate the model.

Over the past several years, Camcore has developed a global NIR model to predict *Eucalyptus* wood chemistry (see the 2017 Annual Report, and Hodge et al. 2018, JNIRS 26:117-132). The model was calibrated using samples from five species (*E. urophylla*, *E. dunnii*, *E. grandis*, *E. globulus* and *E. nitens*), and for each species set, wood samples were taken from different countries and multiple sites. We call the final multiple-species multiple-site model a global model because we believe that it will be useful to predict wood chemistry for wood samples of any eucalypt species from anywhere in the world. In other words, we believe that this model is already a robust model.

As we finalized the global model, we also investigated its robustness by using three sets of wood samples (e.g., *E. urophylla*, *E. dunnii*, and a mix of *E. globulus* and *E. nitens*) to calibrate the model, and use that model to make predictions on the fourth species set (e.g., *E. grandis*). The results indicated that for most scenarios, the quality of the "extrapolation" predictions for the new species would range from excellent to adequate (where adequate means useful for ranking genotypes in a breeding program). Furthermore, the results also indicated that including as few as 10 samples of a "new" species in the calibration dataset makes a significant improvement in the accuracy of predictions for the remaining "new" species samples.

So if we wish to study the wood chemistry of *E. benthamii*, we could use the current model (based on urophylla + dunnii + globulus + nitens + grandis) to predict *E. benthamii*, and we would be fairly confident in our results. But we would be even more confident in the results if we could expand the calibration dataset with wetlab data on 10 to 15 *E. benthamii* samples. In other words, we want to make our global model even more robust, and we began this work in 2018.

Wood samples from a number of new species were provided by Mondi Forests and were received in the fall of 2018: *E. badjensis*, *E. saligna*, *E. macarthurii*, *E. smithii*, and *E. dorrigoensis*. In addition, we received samples from four species of *Corymbia*: *C. henryii*, *C. citriodora*, *C. maculata*, and *C. torelliana*. All samples were prepared according to normal Camcore protocols and NIR scans were taken in November of 2018. From each species, a set of 10 samples will be selected for wetlab analysis based on principal component analysis (PCA) of spectra, and on pulp yield and chemical predictions from the current global NIR models (Table14). We expect to receive wetlab data sometime in early 2019, and will incorporate the new data into the global calibrations, making our already good global model even more robust.

Table 14. Species samples available for expansion of the Camcore global eucalypt NIR model.

Species	Scanned *(actual)*	Wetlab *(target)*
E. badjensis	96	10
E. benthamii	114	10
E. dorrigoensis	150	10
E. macarthurii	133	10
E. saligna	137	10
E. smithii	10	2
C. citriodora	174	10
C. henryi	131	10
C. maculata	180	10
C. torelliana	142	10
10 species	**1267**	**92**

2018 Seed Collections in Central America

This year, Elmer Gutiérrez, field coordinator of Camcore in Guatemala, and tree climber Josué Cotzojay made seed collections of three pine species and *Tectona grandis* in Guatemala and two pine species in Honduras. *Pinus tecunumanii* was collected in two natural populations, one in Guatemala and one in Honduras. *Pinus maximinoi* was collected in San Jerónimo and Cobán in Guatemala, while *P. caribaea* var. *hondurensis* was collected in Limón, Honduras and *P. oocarpa* in El Castaño, Guatemala. The seeds of *Tectona grandis* were collected from a progeny trial established with Grupo DeGuate in Retalhulelu, Guatemala (Table 15).

Tree conservation continues to be one of Camcore's main objectives. Establishment of conservation banks and provenance-progeny trials by our members is our main method to protect genetic diversity of tree populations. New members acquire material with a broad genetic base to use in plant genetic trials containing different selections from the natural forest.

The conservation status of natural pine populations is updated during the seed collections based on recent changes experienced in land use and stress factors from human activities and other agents. Forest fires, pest outbreaks, agriculture expansion, resin extraction and illegal logging are some of the more common factors that reduce natural populations in Central America. Genetic material conserved by Camcore is available to honorary members interested in the establishment of 2nd generation trials with seeds descended from trees originally collected in their own country.

Josué Cotzojay of Camcore collecting cones of *Pinus oocarpa* in El Castaño, Guatemala.

This year, we collected seeds of *Tectona grandis* in a rogued progeny trial, where the three best trees per family plot had been left (see *Tectona grandis* in Camcore article in this report). We will distribute the seeds to our members in West Africa, Indonesia, Kenya and Mexico.

Table 15. Summary of seed collections completed in Central America in 2018.

Country	Species	Provenance	Conservation Status	Latitude	Longitude	Trees
Guatemala	*P. tecunumanii*	San Jerónimo	Critically endangered	15º 03' N	90º 18' W	18
Guatemala	*P. maximinoi*	San Jerónimo	Critically endangered	15º 03' N	90º 18' W	5
Guatemala	*P. maximinoi*	Cobán	Critically endangered	15º 22' N	90º 23' W	15
Guatemala	*P. oocarpa*	El Castaño	Vulnerable	15º 01' N	90º 23' W	20
Guatemala	*Tectona grandis*	La Máquina	Progeny trial	14º 20' N	91º 37' W	277
Honduras	*P. tecunumanii*	Villa Santa	Vulnerable	14º 12' N	86º 17' W	18
Honduras	*P. caribaea*	Limón	Endangered	15º 51' N	85º 23' W	3

Expanding the Camcore Eucalypt Portfolio

Camcore has a long history with pine species from Central America and Mexico; indeed, the need to conserve and test those genetic resources was the driving force behind the founding of the program. However, in response to the needs and interests of our industry partners, over the last 20 years we have worked more and more with eucalypt species. Our first eucalypt seed collections were made of *E. urophylla* in Indonesia from 1997 to 2004. Our next major collections were of *E. pellita* from Papua, Indonesia in 2009, another tropical species, and *E. dorrigoensis*, a cool temperate species from New South Wales, Australia. Over the past nine years, we have continued to add species to the Camcore portfolio, with a goal of having at least a small base population of families of most of the commercially important eucalypts. Today we have family-level collections from 15 important eucalypt species (Table 16). Most of these collections are unimproved families collected from the native range, but we do have improved genetic material of some species. For example, in 2017, several long-term Camcore members (Smurfit Kappa Colombia, and Mondi Forests, Sappi Forests, and SAFCOL in South Africa) donated 130 improved families of *E. grandis* to the Camcore program (see 2017 Annual Report). We also have improved *E. globulus* from Colombia, and improved *E. urophylla* selected from the Camcore provenance-progeny tests.

Camcore members have also been working diligently on the development of eucalypt hybrids. A group of members has recently completed the initial phase of a collaborative hybrid breeding project, and clonal field trials of 7 different eucalypt hybrids will be going into the field in 2019 and 2020 (see article "Eucalypt Hybrid Project: Update" in this report). Our second phase of hybrid breeding involving almost all eucalypt-growing members is now underway. All of us are very excited about the possibility of combining the best traits of two or more species into new hybrids that may be successful in the specific environments where we operate.

At the 2017 Annual Meeting in Sweden, the Technical Committee and Advisory Board recommended that we expand our eucalypt portfolio. Our members face almost every possible environmental challenge, and so as a group, we have interest in drought tolerance, cold and frost tolerance, extreme tropical environments (high temperature, high humidity), extreme pH soils (pH < 3.5 or > 8.0), high-salt soils, and of course, an array of disease threats. Since there are more than 700 species of eucalypts, we needed to winnow the list down to a manageable set from which we could identiry priorities. To help us with this, we contracted Jakob Butler of the University of Tasmania to prepare a literature

Table 16. Camcore's current eucalypt genetic resources of species with family-level collections. Bold indicates a species among the "Big Nine" with excellent commercial value demonstrated worldwide.

Species	Subgenus	*Section*	*Provs*	Fams
C. citriodora	*Corymbia*	*Maculatae*	1	30
C. maculata	*Corymbia*	*Maculatae*	1	30
C. torelliana	*Corymbia*	*Septentrionales*	2	32
E. brassiana	*Symphomyrtus*	*Exsertaria*	6	25
E. camaldulensis	***Symphomyrtus***	***Exsertaria***	**3**	**30**
E. grandis	***Symphomyrtus***	***Latoangulatae***	**13**	**168**
E. longirostrata	*Symphomyrtus*	*Latoangulatae*	4	45
E. pellita	***Symphomyrtus***	***Latoangulatae***	**6**	**99**
E. urophylla	***Symphomyrtus***	***Latoangulatae***	**62**	**1196**
E. badjensis	*Symphomyrtus*	*Maidenaria*	2	30
E. benthamii	*Symphomyrtus*	*Maidenaria*	3	36
E. dorrigoensis	*Symphomyrtus*	*Maidenaria*	5	34
E. dunnii	***Symphomyrtus***	***Maidenaria***	**2**	**36**
E. globulus	***Symphomyrtus***	***Maidenaria***	**9**	**175**
E. nitens	***Symphomyrtus***	***Maidenaria***	**5**	**40**

review. Jakob had recently completed his Ph.D. with Professor Brad Potts, one of the world's foremost experts on the *Eucalyptus* genus.

The resulting document was titled "More Than a Score: 21 eucalypt species with plantation potential", and is organized with a chapter or "digest" for each of the 21 species. Each digest presents a "realized climatic range" based on its natural range in Australia and the species' performance in worldwide trials (e.g., see Figure 10). Each digest also presents information about resistance or susceptibility (as reported in the literature) to a standard list of the main pathogens or pests affecting eucalypt plantations, and any notable tolerances or intolerances to climatic conditions, including frost and drought, specific soil conditions, etc. In addition, the 21 species are given a classification regarding potential in commercial forestry as a pure species, with either *proven*, *likely* or *possible* commercial value based on growth information available in the literature.

The report notes that there are nine eucalypt species that have a proven track record of excellent performance as plantation species (the Big Nine, Harwood 2011), and that Camcore has some genetic resources from seven of these species. Two of the Big Nine that are not represented in our portfolio are *E. saligna* (not summarized in the report), and *E. tereticornis* (one of the 21 species summarized in the report). The other 20 species come from three subgenera (*Symphomyrtus*, *Idiogenes*, and *Eucalyptus*), and in the subgenus *Symphomyrtus*, eight sections are represented. The aggregate climatic range covers almost every possible climate, from wet tropics to very cool temperate.

This report will serve as an invaluable resource in guiding our eucalypt seed collection efforts for the next ten years. Nevertheless, we still have much work to do, and many questions we need to sort through as a group to determine how we should prioritize species:

- What regions or climate zones are most important?
- Do we emphasize more closely-related species for hybridization? Or do we emphasize more diverse species (e.g., subgenus *Eucalyptus*) for genetic diversity?
- Do we emphasize growth? Wood? Pest tolerance? Adaptability to soils?
- Do we only want family collections or will bulk lots be of value?
- Should we make range-wide collections of a few species, or sample more species with less intensive provenance-progeny collections?

Currently, the full report is available only to Camcore members, but it may serve as the foundation for a publication in the future. Jakob and Brad have also provided an extensive database of literature, with more than 241 references from the literature, including PDFs when available. This information is available to Camcore members from the Camcore web page. Many thanks to Jakob and Brad for their help with this project.

E. tereticornis ***(Symphomyrtus Exsertaria)***

Comments

- Related to camaldulensis
- Drought tolerant
- Some tolerance to mod. low pH and salinity
- Susceptible to Leptocybe, pink disease
- Plantations in Brazil, India, Africa
- Uses = timber, pulp, firewood
- **Demonstrated Value**

Climate	Wet ---->	---------------------->	----> Dry
Tropical	Wet tropics		
	Wet subtropics		
		Hot	Hot/dry
		Frost (white gums)	Dry (grey gums)
		Subtropics	
Temperate		Temperate	Temperate dry

Species	Mean annual rainfall (mm)	Rainfall regime	Dry season (months)	Mean max temp hottest month (°C)	Mean min temp coldest month (°C)	Mean annual temp (°C)	Absolute min temp (frost) (°C)
E. tereticornis	500-1500	Summer, uniform	4 -- 8	22 -- 42	6 -- 19	17 -- 27	-6

Figure 10. An example of the summary information available in the report "More than a Score: 21 eucalypt species with plantation potential" by Butler and Potts, 2018. Shown here is *E. tereticornis*, one of the "Big Nine" species.

Camcore Domestic Conservation Projects

Several forest tree species across the United States are currently facing threats from insects, pathogens, catastrophic wildfire, poor forest management, habitat fragmentation, and climate change. Genetic conservation of these threatened hardwood and softwood species continues to be of great interest to both Camcore and the USDA Forest Service (USFS). Gene conservation allows scientists to secure valuable material before populations, or even entire species, become functionally extinct. This material can be used in restoration initiatives and for research projects.

Camcore first collaborated with the USFS in 2003 to collect and conserve seed from Carolina hemlock (*Tsuga caroliniana*) populations across the range of the species. Collected seed has since been sown to establish both ex situ and in situ plantings, placed in long-term cryostorage, and used in numerous associated research projects. Building on our success with Carolina hemlock, Camcore and the USFS have continued to collaborate on gene conservation projects for eleven tree species in the eastern United States.

Small Texas ash tree growing out of limestone rock at McKinney State Park near Austin, Texas.

Fraxinus gene conservation

Since 2017, Camcore has been collaborating with the USFS to conserve genetic resources of four rare ash species (Texas, *Fraxinus texensis*; Carolina, *F. caroliniana*; blue, *F. quadrangulata*; and pumpkin ash, *F. profunda*) occurring across the southeastern United States. In this region, the invasive emerald ash borer (EAB, *Agrilus planipennis*) has caused wide-scale losses of ash trees. During May of 2018, Camcore travelled to central Texas to explore 13 Texas ash sites for potential seed collections. We returned to Texas in late June and were able to collect seed from 80 mother trees in nine of these populations. While collections were largely successful, they may have been a few weeks early. This collection secured seed from across much of the central portion of this rare species. Future Texas ash collections will focus on outlier populations located along the northern and southern limits of the species range. After several years of gradual progress on our efforts to conserve these rare species, the Texas collections made a significant step forward in our efforts.

During the summer of 2017, Camcore visited several blue ash populations in central Kentucky. During this trip, seed production was underwhelming and we were unable to conduct any significant collections, so we decided to return to Kentucky in 2018 in hopes of better crops. The 2018 visit was disappointing because many of the sites we had hoped to collect from had experienced EAB mortality since our previous visit. We hope our future explorations of blue ash populations in Kentucky and Tennessee will locate remaining trees healthy enough to produce seed for our conservation projects.

Table Mountain pine *(P. pungens)*

Between 2010 and 2014, Camcore and the USFS collected seed from 263 Table Mountain pine (TMP, *Pinus pungens*) mother trees in 40 populations located throughout the Appalachian Mountains. While our initial gene conservation project with TMP had concluded, Camcore was asked by the USFS in 2018 to collect additional TMP bulk seed lots from a subset of the southern

Andy Whittier of Camcore climbing a Table Mountain pine in South Carolina for seed collection. Photo by B. Mudder

populations. During late 2018, we were able to collect cones from 25 new mother trees located in five populations in South Carolina. Although TMP cone production was below average in 2018, we were pleased to have secured as much material as we did. Special thanks are extended to Victor Wyant and Bryan Mudder with the USFS for locating TMP sites and helping with the collections. We plan to collect from another 25 trees in early 2019.

Other species

The year's collections of Texas ash seed and TMP cones were successful, but collections from our other conservation projects were disappointing. Cone crops in both eastern (*Tsuga canadensis*) and Carolina hemlock (*T. caroliniana*) as well as Fraser fir (*Abies fraseri*) and red spruce (*Picea rubens*) were low to nonexistent across much of the southeastern United States. For this reason, no seed collections from these species were conducted in 2018. We hope 2019 will be a better year for seed production so that we can continue with these important gene conservation projects.

Conservation Plantings

At the Mountain Research Station in western Waynesville, North Carolina, Camcore constructed a greenhouse in order to establish seedlings from our various domestic seed collections. Seedlings grown here will be used in reforestation efforts, seed orchard establishment, and various related research projects. As of late 2018, we had approximately 1200 2-year-old Carolina hemlock seedlings, 2000 2-year-old eastern hemlock, 1000 2-year-old Fraser fir, 300 2-year-old red spruce, and 1000 year-old TMP seedlings. Throughout a large portion of fall 2018, we were able to transplant many of these seedlings from ray leach tubes to larger pots. The majority of of this material will be outplanted when ready. These seedlings are an important resource for our continued research and conservation of these threatened species.

In October of 2018, Camcore planted our first TMP seedlings. This small in situ planting at the Upper Mountain Research Station in northwestern North Carolina consisted of 64 trees. These seedlings were culled from some of the larger 5-year-old plants growing in our Waynesville, NC greenhouse. Seedlings were planted in some plots of an existing Carolina hemlock trial, 59-99-CB2, that were vacant due to mortality. The primary purpose of establishing TMP in this planting is to evaluate how the species fares on this site and whether these trees will eventually produce seed for use in future planting and research efforts.

These many projects have resulted in nearly \$1.3 million in grant funding from the USFS, produced numerous publications and posters, and helped train five graduate students. These important gene conservation and associated research projects would not be possible without the support of numerous organizations and individuals. Special thanks go to 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 supporters across the Camcore membership.

Carolina and eastern hemlock, Fraser fir, red spruce, and Table Mountain pine seedlings located in western North Carolina at the Mountain Research Station. This material will be used in reforestation efforts, seedling orchard establishment, and other research initiatives.

Pitch Pine Gene Conservation

Pitch pine (*Pinus rigida*) is endemic to the xeric, pine-dominated upland forests of the Southern Appalachian Mountains. Over the last several decades, longer fire intervals due to fire suppression policies, continued outbreaks of southern pine beetle (*Dendroctonus frontalis*), and increasingly frequent droughts have resulted in reduced pine regeneration, allowing hardwoods to become and remain dominant throughout succession. As a result, previously widespread upland pine ecosystems are decreasing. Without fire, seedbed conditions are less conducive to pine regeneration and stands are frequently regenerating as hardwood-dominated sites. In order to reverse this trend, the USFS has identified several sites on which they would like to artificially regenerate pitch pine. In order to meet seedling demands for the species, the USFS has partnered with Camcore to collect pitch pine seed from across the range of the species. The goal of this project is to secure seed from 20 populations distributed across the Southern Appalachian region. Collection sites will be distributed across elevation, ecoregion, and plant hardiness zones in order to maximize the genetic and adaptive variation captured. We will collect seed from 10 to 20 mother trees in each population. Half of the cones from each tree will be kept separate by mother tree, and the other half will be combined into a bulk lot used for reforestation. Preliminary explorations of pitch pine sites began in late 2018 with more planned for the summer of 2019. Plans are to collect from ten populations in 2019 and another ten populations in 2020.

Pitch pine cones, needles and bark.

Hemlock Silviculture Research

Introduction

Camcore has been collaborating with the USDA Forest Service and other state and federal agencies since 2003 to conserve the genetic resources of eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*T. caroliniana*), conifer tree species native to the eastern United States and Canada. They are threatened by an exotic insect from Japan called the hemlock woolly adelgid (*Adelges tsugae*). Since its first detection in Virginia in the early 1950s, the adelgid has infested over fifty percent of the hemlock range and has reduced hemlock populations by over 80 percent in some areas. In addition to gene conservation, the integrated effort to manage adelgid impacts on hemlock ecosystems includes application of chemical insecticides, release of biological control agents, and breeding for host resistance. Until recently, relatively little attention had been given to silvicultural options for managing this pest. Most early efforts focused on cultural methods to improve the health and vigor of individual high-value trees in ornamental and recreational settings, or silvicultural tools to promote the next non-hemlock forest type. Together with the USDA Forest Service Southern Research Station in Asheville, NC, Camcore is taking a lead role in field research to develop silvicultural tools for reintroducing or retaining hemlocks in forests impacted by the adelgid. Two field studies are currently underway, one addressing hemlock reintroduction and the other hemlock retention. The summaries below provide brief updates on both studies.

Hemlock Restoration

This study is evaluating silvicultural strategies for reintroducing eastern hemlock to forests where it was eliminated by the hemlock woolly adelgid. Hemlocks are considered keystone species in the ecosystems they inhabit, and they exert significant influence on what other flora and fauna can survive in these areas. When hemlocks are removed, these forests are changed on a fundamental level as other tree species become dominant and there are shifts in the plant and animal populations that occupy the understory. These changes may cause hemlock to be at a competitive disadvantage when reintroduced.

The hemlock restoration study was initiated in late 2014 on two sites in western North Carolina, DuPont State Forest and Cold Mountain Game Land. This research is evaluating the effects of canopy structure (canopy gap versus thinned), deer exclusion, fertilization, herbicide, and the combination of fertilization plus herbicide on the establishment, survival, and early growth of eastern hemlock seedlings planted into forests previously dominated by mature hemlocks. At this time, we are using the insecticide imidacloprid to prevent adelgid infestations in the research plots.

As of the end of 2018, we have collected four years of data on hemlock growth and survival and the regrowth of competing vegetation. We are currently working on data analysis and manuscript preparation, but some initial trends are worth noting here. Overall seedling survival in the study is 91 percent and is not significantly affected by any

Table 17. Height and diameter (±se) growth responses to canopy structure, fertilization, and competition control treatments in eastern hemlock.

Treatment	Height (cm)	Basal Diameter (mm)
Canopy Structure		
Gap	227.02 (±5.30)	34.63 (±0.90)
Thinned	158.98 (±4.66)	22.94 (±0.58)
Fertilization and Competition Control		
Control	183.06 (±9.14)	24.32 (±0.99)
Fertilization	185.47 (±8.39)	28.37 (±1.20)
Herbicide	194.32 (±11.06)	28.82 (±1.74)
Fertilization plus Herbicide	209.14 (±10.50)	33.63 (±1.83)

Bryan Mudder with the USDA Forest Service measuring hemlock seedling heights in the hemlock restoration study at DuPont State Forest in North Carolina.

of the treatments being tested. Although eastern hemlock is a shade-tolerant species, in this study it is actually performing significantly better in the canopy gap treatment with high sunlight exposure (Table 17). Seedlings in the gaps are 30 percent taller and 34 percent larger in diameter than seedlings under the thinned canopy. Fertilization and herbicide treatments do not significantly increase seedling height growth over the untreated controls when the treatments are applied separately. However, when combined, the fertilization plus herbicide treatment increases height growth by 8 to 13 percent over the control and fertilization and herbicide alone treatments. Similarly, the fertilization plus herbicide treatment increases diameter growth by 15 percent over the fertilization and herbicide alone treatments and 28 percent over the controls.

In 2019 and 2020, we plan to add new components to this study and to follow its development into the future. An unexpected but interesting outcome so far is that deer browsing damage on seedlings has not been a significant issue, so we plan to remove the deer fencing and initiate a hemlock thinning treatment. We also plan to stop imidacloprid protection treatments and introduce biological control agents so that we can better understand how the adelgid and introduced natural enemies respond to the silvicultural inputs in this study.

Target-Tree Release

The objective of this study is to evaluate a target-tree release approach for improving the health of individual living hemlock trees infested with the hemlock woolly adelgid. Several recently published studies, including one by Camcore and our USDA Forest Service colleagues, confirmed anecdotal field reports of better hemlock health and lower adelgid population densities on trees or portions of trees exposed to direct sunlight. These findings suggest that silvicultural methods such as thinning or selective harvesting might be beneficial to hemlock in adelgid-infested forests.

In 2017, Camcore and the USDA Forest Service Southern Research Station received funding from the USDA Forest Service Special Technology Development Program to conduct research aimed at developing new silvicultural strategies to improve the long-term health and retention of hemlocks in Southern Appalachian forests. Target-tree release plots were established to evaluate how increasing the amount of ambient light available to the crowns of eastern hemlocks in intermediate forest canopy positions affects adelgid infestation density and the subsequent health of the trees. Ambient light around the crown of individual trees was increased by creating gaps of two sizes (small or large) using two methods (felling or girdling). Small gaps were created by cutting or girdling all surrounding trees that are rooted in or overhang the drip line radius of the target hemlock. Large gaps were made by cutting or girdling all surrounding trees that are in or overhang a radius around the target hemlock that is equal to the drip line radius of the tree plus twenty-five percent of the height of the tallest trees in the surrounding stand. Subsequent adelgid density and tree health are being compared to unreleased control trees.

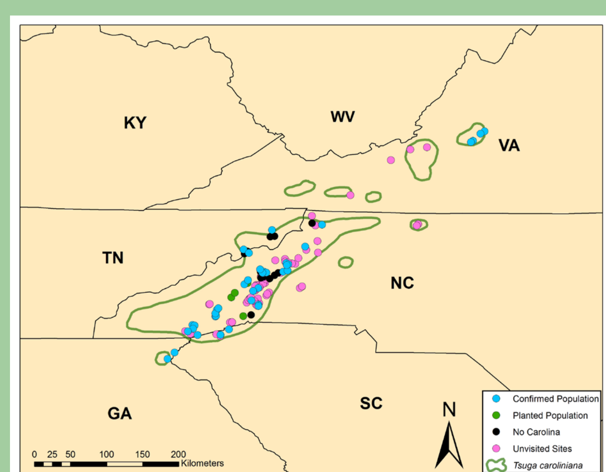
This project is in its early stages, but significant progress has been made since its inception in June 2017. Twenty-one five-tree study replications (105 trees total) have been established. Each five-tree replication includes four plots representing each combination of gap size (small or large) x gap method (felling or girdling) plus an untreated control plot. See photo on next page for an example of the large gap created by the felling treatment. The replications span five states: Maryland (7 replications), Virginia (5), North Carolina (3), Tennessee (3), and Georgia (3). Data collection so far includes a complete set of pre-treatment adelgid density and tree health data for all plots, and at least one full set of post-treatment data on adelgid density and tree health, and a measurement of the regrowth of competing woody vegetation.

Both of these hemlock silviculture studies are still in progress and we urge that the information and data reported above not be used for writing hemlock management prescriptions until the final data analyses and interpretations are completed. Please contact Camcore or the USDA Forest Service if you have any questions about these ongoing research efforts.

Large gap with felling target-tree release treatment before (left) and after cutting (right) in the Jefferson National Forest in Virginia (photographs courtesy of Albert "Bud" Mayfield, USDA Forest Service, Southern Research Station).

Carolina Hemlock Conservation Assessment Project

In order to more fully describe the natural distribution and assess the health of the rare Carolina hemlock (*Tsuga caroliniana*) in the southern Appalachian Mountains, Camcore has embarked on a project to visit all known populations of the species. Progress continues and at the end of 2018, 83 reported populations had been visited and 63 of those contained naturally occurring Carolina hemlock trees that we mapped and inventoried. Another six sites contained populations that appear to have been planted while the remaining 14 sites had no Carolina hemlock. Populations in northeastern Georgia, the southern extent of the species, up to those in central Virginia, the northern edge, have been mapped. Populations range from as few as two trees to an estimated 1500 with an average of about 140 trees per population. The overall health of the visited stands ranges from excellent to poor with no discernable patterns in geography, elevation, or latitude. On sites that contain both Carolina and eastern hemlock, the Carolina trees were generally healthier. Not surprisingly, sites that had been chemically treated fared much better than untreated sites. While hemlock woolly adelgid continues to cause extensive damage in hemlock populations across the eastern US, wildfires in the southeastern US have also resulted in losses of some populations. The Carolina hemlock assessment project continues to provide valuable information on this rare species endemic to the southern Appalachian Mountains.



Data Management Courses

Camcore offers the Data Management Workshop to members to improve their staff's skills in managing data associated with tree improvement research. The overall objectives are to review the purpose and standards for measurements in Camcore trials and to show methods to increase the speed and accuracy for acquiring and validating this data. Topics include systems for file and folder naming, types of field data and methods to code them, designs for genetic trials, and verification of tree growth data. The week-long course includes lectures and discussion and hands-on computer and spreadsheet exercises. Previous courses have ranged in size from 3 to 20 participants and there is usually a wide range of experience levels. The course is structured to allow students to work at an individual pace so that people at each level are challenged.

In 2018, Camcore Data Manager Willi Woodbridge traveled to Ghana and Sierra Leone to conduct the course at both locations of Miro Forestry. Miro has recently established progeny trials and will begin measuring this year so it was a good time for them to learn about handling Camcore trial data. The course includes discussions about data management and how information about Camcore's provenance collections, progeny trials and tree growth data is coded and recorded. Demonstrations on manipulating Windows shortcuts, personalized toolbars and the Excel user interface help users be more efficient in their daily work. Most of the time is spent with exercises in Excel spreadsheets. Students learn how to write formulas using logical functions such as IF(), AND(), OR(), text manipulation functions including LEFT(), RIGHT(), MID(), and data check functions like IFERROR(), SUMIF(), ISNUMBER(). Most students have experience using column filters, but the class teaches ways to get more out of this useful function. Pivot Tables are a very important tool in Excel, so they are practiced many times in the course. Learning all these tools allows students to complete some culminating exercises such as creating a data template for recording measurements from the field, combining trial measurements from different years and identifying invalid and suspicious measurements, and turning a trial design into a data template and field map for trial establishment.

Willi Woodbridge assists students in the data management course at Miro Forestry, Ghana.

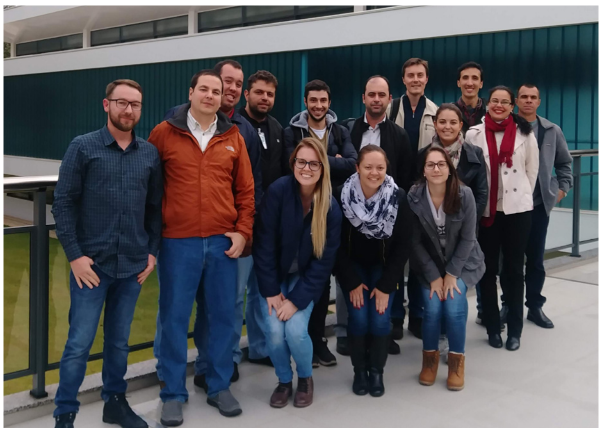
Participants in the data management course at Miro Forestry, Sierra Leone.

All students completed the course with a better understanding of trial layout and data coding and a much broader tool kit for handling data and spreadsheets of any type. The "data management department" at Camcore (OK, it's only 1 person) greatly appreciates the efforts of the participants throughout the course. We also appreciate the managers for allowing their staff to take time from normal duties to improve their skills. Plans are underway for courses in 2019 in Indonesia at Sinar Mas and APRIL.

Ghanean students celebrating the course completion.

Courses in R Programming

In 2018, Camcore continued to offer R training to its members. Three short courses were conducted in Brazil, Ghana and Sierra Leone; all courses were held as a complement to our technical visit. The course objective is to introduce students to the R environment and give them basic tools to analyze their data. Fifteen students from Klabin and WestRock participated in a two-day class hosted by Klabin in its new technology center located in Telêmaco Borba, Paraná, Brazil.



Participants in the R programming course in Brazil. Students are from Klabin and WestRock.

The courses in Ghana and Sierra Leone were both hosted by Miro Forestry. Our class in Ghana was taught in the town of Agogo in the Ashanti Region, with 9 students participating. In Sierra Leone, 8 students joined the class which took place at Miro's office close to Mile 91 in the Tonkolili district of the Northern Province. We are confident that R is a great tool for our members, and we encourage management and researchers to promote the use of this language in their company.

Participants in the R programming course from Miro Forestry Ghana.

Additionally, Juan José Acosta was invited to the Midwestern State University (UNICENTRO) in Irati, Paraná, Brazil by professor Evandro Tambarussi to teach an experimental design analysis course, using R, to graduate students in Forest Science. This course was held in October with the participation of seventeen students and three professors.

Participants in the R programming course from Miro Forestry Sierra Leone

Changes in Camcore

Heuzer Guimaraes is the new Forestry Business Director at WestRock, after working in forestry operations in Colombia. Heuzer had been working for WestRock in previous years and is happy to return to the company in his new position. Congratulations Heuzer for the new challenges at WestRock.

Ali Abdul Ayoub moved from his position as WestRock Forestry Business Director to take the position of Mill Director. We wish Ali a lot of success in his new position in the company.

Nhora Isaza, Tree Breeder with Smurfit Kappa Colombia retired after more than 30 years working with the company. Nhora was a great researcher and a great supporter of Camcore through the years. We wish Nhora a fulfilling life with her family and all the best in her new activities.

Martha Salas with Smurfit Kappa Colombia replaced Nhora Isaza as Tree Breeder for the company, taking charge of the genetics program. Martha finished her M.S. degree at NCSU in 2018 and returned to Colombia to work in her new position. Congratulations Martha!

Nicolás Pombo, Forestry Manager in Smurfit Kappa Colombia was elected a new member of the Camcore executive committee. We appreciate the interest of Nicolás and we know he will provide great input to the program management.

Kitt Payn, Biotechnology Program Leader, Forests, left Mondi at the end of the year to take the position as Director of the Tree Improvement Program at NC State University, replacing Dr. Steve McKeand, who had been with the program for more than 30 years. We wish Kitt great success with the challenges of his new position.

Marius du Plessis, Corporate R&D Head, left Sinar Mas after more than two years working with the company in Indonesia. Marius returned to work for Mondi in South Africa as a Tree Improvement Research Manager, a position that he held with Mondi in previous years. We wish Marius and his family the best in his return to South Africa.

Laercio Duda, Forest Improvement Corporate Head in Sinar Mas moved to Araya Bumi Indonesia to take the position as Forestry Director. Laercio worked with Sinar Mas for more than two years and is now helping ABI to join Camcore as an active member. We wish Laercio success in his new job at this new company.

John Crawford-Brunt left his position as Forestry Technical Manager with York Timbers to take the position of Compliance Manager with York. We wish John a lot of success in his new endeavors.

André Môller replaced John Crawford-Brunt as the Forestry Technical Manager at York Timbers where the Tree Breeding and Nursery departments are among his responsibilities. André comes from SAFCOL where he was the Technical Services Manager.

Lizette de Waal with York Timbers, South Africa, completed her M.Sc. at the University of Pretoria. Her thesis looked at frost tolerance and artificial frost-screening for *Pinus oocarpa* and *P. patula* x *P. tecunumanii* hybrid families. Lizette will continue her work as tree breeder with York. Congratulations, Lizette!

Paola Molina, Tree Breeder with Lumin in Uruguay moved to work as Nursery Manager in the company. Paola worked for several years as a tree breeder in charge of many research projects with Camcore, of which she was a great supporter. We wish Paola success in her new challenges.

Robert Purnell, Chairman of Camcore for the last five years is not with Camcore anymore. Weyerhaeuser sold its subsidiary in Uruguay to Lumin. He is still working with Weyerhaeuser in the US but not in Uruguay. We want to thank Bob for his continuous and strong support for Camcore throughout the years.

Romel Torcat, Research Manager in Masisa Venezuela, left the company to look for new opportunities in South America. Thanks to Romel for his contributions to Camcore. We wish you success in your new challenges.

José Luis Quiaragua is now in charge of the Forestry Division of Masisa Venezuela, taking the responsibilities of the previous Forest Manager, Eduardo Cantero, in addition to his obligations as the Institutional, Social and Environmental Commitment Manager.

Mario Gomes Ladeira with Klabin was assigned new responsibilities within the company, taking Forestry Quality Control in addition to Research Management. Best wishes to Mario in his new responsibilities.

Fabricio Biernaski, Tree Breeder in Klabin, received his doctoral degree in Forestry from Federal University of Paraná, in Brazil. Fabricio's research project was "Seed maturation and types of containers for seedlings and cuttings of *P. maximinoi*". Congratulations to Fabricio on his valuable achievement.

Gisela Andrejow, Tree Breeder in WestRock, finished her Ph.D. in Forestry at the Federal University of Paraná, Brazil. Gisela conducted research on "Identification of *Eucalyptus* species and tree improvement in regions with frost occurrence". We congratulate Gisela for her great academic accomplishment.

Francois van Deventer left Mondi Forests to take a postion as Acacia Breeder with APRIL in Indonesia. Francois has many years of experience as a breeder with tropical and cold temperate eucalypts, and will now bring his skills to work on acacia species.

Valerie Grzeskowiak left Sappi Forestry to take a position as Wood Properties Research Manager with APRIL in Indonesia. We look forward to continuing to work with Valerie on Camcore projects.

Glen Mitchell, a longtime associate of Camcore with various companies in South Africa, left his position with the Sarawak Forestry Corporation in Malaysia to take a position with APRIL in Indonesia. Glen will be working as Head of Extension Services, a liason between the research group and operational nurseries and forest managers

Phillip McIntyre has taken the postion of Planning & Research Manager for PG Bison. Phillip has many years of experience in forest inventory and planning, and is looking forward to learning more about Camcore.

Bongani Noludwe, PG Bison, has been involved with Camcore activities for a number of years within PG Bison. He has taken a new position within the company, and will be the Elliot Area Manager. He will still be involved at a lower level with Camcore research.

Marchalyn Snell-Jordaan has taken the position of Planning Manager with PG Bison, and she will also be working with closely with Camcore. Welcome, Marchy!

Graduate Programs and Training

Juan Pedro Posse, Research Manager with Lumin Uruguay, continues to work on the final stages of his Ph.D. dissertation on the genetic control of wood properties in *Eucalyptus dunnii*. Juan Pedro plans to complete the Ph.D. dissertation and graduate in 2019.

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 University *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, 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 Ph.D. in quantitative genetics and breeding.

Jason Payne is a Ph.D. student working with Camcore's domestic conservation program and directed by Robert Jetton. His research focuses on developing silvicultural options for reintroducing American chestnut to the hardwood forests of the Southern Appalachian Mountains, where it was previously a dominant canopy tree species before being decimated by an exotic fungal blight. Prior to joining Camcore, Jason completed B.S. and M.S. degrees in Forestry at NCSU.

Austin Thomas is a Ph.D. student working with Camcore's domestic conservation program under the direction of Robert Jetton. His research focuses on two projects. One study is evaluating the physical and chemical responses of elite Fraser fir genotypes to infestation by an exotic insect, the balsam woolly adelgid. Fraser fir is commercially important in North Carolina for Christmas trees. The second study is an ecosystem and genetic health analysis of a relic population of eastern hemlock near Raleigh, NC. Prior to joining Camcore, Austin completed his M.S. at Appalachian State University in western North Carolina.

Dominic Manz is a new M.S. student working as part of Camcore's domestic conservation program. We are still working to define Dominic's research project, but it will be related to Camcore's research on silvicultural restoration of hemlocks. Prior to joining Camcore, Dominic completed his B.S. degree in Forestry at NCSU.

Connor Winfield is an undergraduate laboratory assistant with Camcore majoring in Biology and working under the direction of Robert Jetton. Connor received a small research grant from the NCSU Office of Undergraduate Research to fund an independent research experience as part of his B.S. degree program. Connor's project is documenting the arthropod diversity associated with forest type and management activities at a small nature preserve near Raleigh.

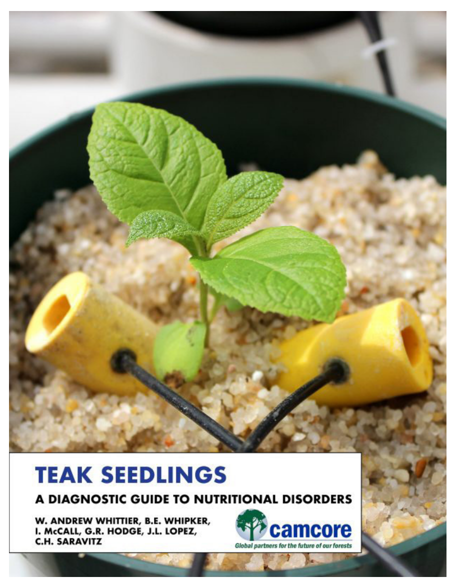
Remembering our Friend Bill Ladrach

William E. Ladrach, a very good friend and well-respected professional forester, passed away on July 20, 2018. As advisory board member from Smurfit Kappa Colombia, one of the four founding members of the program, Bill was one of the stronger supporters of Camcore conservation and testing efforts. He was instrumental in helping initiate the programs in Guatemala and Mexico in 1980 and 1982 respectively. Through SKC, he helped Camcore finance its very first seed collection in Mt. Pine Ridge, Belize, in 1980 and with his wife Gladys, translated many of Camcore's research reports into Spanish. Bill worked with Smurfit Kappa Colombia for twelve years and then returned to the United States to work with Dr. Bruce Zobel as an international consultant. He was also an Assistant Professor in the Department of Forestry and Environmental Resources at NC State University. Bill contributed to the forestry sector in the tropics in several ways, one of which was his book translated into Spanish: "Applied forest management for tropical and subtropical plantations". His great sense of humor and kindness made him a much-appreciated friend in the many places he worked all around the world. Bill will be greatly missed.

William E. Ladrach (on the right in back), celebrating the 25th anniversary of Camcore, along with his coworkers from Smurfit Kappa Colombia, Camcore, including Bruce and Barbara Zobel, in Raleigh, NC, in 2005

Teak Nutrient Disorder Symptom Guide

One of the objectives of Andy Whittier's masters research in working with hydroponically grown teak seedlings was to generate and photograph foliar disorders for each of twelve essential nutrient deficiencies and one toxicity. By subjecting seedlings to a standard Hoagland nutrient solution and comparing them to seedlings grown in the same solution with the absence (or toxic Boron addition) of one of the essential nutrients, he was able to isolate and photograph specific symptoms. In addition to photographing symptoms, foliar nutrient levels were determined for each of the thirteen nutrient disorders at the onset of symptoms. Symptomatic photos and reference foliar nutrient levels were combined with information on the timing of symptom appearance and growth measurements for each treatment and put together in a diagnostic guide to nutritional disorders for teak seedlings. The objective of this guide is to provide nursery managers with a tool to help better diagnose teak nutrient issues in their greenhouses.



This diagnostic guide was printed in the fall of 2018 and is now available to Camcore members in either electronic or printed format. Please contact Camcore to obtain a copy.

Publications and Papers

Publications

Acosta J.J. , Fahrenkrog A.M., Neves, L.G., Resende, M.F.R., Dervinis, C., Holliday, J.A.. Kirst, M. 2019. 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.

Biernaski, F., Nogueira, A.C., Tambarussi, E.V., Mayer Weber, R.L., Stahl, J. 2017. Influência do método de propagação e tipos de recipientes na qualidada de mudas de *Pinus maximinoi* H. E. Moore. Enciclopédia Biosfera, Centro Científico Conhecer - Goiânia, v.14 n.26; p. 2017

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Lapham, M., C.F. Ford, A.E. Mayfield III, R.M. Jetton, S.T. Brantley, D.R. Zietlow, C. Brown, and J.R. Rhea. 2018. Shade and hemlock woolly adelgid infestation increase eastern hemlock foliar nutrient concentration. Forest Science 64: 577-582.

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Lopez, J.L. 2018. Financial returns of tree breeding programs for Eucalyptus plantations in Brazil and Teak in Latin America. Presentation in 2nd DANA Central America & Andes Forest Sector Investment Conference. Cancun, Mexico, November 14-15, 2018.

Lstiburek, M., Bittner, V., Hodge, G.R., Picek, J. and Mackay, T.F.C. 2018. Estimating Realized Heritability in Panmictic Populations. Genetics, Vol. 208, 89–95.

Naidoo, S., Christie, N., Acosta J.J., Mphahlele, M., Payn, K., Myburg, A., Külheim, C. 2018. Terpenes associated with resistance against the gall wasp, Leptocybe invasa, in Eucalyptus grandis. Plant, Cell and Environment.; 41:1840–851. https://doi.org/10.1111/pce.13323

Salas, Martha. 2018. Clonal Variation of Eucalyptus grandis W. Hill ex Maiden in Colombia. NCSU Master of Science Forestry Thesis. 79 pp.

Whittier, W.A. 2018. Nutrient Disorder Foliar Symptoms, Foliar Nutrient Levels and Predictive Near-infrared Spectroscopy Nutrient Models of Teak (Tectona grandis L.f.). NCSU Master of Science Forestry Thesis. 183 pp.

W. A. Whittier, B.E. Whipker, I. McCall, G.R. Hodge, J.L. Lopez. 2018. Teak Seedlings, A Diagnostic Guide to Nutritional Disorders. Camcore. Raleigh, NC. USA.

Conference Presentations

Mayfield, B. and R. Jetton. 2018. Hemlock silviculture and restoration in the southern Appalachians. Northeastern Forest Pest Council Meeting, March 14, 2018, Burlington, VT.

Mayfield, B. and R. Jetton. 2018. Exploring eastern hemlock silviculture and restoration in response to HWA. USDA Forest Service Northeastern Area Forest Health Conference Call, June 5, 2018.

Jetton, R.M. 2018. Hemlock dieback and adaptive forest management. Special Program: Healthy Forests for a Sustainable Future, North Carolina Arboretum, October 15, 2018, Asheville, NC.

Jetton, R. and J. Wang. 2018. Improving forest health and wood utilization. North Carolina Forestry Association Annual Meeting, October 11, 2018, Raleigh, NC.

Jetton, R.M. and A.E. Mayfield III. 2018. Towards silvicultural management of the hemlock woolly adelgid. 59th Southern Forest Insect Work Conference, July 17-20, 2018, San Antonio, TX.

Jetton, R. and B. Mayfield. 2018. Target-tree release to improve the sustainability of eastern hemlock in the Southern Appalachians. East Texas Forest Entomology Seminar, April 20, 2018. Nacogdoches, TX.

Jetton, R. and B. Mayfield. 2018. Target-tree release to improve the sustainability of eastern hemlock in the eastern United States. Southern Appalachian Forest Entomology and Pathology Seminar, March 16, 2018, Crossnore, NC.

Jetton, R.M. 2018. Current status and challenges in pursuing hemlock host resistance. Hemlock Woolly Adelgid Initiative Steering Committee Annual Meeting, January 9, 2018, Annapolis, MD.

Whittier, W.A., Mayfield, A.E. 2018. Hemlock Conservation in the Southern Appalachian Mountains. AC Reynolds Middle School. May 30, 2018. Asheville, NC. USA.

Conference Posters

Mayfield, A.E. III and R.M. Jetton. 2018. Settle down! Examining the effect of sunlight wavelengths on hemlock woolly adelgid crawler settling behavior. 59th Southern Forest Insect Work Conference, July 17-20, 2018, San Antonio, TX.

CAMCORE BOARDS AND COMMITTEES

Jose Pedro Brum of Klabin shows off a perfect core from an 8-year-old *Pinus greggii* x *P. tecunumanii* hybrid tree. Wood quality measurements and physical samples were taken from this trial in the Monte Alegre, Colônia plantation in Paraná, Brazil, as part of the pine hybrid wood characterization project.

Front Cover: Nhora Isaza (left) and Martha Salas, tree breeders from Smurfit Kappa Colombia, in a eucalypt hybrid seedling selection block, recently established in Restrepo, Valle del Cauca. This planting is part of the Camcore Eucalypt Hybrid Project. After 9 to 12 months, selections will be made here and then tested as clones across multiple sites.