# camcore 2019 Annual Report

NC STATE UNIVERSITY

# 2019 CAMCORE ANNUAL REPORT

## International Tree Breeding and Gene Conservation


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# EXECUTIVE SUMMARY

1. Two companies joined Camcore in 2019: Bracell (Brazil), a sister company of APRIL (Indonesia), and Araya Bumi Indonesia. In September, we held our annual meeting in Portugal, where we set out strategic direction for the next ten years.

2. Good progress was made in the Camcore full-sib pine-hybrid breeding projects. For the *P. patula x P. tecunumanii* project, the first full-sib family trials will be planted with rooted cuttings early in 2020, and trial establishment will continue through 2021, with a target of 16 hybrid progeny trials. For the *P. tecunumanii x P. greggii* project, crosses have been made from 2016 through 2019, and will continue one more year. Finally, in 2019, we made a decision to pursue the *P. caribaea x P. tecunumanii* hybrid as our third full-sib breeding project.

3. Eucalypt hybrid breeding work also continued in 2019. In the Phase 1 project, members in South Africa, Brazil, Chile, Colombia and Uruguay established (or sowed seed for) hybrid seedling selection blocks (HSSB). Twelve clonal trials of *E. grandis* hybrids (with *E. pellita, E. globulus, E. smithii,* and *E. dunnii*) were planted in South Africa; more tests will be planted in 2020. The Phase 2 project began in 2018. The hybrids generated from this work will be Camcore genetic material shared among all members. In 2019, some crosses were begun (e.g., *C. torelliana x C. citriodora, E. pellita x E. grandis*), and some crosses were completed (*E. grandis x E. urophylla, E. urophylla x E. dunnii, E. dunnii x E. benthamii*).

4. Characterization of wood properties for pine hybrids and eucalypt species continued in 2019. Two pine hybrid tests in South Africa were sampled. Consistent with previous results, the wood properties of the *P. patula x P. tecunumanii* hybrid look very good. Two euclaypt species tests in South Africa and two tests in Uruguay were sampled. *Corymbia* species appear to have interesting wood properities, showing high density, low lignin, and low syringyl:guaiacyl lignin ratio.

5. Research was completed to identify a total of 427,000 SNP probes to be used on a screening array prior to production of the commercial SNP chip for subtropical and tropical pine species. The commercial chip should be available in mid-2020.

6. A new NIR scanning device (the Texas Instruments DLP NIRscan Nano EVM) was tested and compared against the laboratory-quality Foss 6500 and the handheld Thermo Scientific microPhazir. The study examined four important analytical traits measured in forage grass. Good models were built with all three devices, including the inexpensive Nano.

7. The Camcore global NIR models for *Eucalyptus* were expanded and made more robust with the inclusion of samples from seven *Eucalyptus* species and four *Corymbia* species that were not previously represented in the data set.

8. Some interesting results have already been obtained from the first pine and eucalypt sentinel trials established by Sappi in South Africa. A surprise in the pine trial was that *P. greggii* (South ) showed better tolerance to *Fusarium circinatum* than did *P. patula* (with 36% better survival, and very good growth). In the eucalypt trial, *Corymbia* species showed much less pest/disease incidence than did the eucalypt species. In addition, the two eucalypt species most affected by Destructans leaf blight (*Teratosphaeria destructans*) were *E. grandis* and *E. urophylla*.

9. By the end of 2020, we expect to have around 215 teak selections from Camcore trials that will be available for clonal testing. Seeds of teak for 2$^{nd}$ generation progeny trials were distributed to Miro Forestry Ghana and Sierra Leone in 2019.

10. Seeds from 49 clones of *Gmelina arborea* that had been collected in 2018 from the Camcore clonal seed orchard in Forestal Monterrey, Colombia were shipped to Miro Forestry in Ghana and Sierra Leone for the establishment of 2nd generation progeny trials. More seeds of the species will be collected in the near future to send to other members in Mexico and Kenya. We also shipped rooted cuttings of 55 Camcore clones from Bogotá, Colombia to Miro Forestry, Ghana in west Africa.

11. Camcore's US gene conservation work, funded by the USDA Forest Service, continued in 2019. An important milestone was the establishment of seedling seed orchards of eastern hemlock and Table Mountain pine. Orchard sites were prepared and laid out in late 2019, with plans to plant trees in early 2020.

# RESUMEN EJECUTIVO (Español)

1. Dos compañías se afiliaron a Camcore en el 2019: Bracell (Brasil) una empresa hermana de APRIL (Indonesia), y Araya Bumi Indonesia. En septiembre, realizamos nuestra reunión anual en Portugal donde definimos nuestra dirección estratégica para los próximos diez años.
2. Hubo un gran avance en los proyectos Camcore de mejoramiento genético con los híbridos de pino de hermanos completos. Se plantaron los primeros ensayos de progenie con estacas enraizadas de *P. patula x P. tecunumanii* temprano en el 2020, y se continuarán estableciendo más ensayos en el 2021, con una meta de 16 ensayos. Para el proyecto de *P. tecunumanii x P. greggii*, se han realizado cruzamientos desde el 2016 hasta el 2019, y se continuarán por un año más. Finalmente, en el 2019 tomamos la decisión de desarrollar el híbrido de *P. caribaea x P. tecunumanii* como nuestro tercer proyecto de mejoramiento con semilla de hermanos completos.
3. El trabajo de mejoramiento genético con los híbridos de eucalipto también continuó en el 2019. En la fase 1 del proyecto, miembros de Sudáfrica, Brasil, Chile, Colombia y Uruguay establecieron (o sembraron semillas para) bloques de selección de plántulas híbridas. Doce ensayos de clones con híbridos de *E. grandis* (con *E. pellita, E. globulus, E. smithii*, y *E. dunnii*) fueron plantados en Sudáfrica; más ensayos serán plantados en 2020. La fase 2 del proyecto empezó en 2018. Los híbridos generados a partir de este trabajo serán material de propiedad de Camcore a compartir entre todos los miembros. En el 2019 se iniciaron algunos cruzamientos (*C. torelliana x C. citriodora, E. pellita x E. grandis*) y se completaron otros (*E. grandis x E. urophylla, E. urophylla x E. dunnii, E. dunnii x E. benthamii*).
4. La caracterización de las propiedades de la madera para los híbridos de pino y las especies de eucaliptos continuó en 2019. Se tomaron muestras de dos ensayos de híbridos de pino en Sudáfrica. Consistentes con resultados previos, las propiedades de la madera del hibrido de *P. patula x P. tecunumanii* son muy buenas. También se tomaron muestras de madera en dos ensayos de eucaliptos en Sudáfrica y dos en Uruguay. Las especies de Corymbia tuvieron propiedades interesantes, mostrando valores de alta densidad, bajo contenido de lignina y baja relación siringil:guaiacil.
5. Se completó la investigación para identificar un total de 427,000 SNP para ser usados en un arreglo de prueba previo a la producción del chip SNP comercial para las especies de pinos subtropicales y tropicales. El chip comercial debería estar disponible a mediados del 2020.
6. Se ensayó un nuevo instrumento NIR (Texas Instruments DLP NIRscan Nano EVM), el cual se comparó contra el Foss 6500 de alta calidad para laboratorio, y con el portátil Thermo Scientific micro-Phazir. El estudio examinó cuatro características analíticas importantes en pastos forrajeros. Se construyeron modelos buenos con los tres instrumentos, incluyendo el Nano de bajo costo.
7. Los modelos globales NIR de Camcore para eucaliptos se expandieron y se hicieron más robustos con la inclusión de muestras de siete especies de *Eucalyptus* y cuatro de *Corymbia* que no estaban previamente representadas en el conjunto de datos.
8. Algunos resultados interesantes han sido ya obtenidos de los primeros ensayos centinela establecidos por Sappi en Sudáfrica. Una sorpresa en el ensayo de pinos fue que el *P. greggii* (South) mostró mejor tolerancia a *Fusarium circinatum* que el *P. patula* (con 36% mejor sobrevivencia, y muy buen crecimiento). En el ensayo de eucaliptos, la incidencia de pestes y enfermedades fue mucho menor en las especies de Corymbia que en las especies de eucaliptos. Adicionalmente, las dos especies de eucaliptos mayormente afectadas por el tizón de la hoja Destructans (*Teratosphaeria destructans*) fueron el *E. grandis* y el *E. urophylla*.
9. Para finales del 2020, esperamos tener cerca de 215 selecciones de teca de ensayos de Camcore que estarán disponibles para ensayos de clones. Semillas de teca para ensayos de progenie de segunda generación fueron distribuidas a Miro Forestry Ghana y Sierra Leona en 2019.
10. Semillas de 49 clones de *Gmelina arborea* que habían sido colectadas en 2018 en el huerto semillero clonal de Camcore en Forestal Monterrey, Colombia fueron enviadas a Miro Forestry en Ghana y Sierra Leona para el establecimiento de ensayos de progenie de 2nda generación. Más semillas de la especie serán colectadas en el futuro cercano para enviarlas a otros miembros en México y Kenia. También enviamos estacas enraizadas de 55 clones de Camcore desde Bogotá, Colombia a Miro Forestry en Africa Occidental.
11. El trabajo de conservación de genes en Camcore, financiado por el Servicio Forestal de los Estados Unidos, continuó en 2019. Un hito importante fue el establecimiento de huertos semilleros de plántulas del eastern hemlock (*Tsuga canadensis*) y Table Mountain pine (*Pinus pungens*). Los sitios de los huertos fueron preparados y diseñados a finales del 2019, con planes de plantar los árboles a principios del 2020.

# RESUMO EXECUTIVO (Português)

1. Em 2019, duas novas companhias passaram a fazer parte da Camcore: Bracell (Brasil), uma empresa filial da APRIL (Indonesia) e Araya Bumi (Indonesia). Em Setembro, realizamos nossa reunião anual em Portugal, onde estabelecemos uma direção estratégica para os próximos dez anos.

Obtivemos um bom progresso nos projetos de melhoramento de híbridos de *Pinus* de irmãos completos da Camcore. Para o projeto *P. patula x P. tecunumanii,* os primeiros ensaios com a família de irmãos completos foram plantados com estacas enraizadas no início de 2020, e o estabelecimento do estudo continuará até 2021, com um objetivo de instalação de 16 ensaios com progênies híbridas. Para o projeto *P. tecunumanii x P. greggii*, de 2016 a 2019 foram feitos vários cruzamentos, que continuarão por mais um ano. Finalmente, em 2019, tomamos a decisão de trabalhar com o híbrido *P. caribaea x P. tecunumanii* como nosso terceiro projeto de criação de irmãos completos.

2. O trabalho de melhoramento genético de híbridos de *Eucalyptus* também teve continuidade em 2019. Na Fase 1 do projeto, membros na África do Sul, Brasil, Chile, Colômbia e Uruguai estabeleceram (ou plantaram sementes para) os blocos de seleção de mudas híbridas (HSSB). Três ensaios clonais de híbridos de *E. grandis* (com *E. pellita, E. globulus, E. smithii* e *E. dunnii*) foram plantados na África do Sul; mais testes serão plantados em 2020. A Fase 2 do projeto começou em 2018. Os híbridos gerados a partir deste trabalho serão material genético da Camcore compartilhado entre todos os membros. Em 2019, alguns cruzamentos foram iniciados (por exemplo, *C. torelliana x C. citriodora, E. pellita x E. grandis*), e alguns cruzamentos foram concluídos (*E. grandis x E. urophylla, E. urophylla x E. dunnii, E dunnii x E. benthamii*).

3. Em 2019 teve continuidade a caracterização das propriedades da madeira para híbridos de *Pinus* e *Eucalyptus*. Foram realizados dois testes de híbridos de *Pinus* na África do sul. Consistente com os resultados anteriores, as propriedades da madeira do híbrido *P. patula x P. tecunumanii* parecem muito boas. Foram amostrados dois testes de espécies de Euclayptus na África do Sul e dois testes no Uruguai. As espécies de *Corymbia* parecem ter propriedades da madeira interessantes, mostrando alta densidade, baixa quantidade de lignina e baixa relação siringil: guaiacil lignina.

4. Foi concluída a pesquisa para identificar um total de 427.000 sondas SNP a serem usadas em uma matriz de triagem antes da produção do chip SNP comercial para espécies de pinheiros subtropicais e tropicais. O chip comercial deve estar disponível em meados de 2020.

5. Um novo dispositivo de digitalização NIR (Texas Instruments DLP NIRscan Nano EVM) foi testado e comparado com o Foss 6500, com qualidade de laboratório, e o micro-Phazir portátil da Thermo Scientific. O estudo examinou quatro importantes características analíticas medidas na grama forrageira. Bons modelos foram construídos com todos os três dispositivos, incluindo o Nano mais barato.

6. Os modelos globais de NIR da Camcore para eucaliptos foram ampliados e mais tornados mais robustos com a inclusão de amostras de sete espécies de eucalipto e quatro espécies de *Corymbia* que não estavam anteriormente representadas no conjunto de dados.

7. Alguns resultados interessantes já foram obtidos nos primeiros ensaios com sentinela de pinus e eucalipto estabelecidos pela Sappi na África do Sul. Uma surpresa no experimento com pinheiros foi que *P. greggii* (Sul) mostrou melhor tolerância a *Fusarium circinatum* do que *P. patula* (com 36% de sobrevivência melhor e muito bom crescimento). No ensaio de eucalipto, as espécies de *Corymbia* apresentaram muito menos incidência de pragas / doenças do que as espécies de eucalipto. Além disso, as duas espécies de eucalipto mais afetadas pela queima das folhas de Destructans (*Teratosphaeria destructans*) foram *E. grandis* e *E. urophylla.*

8. Até o final de 2020, esperamos ter cerca de 215 seleções da espécie teca dos testes da Camcore que estarão disponíveis para testes clonais. Em 2019 foram distribuídas sementes de teca para Miro Forestry Ghana e Serra Leoa para ensaios de progênie de segunda geração.

9. Sementes de 49 clones de *Gmelina arborea* que foram coletadas em 2018 no pomar clonal Camcore em Forestal Monterrey, Colômbia, foram enviadas para Miro Forestry em Gana e Serra Leoa para o estabelecimento de ensaios de progênie de 2ª geração. Mais sementes da espécie serão coletadas em um futuro próximo para serem enviadas a outros membros no México e no Quênia. Também enviamos mudas enraizadas de 55 clones Camcore de Bogotá, Colômbia, para Miro Forestry, Gana, na África Ocidental.

10. O trabalho de conservação de genes da Camcore nos EUA, financiado pelo Serviço Florestal do USDA, continuou em 2019. Um marco importante foi o estabelecimento de pomares de sementes por mudas de cicuta e pinheiro de Table Mountain. Os pomares foram preparados e definidos no final de 2019, com planos de plantar árvores no início de 2020.

# MUHTASARI WA TAARIFA KUU (Kiswahili)

1. Kampuni mbili zilijiunga na Camcore mnamo mwaka wa 2019: Bracell (Brazil), kampuni shirika ya APRIL (Indonesia), na Araya Bumi Indonesia. Mnamo Septemba, tulifanya mkutano wetu wa kila mwaka huko Ureno, ambapo tuliweka mwelekeo wa kimkakati wa miaka kumi ijayo.
2. Mafanikio mazuri yalipatikana katika miradi ya uzalishaji wa mseto kamili wa pine. Kwenye mradi wa *P. patula x P. tecunumanii*, majaribio ya familia ya kwanza ya familia kamili yalipandwa kutumia vipandikizi vilivyomalizika mwishoni mwa mwaka wa 2019, na uanzishwaji utaendelea hadi baada ya mwaka wa 2021, ikiwa na lengo la majaribio ya vizazi 16. Kwa mradi wa *P. tecunumanii x P. greggii*, miseto imetengenezwa kutoka 2016 hadi 2019, na itaendelea mwaka mmoja zaidi. Mwishowe, mnamo mwaka wa 2019, tulifanya uamuzi wa kufuatilia mseto wa *P. caribaea x P. tecunumanii* kama mradi wetu wa tatu wa uzalishaji kamili.
3. Kazi ya uzalishaji wa mseto wa Eucalypt pia uliendelea mnamo mwaka wa 2019. Katika mradi wa Awamu ya 1, wanachama huko Afrika Kusini, Brazil, Chile, Colombia na Uruguay walianzisha (au walipanda mbegu) kwenye vitalu vya mseto vilivyochaguliwa (HSSB). Majaribio matatu ya kloni ya mseto ya *E. grandis* (na *E. pellita, E. globulus, E. smithii,* na *E. dunnii*) Zilipandwa huko Afrika Kusini; majaribio ya kloni zaidi yatafanyika mwaka wa 2020. Mradi wa Awamu ya 2 ulianza mnamo mwaka wa 2018. Mseto unaotokana na kazi hii utakuwa jenetiki ya Camcore itakayogawanywa kati ya wanachama wote. Michanganyiko mingine ilianzishwa mwaka wa 2019 (kwa mfano, *C. torelliana x C. citriodora, E. pellita x E. grandis*), na michanganyiko mingine ilikamilishwa *(E. grandis x E. urophylla, E. urophylla x E. dunnii, E. dunnii x E. benthamii)*.
4. Tabia ya miundo ya miti ya pine na aina mseto ya eucalypt iliendelea mnamo mwaka wa 2019. Mifano ya vipimo viwili vya mseto wa pine nchini Afrika Kusini viljaribiwa. Msimamo na matokeo yaliyopita, miundo ya miti ya mseto ya *P. patula x P. tecunumanii* inaonekana mizuri sana. Majaribio ya vipimo viwili vya aina ya euclaypt huko Afrika Kusini na vipimo viwili huko Uruguay vilifanywa. Aina za *Corymbia* zinaonekana kuwa na miundo ya miti inayovutia, inaonyesha kiwango cha juu cha uzito, lignin ya chini, na uwiano ya syringyl: guaiacyl lignin ya chini.
5. Utafiti ulikamilika ili kubaini jumla ya chunguzi 427,000 za SNP ili zitumike kwenye safu ya uchunguzi kabla ya utengenezaji wa chipu ya SNP ya kibiashara ya aina ya pine ya kitropiki na pia tropiki ndogo. Chipu ya kibiashara inapaswa kupatikana katikati ya mwaka wa 2020.
6. Kifaa kipya cha skana cha NIR (chombo cha Texas cha DLP NIRscan Nano EVM) kilipimwa na kulinganishwa dhidi ya Foss 6500 ya maabara na kifaa kishikizi cha Sayansi, Thermo Micro-Phazir. Utafiti ulichunguza sifa nne muhimu za uchambuzi zilizopimwa katika nyasi lishe. Aina nzuri zilijengwa na vifaa vyote vitatu, pamoja na Nano ya bei ghali.
7. Mifano za Camcore za eucalypts ulimwenguni zilipanuliwa na kuimarishwa zaidi kwa kuhusishwa kwa sampuli kutoka kwa spishi saba za eucalypt na spishi nne za *Corymbia* ambazo hazikuwakilishwa hapo awali kwenye seti ya data.
8. Baadhi ya matokeo ya kuvutia yamepatikana kutoka kwa majaribio ya kwanza ya pine na eucalypt ya sentinel iliyoanzishwa na Sappi huko Afrika Kusini. Cha kushangaza ni kwamba jaribio la pine *P. greggii* (Kusini) lilionyesha uvumilivu bora kwa duru ya *Fusarium circinatum* kuliko ilivyofanya *P. patula* (iliyo na maisha bora ya asilimia thelathini na sita, 36%, na ukuaji mzuri). Katika jaribio la eucalypt, spishi za *Corymbia* zilionyesha dalili ndogo ya kuingiliwa na wadudu ama kapatwa na magonjwa kuliko aina ya eucalypt. Kwa kuongezea, spishi mbili za eucalypt zilizoathiriwa zaidi na maangamizi ya jani (Teratosphaeria destructans) zililikuwa *E. grandis* na *E. urophylla*.
9. Kufikia mwisho wa mwaka wa 2020, tunatarajia kuwa na chaguzi za teak 215 kutokana kwa majaribio ya Camcore ambazo zitapatikana kwa upimaji wa kloni. Mbegu za teak za majaribio ya kizazi cha 2 zilisambazwa kwenye Misitu ya Miro huko Ghana na Sierra Leone mnamo mwaka 2019.
10. Mbegu kutoka kwenye kloni 49 za *Gmelina arborea* ambazo zilikusanywa mnamo mwaka wa 2018 kutoka kwenye shamba la Camcore la kloni ya mbegu za miti huko Forestal Monterrey, Colombia zilisafirishwa hadi Msitu wa Miro nchini Ghana na Sierra Leone kwa ajili ya uanzishwaji wa majaribio ya kizazi cha pili. Mbegu zaidi za spishi zitakusanywa katika siku za usoni na kupelekwa kwa wanachama wengine huko Mexico na Kenya. Tulisafirisha pia vipandikizi 55 vya kloni za Camcore kutoka Bogotá, Colombia hadi Msitu ya Miro, Ghana magharibi mwa Afrika.
11. Kazi ya utunzaji wa jeni za Camcore za kimarekani, iliyofadhiliwa na Huduma ya misitu ya USDA, iliendelea mnamo mwaka wa 2019. Hatua muhimu ya uanzishwaji wa bustani za mbegu za miche ya hemlock ya mashariki na pine ya Mlima Table. Sehemu za bustani zilitayarishwa mwishoni mwa mwaka wa 2019, na mipango ikawekwa ya kupanda miti mapema mwaka wa 2020.

# *RINGKASAN EKSEKUTIF (Bahasa Indonesia)*

1. Dua perusahaan bergabung dengan Camcore pada tahun 2019: Bracell (Brasil), anak perusahaan APRIL (Indonesia), dan Araya Bumi Indonesia. Pada bulan September, kami mengadakan pertemuan tahunan di Portugal, di mana kami menetapkan arahan strategis untuk sepuluh tahun ke depan.

2. Kemajuan yang baik diperoleh dalam proyek "full-sib" Pinus hibrida Camcore. Untuk proyek *P. patula x P. tecunumanii*, percobaan pertama "full-sib" family ditanam dengan stek berakar pada akhir 2019, dan pembangunan percobaan akan berlanjut hingga tahun 2021, dengan target 16 percobaan uji keturunan hibrida. Untuk proyek *P. tecunumanii x P. greggii*, persilangan telah dimulai dari tahun 2016 hingga tahun 2019, dan akan berlanjut satu tahun mendatang. Akhirnya, pada tahun 2019, kami memutuskan untuk melanjutkan *P. caribaea x P. tecunumanii* hibrida sebagai proyek perbanyakan "full-sib" ketiga kami.

3. Kegiatan perbanyakan Eukaliptus hibrida juga berlanjut pada tahun 2019. Dalam proyek Fase 1, anggota di Afrika Selatan, Brasil, Chili, Kolombia dan Uruguay membangun (menabur benih ) blok seleksi pembibitan hibrida (BSBH). Tiga percobaan klonal *E. grandis* hibrida (dengan *E. pellita, E. globulus, E. smithii,* dan *E. dunnii*) ditanam di Afrika Selatan; uji yang lebih banyak akan ditanam pada tahun 2020. Proyek Tahap 2 dimulai pada tahun 2018. Hibrida yang dihasilkan dari proyek ini adalah materi genetik Camcore yang dibagikan ke semua anggota. Pada tahun 2019, beberapa persilangan mulai dilakukan (misalnya, *C. torelliana x C. citriodora, E. pellita x E. grandis*), dan beberapa persilangan telah diselesaikan (*E. grandis x E. urophylla, E. urophylla x E. dunnii, E. dunnii x E. benthamii*).

4. Karakterisasi sifat kayu untuk Pinus hibrida dan spesies Eukaliptus berlanjut pada tahun 2019. Dua uji Pinus hibrida di Afrika Selatan diambil sampelnya. Konsisten dengan hasil sebelumnya, sifat kayu hibrida *P. patula x P. tecunumanii* terlihat sangat baik. Dua uji spesies Eukaliptus di Afrika Selatan dan dua uji di Uruguay diambil sampelnya. Spesies Corymbia tampaknya memiliki kelayakan kayu yang menarik, menunjukkan kerapatan yang tinggi, rendah lignin, dan rasio syringyl: guaiacyl lignin yang rendah.

5. Penelitian untuk mengidentifikasi total 427.000 SNP "probe" yang akan digunakan pada "array " skrining sebelum produksi chip SNP komersial untuk spesies Pinus subtropis dan tropis telah diselesaikan. Chip komersial harus tersedia pada pertengahan tahun 2020.

6. Perangkat baru pemindai NIR (Texas Instruments DLP NIR scan Nano EVM) telah diuji dan dibandingkan dengan Foss 6500 berkualitas laboratorium dan Thermo Scientific micro-Phazir genggam. Studi ini meneliti empat sifat analitik penting yang diukur pada rumput hijau. Model yang bagus dibangun dengan ketiga perangkat, termasuk Nano yang murah.

7. Model NIR global Camcore untuk Eukaliptus diperluas dan dibuat lebih kuat dengan memasukkan sampel dari tujuh spesies Eukaliptus dan empat spesies Corymbia yang sebelumnya tidak diwakili dalam kumpulan data.

8. Beberapa hasil menarik telah diperoleh dari percobaan "sentinel" pinus dan Eukaliptus pertama yang dibuat oleh Sappi di Afrika Selatan. Kejutan dalam uji coba pinus adalah bahwa *P. greggii* (Selatan) menunjukkan toleransi yang lebih baik terhadap *Fusarium circinatum* dibandingkan dengan *P. patula* (dengan kelangsungan hidup 36% lebih baik, dan pertumbuhan yang sangat baik). Dalam uji coba Eukaliptus, spesies Corymbia menunjukkan insiden hama / penyakit jauh lebih sedikit daripada spesies Eukaliptus. Selain itu, dua spesies Eukaliptus yang paling terkena dampak hawar daun "Destructans" (*Teratosphaeria destructans*) adalah *E. grandis* dan *E. urophylla*.

9. Pada akhir 2020, kami berharap memiliki sekitar 215 Jati pilihan dari uji coba Camcore yang akan tersedia untuk uji klon. Bibit Jati untuk percobaan generasi ke-2 didistribusikan ke Miro Forestry Ghana dan Sierra Leone pada tahun 2019.

10. Benih dari 49 klon *Gmelina arborea* yang telah dikumpulkan pada tahun 2018 dari kebun benih klon Camcore di Forestal Monterrey, Kolombia dikirim ke Miro Forestry di Ghana dan Sierra Leone untuk pembangunan uji coba keturunan generasi ke-2. Benih spesies yang lebih banyak akan dikumpulkan dalam waktu dekat untuk dikirim ke anggota lain di Meksiko dan Kenya. Kami juga mengirimkan stek berakar dari 55 klon Camcore dari Bogotá, Kolombia ke Miro Forestry, Ghana di Afrika Barat.

11. Pekerjaan konservasi genetik Camcore AS, yang didanai oleh USDA Forest Service, berlanjut pada tahun 2019. Tonggak pentingnya adalah pembentukan kebun benih semai Hemlock timur dan Pinus "Table Mountain". Lokasi kebun disiapkan dan ditata pada akhir 2019, dengan rencana penanaman pohon pada awal 2020.

# Message From the Director

Camcore completed its 39th year in 2019, and it was a productive year in breeding, research, and planning.

Every year, we are more convinced that hybrids will play a huge role for forest industry around the world, and we continue to expand our work in pine and eucalypt hybrids. We have two ongoing full-sib pine hybrid breeding projects, with *P. patula x P. tecunumanii* and *P. tecunumanii x P. greggii*, and in 2020, we will begin a third project with *P. caribaea x P. tecunumanii*. The first clonal eucalypt hybrid trials from a Camcore project were planted in 2019, and we are actively working toward more than 25 hybrid combinations for the second phase of that work. In the long term, we will need to understand the quantitative genetics of hybrids in order to optimize our breeding and deployment strategies. We have begun that work with one of our Camcore graduate students, Luis Ibarra, who is studying the quantitative genetics of three different tree hybrids (one pine and two eucalypt combinations).

Another important development for the future is the advent of new molecular tools that can be used in operational breeding programs. Our work in collaboration with the Forest Molecular Genetics group at the University of Pretoria to develop a tropical pine SNP chip has been very productive. We are confident that the end result will be a multi-species 50K SNP chip, and that it should be commercially available by mid-2020. The tropical pine SNP chip, and similar chips for other tree species (e.g., *P. taeda*, *P. radiata*, and multiple species of eucalypts) are available to all Camcore members at a discounted (and very affordable!) price. These tools will have applications in hybrid verification, population genetics, and genomic selection. Genomic selection methodologies will not be economically viable in all situations, but for large-scale breeding and plantation programs, there will definitely be useful applications. We are currently working closely with three Camcore members to help them develop cost-effective applied genomic selection projects in their internal breeding programs.

Lastly, a major accomplishment in 2019 was the strategy planning done at the Annual Meeting in Portugal. We reaffirmed that the four main working areas or themes of Camcore activities would continue to be of importance for the next ten years: Breeding and Genetic Improvement, Species Characterization, Development of Enabling Technology, and Gene Conservation. We also identified a need for Education and Training, specifically in the area of breeding and quantitative genetics. We prioritized research areas for the future, and there was a consensus that climate change and forest health issues will become more pressing in the future. This points to an important role for Camcore in providing guidance and assistance to members in this area.

Two companies joined Camcore in 2019. One is Bracell in Brazil, which owns land in both Bahia and São Paulo states, and grows eucaltypts for kraft and dissolving pulp. The other new company is Araya Bumi Indonesia (ABI), a part of the Djarum group. ABI is a young company operating in four regions of Kalimantan, and currently planning to produce eucalypts and *Acacia* for solid wood products. The forest industry is competitive, and sometimes we lose good Camcore members due to economic or political difficulties. But our 39-year history has been one of slow, steady growth (like a forest!), and we see opportunities for additional new members in southeast Asia and some parts of Latin America.

All of us on the Camcore staff are excited about the future. The work is interesting, challenging, and fun, and it has value for our members, for the environment, and for the world. It's hard to imagine a better job.

Gary Hodge, Director

A rainy day in a forest genetics trial is better than a dry day in the office!

# 2019 Camcore Membership

## Active & Associate Members

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

**Brazil**
- ArborGen do Brasil (Associate) 2013
- Bracell 2019
- Klabin, SA 1987
- WestRock Brazil 1993

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

**China**
- Guangdong Academy of Forestry (Associate) 2013

**Colombia**
- Smurfit Kappa Colombia, SA 1980

**Ghana**
- Miro Forestry Ghana 2017

**Indonesia**
- APRIL Indonesia 2018
- Araya Bumi Indonesia 2019
- Sinarmas 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

**Uruguay**
- Montes del Plata - EuFores SA 2006
- Lumin 2019

**Venezuela**
- Masisa Terranova de Venezuela, SA 2000

## 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 2019 Annual Meeting in Portugal

Camcore gathered in Porto, Portugal from September 3rd to 11th for the 2019 annual meeting, marking our 39th year as a global leader in the breeding and conservation of forest genetic resources for the benefit of industry, society, and the environment. This year's meeting was divided into three parts; two days of technical sessions, two days of strategy sessions, and two days of field tours to learn about forestry operations and tree breeding in Portugal. It was attended by 31 participants and 6 spouses representing 13 countries and 17 active and 2 associate members. This was Camcore's second annual meeting in Europe with one previous meeting being held in Sweden in 2017.

The meeting opened on September 3rd with the executive and technical committee meetings followed in the evening by a welcome dinner at Pateo da Mariquinhas Casa de Fados. Here participants had their first opportunity to sample Portuguese fare, including the traditional salt cod stew Bacalhau. We were also treated to a performance of the traditional Portuguese music known as Fado. Distinguished by its expressive and profoundly melancholic tones and lyrics, Fado is considered the musical expression of the resignation and hopefulness of the Portuguese people as they navigate the realities of everyday life.

The following morning began the first of two days of technical sessions. After a brief welcome and introductions, Camcore Director Gary Hodge opened the session with his annual "State of Camcore" address. This was followed by a series of presentations by Camcore staff that reviewed progress made over the past 10 years in a number of important research areas. Gary Hodge and Juan Lopez reviewed pure species and hybrid breeding of pines and *Eucalyptus.* Juan also presented an update on the testing of teak and *Gmelina.* Juan José Acosta reviewed progress made on pine and *Eucalyptus* wood properties, the testing of new NIR devices, and the development of R-code to streamline NIR modeling and genetic test analysis. Robert Jetton reviewed a number of topics broadly classified as silviculture, including studies on disease and frost resistance, species-site matching and adaptation to climate change, and nutrition. We also heard research updates from several Camcore members. Gert van den Berg and Andre Nel from Sappi reviewed the company's hybrid deployment strategy and progress with sentinel trials. We also heard from Gabriel Dehon Rezende of Bracell who shared an update on research to understand the etiology of a widespread physiological disturbance impacting *Eucalyptus* in Brazil and the deployment of clonal composites to improve plantation sustainability in a changing world. The session closed with an interesting talk by Claudio Balocchi on Arauco's plan for the release and deployment of its *E. globulus* x *E. nitens* (GloNi) clones to private forest owners to improve overall plantation productivity in Chile.

Day two of the technical sessions continued with 10-year reviews by Camcore staff on a number of special research projects, gene conservation efforts for pines, *Eucalyptus*, teak, and *Gmelina*, R and Excel trainings provided by Camcore, and Camcore's domestic conservation and restoration project in the United States. We also reviewed more recent projects on SNP chip development, genomic selection pilot projects, and genetic material sterile transfer. Although much of what we did during these technical sessions was looking back, we also took the opportunity to look forward with Gary Hodge providing an intriguing overview of

Kellen Gatti (Bracell Bahia) and Gisela Andrejow (WestRock Brazil) with an impressive specimen of *Eucalyptus botryoides* in the 19th Century arboretum at Raiz.

the potential for integrating ground-based Lidar imaging into tree improvement to streamline data capture and quality. The technical sessions closed with our first opportunities to learn about forests and forestry operations in Portugal. João Pinho from Instituto da Conservação da Natureza e das Florestas (ICNF) provided an overview of the forest biomes of Portugal including land cover types, ownership statistics, species versatility, productivity, and conservation. He was followed by his colleague Francisco Goes from the Portuguese Pulp and Paper Industry Association (CELPA) who discussed the history of *Eucalyptus* plantation forestry in Portugal and recent outreach efforts to improve the management and productivity of plantations throughout the country.

The next morning we began two days of strategy sessions. The strategy sessions are a special event within Camcore that are held once every 10 years to discuss and set a roadmap for the future direction of the program. This year we were pleased to have long-time friend of Camcore Dr. Barry Goldfarb lead our strategy discussions. Barry is a former Department Head of Forestry and Environmental Resources at N.C. State, and his familiarity with Camcore, tree improvement, and plantation forestry allowed him to effectively facilitate these sessions. Our discussions focused on seven key topics: Camcore strengths, weaknesses, and opportunities for improvement, prioritization of new *Eucalyptus* species, establishment of Camcore gene banks and seed orchards in Colombia, Camcore membership categories, opportunities with *Acacia*, future research priorities, and Camcore staff needs and skills. Outcomes from these strategy discussions are summarized in this annual report (pages 11-13). Following the end of the final strategy session a short closing business meeting was held where we reviewed the Camcore budget, elected new members to the executive committee (see Changes in Camcore), and made plans for the 40th Anniversary celebration in Raleigh in 2020.

With the technical and strategy sessions complete, everyone enjoyed a well-earned day off to explore the history, architecture, and culture of Porto. Some of the more popular activities during the day were boat tours along the Douro River to view the city's riverfront and distinctive bridges, tours and tastings at one (or more) of the many port wine caves, visits to the beach and botanical garden, and shopping along Rua de Santa Catarina, Porto's most famous pedestrian thoroughfare. Of particular note among many meeting attendees was visiting the Livraria Lello bookshop whose neo-gothic interior design and distinctive staircase were the inspiration for Harry Potter's library in the eponymous movie series. Some ended the afternoon with a café stop to enjoy a coffee and Pastel de Nata, the traditional Portuguese custard tart.

Mike Cunningham (ArborGen do Brasil) , Ricardo Austin (Arauco Argentina), Mario Ladeira (Klabin), and André van der Hoef (Sinarmas Forestry) observing *Eucalytus globulus* cuttings in Altri's Furadouro Nursery.

Recharged, we spent the next two days on field tours in order to see Portuguese forestry first hand. Day one was hosted by **The Navigator Company** and **Raiz**, the research and development arm of Navigator. We started with a stop at the Raiz R&D center where we heard presentations by Nuno Borralho and João Melo Bandeira on the overall structure of Navigator, the mission and research focus areas of Raiz, and the ecological context for the planting of *Eucalyptus* in Portugal. Following a short coffee break we enjoyed a tour of the Raiz laboratory facilities where we learned about their wood and paper characterization projects and phytosanitary research. The morning was capped off by a visit to a nearby *Eucalyptus* arboretum established in the late 19th century where attendees appreciated some truly impressive specimens of several important commercial species. The afternoon included field stops to observe Navigator's forestry operations, see tree breeding trials, and learn about the decision support tool the company uses to classify sites for species deployment. The day ended with a stop to learn about forest fire protection efforts in Portugal and interact with one of the helicopter-based firefighting teams. Forest fires are of increasing importance in Portugal with up to 350,000 ha burned annually in recent years, including several large fires that were active during our visit to the country.

After returning to Porto for the night, we departed early the next morning for the second day of field tours hosted by **Altri Florestal.** Our first stop was the Furadouro Research Center where Luis Fontes and his colleagues gave indoor presentations about Portuguese forestry, the structure of the Altri Group and Altri Florestal's role within the larger company, their efforts in forest protection from insects, disease, and forest fires, and their commitment to maintaining biodiversity and conserving patches of native forest within their land holdings. After lunch we made a series of field stops to see *Eucalyptus* seed orchards, hybrid trials, and one of the company's biodiversity conservation stations. The day ended with a visit to Altri's Viveiros do Furadouro Forest Nursery led by nursery manager Ivone Neves. The nursery produces some 8 million seedlings and cuttings each year for the company's use and private customers. Approximately 75% of the production is focused on *Eucalyptus* species and hybrids, with the remaining 25% consisting mostly of native tree species for various reforestation and conservation purposes.

On our return trip to Porto for the evening we stopped at the São João Winery and Restaurant for an excellent farewell dinner that included opportunities to taste and enjoy some of the fine wines and ports produced there. We all departed Porto the next morning with renewed friendships, strengthened partnerships, an appreciation for Portuguese forestry, and confidence for the future of Camcore and the important work we all do together.

Meeting participants and spouses pause for a group picture in a *Eucalyptus* seed orchard at Altri Florestal.

# Overview: Camcore Strategy 2020-29

Two full days of the 2019 Annual Meeting in Portugal were dedicated to strategy discussions to guide our work for the next ten years from 2020 to 2029. We went through a similar exercise in 2010 in Brazil, and it was productive and useful. The goals we set for ourselves in 2010 provided focus for our research and breeding efforts, and we made good progress on almost all of them. So it made sense for us to do this again in 2019.

Barry Goldfarb, former Head of the Department of Forestry & Environmental Resources, and long-time friend of Camcore acted as moderator for the strategy meeting, guiding, prodding and shepherding us through two intense days. Meeting participants were divided in five groups for breakout discussions, followed by sessions where the breakout groups reported back to the whole body. The five groups were named after the South African Big 5, with the animals randomly assigned; however, each group was made up of participants from member companies with similar environments and commercial species. We began with an analysis of strengths and weaknesses, followed by discussions of membership policy, genetic material use policy, new eucalypt species, and research priorities. We also discussed the skills and staffing necessary to address our breeding and research priorities. Here we will provide a brief summary of some key findings and conclusions.

## Eucalypt Species Prioritization

One of the important tasks was to develop priorities for Camcore efforts for collections of genetic material from 2020 to 2029. We actually began this work in 2018, commissioning Jakob Butler and Brad Potts of the University of Tasmania to develop a list of lesser-known but promising *Eucalyptus* species that we should consider. Jakob and Brad produced an excellent report entitled “More Than a Score: 21 eucalypt species with plantation potential”. In Portugal, we set aside a major breakout session to discuss these species. It became clear that there was interest not just in the 21 "new" species, but also in perhaps expanding our collections of some species we already have in the Camcore portfolio (e.g., *E. benthamii* or some *Corymbia*), or adding some important commercial species that Camcore does not have (e.g., *E. tereticornis*). We then collectively ranked the species with an exercise where each member company allocated "coins" of different denominations to seven species of interest: one \$5 coin to their highest priority species, three \$3 coins to three other species, and three \$1 coins to species of interest, but lower priority. Each member then explained why they prioritized the species in that way, i.e., what traits that species might offer that would be valuable either in pure species or hybrid combinations, e.g., drought, cold or frost tolerance, adaptation to high temperature, high humidity, or extreme pH, resistance to particular disease threats, or wood properties of interest.

After compiling all rankings, we now have a smaller set of around 12 species that will be our focus for the next few years. Several of these species have wood properties of interest, and several have potential on very harsh soils. The species are adapted to a range of environments, from the wet tropics and subtropics to cold temperate sites, so every member will have interest in at least some of these 12. Our next step is to begin evaluating what opportunities we have to make collections -- where, when, whether we can find improved material, and how much it will cost. Following the receipt of the Butler and Potts report, we had already begun some enquiries in 2019, and at the end of 2019, we made collections of one of the highly ranked species, *E. amplifolia*, from a breeding program in the southeast USA (see article on page 48).

## Gene Banks in Colombia

In May 2018, NC State University and the Universidad Nacional de Colombia (UNAL) signed a memorandum of understanding aimed at promoting collaborations and exchanges between the two universities. UNAL is a public and national research university in Colombia. It is the largest university in the country with more than 53,000 students, and with a Department of Forestry training foresters since 1951. We discussed an opportunity to establish long-term gene conservation banks and breeding orchards on UNAL lands. This would allow us to conserve our most important genetic material, establish trials, and conduct research, etc. In addition, we can collaborate with UNAL faculty, and graduate and undergraduate students in teaching, training and research. Participants in the strategy meeting considered this a good opportunity, with potential for long-term benefit to Camcore, and little downside risk. We will pursue this further and develop a workplan in 2020.

## Education and Training

An important theme that emerged during the meeting was the worldwide decline in university-level forest genetics training. Many members expressed concern about the difficulty of recruiting trained breeders and/or training young forest researchers in the critical areas of forest genetics. The participants believe that Camcore and NC State University may be able to help address this situation by making "training and development" a more formal component of our activities. This could involve more on-site short courses and training, or perhaps development of on-line training modules in various aspects of forest genetics and tree breeding.

## Research Priorities

A major task in our meeting was to outline research priorities for the next ten years. Over the past 10 or so years, we have done a tremendous amount of work in the areas of wood property characterization for eucalypt species and pine hybrids. Some of this work will continue, but we think we can address some other topics as well. In Portugal, we spent one session brainstorming about possible topics, and came up with a list of 36 different ideas. Each of the 25 participants then voted for 10 of those ideas as higher priority. When all the ballots were tallied, there were 251 votes (so someone voted 11 times!), but we felt that we had a good indication of the group's interest. Some specific themes emerged that were generally given high priority.

*Ground Lidar for Phenotyping*

Airborne lidar is becoming more and more commonly used for forest inventory, both for academic research and in forest industry planning departments. A similar technology, ground lidar (or terrestrial lidar) may have utility for very accurate phenotyping of genetic trials. There may be

The research farm at Paysandu, one of three such farms belonging to the Universidad Nacional de Colombia (UNAL). We hope to develop a long-term agreement with UNAL to conserve and breed important Camcore genetic material.

opportunity to reduce cost and time of trial measurements. Perhaps of even more interest, there may be opportunity to vastly improve our measurements of tree form and usable timber volume using this technology.

*Hybrid Breeding Research*

There were three research topics identified related to hybrid breeding:

- Crossing compatibility among eucalypts and corymbias.
- Further work on new and promising pine hybrids.
- Commercial delivery of pine hybrids by F2 seed.

*NIR Research*

In the area of NIR, there was interest and excitement over the promising results using the Texas Instrument Nano device (see article in this report on page 42). Two research topics of interest involving this new device were identified:

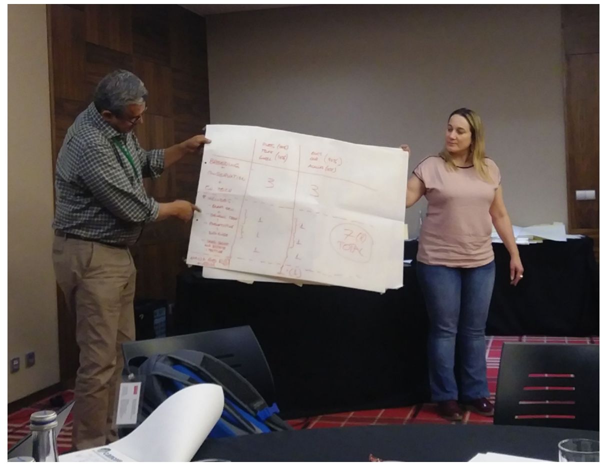
- Transferring wood chemistry models from the Foss 6500 to the Nano.
- Testing the Nano for utility to predict foliage nutrient status, and for species/clone discrimination.

*Literature reviews to identify new species*

The Butler and Potts report on 21 eucalypt species has been well received and is considered to be very helpful. Participants thought that we should produce similar reports on other genera, including *Pinus, Corymbia,* and *Acacia.*

*Climate Change and Forest Health*

Lastly, there were a number of highly-rated topics that are all related to climate change. We are not interested in doing climate change research specifically, rather our interest is in species-site matching, and growth-and-yield projections in response to climate change. We need to be able to use our data on different species tested in diverse climates around the world to understand what are the potential impacts, and to direct how we respond in our breeding programs. There was also a strong consensus that forest health issues will become more pressing in the future, and there is a clear need for Camcore to provide guidance and assistance to members in this area.



Gabriel Dehon Rezende of Bracell and Regiane Abjaud Estopa of Klabin give feedback from the Elephant group to the whole meeting regarding long-term Camcore staffing needs.

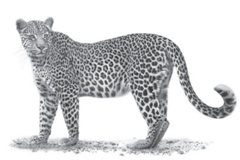
**Staff and Skills**

Finally, we discussed characteristics, skills, and experience we need in our staff to be able to accomplish all that we hope. Forestry is a complex profession requiring some level of knowledge and expertise in silviculture, biology, chemistry, soil science, management, and business. Camcore is in the business of forest genetics, so all of us on staff must be, to some extent, "jacks of all trades". We clearly need Camcore staff members with excellent skills in tree breeding, quantitative genetics, molecular genetics, and forest health. We also need to know something about wood properties, plant physiology, statistics, and nursery management, and it is important to have experience or familiarity with industrial plantation forestry. We also need excellent skills in teaching and communication, and in oral and written communication in both formal and informal situations. Most groups indicated that we might need 6 to 7 specialist positions within Camcore (not including the director) to properly address our needs -- this would be a significant expansion of the staff.

In addition, just as important as the technical skills mentioned above, there is an array of human or personal skills needed: an awareness of international cultures and differences, a willingness to travel, a sense of adventure, flexibility and adaptability, a constant desire to learn, the ability to work as a team member, leadership, vision, and a passion for our work. That is a long, and perhaps somewhat daunting list. But it does give us something to strive for each day, and will help us plan for the future.

After four days of meetings (two days of normal annual meeting business, followed by two days of strategy discussions), one of our breakout groups closed our final session with a brief statement summarizing their thoughts on Camcore's past ten years, and our plans for the next ten years: "We're happy!". The entire Camcore staff would like to express thanks to the Advisory Board and our member companies. It is a privilege to be able to do this work. We look forward to the next ten years.




# 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

Gary Hodge visited **Arauco Argentina** (AA) in February. We are still very excited about the potential of the *P. caribaea* var. *hondurensis* x *P. tecunumanii* (low elevation) hybrid (CAR x TEL) in the Misiones region. Data indicate that this hybrid produces almost 40% more volume than *P. taeda* at age 8 years. Arauco will aggressively pursue the CAR x TEL hybrid going forward. We outlined a grafting plan for CAR to develop low-height breeding orchards similar to what the company has for *P. taeda* and *P. tecunumanii*. Arauco will continue to develop its *P. taeda* somatic embryogenesis crossing program, and we discussed strategies to eventually produce new SE clones that will outperform the ones currently being used commercially. Another development of interest is the excellent growth of *E. amplifolia* in the delta region of the Rio de la Plata. We are working to assist AA in the purchase of seed for pilot-level commercial deployment.

Germán Raute in the Arauco Argentina clone bank of *P. caribaea* var. *hondurensis* at Puerto Segundo. The trees are 20 years old and are too tall for breeding, so they will be grafted into a low-height breeding orchard in order to make hybrid crosses.

Kellen Gatti in the Bracell *Eucalyptus* breeding orchard that will contain some 1300 mother plants from many species.

### Brazil

Camcore staff visited Brazil in May. Gary Hodge and Juan Lopez visited new member **Bracell** in Bahia. The company has around 90,000 ha planted, with a planned rotation age of between 5½ to 6 years, and a product objective of both kraft and dissolving pulp. About 70% of the landbase can be classified as "Dry", with precipitation between 500 and 700 mm, and 30% as "Wet" with precipitation between 1600 and 1800 mm and much better growth. However, both land types have a 7- to 8-month dry season, so *E. pellita* will play an important role, either as a pure species or as a hybrid partner. Bracell is part of the RGE group, along with sister company APRIL (Indonesia), and there is a large RGE group corporate breeding orchard at Bracell where the company will do a huge proportion of the eucalypt crossing for RGE. Currently, the orchard has some 400 mother plants of different eucalypt species (e.g., *E. pellita*, *E. urophylla*, *E. tereticornis* and *E. camaldulensis*), with a goal to increase to 1,300 mother plants. Bracell has made some 2000 phenotypic selections of *E. urophylla* genotypes on dry sites based on growth and form. We discussed options to evaluate all 2000 trees for wood chemistry using NIR prior to field testing.

Gary Hodge and Juan José Acosta visited **Klabin**, which is planning an expansion of mill capacity from around 1.5 million tons per year currently to 2.5 million tons per year. To help provide wood for the long term, Klabin is looking to acquire up to 70,000 ha of additional land. In the area of pine breeding, Gary and Juan José are helping Klabin with genomic selection projects for both *P. taeda* and *P. maximinoi*. These two species are the primary commercial pine varieties for Klabin, although pure *P. tecunumanii*, *P. patula* x *P. tecunumanii*, and *P. greggii* x *P. tecunumanii* may all have potential for the future. Within the eucalypt program, we discussed opportunities to streamline the clonal testing program to allow for larger numbers of clones to be screened for growth and wood properties.

Gary and Juan José also visited **WestRock.** The topic of genomic selection (GS) was a main point of our discussions there, and we are helping WestRock with a project to develop GS models specific to a population of 5 full-sib *P. taeda* families that are being used for commercial plantations. Currently, the full-sib seed is produced through controlled pollination and multiplied by vegetative propagation. The idea is to identify the better seedlings in each family with GS, and increase gain by only multiplying the superior genotypes.

Mara Engel, Gisela Andrejow, and Waldemar Da Veiga (WestRock) with one of the top full-sib families of *P. taeda*. This family is part of a research project examining if genomic selection can identify the best trees within the full-sib family for deployment into commercial plantations.

In 2019, DNA sampling was done on 384 progeny relevant to one full-sib family, and analysis is underway to calibrate GS models for growth and wood traits. In the area of eucalypt improvement, we discussed the WestRock *E. benthamii* testing and selection program, and the establishment of a new *E. benthamii* seed orchard.

### Chile

Gary Hodge and Juan Lopez visited **Arauco Bioforest** in Chile in April. We discussed a number of issues related to the Arauco pine and eucalypt breeding programs. Arauco Chile cooperates with Arauco Argentina in the development of SE clones of *P. taeda*, and we discussed using genomic selections to pre-screen clones prior to field testing. Arauco is also interested in importing green cones of *P. tecunumanii*, *P. maximinoi*, and *P. oocarpa* to begin preliminary research on somatic embryogenesis protocols.

The Arauco breeding program with *E. globulus* x *E. nitens* (GloNi) hybrids has been tremendously successful. After 17 years of breeding and testing, they have identified several GloNi clones that grow as fast as *E. nitens* but have the wood properties of *E. globulus*. Looking to the future, and considering mill expansions, Arauco estimates that around 40% of their mill furnish will come from third-party landowners, and these lands are typically planted with lower-quality genetic material, i.e., slower growing and with inferior wood properties. Arauco has made a very interesting strategic decision to release a set of 5 outstanding GloNi clones to private nurseries, with the idea to sell high-quality genetic plants to third-party landowners. Arauco reckons they will benefit by being able to feed their mill with lower-cost, higher-quality wood. In September, Gary and Juan José met with Christian deVeer and Jaime Zapata in Raleigh, where we reviewed their analytical process used to calculate BLUPs in the Arauco Chile *Eucalyptus* genetic program.

### Colombia

Juan José Acosta and Robert Jetton visited **Smurfit Kappa Colombia** in March 2019. Two days of field visits to La Cumbre, Sinai, and La Suiza focused primarily on pine trials. We visited provenance-progeny trials of *P. oocarpa*, 2nd generation trials of *P. tecunumanii* LE, the *P.*

*tecunumanii* LE hedge recycling study, the *P. tecunumanii* LE clonal seed orchard at La Cumbre, and the pine hybrid trials at Sinai and La Suiza. Field discussions centered on topics related to the movement of selections into clonal conservation parks or breeding areas, the value of including phytosanitary assessments as part of routine data collection in breeding trials, ideas for adding value with studies on wood properties and silvicultural management after trials have fulfilled their purpose for Camcore, and the potential of the *P. greggii* (S) x *P. tecunumanii* hybrid for Camcore members in South America. A common theme among many of these studies is the continued outstanding performance of *P. maximinoi* where it is included as a control, and we continue to encourage SKC to give priority to increasing plantation deployment of this species. The visit ended with a day of indoor meetings to discuss strategic activities for tree breeding and forest health research at SKC. We also discussed opportunities for SKC to integrate SNP-chip technology into its clonal eucalypt breeding program, to do quality control in seed orchards, to optimize production of cuttings for pine family forestry, and to conduct research on the establishment and management of pine breeding areas. Discussions on forest health focused on the current status of laboratory and field screening studies designed to determine the relative resistance and susceptibility of several eucalypt species to pathogens of concern to Camcore members, and the structure of the SKC Forest Health Protection Program. Carlos Rodas and his team have graciously agreed to allow this program to serve as a model for Miro Forestry who is working towards the implementation of its own forest health monitoring program in Ghana and Sierra Leone.

### Ghana and Sierra Leone

Juan José Acosta and Robert Jetton visited **Miro Forestry** in Ghana and Sierra Leone in June 2019. We had the opportunity to visit Camcore provenance-progeny trials of *E. urophylla*, *E. pellita*, and *E. camaldulensis*, as well as a number of other non-Camcore trials of *urograndis*, *Corymbia citriodora*, *Gmelina arborea*, *Acacia mangium*, and *Tectona grandis*. These visits inspired fruitful field discussions on the purpose of trial designs, data collection schedules, and future use of the trials for seed production and/or clonal selections.

Charlie Bosworth (left) and Menason Essakku (right) of Miro Forestry Ghana, with Robert Jetton (center) from Camcore in a 2-year-old clonal *Eucalyptus* test.

We discussed the possibility of adding value to some trials by using them for pruning and fertilization studies and assessing genotype susceptibility to pests and pathogens. Although the field days were long, it was great to see the progress Miro is making in its species testing program that is helping the company to focus on those species and genotypes best suited for their environments for future commercial production. We also visited the company's nursery facilities in both countries and provided advice on managing clonal hedges and optimizing propagation protocols for rooted cuttings. Noteworthy was the excellent job Menason and his team in Ghana have done establishing hedges for 55 improved *Gmelina arborea* clones selected from Camcore trials in Colombia that were transferred to Miro for testing in Ghana and Sierra Leone. Indoor meetings during the visits focused on two topics: the development of breeding roadmaps to help Miro to track progress in its tree improvement programs, and the design and structure of the forest health monitoring program the company will utilize to begin building a database of known and potential pest and pathogen threats to plantations.

## Indonesia

Gary Hodge and Juan José Acosta visited three members in Indonesia in July. This included the first trip to **Araya Bumi Indonesia** (ABI) since the company joined Camcore in early 2019. ABI is a young company, but it has a strong and enthusiastic research team. Good progress has been made by the team in a number of research areas, as well as in the breeding program. In 2019, the company made its first harvest of improved seed from its own seed production areas and seedling seed orchards of *E. pellita*, *Acacia mangium*, and *A. crassicarpa*. A set of 39 *E. pellita* clones has been established in two clonal trials. More than 300 additional selections have been made and can be included in clonal tests in the future. We outlined a plan to send Camcore families of *E. urophylla*, *E. pellita*, *E. brassiana*, and *E. longirostrata*, and in 2020, we plan to send families of *Corymbia citriodora*, *C. maculata*, and *C. torelliana*.

The 2019 visit to **Sinarmas Forestry (SMF)** was to their project in Kalimantan. The soils in this region are mineral soils, and much better suited to eucalypts than to acacia, so our focus was on visiting various *Eucalyptus* clonal trials: row-plot trials, block-plot trials, and commercial plantations. In this region, eucalypts face challenges from numerous pathogens, including bacterial wilt disease (BWD) caused by a *Ralstonia* species. SMF has been developing protocols to do artificial screening for BWD, and we discussed options to refine the techniques and modify the testing design to increase the number of clones that can be screened. Camcore undertook a special BLUP analysis of some SMF clonal eucalypt trials planted in all of their operating regions. There were 200 tests that were classified based on soil type (Mineral, Clay and Peat), with growth data ranging from 1 to 5 years old. Both survival and growth data were used in a meta-analysis to identify a small set of clones with high commercial potential for each soil type.

The Araya Bumi Indonesia research team in a 7-month-old *E. pellita* clonal trial. The tree in the photo is the #5 ranked clone out of 39 clones in the test, based on 6-month data.

The 2019 visit to **APRIL** was to their project in the Lake Toba region on Sumatra. This region is higher elevation than most of the other forestry areas in Indonesia, so *E. grandis* (and hybrids), along with other species, play a bigger role than in the low elevations where *E. pellita* and *Acacia* species are the primary options. There is a very good collection of *Eucalyptus* genetic resources here, e.g., *E. grandis*, *E. dunnii*, *E. urophylla*, *E. camaldulensis*, etc. Much of this material was collected and developed over many years by Paul Clegg, who we had the pleasure to meet on this visit. Even with a milder climate, the disease challenges in this part of Sumatra are still significant. We saw examples of clones that had been selected and were performing well in operational plantations for 5 to 10 years suddenly show disease susceptibility, very low survival, or very poor growth. This may reflect changes in climate and/or introduction of new pathogens. We discussed the use of clonal mixes in operational plantations as an option to mitigate risk.

Also of interest is that in addition to eucalypts and *Acacia*, we saw quite a few pines on this visit. With APRIL, we saw plantations of *P. merkusii*, a species native to Sumatra, as well as trials of *P. oocarpa* and *P. tecunumanii*, and it is clear that pines can certainly survive and grow well here. We also saw an old species trial of three varieties of *P. caribaea* and *P. merkusii* on Kalimantan as part of the SMF visit. Both APRIL and SMF expressed some interest in pines, so we may look for opportunities to do small projects in this area in the future.

We now have three member companies in Indonesia and we think there are opportunities to attract other organizations to join as well. All three current members sent representatives to the Annual Meeting in Portugal, and we discussed plans for our first regional meeting in Indonesia in 2020. We also hope to identify regional research or breeding projects that we can collaborate on in the future.

APRIL and SMF both hosted Data Management Workshops in May. The classes were held at the companies' research facilities and each had 14 participants. It was Willi Woodbridge's first class in Indonesia (see article on page 52 in this report).

### Kenya

The **Kenya Partnership** is a joint Camcore membership formed by the **Kenya Forest Research Institute** (KEFRI)**, Kenya Forest Service** (KFS), and the **Tree Biotechnology Programme Trust** (TBPT). The group is working with Camcore on several research projects, including controlled pollination of pines and eucalypts. With pollen provided by Camcore, the Kenya Partnership plans to make crosses to obtain seeds of *P. patula* x *P. tecunumanii*, a hybrid with great potential in the country. Second generation block plots of the hybrid should be established with seeds to be collected from selected trees in the Camcore hybrid trial in Muguga, Central Province. KEFRI, KFS and TBPT are also involved in a Camcore project to produce and receive seeds of *Eucalyptus* hybrids and are committed to produce seeds of *E. urophylla* x *E. camaldulensis*. The pollen of the male trees will be collected by themselves to make crosses with female grafts of *E. urophylla* grown in the TBPT nursery. Pine and eucalypt hybrids have great commercial potential for tree farmers in Kenya, increasing productivity and complementarity of traits between species.

### Mexico

In July, Juan Lopez visited **Proteak** in Mexico. The company has made progress in several Camcore projects: teak testing and breeding, eucalypt hybrid crossing, and planting *E. urophylla* clonal trials. Proteak has four Camcore teak provenance-progeny trials that are almost five years old, so it is time to make early selections of the best trees of the best families. In addition to the selections from the company's trials, Camcore will send Proteak several ramets of 99 clones selected in Guatemala, and 36 clones selected in Colombia. In the short term, Proteak will have approximately 200 clones available for the establishment of clone x site interaction studies. Camcore and Proteak will explore the opportunity to develop protocols for teak tissue culture propagation with one of the local universities in Mexico. A key issue to work out is the exchange of clones between countries.

The Proteak team has also been working hard to implement the protocols sent by Camcore for making controlled-pollination crosses of *Eucalyptus* species in the greenhouse. They have been working with pollen collection, processing and utilization, and some hybrid seeds have been produced. Pollen of *E. urophylla* and *E. pellita* was sent to Camcore in Raleigh for crosses with other species at other companies. With good flowering of the grafted selections of *E. urophylla*, Proteak will be able to make crosses and collect seeds of the hybrid made with *E. grandis* pollen sent by Smurfit Kappa Colombia. Proteak has planted five clonal trials of *E. urophylla* with selections from Camcore and other sources. The company will use the best clones of these trials for commercial plantations. Selected clones from Camcore will be available to other Camcore members with interest in this species. Excellent job by Proteak!

Also in July, Juan Lopez and Robert Jetton visited **Uumbal** to help define a strategy for the company's pine tree breeding and phytosanitary programs to be implemented with Camcore's help. In the relatively short time the company has been with Camcore, Uumbal has established a

Marynor Ortega and Secundino Torres of Proteak standing in a Camcore teak provenance-progeny trial in which genetic selections will be made at age 5. Selected trees will be tested in clonal trials with clones from Guatemala and Colombia.

Robert Jetton (left) and Juan Lopez (right) of Camcore, with Sergio Hernandez (center) from Uumbal in a young plantation of *P. caribaea* x *P. tecunumanii* hybrid trees in Mexico.

significant number of trials with several species of pines for resin production. It is time for the company to deploy selected material from their trials to commercial plantations to realize genetic gains. We recommended early selections in five-year-old Camcore trials of *P. caribaea* var. *hondurensis*, *P. caribaea* var. *bahamensis*, and *P. elliottii*. These species, as well as their hybrids, all have great commercial potential for Uumbal. Establishment of clonal seed orchards should be an objective in the short term. Controlled crosses of pine selections from the trials will allow Uumbal to obtain improved seeds for the implementation of family forestry, so Uumbal will begin looking at flowering on different sites for the planting of the clonal seed orchard. Uumbal has a well-structured sanitary program, but we discussed some opportunities for improvement. Uumbal should make some adjustments to decrease susceptibility of commercial plantations to the *Ips* bark beetles. These include adopting a new system for thinning, considering reducing the number of trees planted per hectare, and investing more in good quality traps to monitor the beetle populations. Aerial pesticide application for mites and other pests should be the last resort, justified only when the attacks are severe and with no other options available.

### South Africa

Gary Hodge and Juan José Acosta visited South Africa in November and visited all seven Camcore members, and participated in the Regional Meeting.

First, Gary and Juan José went to George for a joint visit with **MTO** and **PG Bison**. MTO has expanded its land base from the pine lands in the Cape Region to include some 20,000 ha in the Mpumalanga lowveld which will be primarily *Eucalyptus* plantations. These lands will probably focus on a 9- to 10-year rotation for transmission poles. The lands in the Cape regions include some sites suitable for *P. radiata*, but a higher proportion of sites might be suitable for *P. elliottii*, the *P. elliottii* x *P. caribaea* hybrid, or possibly *P. maximinoi*. *Pinus elliottii* is hardy and has acceptable form and wood properties, but has substantially slower growth than the other two options. The hybrid grows well, but there are some concerns about wood quality, and *P. maximinoi* is still a very new species for the Cape. We are working with MTO to help convert some *P. maximinoi* progeny tests into seedling seed orchards. The thinning decisions will be made using both growth data, and 5- and 8-year-old TreeSonic acoustic velocity, which measures timber stiffness.

A higher proportion of PG Bison lands in the southern Cape are suited for *P. radiata*, so this species will still be important for the company. PGB is investigating if new mill technology will allow them to shorten the rotation from 27 to 22 years with fewer thinnings. In the north Eastern Cape, PGB is considering a shift from pine to eucalypt fiber (*E. nitens* and *E. benthamii*) for their medium-density fiberboard (MDF) products, and target their pine plantations for pine sawtimber rather than MDF. Camcore has good *E. benthamii* genetic resources, and many 5-year measurements were received in 2019. In 2020, we hope to help PGB make selections for an *E. benthamii* clonal seed orchard.

We next visited **Mondi** where we discussed an array of topics, including the following: *E. grandis* breeding, *E. grandis* x *E. nitens* breeding and clonal testing strategy, F2 *E. grandis* x *E. urophylla* breeding, research on the use of NIR spectroscopy to predict pine pollen viability, and testing strategies for Mondi's internal pine hybrid breeding program. Related to the last topic, we also discussed the vegetative propagation that Mondi is doing in support of the Camcore *P. patula* x *P. tecunumanii* breeding project. Distribution of the first set of progeny tests for this project was scheduled for early 2020. We also discussed

Mondi wood and tree-breeding staff collected data and samples from 540 pine hybrid trees in Ncalu, Mpumulanga, South Africa.

strategies related to current commercial pine hybrid deployment of *P. elliottii* x *P. caribaea*, and *P. patula* x *P. tecunumanii*. Finally, we want to acknowledge the help that the Mondi research staff provided to Willi Woodbridge in the collection of wood samples from a pine hybrid trial in Ncalu and a eucalypt species trial in Msibi Mooihoek. Mondi has a dedicated wood research staff and they were joined by tree-breeding workers to sample 700 trees in total. Results are summarized later in this report.

Gary and Juan José's visit to **Sappi** also covered a long list of topics. Sappi is investigating the use of genomic selection in both their *E. dunnii* pure species breeding and their *E. grandis* x *E. nitens* hybrid breeding efforts. The Sappi breeding program for *E. dunnii* is quite large and involves multiple acquisitions from multiple provenances made over a number of years. We worked with the Sappi breeding team to focus the sampling on one of the smaller provenance populations with progeny tests from a 1st generation population (to build a model) and from a 2nd generation population (to validate the model). For future GS studies, we identified a very good *E. dunnii* population with multiple field tests, a small number of related families, and clonal replication. We also discussed a study with the Sappi *E. urophylla* x *E. grandis* population to do a GWAS (Genome-wide association study) for pest and disease tolerance. Finally, we discussed a very interesting Sappi study comparing growth of F1 *P. patula* x *P. tecunumanii* (produced from controlled pollination) to F2 *P. patula* x *P. tecunumanii* (produced from open pollination of F1 hybrid trees). It is a small experiment, and there is a limited number of families, but the results suggest there is little difference in means for growth and in uniformity between F1 and F2 populations. We hope to see these results written up for publication sometime in 2020.

Andy Whittier traveled to Sappi to conduct wood research. Working with Sappi staff, the group sampled 540 hybrid pine trees in a trial in Grootgeluk and 180 eucalypt trees at a Nooitgedacht trial. Results are reported later in this report.

Gary and Juan José next visited **SAFCOL**. SAFCOL also hosted the Regional Meeting (see article on page 23), so this two-day visit took place before and after meeting. SAFCOL is a participant in the tropical pine SNP chip consortium, and we discussed ways to make the best use of their genotyping commitment over the next three years. Possibilities include evaluating the relatedness among their *P. pseudostrobus* selections, and evaluating the hybrid percentage (and variation) in F2 *P. patula* x *P. tecunumanii* seed collected in the F1 hybrid seedling seed orchard. We also made plans to help SAFCOL with data analysis to guide thinning decisions in their clonally-replicated seedling seed orchard of *P. patula*.


The Sappi breeding team and Gary Hodge in a 2-year-old *E. dunnii* progeny test in Mpumalanga. Camcore is working with Sappi to develop genomic selection models for use in their *E. dunnii* program.

Sifiso Nzama of SAFCOL with cuttings of *E. grandis x E. dunnii* and *E. grandis x E. brassiana*. The plants are being propagated for the 1st phase of the Camcore *Eucalyptus* hybrid project, and will be distributed to members in South Africa for testing.

**York Timbers** is also part of the tropical pine SNP chip consortium, and as with SAFCOL, we discussed ways to make best use of their genotyping commitment. One option might be to pursue a genomic selection application for their full-sib *P. patula* x *P. tecunumanii* population. York has been a leader in trying many pine hybrid combinations in their internal breeding program, so another possible use of the SNP chip might be to verify hybridity in their current field trials. We also discussed the design of some species-site (GxE) trials to examine exactly where to plant *P. patula*, *P. patula* x *P. tecunumanii* (high elevation), and *P. patula* x *P. tecunumanii* (low elevation) in the lowveld to highveld gradient. Other variety options include *P. maximinoi*, and *P. greggii* hybrids with *P. patula* or *P. tecunumanii*. York's primary product objective is pine sawtimber and plywood, so stem form and taper are of critical importance. The research staff is doing some very interesting work to improve their assessments of form traits using a laser caliper tool.

**Merensky** has had some major changes in their organization and have greatly reduced their forestry operations. They leave Camcore after many years of successful cooperation.

### Uruguay

In December, Juan Luis Lopez and Juan José Acosta visited two Camcore members in Uruguay. They also had the opportunity to visit **La Universidad de la República** in Tacuarembó, where they made three presentations about Camcore research to students and professors.

Juan José Acosta and Juan Luis Lopez also visited **Montes del Plata (MDP)**. After hard work, the company was able to make pollen collections of *E. dorrigoensis* in an 8-year-old Camcore trial. In 2019, 6 cc of pollen were collected from 10 selected trees that will be used for crosses MDP will make with *E. dunnii* as part of the Camcore eucalypt hybrid program. *E. dorrigoensis* has shown great adaptation to the environmental conditions of Uruguay, (quick growth and high survival) and will likely make a promising commercial hybrid with *E. dunnii*. We also recommended the possibility of implementing a joint project with Lumin to establish seedling selection blocks with *E. grandis* seeds to be received from Camcore in 2020. Montes already established a first *E. grandis* provenance-progeny trial with 112 treatments, including controls of improved material in Uruguay with seeds received in 2019. Camcore will continue helping the company with the evaluation of age-age correlations in *E. dunnii* clonal trials

The research team at Montes del Plata collected wood quality data and samples form a eucalypt species trial in Rincón del Río, Durazno, Uruguay. The trip was organized by Romeo Jump (not pictured).

measured yearly, and writing an R program to analyze the results of genetic studies in the company.

Romeo Jump also visited Montes del Plata for a wood research project. Working with Monica Heberling, Cristian Montouto and the research team, Romeo sampled 360 trees from two eucalypt species trials. Romeo and Camcore appreciate the great effort made by our Uruguayan colleagues.

During the visit with **Lumin**, Juan Luis and Juan José discussed the company's breeding programs for *P. taeda, P. greggii* var. *australis*, *P. maximinoi, P. tecunumanii, E. grandis, E. dunnii, E. dorrigoensis, E. benthamii,* and other species of eucalypts with potential as hybrid partners. In field visits, they saw the 9-year-old *P. greggii* 2nd generation trial at Paso Serpa that shows the great potential of this species, growing substantially faster than *P. taeda*. This trial and a replicate in Fraile Muerto tract will be thinned. The replicate will be converted to a seedling seed orchard and the one in Paso Serpa will be used to conduct wood tests for plywood in the industrial plant in 5 or 6 years when the proportion of mature wood will be greater. Seeds will be collected in these and other Camcore trials for the establishment of 3rd generation studies. They also visited a *Eucalyptus* block planting established in 2016 with hybrids from the first phase of the Camcore hybrid project. These trials are old enough to begin selecting candidate hybrid trees for clonal trials. A second set of hybrids will be sown in 2020 for the establishment of more hybrid seedling selection blocks. Lumin is also taking an active part in the 2nd phase of the hybrid program, contributing pollen of *E. benthamii* and *E. dunnii*, and making crosses of *E. grandis x E. dunnii*.

Compression wood has been an issue in the plywood plant at Lumin when *P. taeda* is used as raw material. Camcore will help Lumin to design and conduct a wood study with the resistograph to detect compression wood, based on resistance differences between the two halves of the stem at breast height. Currently, Camcore is helping Lumin with an *E. grandis* splitting study. Finally, Lumin is planning to establish sentinel trials of pines and eucalypts to monitor insects and disease, following the method proposed in the 2015 Camcore Annual Meeting, similar to the Sappi sentinel trials discussed in this report (see page 35).

Gerardo Osorio and Juliana Ivanchenko (Lumin, Uruguay) in a 2nd generation Camcore test of *P. greggii* var. *australis*. The *P. greggii* in this test has better volume at age 9 years than *P. taeda*.

**Venezuela**

Despite the great challenges faced by private industry in Venezuela, **Masisa** (Terranova de Venezuela) is still interested in working on research and development projects with Camcore. The company has several interesting Camcore trials with eucalypt and pine species adapted to very harsh environmental conditions on its forestry land. Commercial plantations of *P. caribaea* var. *hondurensis* are growing in poor, deep, sandy soils. Genetic trials with *E. urophylla*, *E. camaldulensis* and *E. brassiana* show some level of adaptation to these conditions that can be improved with provenance and family selections. Camcore hopes to be active again in Venezuela in the future.

# Southern Africa Regional Meeting

The 2019 Southern Africa Regional Meeting was held at the SAFCOL Platorand Training Center, and was hosted by SAFCOL with assistance from York and Sappi on the field visits. The meeting was well attended, with 28 attendees representing all the South Africa Camcore members. We spent one full day with indoor presentations and discussions, covering recent accomplishments of Camcore. We reviewed the *P. patula* x *P. tecunumanii* hybrid project, including the scheduling of delivery of progeny tests, the status of the tropical pine SNP chip, some early results from Sappi's Disease Sentinel Trials, the Camcore *Eucalyptus* hybrid projects, comparison of NIR devices, and the expansion of the Global Eucalypt NIR model. That evening, we enjoyed a wonderful braai on the Tweefontein research station grounds sponsored by Camcore and SAFCOL, with plenty of steaks, lamb chops, sausage, wine, and a giant pot of pap (maize meal, or "grits" if you're from North Carolina).

Charlie Clarke (York) in a SAFCOL species/hybrid trial is happy to find a *P. tecunumanii* tree with outstanding phenotype for sawtimber and plywood.

The following day, we had a very good field trip, beginning with visits to SAFCOL's *P. maximinoi* and *P. patula* x *P. tecunumanii* seed stands at Tweefontein. These are thinned trials which will be used to produce commercial seed, and we had some interesting discussions here, in particular about the benefits and risks of planting F2 hybrid seed. Our next stop was the SAFCOL pine hybrid trial at Sptizkop, followed by a visit to York's pine hybrid trial at Maggsleigh. We enjoyed a nice lunch (including some leftovers from the previous night's braai) on York property at beautiful Maggsleigh Dam. We closed the day with a visit to a Sappi *P. elliottii* x *P. caribaea* (PECH) trial at Rhemay. Somewhat surprisingly for this drier site, *P. patula* x *P. tecunumanii* (low) was beating all of the PECH hybrids in the trial.

The Regional Meetings are always great opportunities for information exchange, vigorous discussion, and generation of new ideas, and the 2019 meeting was no exception. Many thanks to SAFCOL for hosting, and most of all to Bonnita Meyer for all her work in coordinating the meeting, including bringing her husband and children along to help with the braai!

A scenic lunch break at York's Maggsleigh Dam property during the field day of the 2019 Southern Africa Regional Meeting.

# Pine and Eucalypt Breeding

As part of the 2019 Annual Meeting, we reviewed our progress in pine and eucalypt breeding over the past ten years. One can always see room for improvement, but overall, we think we took major steps toward our goals.

*Pine Breeding Goals: 2010 to 2019*

At the 2010 Strategy Meeting in Brazil, there were two primary goals outlined for the pine breeding program.

1. Complete a cycle of improvement for the main pine species within 10 years.
2. Complete 2nd generation trial establishment and make selections.

We have native-stand collections from 27 pine species, but the "main" Camcore pine species are those which have shown the most potential for fast-growing plantations: *P. caribaea, P. greggii, P. tecunumanii, P. maximinoi,* and *P. patula.* With the exception of *P. maximinoi,* these are also the species that seem to have the best potential as hybrid partners. For these five species, Camcore members have successfully established and measured 152 2nd generation tests, and 2nd generation selections have been made in each species (from trials in one or more of the the following: Argentina, Brazil, Chile, Colombia, South Africa, and Venezuela) (Table 1).

*Eucalypt Breeding Goals: 2010 to 2019*

From 1996 to 2004, Camcore made *E. urophylla* mother-tree collections from more than 1100 trees in 62 provenances from all seven Indonesian islands where the species occurs. But that was our only project with a eucalypt species. The minutes of the 2009 Annual Meeting reflect a strong commitment to increased Camcore involvement in *Eucalyptus* testing and improvement. At the 2010 Strategy Meeting in Brazil, we decided to identify the best 10 eucalypt species for current and "desired" new members, which meant a focus on some of the more well-known commercial species to attract new members. From 2010 to 2016, Director Bill Dvorak had great success in acquiring eucalypt genetic resources for the program. During that time, Camcore gained family-level collections of 14 different *Eucalyptus* and *Corymbia* species, most of those with demonstrated commercial importance. In addition, we established a collaborative species-testing project with CSIRO, Australia, to look at some lesser-known and drought-hardy species. From 2016 to 2018, Camcore acquired an excellent genetic base of *E. grandis,* including a set of 108 unimproved families from 11 provenances in Australia. In addition to these native-range collections, several of Camcore's oldest members donated improved families of *E. grandis* developed in their internal breeding programs. Smurfit Kappa Colombia (SKC) donated 50 families (from 1st, 2nd and 3rd generations of improvement), Mondi donated 40 families, SAFCOL donated 21 families, and Sappi donated 19 families. In addition, we received a donation of 120 families of improved *E. globulus* from a collaborative breeding effort of SKC, Tekia, and CONIF (Corporación Nacional de Investigación y Fomento Forestal) in Colombia.

Camcore members have planted 193 provenance-progeny tests of 11 *Eucalyptus* species (not including 275 tests of *E. urophylla*), an additional 58 tests of *Corymbia* species, and another 130 mixed *Eucalyptus* species trials (Table 2). This adds up to 656 Camcore *"Eucalyptus"* tests that

**Table 1.** Pine 2nd generation tests established and measured, 2nd generation selections completed.

| Species | Planted | Measurements | | | Selections? |
|---|---|---|---|---|---|
| | | age 1 | age 3 | age 5 | |
| *P. caribaea* | 30 | 22 | 17 | 8 | Argentina, Brazil, Venezuela |
| *P. greggii* | 14 | 11 | 12 | 5 | Brazil, Chile, Colombia South Africa |
| *P. maximinoi* | 51 | 48 | 42 | 25 | Argentina, Brazil, Colombia, South Africa |
| *P. patula* | 14 | 10 | 10 | 12 | Brazil, Chile, Colombia, South Africa |
| *P. tecunumanii* | 43 | 38 | 37 | 27 | Brazil, Colombia, South Africa, Venezuela |

have generated growth data. Selections for the next generation of breeding have been made for *E. urophylla, E. pellita,* and *E. dorrigoensis*, with more species to come.

*Outlook for 2020 to 2029*

Going forward, Camcore is well positioned for breeding both pines and eucalypt species. We have excellent resources for both pure species breeding and for inter-species hybrids. In Portugal in 2019, we developed a priority list from a list of 21 promising "new" eucalypt species (from the report developed for us by Butler and Potts at the University of Tasmania). This will guide our collection and acquisition efforts over the next few years. We will also take that time to investigate options for future collections of new pine and *Corymbia* species, and evaluate if there is any contribution that Camcore could make in the area of *Acacia* genetic resources.

**Table 2.** *Eucalyptus* and *Corymbia* tests established and measured.

| Species | # Fams | Planted | Measurements | | |
|---|---|---|---|---|---|
| | | | age 1 | age 3 | age 5 |
| *C. citriodora* | 30 | 20 | 3 | 6 | |
| *C. maculata* | 30 | 22 | 4 | 6 | |
| *C. torelliana* | 32 | 16 | 3 | 6 | |
| *E. brassiana* | 25 | 13 | 5 | 4 | |
| *E. camaldulensis* | 30 | 25 | 5 | 4 | 3 |
| *E. grandis* | 168 | 9 | 1 | 2 | |
| *E. longiostrata* | 45 | 19 | 2 | 4 | |
| *E. pellita* | 99 | 45 | 14 | 14 | 9 |
| *E. urophylla* | 1116 | 275 | 129 | 125 | 25 |
| *E. badjensis* | 30 | 15 | 5 | 5 | |
| *E. benthamii* | 36 | 25 | 11 | 7 | 1 |
| *E. dorrigoensis* | 34 | 19 | 16 | 17 | 14 |
| *E. dunnii* | 36 | 7 | | 2 | |
| *E. globulus* | 175 | 8 | 1 | | |
| *E. nitens* | 40 | 8 | 1 | 1 | |
| Mixed Eucs | *na* | 130 | 55 | 47 | 34 |

## Teak Update

Currently, Camcore has several provenance-progeny trials of teak in different countries:

- One 8-year-old trial in Tekia, Colombia, where we have 152 selected trees, out of which 36 clones have been rooted as mother plants.
- One 9-year-old trial in Grupo DeGuate, Guatemala with 99 selections.
- Four trials: two 5-year-old and two 4-year-old in Proteak, Mexico. Based on 5-year-old assessments, we will make selections in these trials in 2020 and 2021.

Assuming that we make 80 more selections from Proteak trials in 2020, there will be 215 clones available to Camcore members for clonal trials. We are in the process of growing mother plants of these clones with the purpose of distributing rooted cuttings for clonal trials at Proteak, Miro Forestry, Sinarmas and KEFRI. We are making an effort to propagate and exchange plants *in vitro* among members in the near future. Our clones of teak, *Gmelina* and *Eucalyptus* hybrids will be mostly shared among members through tissue culture. With Proteak, we are considering the possibility of developing protocols for tissue culture with a local university in Chiapas in Mexico. Seeds of teak for 2nd generation progeny trials were distributed to Miro Forestry Ghana and Sierra Leone in 2019.

Elmer Gutiérrez and Josué Cotzojay standing with one of the 99 selected trees in the Camcore teak provenance-progeny trial in Guatemala.

# Gmelina Update

Seeds of 49 clones that had been collected in 2018 from the Camcore clonal seed orchard in Forestal Monterrey, Colombia were shipped to Miro Forestry Ghana and Miro Forestry Sierra Leone for the establishment of 2nd generation progeny trials. More seeds of the species will be collected in the near future to send more trials to Proteak in Mexico and KEFRI in Kenya.

The 55 Camcore clones rooted by Forestal Monterrey Colombia were sent to Bogotá for export to Ghana in West Africa. Personnel of FMC did a great job in packaging and shipping the material. El Semillero, the company that shipped the plants from Bogotá to Accra, Ghana, provided an excellent service, helping with the paperwork and sending the plants on time. Rooted cuttings with substrate in container tubes packed in Styrofoam coolers arrived in Ghana in good shape. All 275 plants sent (five plants/clone x 55 clones) arrived alive. Miro Forestry made a great effort to coordinate the reception and release of the plants from customs. Miro staff put the small trees in nursery beds to recover from the stress experienced during the process. A few weeks later, all the trees were growing vigorously in the nursery.

A second set of plants with the same number of clones and ramets was shipped to Smurfit Kappa Colombia's nursery in Restrepo, Valle, where the company propagated the hedges for the establishment of a conservation bank. Camcore selected these clones from several 1st generation progeny trials, so it is critical to conserve this valuable genetic material.

Menason Essakku and Akanvae Awekeya Vitus from Miro Forestry with rooted cuttings of Camcore *Gmelina arborea* from hedges of the 55 clones received from Forestal Monterrey, Colombia. This material will be used for the establishment of clonal trials in West Africa.

# Pine Hybrid Project Update

### Bulk hybrid trials

Out of the 90 pine hybrid trials established by Camcore members in seven different countries between 2007 and 2017, 46 are now age eight years or older. Most of these trials were measured for growth, and some of them sampled for wood properties at age eight. Results of data analysis at five and eight years were presented in the 2018 Annual Report, with some hybrids showing commercial potential in different regions of Latin America and Africa. Most of these trials are still growing in the field and Camcore will test some of them for wood properties at older ages when a significant portion of the wood will be mature. We continue to measure wood properties (MOE, wood resistance, and chemical composition) in standing trees at eight years. In 2019, two more trials of the second series were sampled in South Africa, one each at Mondi and Sappi.

Some of the most recently planted trials are yielding early results at age three and show that some hybrids are competing well with the traditionally planted pure species. These include *Pinus patula* x *P. tecunumanii* low elevation in Brazil and Colombia, and *P. radiata* x *P. elliottii* and *P. greggii* var. *australis* x *P. oocarpa* in the Cape area of South Africa. By 2024, all of the available trials will have been measured at eight years of age providing valuable information on potential hybrids to be used by Camcore members for commercial plantations.

### *P. patula x P. tecunumanii* in South Africa

This project was conceived at the 2012 annual meeting and initiated in 2013. The seven South African members planned crosses between the two species using Camcore selections with the objective of producing seeds of 300 full-sib families to be used to establish hybrid progeny trials. Forty-three maternal clones of *P. patula* and 95 paternal clones of *P. tecunumanii* (low and high elevation) were used to make the crosses. DNA fingerprinting was completed for all the parents, and will be done for the best families in the trials to verify paternity.

Seeds were sown at Mondi's nursery in two batches in 2018, one in July and one in December. Germination of the seeds was only 17%, which is not unusual for pine hybrids. By September of 2019, 38 families had been established in sand beds in the nursery, 19 families with one parent of *P. tecunumanii* low elevation (672 hedges) and 19

Nokukhanya Maplanka (Mondi Forests) is in charge of *P. patula x P. tecunumanii* hedge management for the hybrid testing effort in South Africa.

families with *P. tecunumanii* high elevation (690 hedges). In order to obtain an adequate number of rooted cuttings for the trials, a target of 50 hedges per family was chosen. Based on estimates of cutting production, we expect that the first two trials will be planted early in 2020, followed by two more trials in October, three in November, and three in December. In 2021, three more trials will be planted in January and three in February for a total of 16 hybrid progeny trials.

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

The tree breeding program for the hybrid between *P. tecunumanii* and *P. greggii* var. *australis* was started in 2016 by seven Camcore members in Latin America (Argentina, Brazil, Colombia, Mexico and Uruguay). The objective was the same as that of the *P. patula* x *P. tecunumanii* in South Africa, to produce seeds of 300 full-sib families for progeny trials. The mating plan was defined with crosses among 50 *P. greggii* males and 50 *P. tecunumanii* females (25 high elevation and 25 low elevation).

The first controlled pollination crosses were made in several clonal seed orchards of *P. tecunumanii* at Smurfit Kappa Colombia in 2016 and additional crosses have been made every year. Close to 52,000 seeds have been collected from about 4,500 cones. We still have 2020 to make more crosses to complete the mating plan designed by Camcore. By 2021, we should start distributing seeds of different families for the establishment of hybrid progeny trials by the participating members.

### *P. caribaea x P. tecunumanii*

Based on results from the bulk hybrid trials, *P. caribaea x P. tecunumanii* shows great commercial potential for different regions of Africa and Latin America, demonstrating excellent growth rate and very good form. Although the land that is suitable and currently available for this hybrid is somewhat limited (or is planted with eucalypts), with a warming climate, we expect that this hybrid could have a much wider footprint in the future. In 2020, we will begin discussions and plan a full-sib hybrid breeding program that will involve all Camcore members.

Adriana Marin standing in an 18-year-old hybrid trial with *P. caribaea x P. tecunumanii* (left) vs *P. caribaea* (right) at Smurfit Kappa Venezuela.

# *Eucalyptus* Hybrid Project

**Phase 1**

In 2011, a group of 12 of our members with internal eucalypt breeding programs initiated a new hybrid project coordinated by Camcore. Each of the participant companies crossed two species to produce seeds to share with the other members. In 2015, seeds from the 12 crosses were distributed to the members for the establishment of hybrid seedling selection blocks (HSSB), which are small planting blocks by family, with spacing of 1.5 m x 1.5 m. These HSSB allow for early screening (1.5 years) of the trees that will go to the clonal trials. Trees with good growth, form, sprouting and rooting ability are taken to the clone x site interaction studies. Members in South Africa, Chile, Colombia and Uruguay established eight HSSB. In 2019, three other members in South America sowed the seeds in Brazil and Chile for planting HSSB. Lumin and Smurfit Kappa Colombia will cut their planting blocks in 2020 for hedge production.

Mondi produced seeds of 25 full-sib families of *E. grandis* x *E. nitens*. Half of this seed will be used in Uruguay and the other half will be sown in South Africa for the establishment of HSSB.

With the rooted cuttings of *E. grandis* x *E. pellita*, *E. grandis* x *E. globulus*, *E. grandis* x *E. smithii*, and *E. grandis* x *E. dunnii*, Sappi planted two and Mondi planted one clone x site interaction trial per hybrid in 2019. In 2020, Mondi, York, SAFCOL, and Merensky will plant more clonal trials with the same hybrids. All data from all clonal trials will be shared among the 12 participants, and eventually clonal selections can also be exchanged. Great progress was made in this program in 2019!

**Phase 2**

The second phase of this program started in 2018, when Camcore members decided to expand the number of hybrid combinations in a second major effort to look for commercial clones. This project is a cooperative-wide effort, and material generated from this work will be considered shared Camcore genetic material. Several members put in a lot of work in 2019, harvesting, shipping, and using pollen for crosses. Some other members were able to harvest seeds of crosses already made in previous years.

Smurfit Kappa Colombia provided seeds of 20 full-sib families of *E. grandis x E. urophylla* that we have already received in Raleigh. Klabin in Brazil will contribute seeds of 27 families of *E. urophylla* x *E. dunnii* already harvested. In December 2019, Sappi collected seeds of *E. dunnii* x *E. benthamii* that will be sent to Camcore in Raleigh. WestRock made seed collections of the same hybrid in December and will ship them to Camcore.

Other members received or collected pollen and started making crosses in 2019 to harvest seeds in 2020. York Timbers made crosses of *E. grandis* x *E. benthamii* with pollen from Mondi. Miro Forestry Sierra Leone is making crosses of *C. torelliana* x *C. citriodora* with its own pollen. Miro Forestry Ghana is making crosses of *E. pellita* x *E. grandis* with pollen from York.

The members made a big effort in pollen collection in 2019. Mondi sent pollen of *E. benthamii* and *E. nitens* for crosses in MTO, Sappi, and York in South Africa. Proteak in Mexico provided pollen of *E. urophylla* and *E. pellita* for crosses in Sinarmas and APRIL in Indonesia, and Arauco in Chile. Arauco Chile made pollen collections of *E. globulus* and *E. nitens* for crosses with *E. pellita* in Sinarmas and *E. grandis* in York. WestRock collected pollen of *E. benthamii* and *E. dunnii* to be used for its own crosses with *E. dunnii* and crosses with *E. pellita* x *E. camaldulensis* in Sinarmas. Smurfit Kappa Colombia sent pollen of *E. grandis* for crosses with *E. urophylla* in Proteak and *E. pellita* in APRIL. Lumin collected pollen of *E. benthamii* for crosses with *E. globulus* in Arauco, Chile. York sent pollen of *E. grandis* to Miro Forestry Ghana for crosses with *E. pellita*. Sappi harvested pollen of *E. dunnii* for crosses with *E. pellita* in Sinarmas. Montes del Plata collected *E. dorrigoensis* pollen that will use for its own crosses with *E. dunnii*. Klabin collected pollen of *C. torelliana* that Mondi will receive for crosses with *C. maculata*. Camcore is planning to make collections of *E. amplifolia* pollen in Valdosta, Georgia in 2020 for hybrid crosses with *E. globulus* in Arauco, Chile.

# Wood Properties of Pine Hybrids

In 2019, we continued to study the wood properties of pine hybrids. In the 2018 Annual Report, we summarized results from 12 pine hybrid trials. In 2019, we sampled an 8-year-old Mondi test at Ncalu, KZN (98-18-H02C2), and an 8-year-old Sappi test at Grootgeluk, Mpumalanga (98-07-H02E). Here we report on the new results from those two tests in South Africa. Many thanks to Nicci Edwards, Noku Maplanka, and Mmoledi Mphahlele of Mondi and Wesley Naidoo, Lebogang Mphahlele, and Wendy Nkontwana of Sappi and all the members of the wood sampling teams.

Sappi workers joined Andy Whittier of Camcore to collect data and samples from 180 pine hybrid trees from a Camcore trial in Grootgeluk, South Africa.

## Materials and Methods

The varieties in these two trials are:

| Hybrid / Species | Code |
|---|---|
| *P. caribaea* x *P. oocarpa* | CARxOOC |
| *P. caribaea* x *P. tecunumanii LE* | CARxTEL |
| *P. elliottii* x *P. caribaea* | ELLxCAR |
| *P. elliottii* x *P. taeda* | ELLxTAE |
| *P. patula* x *P. elliottii* | PATxELL |
| *P. patula* x *P. greggii S* | PATxGRS |
| *P. patula* x *P. oocarpa* | PATxOOC |
| *P. patula* x *P. tecunumanii HE* | PATxTEH |
| *P. patula* x *P. tecunumanii LE* | PATxTEL |
| *P. tecunumanii LE* x *P. caribaea* | TELxCAR |
| *P. tecunumanii HE* x *P. oocarpa* | TEHxOOC |
| *P. elliottii* | ELL |
| *P. patula* | PAT |
| *P. taeda* | TAE |

In each test, we randomly selected about 30 trees per treatment (hybrid or control lot) from defect-free candidates. Field measurements and wood samples were taken at breast height. Drills were used to collect wood shavings from just inside the bark to just short of the pith. Oven-dried shavings were ground into woodmeal, and scanned on a FOSS 6500 NIR spectrophotometer. Camcore's Global Pine NIR models were used to predict *lignin and cellulose* content. *Modulus of elasticity (MOE)* measures wood stiffness, and was estimated in standing trees with the TreeSonic acoustic tool. The IML Resistograph was used to record the *resistance profile* of the trees. This device 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. Resistance is directly proportional to the density of the wood, and this is measured at multiple points (10 per mm) along the drilling path from bark to bark.

Generalized linear models (GLM) were fit for all traits. Significance of each modeled trait was evaluated, and if variation between treatments was observed, LSMEANS and standard errors were also calculated and plotted.

## Results

*Resistance (Density)*

The resistance figures presented in Figure 1 represent "core density", i.e., the density that we would have observed in a bark-to-bark increment core. TAE had much higher resistance than all of the other varieties in these two trials, and was some 175 resistance units above the two *P. elliottii* hybrids in these tests (PATxELL, ELLxTAE). Density is directly and linearly related to resistance, but the specific conversion factor may vary from site to site, or from season to season. A rough estimate is that 100 resistance units is approximately equivalent to 10 kg/m$^3$, so TAE core density is approximately 18 kg/m$^3$ higher than the next two varieties. For all non-TAE, the range in resistance was only 917 to 1017 (for ELL and PATxELL, respectively), a range of about 10 kg/m$^3$.

*Modulus of Elasticity*

There was a large range in MOE (green timber), from over 12 GPa (TEHxOOC and

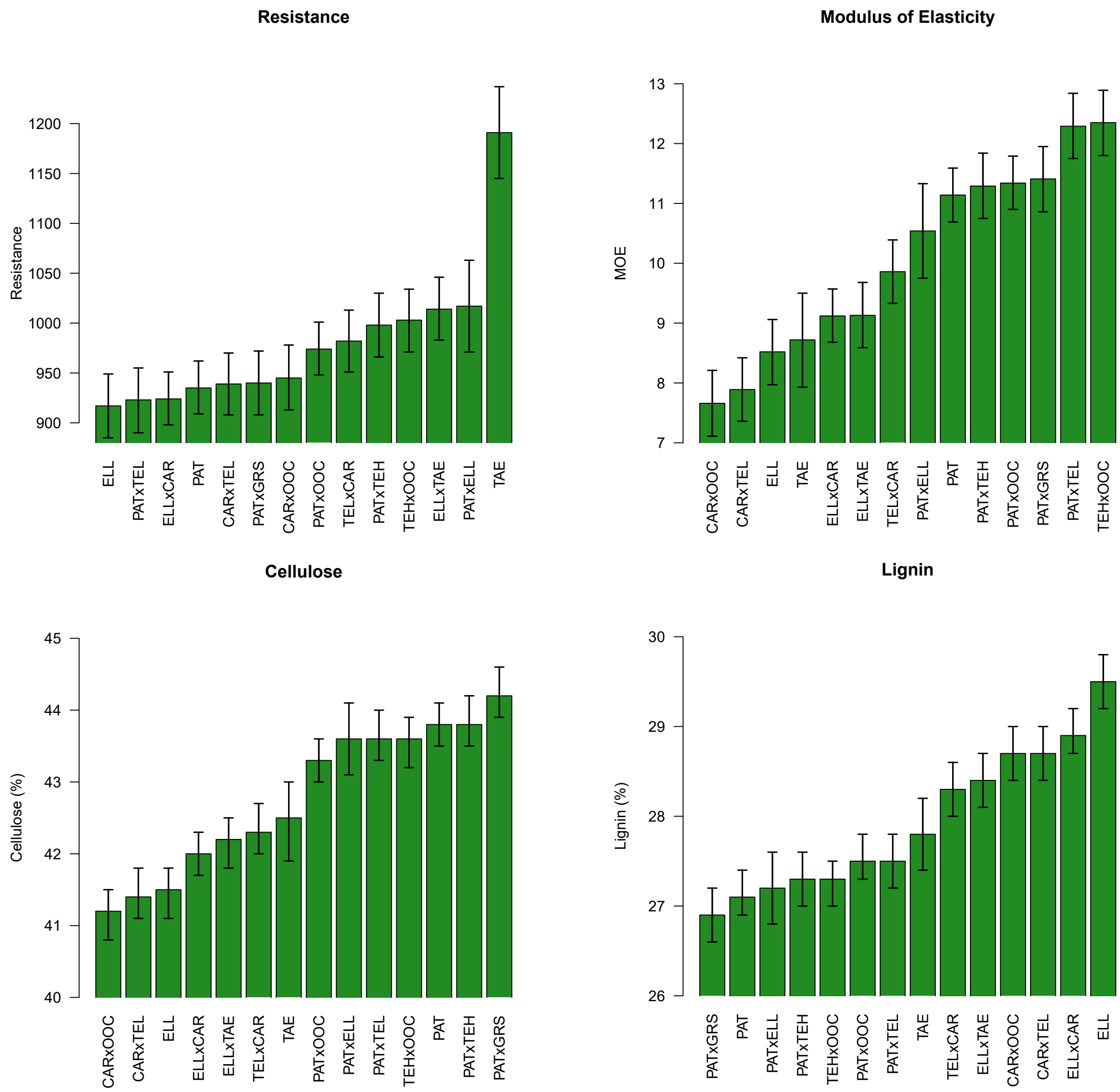



**Figure 1.** LS means and standard errors for important wood property traits of 13 pine hybrids/ species. Traits measured in two 8-year trials in South Africa

PATxTEL) to under 8 Gpa (CARxOOC and CARx-TEL) (Figure 1). The other CAR hybrids (ELLx-CAR and TELxCAR) were also in the lower half of the distribution for this trait.

*Cellulose and Lignin*

If pulp is the product objective, high cellulose and low lignin are desirable. Varieties with a favorable combination include PATxGRS and PATxTEH. Another important hybrid, PATxTEL, was quite good, and not significantly different from the best hybrid (PATxGRS) or the pure species PAT for these traits. In general, the various CAR hybrids were below average for the chemical traits, although TELxCAR is more intermediate.

## Discussion

In general, these results correspond well to the rankings observed in the 12 trials reported on in the 2018 Annual Report. Camcore has a large breeding effort for *P. patula* x *P. tecunumanii* hybrids, so the good peformance of PATxTEL and PATxTEH (above average for all four wood traits) is encouraging. Another hybrid of interest is the *P. caribaea* x *P. tecunumanii* LE, due to its very good growth in subtropical climates. In these two trials, the wood properties of CARxTEL are similar to ELLxCAR (a likely commercial competitor in South Africa), but slightly worse than *P. taeda* (TAE), a likely competitor in Brazil and Argentina. A breeding effort for the CARxTEL hybrid will likely need to include a focus on wood properties.

# Wood Properties of Eucalypt Species:

## Four Trials in South Africa and Uruguay

In 2019, we continued our work on evaluating the wood properties of tropical, subtropical and temperate *Eucalyptus* and *Corymbia* species. This work began in 2016, and has been reported in the past few annual reports. In 2019 we sampled two tests in South Africa, a 7-year-old Mondi test in Msibi Mooihoek, Mpumalanga (97-18-07C1), and an 8-year-old Sappi test in Nooitgedacht, Mpumalanga (97-07-07N1). We also sampled two 8-year-old tests in Uruguay at Montes del Plata: one in Rincón del Río, Durazno (97-54-07D2) and one in El Minero, Soriano (97-54-06D). This report summarizes just those four tests, aggregated together as a single region.

### Materials and Methods

The varieties in these four trials are:

| Species | Code |
|---|---|
| *E. badjensis* | EBAD |
| *E. benthamii* | EBEN |
| *E. dunnii* | EDUN |
| *E. globulus* | EGLO |
| *E. grandis* | EGRA |
| *E. grandis x E. nitens* | EGXN |
| *E. macarthurii* | EMAC |
| *E. nitens* | ENIT |
| *E. saligna* | ESAL |
| *E. sideroxylon* | ESID |
| *E. smithii* | ESMI |
| *C. maculata* | CMAC |

In each test, we randomly selected about 30 trees per treatment (hybrid or control lot) from suitable defect-free candidates. Field measurements and wood samples were taken at breast height to assess the following wood traits:

*Modulus of Elasticity (MOE)*

MOE measures wood stiffness and is a good overall indicator of strength, and this was estimated in standing trees with the TreeSonic acoustic tool.

*Resistance*

The IML Resistograph was used to record the resistance profile of the trees. This device 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. Resistance is directly proportional to the density of the wood, and this is measured at multiple points (10 per mm) along the drilling path from bark to bark.

*Chemical Traits*

Drills were used to collect wood shavings from just inside the bark to just short of the pith. Oven-dried shavings were ground into woodmeal, and scanned on a FOSS 6500 NIR spectrophotometer. Camcore's Global Eucalypt NIR models were used to predict glucose, xylose and lignin content, and the proportion of syringyl / (syringyl + guaiacyl lignin) or S/(S+G)%.

*Data Analysis*

Generalized linear models (GLM) were fit for all traits. Significance of each modeled trait was evaluated, and if variation between treatments was observed, LSMEANS and standard errors were also calculated and plotted.

### Results and Discussion

*Resistance (Density) and MOE*

The best species for resistance were *E. sideroxylon*, *E. globulus*, *E. nitens*, and *E. smithii* (Figure 2). *Eucalyptus sideroxylon* is a a slow-growing, dryland species, so perhaps it makes sense that this is a high-density wood. For MOE, the best species in these trials were *E. smithii*, *E. dunnii*, *E. grandis*, and the *E. grandis* x *E. nitens* hybrid. Somewhat surprisingly, these data indicate that *E. smithii* might be suitable for some solid wood products. *Corymbia maculata* was intermediate for both resistance and MOE in these trials. *E. badjensis* was below average for both traits (ranked 9$^{th}$ and 11$^{th}$, respectively), and *E. benthamii* was below average for resistance, and intermediate for MOE (ranked 10$^{th}$ and 8$^{th}$, respectively).

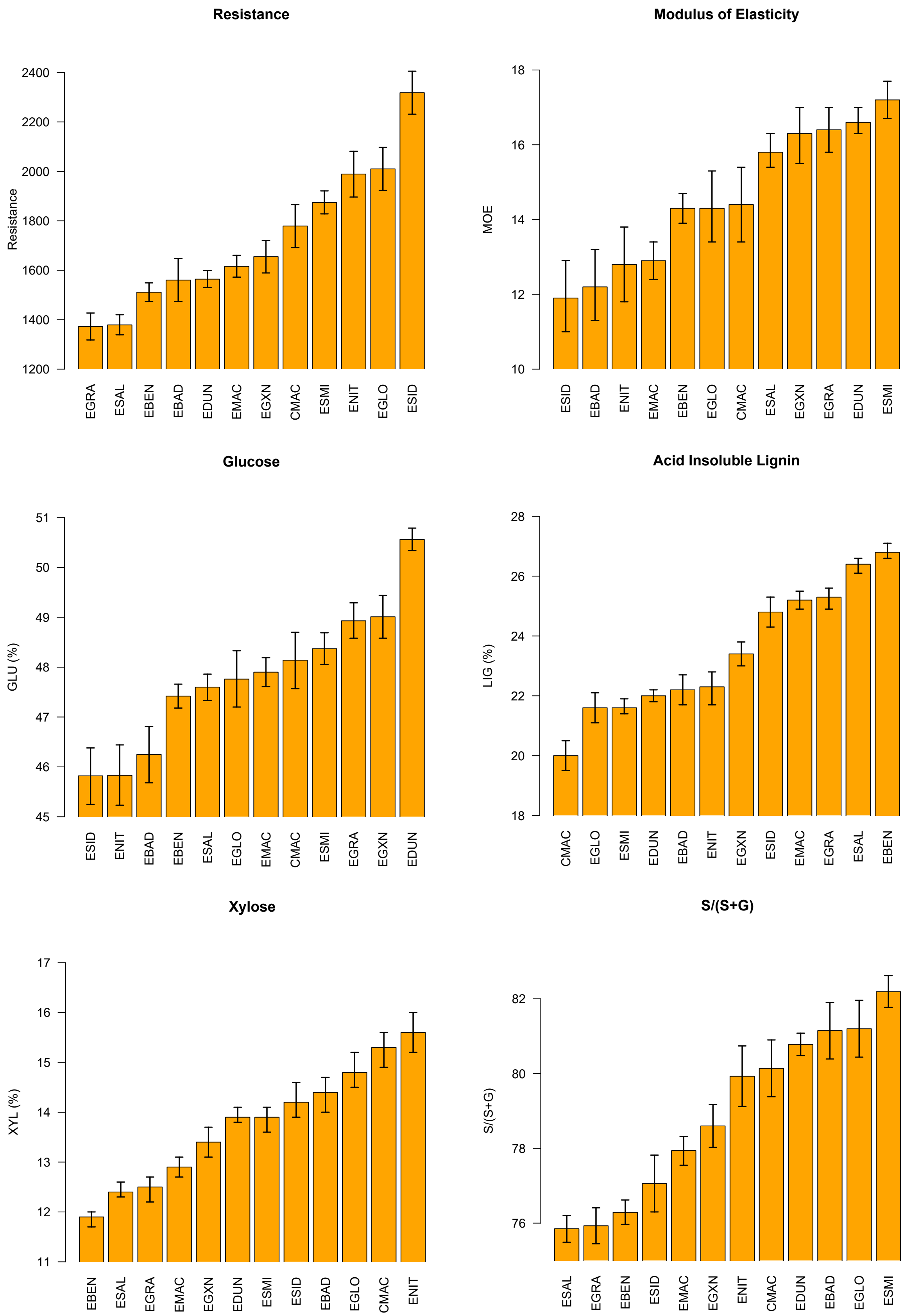



**Figure 2.** LS means and standard errors for important wood property traits of 12 *Eucalyptus* species. Traits measured in four 7- to 8-year-old trials: two in South Africa and two in Uruguay.

*Wood Chemistry*

For pulp production, high glucose, low lignin, and high S/(S+G) ratio are desirable. In these trials, the best species for pulp traits were *E. dunnii* (ranked 1st, 4th, and 4th out of 12 species, for glucose, lignin and S/(S+G), respectively), and *E. smithii* (ranked 4th, 3rd, and 1st). *E. grandis* showed high glucose, but also quite high lignin and low S/(S+G). *E. globulus* is generally recognized as the best pulpwood species in the world. In these trials, *E. globulus* was intermediate for glucose, but had very low lignin and very high S/(S+G). So, it retained generally good pulping characteristics, despite being somewhat off site in these trials in South Africa and Uruguay.

*E. benthamii* did not show favorable chemical properties, with low glucose, high lignin, low xylose and low S/(S+G) (ranked 9th, 12th, 12th, and 10th out of 12 species, respectively). This species is very hardy, tolerating both frost and high temperatures and humidity, so it may have a role in some environments; however, some work on improving the wood properties will be necessary.

*Corymbia maculata* had intermediate glucose content (similar to *E. smithii* and *E. globulus*), but very low lignin (around 20% lignin, compared to almost 22% for *E. smithii* and *E. globulus*). *C. maculata* also had favorable S/(S+G), ranked 5th out of 12 species. Interestingly, *C. maculata* had very high levels of xylose, just behind *E. nitens*.

**Summary and Outlook**

To date, we have assessed wood properties in 10 *Eucalyptus* / *Corymbia* species trials. We will continue sampling eucalypt species trials in 2020 and 2021, with a plan to sample 4 more trials in South America and 5 more trials in South Africa. At the end of that time, we should have a fairly clear picture of wood properties of the different species across a range of environments. This data should be helpful to us in guiding our pure species and hybrid breeding efforts.

## *Eucalyptus* Disease Screening Update

For the past few years Camcore has been collaborating with Smurfit Kappa Colombia to develop protocols and screen *Eucalyptus* species for susceptibility to several pathogens of concern across the Camcore membership. Laboratory screening studies with *Austropuccinia psidii* (the myrtle rust pathogen) are complete, as reported in the 2018 annual report. Results are currently being prepared for publication in a peer-reviewed journal. Field-screening studies for three additional pathogens were all started during 2019. Trials for *Botryosphaeria* and *Ceratocystis* were established at El Cedral in February 2019, and the trial for *Chrysoporthe* was planted at Vanesa in May 2019. Seedlings at both sites have acclimated and are growing well. We hope that inoculations will proceed in March 2020 with initial data on canker development and susceptibility rankings to be collected later in the year. If you would like more information on this project, you can contact Camcore Forest Health Specialist Robert Jetton or SKC Director of Forest Health Protection Carlos Rodas.

One of two mixed species *Eucalyptus* trials planted at El Cedral for pathogen screening. Inoculations are planned for sometime in 2020.

# Pine and Eucalypt Sentinel Trials at Sappi

*Sentinel trials for the early detection of new insect and disease occurrences on trees have recently become a focus of Camcore's forest health efforts in support of its pine and eucalypt breeding programs. The first series of these sentinel trials was established by Sappi in South Africa in 2019. Jolanda Roux and Andre Nel provide the following update.*

## Introduction

Pest and pathogen incidences of commercial forestry species have over the past three decades increased significantly in all countries where plantation forestry occurs. Not only has the number of pest and pathogen reports increased, but the interval between new pest and pathogen reports has decreased (Hurley et al. 2016). It has become increasingly important to collaborate internationally in order to obtain early warning regarding possible future pest and disease threats.

Internationally, sentinel plantings are increasingly being used for the early detection of new insect and disease appearances on trees (Britton et al. 2010; Vettraino et al. 2015). They can be used as "trap trees" for detecting new incursions of pests and pathogens into a country as a "canary in a coal mine" scenario. These plantings can also adopt various other strategies and have multiple additional uses (Roux and Kanzler 2017). Sappi, for example, has established two eucalypt sentinel trials from which valuable data on pest and disease susceptibility of current and pre-commercial varieties have been obtained (Roux and Noeth 2018).

Through initiatives such as Camcore, it is possible to test key germplasm in countries where pest and diseases occur that are not yet in one's own country. Sappi established the first of the Camcore pine and eucalypt sentinel trials in South Africa in 2019. The trials were established to provide Camcore with information regarding the susceptibility of various species to the major pests and diseases in South Africa. Of particular interest to Camcore is the susceptibility of eucalypt species to *Teratosphaeria destructans*, the cause of Destructans leaf blight disease. This disease is currently only known in South Africa, China and South East Asia. This report presents results of the first pest and disease evaluation of the pine trials planted in Mpumalanga and two pest and disease evaluations of the eucalypt trial planted in Zululand.

## Pine Sentinel Trials

Two pine sentinel trials were established in Mpumalanga, one at HL Hall in January 2019 (Camcore Test 99-07-S19A2; Sappi Test PST0059T) and the other at Mooifontein in February 2019 (Camcore Test 99-07-S19A1; Sappi Test PST0058T). The Mooifontein trail contains 13 pine genotypes including pure species and hybrids (Figure 3) while the HL Hall trial has 10 genotypes (*P. greggii* S, *P. greggii* N, and *P. tecunumanii* LE were not available for planting at this site). Although the primary aim of these trials is to detect new and previously unknown pests and diseases, they have several additional benefits including the comparison of various tree genotypes' tolerance against known pests and diseases.

The trials were evaluated for survival and the presence of pests and diseases in May 2019. Survival at three months post planting was higher at HL Hall (93%) than at Mooifontein (73%). A total of 339 dead/dying/missing trees were recorded at Mooifontein, with higher levels of mortality observed for *P. patula* relative to all other genotypes (Figure 3). Sixty-six dead/dying/missing trees were recorded at HL Hall, with *P. patula* again showing the highest levels of mortality. Of particular note for Camcore's pine program is the performance of *P. greggii* S at Mooifontein with 36% better survival relative to *P. patula*.

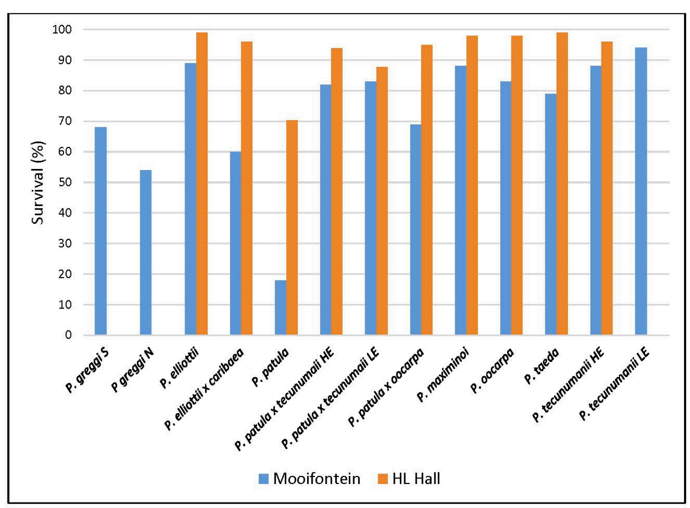



**Figure 3.** Summary of three-month survival for pine genotypes in the sentinel trials at Sappi.

Symptoms observed on trees in the two trials included browsing by unknown animals, reddening of needles, tip wilting and completely brown needles. Some dying/dead plants were found to have severe J-roots. It was not possible to determine the cause of death of completely dead trees as these trees were already too dry for analyses and were not sampled. Thirty-six samples from the two sentinel trials were collected for analyses. Of these, 27 were from the Mooifontein trial and 9 from the HL Hall trial. *Fusarium sp.* were obtained from 26 of these samples (72%). These cultures were submitted to the TPCP diagnostic clinic for confirmation of their identities. Of the samples submitted, 15 (58%) were confirmed as being the pitch canker fungus (PCF), *Fusarium circinatum*. The remaining trees produced *Diplodia sp.*, unknown *Fusarium sp.*, or no fungal/bacterial growth when analyzed. No unknown pests or diseases were encountered during this first evaluation.

The highest numbers of dead, dying and missing trees in both trials were found in *P. patula*. It is highly likely that most of these plants had died from infection by *F. circinatum* as *P. patula* is known to be highly susceptible to this pathogen (Hodge & Dvorak 2006). It was, therefore, not surprising that 41% of the plants identified with this pathogen represented *P. patula*. This was followed by *P. greggii* S, representing 33% of the plants with *F. circinatum*. Surprisingly, two *P. oocarpa* plants were found to be dying of *F. circinatum*. In screening trials, *P. oocarpa* has been found to be highly tolerant to infection by the pitch canker fungus. Results from previous studies showed that *P. oocarpa* is highly resistant followed by *P. tecunumanii* LE > *P. maximinoi* > *P. tecunumanii* HE > *P. patula* (Hodge & Dvorak 2006). A similar trend for mortality was observed in the two sentinel trials, confirming the ranking of pine genotype susceptibility to *F. circinatum*.

The high level or mortality at the Mooifontein site could be correlated to the harsher site conditions compared to HL Hall. This is especially relevant if one considers that of the samples analyzed, 42% were confirmed to be dying of infection by the pitch canker fungus, *F. circinatum*. It has been reported that mortality caused by the PCF is strongly influenced by environmental conditions and cultural practices and is higher on stressed plants (Blakeslee and Jokela 1999; Hammerbacher et al. 2009). Because most of the *P. patula* at the Mooifontein trial was already too dead for sampling, it can only be speculated as to how many of them died as a result of PCF. It is recommended that for future sentinel or other trials using *Pinus* genotypes, sampling for pests and pathogens be done at multiple intervals, starting before three months post planting, in order to positively identify the cause of death.

### Eucalypt Sentinel Trials

The eucalypt screening trial was established in Zululand at the Trust plantation in April 2019 (Camcore Test 97-07-S19A; Sappi Test EST0033K). A total of 12 eucalypt species were included in the trial (*E. brassiana*, *E. camaldulensis*, *E. grandis*, *E. longirostrata*, *E. pellita*, *E. urophylla*, *C. citriodora*, *C. henryi*, *C. maculata*, *C. torelliana*, *E. benthamii* and *E. dunnii*). Two pest and disease assessments have been completed since the trial was established, the first in August 2019 when half of the trial replications were evaluated and the second in October 2019 when the entire trial was evaluated.

Pests and diseases encountered during the August 2019 evaluation were: Destructans leaf blight (*Teratosphaeria destructans*), *Gonipterus sp.* 2 (eucalypt weevil), *Leptocybe invasa* (eucalypt gall wasp), *Phakopsora myrtacearum*, *Teratosphaeria suttonii* and thrips. Pest and disease levels were generally low.

*Eucalyptus camaldulensis* had the highest number of trees affected by pests/diseases, with 123 of the trees evaluated being affected (Figure 4). This was followed by *E. urophylla* and *E. longirostrata*. *Eucalyptus* species had higher pest and disease incidences and scores than the *Corymbia* species. *Corymbia* species scored zero for the major pests and diseases and were only affected by thrips, mostly on the lower most leaves. *Eucalyptus dunnii* and *E. benthamii* were only affected by *P. myrtacearum* and thrips. Of the *E. camaldulensis* trees, 40% were affected by *Leptocybe* and 68% by the rust fungus, *P. myrtacearum*. *Eucalyptus longirostrata* had high numbers of *Leptocybe* (35% of trees affected). The highest number of trees affected by Destructans leaf blight was in *E. grandis* followed by *E. urophylla* trees.

Pests and diseases encountered during the

October 2019 evaluation were: Destructans leaf blight, *Glycaspis brimblecombei* (red gum lerp psyllid), *Gonipterus sp*. 2, *Ellimenistes sp.* (grey weevil), *Leptocybe invasa*, *Phakopsora myrtaceaurm*, *Spondyliaspis* cf. *plicatuloides* (shell lerp psyllid) and shoot psyllids. The majority of pests and diseases were present at low severity levels. As in the August 2019 evaluation, *Eucalyptus* species had more pests and diseases than the *Corymbia* species (Figure 5). *Corymbia torelliana* was not affected by any pest or disease in either of the two evaluations. *Eucalyptus camaldulensis* on the other hand, was affected by all the pests and diseases observed in the trial.

The most common pest observed was the red gum lerp psyllid, *Glycaspis brimblecombei*, followed by Destructans leaf blight and *Phakopsora* rust. Although present, levels of *Gonipterus sp*. 2 was very low. Levels of *L. invasa* had decreased since August 2019 and no new thrips damage was observed. A weevil, *Ellimenistis sp.*, and shoot pshyllids were observed at very low levels (23 and 14 records respectively). *Teratosphaeria suttonnii* was restricted to the lower, older leaves on trees, as is common of this fungus.

*Eucalyptus camaldulensis* had the highest *Glycaspis* incidence, with 73% of the trees in the trial affected by this pest. The highest incidence of Destructans leaf blight was on *E. grandis* and *E. longirostrata*. *Phakopsora* rust was most common on *E. dunnii* and *E. camaldulensis*.

No previously unknown pests or diseases were observed during either evaluation period. The trial will continue to be monitored and evaluated at regular intervals. During the first year, evaluations will be done at shorter intervals (every 3 months), whereafter intervals will be adjusted to 6 and 12 months depending on the incidence and severity of pests and diseases observed.

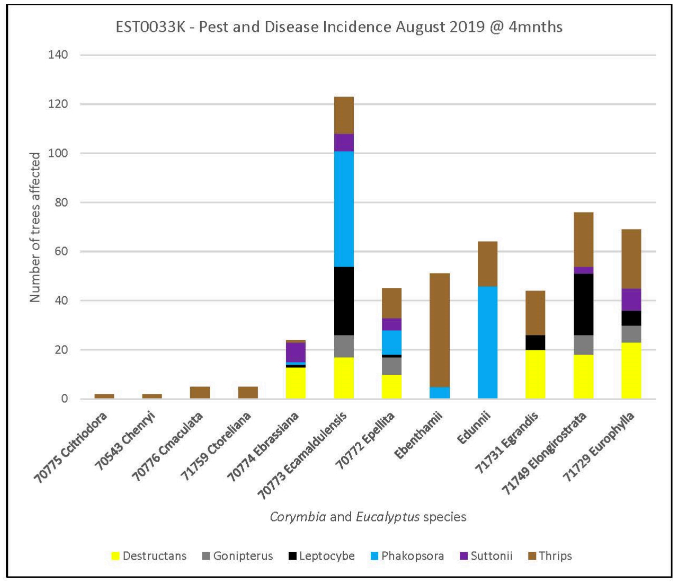



**Figure 4**. Summary of pests and diseases observed on eucalypt species during the August 2019 evaluation.

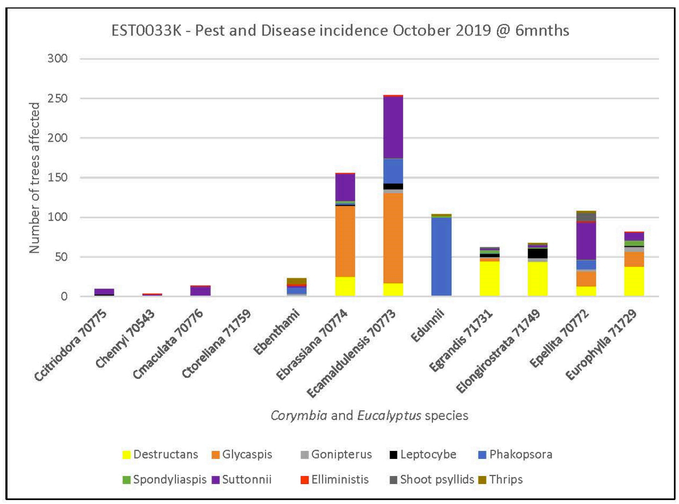



**Figure 5.** Summary of pests and diseases observed on eucalypt species during the October 2019 evaluation.

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# Tropical Pine SNP Chip: Update

*Colin Jackson completed his MS degree in May 2019, supported by Camcore and the NC State University Tree Improvement Program. Colin's thesis is titled " Single Nucleotide Polymorphism Discovery and Probe Design Using RNA-Seq and Targeted Capture in Tropical and Subtropical Pine Species". This article is a summary of Colin's thesis, and a status report on our progress toward an operational SNP chip.*

## Introduction

Despite traditional breeding and testing methods being effective in consistently producing better trees, the cost and labor associated with the methods are spurring breeding programs to explore the implementation of genomic technologies. Currently, with the advent of Next Generation Sequencing technologies, the ability to identify and exploit genomic variation has been revolutionized. However, given the large size of pine genomes and their highly repetitive nature, there are still many challenges in developing and implementing genomic technologies. Due to these challenges, reduced representation sequencing methods are an attractive option to reduce cost and computational burdens. Of these reduced sequencing methods, RNA sequencing (RNA-Seq) and targeted capture sequencing are among the most popular. The objectives of this study were to 1) utilize RNA-Seq and targeted capture sequencing for SNP discovery in tropical pine species and 2) assess these SNPs and their probes for potential use on a commercial genotyping array.

## Materials and Methods

*Plant Material: RNA-Seq*

RNA sequence data was generated for five pine species (*Pinus greggii, P. maximinoi, P. oocarpa, P. patula,* and *P. tecunumanii*) through a pathogen challenge experiment for pitch canker *Fusarium circinatum.* The pathogen challenge, RNA extraction and sequencing steps outlined in this project were performed by Erik Visser at the University of Pretoria as part of a previous unrelated study. Seedlings consisted of between one and four families and were sourced from various companies throughout South Africa.

*Plant Material: Targeted Capture*

A total of six species were selected for targeted capture: *P. greggii, P. maximinoi, P. oocarpa, P. patula, P. tecunumanii,* and *P. caribaea.* Within these species, sub-species were represented for *P. greggii* (north and south), *P. patula* (var. *patula* and var. *longipedunculata*), and *P. tecunumanii* (high and low elevation). Foliage samples were taken from 1st-generation genetic material established in Camcore field trials across South Africa for the extraction of genomic DNA. For the six species, a total of 81 pooled samples were created. Each pooled sample contained DNA from between 4 to 8 trees from different families and represented a single provenance of a given species. A total of 567 trees were sampled.

*Capture Probe Design*

A custom set of 40K target capture probes was developed by RAPiD Genomics to facilitate target capture sequencing. Of these 40K probes, 30K were designed from single-copy regions of the v2.01 *Pinus taeda* genome assembly and 10K were designed from the *P. patula* and *P. tecunumanii* transcriptome assemblies.

*SNP Discovery and Probe Design*

SNP discovery for both RNA-Seq and targeted capture data was implemented through a custom pipeline using bioinformatics software, and had three main phases: quality control, alignment, and variant calling.

SNPs that were successfully called were subjected to probe design. To meet technical specifications, probes were designed using custom programs to extract the 35 bases upstream and downstream, left and right flanking regions, of a SNP. These probes were then trimmed if there was another SNP within the 35bp flanking regions. Probes with either the left, right, or both flanks equaling 35 bases were selected for characterization.

*Probe Description: RNA-Seq*

Probes that survived filtering based on the previously mentioned technical specifications were further characterized. This was done to determine their similarity between species and their potential behavior once submitted for scoring for the screening array. Probes for each species underwent two separate characterization phases: the number of times each flanking sequence mapped to the *P. taeda* genome assembly and the number of flanking sites that map to the same location in the *P. taeda* genome.

The characterization of a probe's flanking site's ability to map to more than one location to the *P. taeda* genome was done utilizing a series of software that gives all possible alignments for a read regardless of its mapping score or redundancy.

The left and right flanking regions of the probes were assessed for shared mapping locations to the loblolly genome using a series of software and custom programs. In short, flanking regions were mapped to the loblolly reference genome and the overlap of each region tracked between each other. If mapping locations were within two bases of each other, the site was considered shared by those flanking regions. An incidence matrix was constructed for downstream analysis.

Principal component analysis (PCA) was performed to assess probe correlation between species. PCA was performed on the incidence matrix for shared mapping assessments. A random sample of 50,000 observations from the matrix was selected and used for the analysis.

*Probe Description: Targeted Capture*

SNPs were characterized at the species and subspecies level through creation of incidence matrices and principal component analysis (PCA). Furthermore, left and right SNP probe flanking regions that reached the full 35mer length were assessed for repetitive mapping to the loblolly pine reference genome.

Species- and subspecies-level incidence matrices were created for all SNPs generated by variant calling. The generated matrices were then subsetted to include only those SNPs that had a probe successfully designed for it and were used to illustrate how SNPs were shared among the species. Principal component analysis was performed at the species and subspecies levels on a random sample of 50,000 observations within the incidence matrices to assess concurrence of SNP between species and subspecies.

The repetitive mapping of flanking regions to the loblolly pine genome assembly was done utilizing the same protocol as the RNA-Seq derived flanking regions mentioned before.

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## Results

*Variant Calling and Probe Design*

Initial variant calling for RNA-Seq data generated between 426K to 1.1 million SNPs per species. From these datasets, between 175K to 301K probes were successfully designed per species that were then further characterized. In total 1,319,369 probes were successfully created from the design phase. These probes fell into three categories based on presence of a full 35mer flanking site: left flank only (442K), right flank only (425K), or both (451K).

Variant calling within targeted capture data yielded a list of 3.4 million raw SNPs. Results from the top-down filtering of the raw SNPs created a list of about 418K SNPs while bottom up generated a list of approximately 1.3 million SNPs. A total of 403K SNPs were common across both filtered datasets. Sets were merged to create a list of 1,356,522 SNPs for probe design.

Probe design processes performed on the approximately 1.3 million SNPs selected yielded a total of 562K probes. Of these probes, 228K were left flanking region only while 227K were generated with only a right flanking region. 107K probes were generated with both.

*Probe Description: RNA-Seq*

The left and right flanking regions of the probes generated were assessed separately for repetitive mapping and shared mapping locations. In order to be included in the dataset a flank must have reached the full 35bp length for that flank side.

Repetitive mapping analysis of the left and right flanking 35mer regions to the *P. taeda* genome revealed that over 50% of flanking regions mapped to a unique location for each species. Alignment percentage for all species' left and right flanking regions was greater than 90%.

Analysis of the shared mapping locations of left and right flanking regions revealed a high proportion of flanks mapping to a unique location in the v2.01 *P. taeda* genome assembly (Figure 6). *Pinus maximinoi* exhibited the largest number of unique locations distinguishing it as an outlier in behavior when compared to the other species.

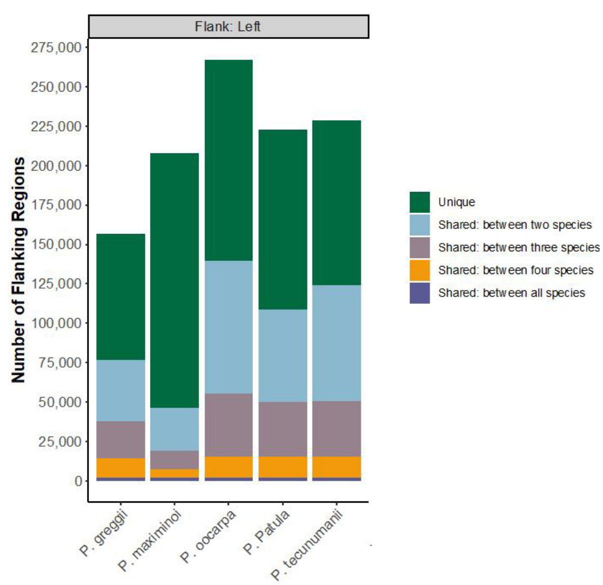



**Figure 6.** Number of shared and unique mapping locations of the left flanking regions for five specie mapping to the v2.01 *P. taeda* genome assembly.

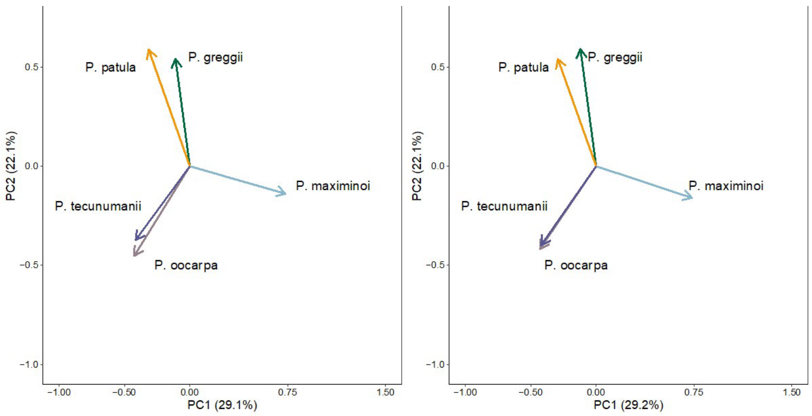



**Figure 7.** Principal component analysis of the shared mapping locations for the left and right flanking region using RNA seq.

Principal component analysis revealed 29% and 22% of variance associated with shared mapping location were explained by component one and two respectively for both the left and right flanking region. Correlations between pairs of species were shown with *P. patula* / *P. greggii* and *P. tecunumanii* / *P. oocarpa* pairs having loading angles which are close to one another (Figure 7). Left and right flanks paired in a similar manner indicating biological consistency between datasets.

*SNP/Probe Description: Targeted Capture*

SNPs with successful probes were further characterized at the species, subspecies, and provenance level. About 26K SNPs are shared across all study species (Figure 8). *Pinus caribaea* and *P. maximinoi* acted as outliers with a much lower proportion of SNPs shared between two, three, or four species. SNP sharing at the subspecies level exhibited the same overall pattern as at the species level. Across subspecies, about 24K SNPs were shared while about 26K SNPs were shared between eight subspecies. *Pinus maximinoi* exhibited a much higher proportion (63%) of private SNPs than other subspecies.

Principal component analysis performed on the species and subspecies SNP sharing matrices both showed *P. maximinoi* behaving very differently than the other species (Figure 9). At the species level, 46% and 17% of the variance was explained by component one and two respectively. Loading angles of the species, except for *P. maximinoi*, were fairly similar indicating correlation between them. Looking at the subspecies level, 48% and 11% of variance was explained by component one and two respectively. Loadings segregated by subspecies within species, grouping *P. greggii, P. patula,* and *P. tecunumanii* subspecies together, indicating stronger correlation between closer related species.

The left and right flanking regions for probes were assessed for repetitive mapping to the loblolly pine genome reference. Greater than 90% of probes mapped to a single location in the genome.

## Discussion

Between the two datasets utilized in this study, a large number of SNPs were discovered and selected for probe design. A total of 5.3 million SNPs were identified between the five pine species assessed in the RNA-Seq study, from which 1.3

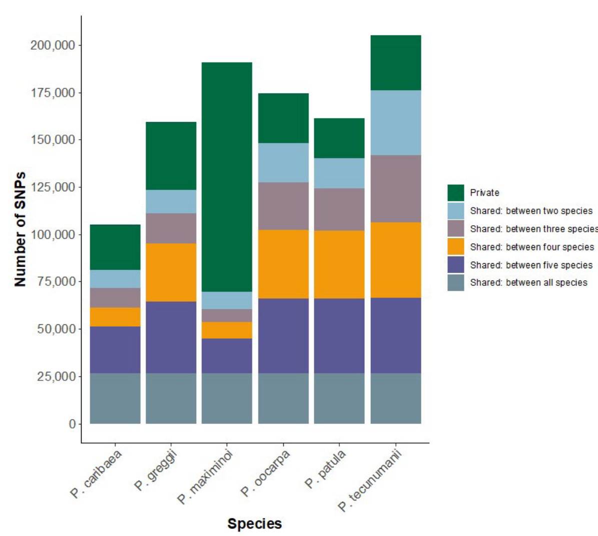



**Figure 8.** SNPs with successful probes shared at the species level.

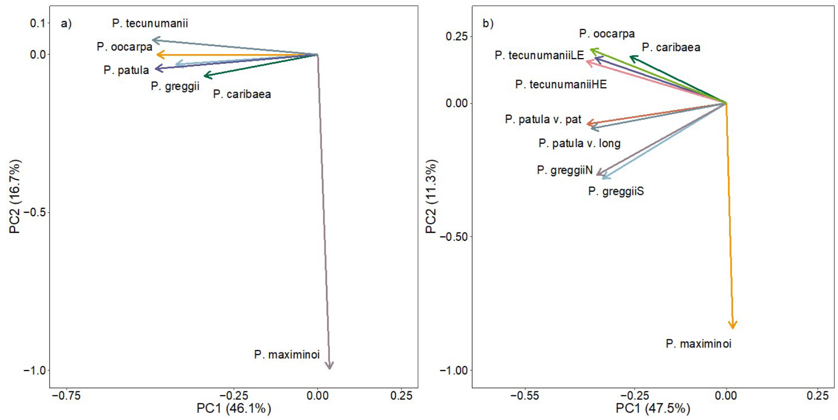



**Figure 9.** Principal component analysis of the SNPs shared among species using targeted capture.

million probes were successfully designed for assessment. For targeted capture sequencing, a total of 3.4 million SNPs were identified within six pine species, from which 562K probes were designed. This generated a total of 1.8 million probes for assessment from the two datasets.

Assessment of SNP sharing between species shows that there are a large proportion of SNPs that are unique to a given species for the RNA-Seq dataset and to a lesser extent in the targeted sequencing. Additionally, correlation of SNP sharing between more closely related species indicates that the SNPs identified and probes designed are behaving as expected from biology

Ultimately, the assessment of the probes generated in this study through scoring and use on a screening array will provide definitive answers to their utility on a commercial genotyping array. However, results from this study will be valuable in helping to choose SNPs that give the appropriate species sharing distribution as well as identifying species-specific SNPs to be included on the final version of the array. These sorts of species distribution considerations will be an important part of the design phase moving forward. Particularly, in the future of this study, there is a need for a set of SNP probes that are shared across species, making the array valuable for populations of each species assessed. However, the need for transferability will ideally be balanced with species specific SNPs that will be valuable in species and hybrid cross identification.

The completion of the commercial array for these species will provide tree improvement managers, breeders, and scientists a powerful tool to aid in the management and conservation of tropical pine species. The array will provide users with a highly transferrable, reproducible, and computationally friendly technique to assess their populations. This makes the array useful to a wide range of individuals and applications by removing the need for special bioinformatics knowledge or infrastructure, helping usher in the use of molecular breeding technology in commercial pine breeding programs.

## Ongoing Work

Recently, 427K probes were selected to be used on a screening array prior to production of the commercial array. Of these 427K probes, 323K were RNA-Seq derived with the other 104K sourced from targeted capture data. Decisions were informed using the results reported above in conjunction with recommendation scoring performed by Thermo Fisher. Upon the completion of the screening array, 576 samples were submitted for screening across the species above along with *P. elliottii* and the *P. elliottii x P. caribaea* var. *hondurensis* hybrid. Preliminary results from this screening indicate ~50% of selected markers are recommended for use on the commercial screening array. Further assessment is underway to select the most informative 50K markers for use on the commercial array. All Camcore members will be eligible to use the commercial array at the discounted price of $20 per sample. Non-consortium / non-Camcore members will pay $44 per sample.

# Comparison of Laboratory and Handheld NIR Devices

Camcore has been working with Near-infrared spectroscopy (NIR) since 2000. Most of our work has been with a very high-quality laboratory machine, the Foss 6500. We have also done work with a handheld scanner, the Thermo Scientific MicroPhazir, which has given good results (e.g., see the 2015 Annual Report). In 2019, we began testing a new device, the Texas Instruments DLP NIRscan Nano EVM. We collaborated with Dr. Miguel Castillo who works in the area of Forage and Grassland Management at NC State University, to test and compare the different devices to develop NIR models for some important grass crop traits. A full manuscript on this research has been submitted for publication, but here we present a summary report.

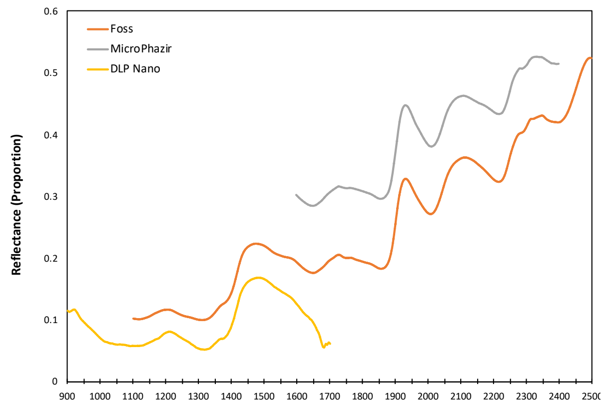



**Figure 10.** Raw NIR spectra from a typical forage sample measured by three different NIR devices.

## Materials and Methods

*Sample Preparation*

Samples from two warm-season perennial grass species, switchgrass (*Panicum virgatum* L.) and bermudagrass (*Cynodon dactylon* (L.) Pers), were used for this project. Switchgrass has dual potential as a bioenergy and forage crop. Bermudagrass is the most important warm-season grass species for livestock production in the southeast USA. The complete database had a total of 210 samples (138 switchgrass + 72 bermudagrass). Sampling protocol for both forages consisted of clipping within an area ≥ 3 $m^2$; then, a subsample of approximately 1 kg was dried in a forced-air oven at 60ºC until the samples achieved constant weight. The dried samples were ground using a Christy & Norris laboratory mill (Christy Turner Ltd, Suffolk, UK) to pass through a 1-mm screen and subsequently stored in Whirl-Pak bags. Wet chemistry analyses were performed by Dairy One Laboratory (Ithaca, NY). The traits measured were Crude Protein (CP), Neutral Detergent Fiber (NPF), Acid Detergent Fiber (ADF) and In-vitro True Digestibility (IVTD).

*NIR Devices*

For each sample, 4 g of ground material was placed in spinning-sample module cups of the FOSS 6500 NIRsystems and then scanned using the laboratory (Foss) and the two handheld NIR spectroscopy devices (MicroPhazir, Nano). The Foss reflectance readings were taken for NIR wavelengths from 1100 to 2500 nm, at 2 nm intervals, with a total of 32 scans averaged to produce a single reflectance spectrum for each sample. The MicroPhazir measures at wavelengths 1600 to 2400 nm, at 8 nm intervals, and the Nano measure at wavelengths 900 to 1700 nm, at 5 nm intervals. For the handheld devices, samples were scanned in four positions by rotating the sample cups 90 degrees, and NIR models were built with the mean reflectance spectrum of each sample. As expected, the average raw spectrum was very different among the three devices; however, it is interesting to note that "peaks and valleys" in the spectrum followed the same shape although at different reflectance values (Figure 10).

*NIR Model Development*

We split the population into two sets, training and validation sets. The training set consisted of ~75% of observations and this set was used for model development. The remaining ~25% of observations are referred to as the external validation set. The calibration and validation data sets were kept balanced for the different species.

Model development was performed using the data analysis pipeline written in R (R Core Team, 2016) that was used for the global eucalypt NIR model (Hodge et al. 2018, JNIRS). Briefly, the pipeline has two separate phases: 1) transformations and outlier detection and 2) model training, cross-validation, and prediction of new observations. Several transformations are examined (including Multiplicative Scatter Correction (MSC), Standard Normal Variate (SNV) and Detrend (DT), and second derivative of Savitzky-Golay smoothing with two different window sizes of 5 and 7 points (SG5 and SG7). Partial least squares regression (PLS) was implemented using the R-package pls and model performance was evaluated using leave-one-out (LOO) cross-validation. Desirable models are those that 1) maximize the cross-validation $R^2_{CV}$, 2) minimize the standard error of cross-validation (SECV), and 3) have a small number of latent variables (projection factors). Based on the aforementioned criteria, the best models for each NIR device and each analyte were selected to predict CP, NDF, ADF, and IVTD.

*NIR Model Comparison*

The three devices were compared primarily by examining the predictions for the validation data set. We compared the Pearson correlation of the wet chemistry values and the predicted values, coefficient of determination ($R^2$) and standard error of predictions (SEP). Validation scatterplots for CP, NDF, ADF and IVTD were created by plotting the wet chemistry values on the x-axis and the NIR predicted values on the y-axis (Figure 11).

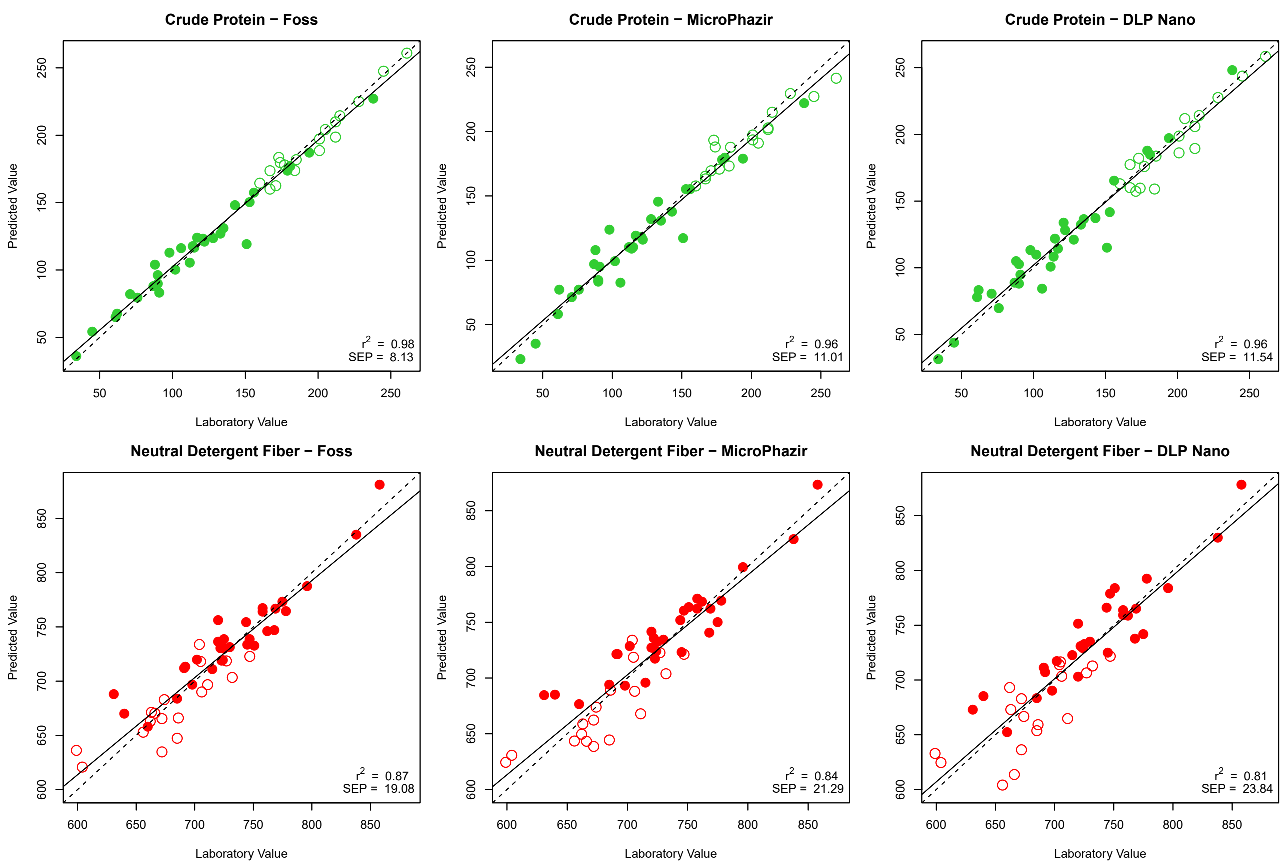



**Figure 11.** Laboratory-measured values versus NIR predictions for Crude Protein and Neutral Detergent Fiber content of switchgrass (solid circles) and bermudagrass (open circles) forage samples. NIR models were calibrated using 75% of the data set; the plots represent validation predictions made for an independent data set representing 25% of the samples.

## Results and Discussion

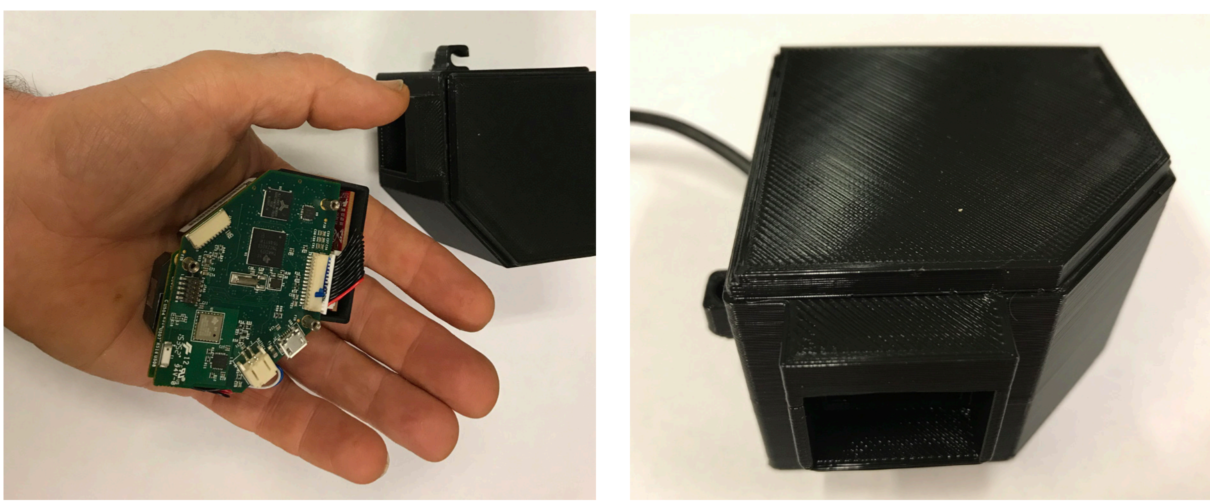
In general, for the calibration data sets, good NIR models were developed for all traits on all three devices. The $R^2$ of cross-validation values were $R^2_{CV} > 0.96$ for CP and IVTD, $R^2_{CV} > 0.86$ for NDF, and $R^2_{CV} > 0.76$ for ADF. Models with greater $R^2_{CV}$ had lower standard errors of cross-validation (SECV). SECV values were lowest for CP ($\leq 10.1$), ranged from 18 to 19 for NDF, from 26 to 28 for ADF, and from 19 to 31 for IVTD.

The utility of the NIR models was further assessed using the external validation samples. Looking at the $R^2$ of prediction, all three devices gave similar results. For CP, $R^2_P$ ranged from 0.96 to 0.98. For IVTD, $R^2_P$ ranged from 0.90 to 0.97. For ADF, $R^2_P$ ranged from 0.87 to 0.92. Finally, for NDF, $R^2_P$ ranged from 0.81 to 0.87. Figure 11 shows the plots of wetlab and NIR predicted values for the validation data sets for the two traits with the highest and lowest $R^2_P$ values, CP and NDF, respectively. The Foss models consistently produced calibrations with the best fits, i.e., with the highest $R^2_{CV}$ and $R^2_P$, and lowest SECV and SEP. However, the two handheld devices produced NIR models with very similar performance. For example, the Foss had $R^2_P$, = 0.87 and 0.98 for NDF and CP, respectively. The corresponding values for the MicroPhazir were $R^2_P$, = 0.84 and 0.96, and for the Nano were $R^2_P$, = 0.81 and 0.96.

## Conclusions and Implications

Successful NIR models were developed using all three devices for all forage traits. The Foss laboratory device produced the best models, however the less expensive handheld devices produced models with similar precision.

Going forward, we will continue to test the handheld devices for important wood chemistry traits. It is important to note that the forage traits examined in this study are similar to the major wood components of glucose and lignin, in that they make up a large portion of the sample. For example, mean CP content of these samples was 14%, ADF content was 38%, and NDF content was 70%. For wood samples, mean xylose content is around 13%, klason lignin content is around 25%, and glucose content is around 47%. In wood, sugars such as arabinose, galactose or mannose typically make up less than 2% of the total mass. We know that the very precise Foss 6500 can produce good models for these traits; but it is not yet clear how the handheld devices would perform for these traits. Nevertheless, at this point, the performance of the handheld devices is very encouraging, especially since the Nano is relatively inexpensive; current market price is around US$ 1000.



The Texas Instruments DLP NIRscan Nano EVM. The miniature NIR scanner can be powered by a USB connection or by battery. The device comes without a case, so Camcore is developing cases that can be produced with a 3D printer.

# Expanding the Global Eucalypt NIR 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, Acosta 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*) from different countries and multiple sites. We call this 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 2019, we sought to increase the robustness of that model by adding samples of 102 trees from 11 different *Eucalyptus* and *Corymbia* species.

**Table 3.** Species samples available for expansion of the Camcore global eucalypt NIR model.

| Species | Scanned | Wetlab |
|---|---|---|
| *E. badjensis* | 96 | 10 |
| *E. benthamii* | 114 | 10 |
| *E. dorrigoensis* | 150 | 10 |
| *E. macarthurii* | 133 | 10 |
| *E. pellita* | 30 | 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 |
| **11 species** | **1297** | **102** |

## Methods

Wood samples from 1267 trees from 10 species were provided by Mondi Forests (Table 3), and an additional 30 trees of *E. pellita* provided by Merensky. All samples were NIR scanned, and 102 samples, some from each species, were selected for wetlab analysis based on pulp yield and chemical predictions from the 2017-19 global NIR models. As in the past, wetlab chemistry was done by Shawn Mansfield at the University of British Columbia. Typically, 10 samples from a "new" species were sent for analysis; our research indicates 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.

## Results and Discussion

*Model Extrapolation to "New" Species*

Figure 12 (left) shows the results of using the 2017-19 global model to predict wood chemisty of these new species. For three of the four traits (Xylose, Insoluble Lignin, and S/(S+G) (i.e., syringyl lignin percentage), the extrapolation predictions for the new species look quite good, with high correlations between predicted and lab values ($R_p$ = 0.95, 0.95, and 0.84, respectively). The Glucose predictions were less satisfactory, with a correlation of $R_p$ = 0.38. It is clear from the plot that the global model under-predicts Glucose for *Corymbia* and over-predicts for the mixed eucalypts, contributing to the low correlation. However, considering only one genus at a time, the correlation is significantly better, with $R_p$ = 0.63 for the mixed eucalypts, and $R_p$ = 0.47 for the corymbias.

*"New" Species in the Calibration Model*

When the new species are included in the global calibration model, then all four wood chemical traits are predicted with high precision and essentially no bias (Figure 12, center). For Xylose, Insoluble Lignin. and S/(S+G), the cross-validation between the predicted and the lab values have $R_{cv}$ = 0.97, 0.95, and 0.92, respectively. For Glucose, the correlation is now very good ($R_{cv}$ = 0.85), and is quite sufficient for selection purposes.

*Global Eucalypt Model 2020*

The "new and improved" global model now includes a total of 290 samples (50 *E. urophylla*, 50 *E. dunnii*, 41 *E. globulus* and 9 *E. nitens,* and 38 *E. grandis,* along with 62 additional samples of mixed eucalypt species, and 40 *Corymbia* samples). These models predict the four important wood chemistry traits with a high degree of precision (Figure 12, right), with $R_{cv}$ > 0.95 for Xylose, Insoluble Lignin and S/(S+G), and $R_{cv}$ = 0.84 for Glucose. In addition, we can predict other minor sugars (mannose, arabinose, and galactose) with $R_{cv}$ = 0.85 to 0.94.

Going forward, we do not think we need to expand this global model further; it is already sufficiently robust and precise enough to be very useful in breeding programs for *Eucalyptus* (and probably *Corymbias*). Perhaps we can begin working on another genus -- *Acacia* for example?

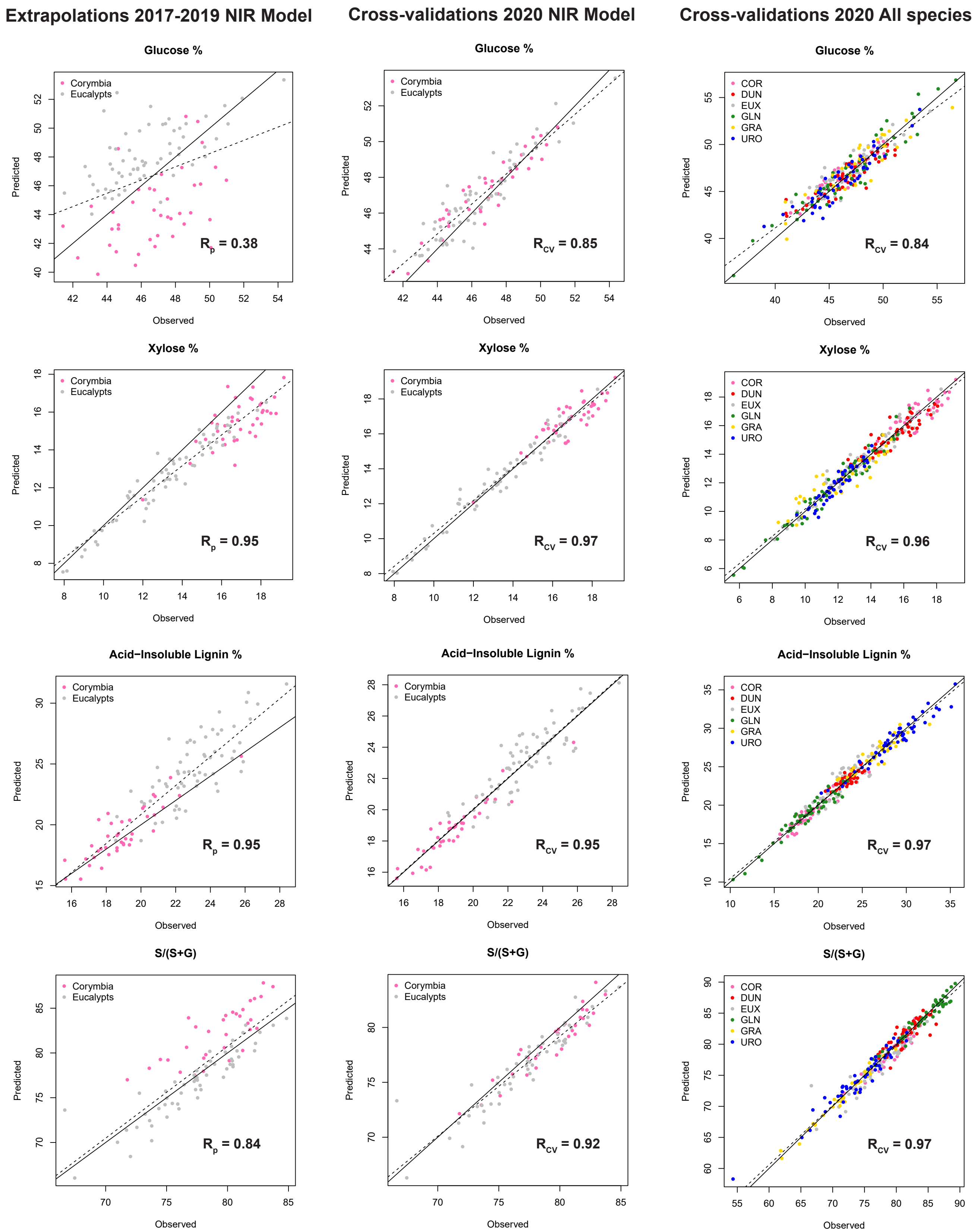



**Figure 12.**
**Left:** Extrapolation predictions from the 2017-19 Global NIR model for corymbias and new mixed eucalypts.
**Center:** Cross-validation predictions from the 2020 Global NIR model for corymbias and new mixed eucalypts.
**Right:** Cross-validation predictions from the 2020 Global NIR model for all species.

# 2019 Seed Collections in Central America

We continue making seed collections in Guatemala and Honduras every year. In 2019, Elmer Gutiérrez and Josué Cotzojay visited seven natural stands of *P. tecunumanii, P. maximinoi* and *P. caribaea* (Table 4).

The main purpose of the collections is for *ex situ* conservation of these populations. Camcore members establish progeny trials and conservation banks in which these gene pools are available for future use. Catastrophic or large-scale events, like the *Dendroctonus* bark beetle attack in Honduras in 2015 that affected more than 500,000 hectares, can deplete the genetic resources in some natural stands. In addition to high-impact events, there are other ongoing threats that contribute to the depletion of genetic diversity like forest fires, pest outbreaks, agriculture and cattle expansion, resin extraction and illegal logging.

New members of Camcore with interest in pines receive seeds of different species and provenances to expand the genetic diversity required for successful tree breeding programs. We continue to maintain our good relationships with government agencies in Central American countries as a way to help with the conservation of their native genetic base. These resources are available for utilization in these countries whenever the government requests them.

Josué Cotzojay of Camcore climbing a *P. maximinoi* tree for seed collection in San Juan Sacatepéquez, Guatemala.

**Table 4.** Summary of seed collections completed in Central America in 2019.

| Country | Species | Provenance | Conservation Status | Latitude | Longitude | Trees |
|---|---|---|---|---|---|---|
| Guatemala | *P. tecunumanii* | San Jerónimo | Critically Endangered | 15° 00' N | 90° 16' W | 13 |
| Guatemala | *P. tecunumanii* | San Miguel | Endangered | 15° 15' N | 91° 45' W | 3 |
| Guatemala | *P. maximinoi* | Cobán | Critically Endangered | 15° 46' N | 90° 20' W | 6 |
| Guatemala | *P. maximinoi* | San Juan Sacatepéquez | Vulnerable | 14° 41' N | 90° 38' W | 17 |
| Honduras | *P. tecunumanii* | Villa Santa | Vulnerable | 15° 17' N | 85° 38' W | 20 |
| Honduras | *P. tecunumanii* | Los Planes | Vulnerable | 14° 47' N | 87° 50' W | 20 |
| Honduras | *P. caribaea* | Limón | Endangered | 15° 51' N | 85° 23' W | 24 |

# New Species Collection: *E. amplifolia*

At the 2019 Annual Meeting in Portugal in September, we identified *Eucalyptus amplifolia* as a species of interest in the expansion of the Camcore eucalypt portfolio. In December 2019, we completed a collection of this species from an improved population in Georgia.

*Eucalyptus amplifolia* is a relatively cold -tolerant eucalypt suitable for the wet subtropics. The native range in Australia is primarily in New South Wales, from sea level to 920 m elevation. It can grow in rather warm climates (mean maximum temperature of the hottest month from $24^o$ to $29^oC$), but also can tolerate strong frosts (down to $-12^oC$).

The population in Florida is derived from work done by the University of Florida (UF) since 1980. This work involved many collaborators and funding from the US Dept of Energy, the USDA Forest Service, as well as other governmental and private organizations, largely coordinated by Professor Don Rockwood of UF.

The *E. amplifolia* orchards are located in Valdosta, Georgia (USA), latitude $32^o$ 10' N. Mean annual precipitation is 1374 mm, with no significant dry period. The high average monthly temperature is $33^oC$, and low average monthly temperature is $4^oC$, with some 30 to 40 frost events per year.

The UF breeding strategy for *E. amplifolia* (and other species) focused on early selection, seedling seed orchards, and the rapid turnover of generations. There are three orchards currently producing seed:

- AO_03 = a seedling seed orchard (SSO) established in 2003
- AO_10 = a SSO established in 2010, and
- AO_13 = a clonal seed orchard (CSO) established in 2013.

The Camcore collection was completed in late 2019, and a total of 38 families were collected, focusing on families and trees which exhibited good growth, good form, frost tolerance and wind firmness. The seed was air dried in Georgia, and then transported to Raleigh for cleaning and processing. From SSO AO_03, 18 families were collected, and from SSO AO_10, 6 families were collected. From CSO AO_13, 14 families were collected. For several of these 14 mother clones, seed collections from multiple ramets were made and kept separate. There were 100 different clones in the orchard, and the different ramets of the same clone in our collection were surrounded by different males.

We plan to begin distributing these families to interested members in the first half of 2020. It should be noted that it is possible to purchase commercial amounts of *E. amplifolia* seed from these seed orchards. Interested parties should contact Camcore for more information.

Mark Crawford in the *E. amplifolia* seed orchard of Florida Fast Growing Trees in Valdosta, Georgia.

# Camcore Domestic Conservation Projects

In 2003 Camcore began working with the USDA Forest Service (USFS) to collect and conserve seed from threatened Carolina hemlock (*Tsuga caroliniana*) populations located in the southeastern United States. Following the success of that project, we expanded our partnership with the USFS through conservation projects with an additional ten domestic tree species. Over the last 17 years, Camcore has helped to conserve seed from over 1700 trees across 265 locations for 11 threatened tree species (Table 5).

Our work with the USFS to conserve these tree species is due to threats from insects, pathogens, wildfire suppression policies, habitat fragmentation, climate change, sea level rise, and other disturbances. Collected germplasm is shared between Camcore and the USFS and currently resides in cryostorage, cold storage, and in seed orchards, both *in situ* and *ex situ*. The goal of these conservation efforts is to obtain genetic material before populations, or entire species, are functionally eliminated. Conserved germplasm is to be maintained in perpetuity for use in breeding, research, and restoration efforts.

## Seed Conservation

Due to low domestic cone production in 2019 across much of the southeastern US, we dedicated our 2019 domestic efforts towards our hemlock silviculture research projects and establishing *in situ* conservation orchards. Domestic cone collections completed in 2019 consisted of an additional ten red spruce trees from the previously collected Roan Mountain, NC/TN population as well as 33 Carolina hemlock trees from our seed orchard located on the Upper Mountain Research Station (UMRS) in northwestern North Carolina. The 2019 collections from this orchard mark the fourth year of collections from this site. Previously collected UMRS seed appeared to be infertile, most likely due to the young age of the trees. We are optimistic that our 2019 UMRS collection may finally yield viable seed. While no seed collections were made from pitch pine populations in 2019, we did make significant progress in scouting sites from which to collect in the future.

## Seed Orchards

After 17 successful years of seed collections, 2019 was marked by substantial progress in placing a portion of this germplasm into seed orchards. Following several months of planning we headed out to the field in December and began laying out planting flags for both an eastern hemlock and Table Mountain pine orchard at the USFS Beech Creek Genetic Resource Management Area (GRMA) in NC, and the Chilhowee GRMA in TN. The eastern hemlock orchards will both be made up of 300 seedlings comprised of material from many of our southern US collected provenances. Table Mountain pine orchards will each contain 168 seedlings germinated from Camcore-collected seed as well. Seedlings for these orchards were greenhouse grown at our facilities on the Mountain Research Station (MRS) in Waynesville, NC over the last three years. These new seed orchards are located on USFS lands and will be jointly managed by Camcore and the USFS with future seed produced to be shared between both parties. Seed from these orchards will be instrumental for future research and restoration efforts. Camcore greatly appreciates the support from USFS staff in helping

Mike Brod, Drew McCarley, and Justin Seaborn of the USDA Forest Service planting an Eastern hemlock seed orchard at the Beech Creek Genetic Resource Management area in Murphy, North Carolina.

**Table 5.** Summary of seed collections completed in the USA 2003 - 2019.

| Species | Common Name | Provs | Families |
|---|---|---|---|
| *Tsuga caroliniana* | Carolina Hemlock | 29 | 220 |
| *Tsuga canadensis* | Eastern Hemlock | 81 | 593 |
| *Pinus pungens* | Table Mountain Pine | 44 | 294 |
| *Chamaecyparis thyoides* | Atlantic White Cedar | 33 | 255 |
| *Fraxinus texensis* | Texas Ash | 9 | 76 |
| *Fraxinus caroliniana* | Carolina Ash | 3 | 14 |
| *Fraxinus profunda* | Pumpkin Ash | 1 | 1 |
| *Fraxinus quadrangulata* | Blue Ash | 6 | 19 |
| *Picea rubens* | Red Spruce | 19 | 137 |
| *Abies fraserii* | Fraser Fir | 13 | 134 |
| | *Totals* | 238 | 1743 |

to actualize these important conservation plantings.

In addition to the establishment of the eastern hemlock and Table Mountain pine orchards, preliminary discussions and site visits with the NC Forest Service were undertaken in late 2019. The goal of these talks was to establish a 500-seedling Carolina hemlock orchard located in the mountains of NC. Similar to the Beech Creek and Chilhowee orchards, the Carolina hemlock seedlings for this proposed orchard are comprised of three-year-old potted material germinated from Camcore collected seed and grown at the MRS. We are eager to continue the planning of this new Carolina hemlock conservation orchard and are tentatively looking towards establishment in early 2020. This new Carolina hemlock orchard located near Linville, NC will mark our third *in situ* planting in NC for this species.

Albert (Bud) Mayfield of the USDA Forest Service demonstrating how to plant seedlings for the Hemlock Restoration Study Phase II.

## Hemlock Silviculture

By 2014 it was reported that the invasive hemlock woolly adelgid (HWA) had infested approximately one half of the 2.3 million acres of hemlock-dominated forests in the eastern US. Commonly utilized efforts to combat this destructive pest include chemicals, biocontrol, and to some extent breeding. Adding to these techniques Camcore is investigating silviculture methods to both determine how to best reintroduce hemlock as well as how altering sunlight levels affects tree health and HWA presence.

In anticipation of a successful HWA management strategy, Camcore is actively researching how to best grow hemlock trees so that we can effectively deploy collected germplasm back into natural forests. Part one of this three-part study was implemented in the mountains of NC in the winter of 2014-2015 using 1536 nursery-grown eastern hemlock seedlings. After four years growth, data has shown that shade-tolerant eastern hemlock is significantly larger when planted in small gaps versus thinned stands. The application of both fertilizer and herbicide also improves tree growth over either of these treatments alone and the no-treatment control. In early 2019, low levels of HWA were found in some of the plantings indicating that insecticide applied during establishment had lost its effectiveness and that the study could now be converted into an insectary for use in future HWA research. Thinning of the study by one half was done in February of 2019 in order to open up the plantings and further promote growth.

The second part of our hemlock reintroduction silviculture study began during the winter of 2018-2019 with a donation of nearly 2500 eastern and Carolina hemlock bare-root seedlings by the North Carolina Forest Service. These seedlings were promptly potted by Camcore and the USFS and grown for one year at our facilities on the Mountain Research Station. In

December of 2019, we planted 1280 of these seedlings, half eastern and half Carolina hemlock, into a study located just southwest of Asheville, NC. This second phase of the silviculture study will follow the effects of different levels of sunlight, insecticide application, species, and herbicide application on tree growth. Special thanks are extended to the USFS for providing space and the labor to help implement the study. We also greatly appreciate the planting assistance from the Hemlock Restoration Initiative for providing both employees and volunteers to help in the study establishment.

Building on research conducted by Camcore and the USFS in 2014 and 2015 that showed increasing light levels on potted hemlock seedlings lowered HWA infestation rates and improved seedling carbon balance, we initiated a study looking at how varying light levels on natural trees affected tree health. This study was implemented on 105 trees in native forests from Georgia to Maryland. Treatments include two gap sizes, two gap creation methods and a no-treatment control. While this study is ongoing and results are far from conclusive, early data suggests that increasing sunlight exposure on infested trees may lower the HWA load in trees while increasing the amount of new growth. While it is impractical and premature to suggest cutting gaps around all infested hemlocks, it is our hope that this silviculture study may one day help develop an integrated pest management strategy for HWA control.

### Carolina hemlock species assessment

In order to more fully understand the distribution of Carolina hemlock in the southern Appalachian Mountains, Camcore has been visiting, mapping, and assessing the health of all reported natural populations of the species over the last several years. At the start of this project, we knew of 32 confirmed Carolina hemlock populations. This number quickly rose to 133 populations through early research and meetings with folks familiar with the species. This dramatic jump in populations resulted in the initial explorations and mapping taking longer than expected. In 2019, a total of 25 reported Carolina hemlock populations were explored, raising the number of visited sites to 105 since project inception. From these 105 site visits, we have confirmed and mapped 77 sites containing natural Carolina hemlock trees. The remaining 28 visited sites either contained no Carolina hemlock, only planted trees, or had access issues that prevented our visit. Health across visited populations varied from poor to very healthy. Health of the populations appeared to be correlated with chemical treatments and increased sunlight levels. There were no obvious trends in health across elevation or latitude. Carolina hemlock has been located at elevations from 434 to 1580 meters and is most frequently found on northern and western aspects. Average elevation across all confirmed sites was 977 meters.

Ashleigh Hillen (Camcore) inspecting a healthy Carolina hemlock at Kitsuma Peak in western North Carolina for the Carolina assessment project in 2019.

Andy Whittier (Camcore) talking to students from TC Henderson elementary school about our work with gene conservation of US species. This work has brought much recognition to Camcore over the past 15 years.

# Data Management Courses

Two Data Management Workshops were hosted by Camcore members APRIL and Sinarmas in 2019, the first time the course has been held in Indonesia. Both companies had a group of 14 tree breeding and research staff that attended the week-long sessions in Kerinci for APRIL and Perawang for Sinarmas.

Camcore offers the Data Management Workshop to members to improve their staff's skills in managing data associated with tree improvement research. The 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 course includes lectures, discussion and hands-on computer and spreadsheet exercises. The workshop begins with some discussions about data management and how Camcore codes and records information about provenance collections, trial establishment, and tree growth data. Demonstrations about how to manipulate Windows shortcuts, personalized toolbars and the Excel user interface help users be more efficient in their daily work. The large part 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(). Pivot Tables and the Autofilter function are important tools in Excel, so they are practiced many times in the course. The students liked some more advanced techniques such as VLOOKUP() functions and recording macros. Learning all these methods 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 measurements, and creating a trial design and making a data template and field map for trial establishment. Teacher Willi Woodbridge knew a number of staff from both companies that were graduates from previous courses in other countries, but he was pleased to meet all the new students that participated in 2019. Everyone worked hard and learned a lot, regardless of their experience level prior to the course.

Courses are being planned for South Africa in 2020. The course hasn't been held there for 10 years, so Willi is expecting a record number of students!


# Changes in Camcore

**Carlos Gioia** left Uumbal after five years working with the company on research and development in Mexico. Carlos decided to return his country Argentina, where he rejoined Arauco as chief of research and development. Carlos did a great job establishing and managing several Camcore research projects and trials with Uumbal. We are glad to have Carlos working with Camcore again in his new job.

**Laercio Luiz Duda** who was working as Forestry Director in Araya Bumi Indonesia (ABI) left the company in 2019. Laercio has always been a good friend of Camcore and played important roles in research projects with the program, working with several members in the past, including WestRock in Brazil and Sinarmas Forestry and ABI in Indonesia. We wish success to Laercio in his new professional activities.

**Ricardo Paím** retired from WestRock in November 2019, after working for 27 years with the company. Ricardo was always a great supporter of Camcore, making significant contributions to the program on research projects. We want to thank Ricardo and wish him a well-deserved and happy retirement.

**Christi Sagariya** left Miro Forestry Sierra Leone where he worked as the tree-breeding manager in charge of research and development, including nursery management. Christi was very enthusiastic working on Camcore projects. We wish him success in his new endeavors.

**Arnulf Kanzler** went to work with Sinarmas Forestry in Indonesia, after working in Sappi for 28 years. He took the position of Program Leader in Forest Improvement at Sinarmas in June 2019. Arnulf will provide a lot of knowledge and experience to Sinarmas, contributing significantly to the forestry sector of Indonesia and the company. In the Camcore annual meeting in Portugal, Arnulf was elected to the Camcore Executive Committee. Arnulf's leadership and contributions will continue to be appreciated in all Camcore activities.

**André Nel** was promoted to the position of Program Leader of eucalypt and pine breeding in Sappi as part of restructuring of the tree-breeding program in the company. André has been working for many years with Sappi and we are sure he will be very successful in his new challenges.

**Gert van der Berg** was promoted to the position of Program Leader of the eucalypt hybrid program in Sappi. Gert has vast experience working with *Eucalyptus* and we know he will make important contributions in his new position and his dedication to Camcore projects in South Africa.

**Phillip McIntyre,** who has been working in forestry planning for years with PG Bison, was given additional responsibilities within the company and was named Planning and Research Manager in 2019. We welcome Phillip and we are glad to have him as the new contact with Camcore to develop research projects for the company.

**Mário César Gomes Ladeira** left his position as director of research, development and forest quality with Klabin (Brazil) to take the position of Senior Director of Research and Forest Development for Bracell (Bahia, Brazil). Mário was elected to the Camcore Executive Committee at the 2019 Annual Meeting in Portugal, while representing Klabin. He will continue as an Executive Committee member now representing Bracell.

**Bruno Alfonso Magro** has taken over the position of director of research, development and forest quality with Klabin (Brazil). We look forward to getting to know Bruno and working with him in the future.

**Ben Pienaar**, Forestry Research Director with Mondi was officially named Chairman of the Camcore Advisory Board in the annual meeting in Portugal. Ben has been a great forestry leader with Mondi and a valuable supporter of the Camcore program in South Africa. We are very pleased to have Ben as the new chair of Camcore.

# Graduate Programs and Training

**Juan Pedro Posse**, Research Manager with Lumin Uruguay, continues to work on the final stages of his PhD dissertation on the genetic control of wood properties in *Eucalyptus dunnii*, under the direction of Gary Hodge. Juan Pedro plans to complete the PhD dissertation and graduate in 2020.

**Colin Jackson** successfully completed his MS degree in the spring of 2019, under the direction of Juan Jose Acosta, Fikret Isik and Gary Hodge. His thesis dealt with molecular genetic data related to the tropical pine SNP chip, and his work was very important to the development of the set of 450K SNPs currently under assessment in the last stage of development of the operational screening chip. Colin began a PhD program in the fall of 2019, and will continue working with us on applications of the operational SNP chip for tropical pine breeding. Colin is being jointly funded by Camcore and the NC State University *P. taeda* Tree Improvement Program.

**Luis Ibarra** began studying for an MS at NC State in 2017, funded by the Camcore graduate student stipend, and supported by Arauco Bioforest in Chile. In 2018 he converted to a PhD program, and he continued that work in 2019. He is working under the direction of Gary Hodge and Juan Jose Acosta. His dissertation will focus on hybrid quantitative genetics and breeding, and he will examine data from three hybrid breeding programs involving *P. patula x P. tecunumanii, E. globulus x E. nitens,* and *E. grandis x E. nitens.*

**Gustavo Martins** began working on a PhD in 2019, funded by the Camcore graduate stipend, and supported by APRIL, Indonesia. He is working under the direction of Gary Hodge and Juan Jose Acosta. His dissertation will focus on quantitative genetics of *Acacia mangium* for growth traits and wood properties.

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

**Jason Payne** is a PhD student working as part of Camcore's domestic conservation program under the direction of Robert Jetton. His research focuses on the development of 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 BS and MS degrees in Forestry and NCSU.

**Dominic Manz** is an M.S. student working as part of Camcore's domestic conservation program under the direction of Robert Jetton. For his research he is assessing the susceptibility of eastern and Carolina hemlocks to the root rot pathogen *Phytophthora cinnamomi*. He is currently writing up his study results and plans to continue with Camcore as a PhD student beginning in summer 2020 when he will begin a project related to scale insect management in Fraser fir Christmas tree plantations. Prior to joining Camcore, Dominic completed his BS degree in Forestry at NCSU.

# Publications and Papers

## Publications

Acosta JJ, Castillo MS, Hodge G (2020). Comparison of Desktop and Handheld Near-Infrared Spectroscopy Devices to Determine Forage Nutritive Value (submitted to Crop Science).

Acosta JJ, Fahrenkrog AM, Neves LG, Resende MFR, Dervinis C, Davis JM, Holliday JA, Kirst M (2019). Exome Resequencing Reveals Evolutionary History, Genomic Diversity, and Targets of Selection in the Conifers Pinus taeda and Pinus elliottii, Genome Biology and Evolution, Volume 11, Issue 2, 1 February 2019, Pages 508-520, https://doi.org/10.1093/gbe/evz016

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Jetton, R.M. and W.A. Whittier. 2019. Effect of seed coat sterilization and photoperiod treatments on the germination of Atlantic white-cedar seeds. Tree Planters’ Notes 62: 14-19.

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Tyrmi J, Vuosku J, Acosta JJ, Li Z, Sterck L, Cervera M, Savolainen O, and Pyhäjärvi T (2019). Genomics of clinal local adaptation in Pinus sylvestris under continuous environmental and spatial genetic setting (submitted to G3: Genes | Genomes | Genetics)

Whittier, W.A., Hodge, G.R., Lopez, J.L., and Sarvitz, C. 2019. Studies to Evaluate Hydroponic Culture of Teak. Tree Planters' Notes, 62 (1, 2) (2019), 44-51.

## Conference Presentations

Acosta JJ, Jackson C, Christie N, Caballero M, Marais C, Hodge G, Whetten R, Isik F, Wegrzyn J, Myburg A (2019). SNP Discovery and Probe Design Using RNA-seq and Target Capture in Tropical and Subtropical Pines. IUFRO Forest Tree Biotechnology Conference, 23-28 June 2019, Raleigh, NC.

Acosta, J.J, J.L. López, W.C. Woodbridge, R. Jump, and G. R. Hodge. Comparison of Chemical and Physical Wood Properties of Eucalyptus Species grown in Chile, Uruguay and South Africa. For "Eucalypt genetics: fundamental and applied research in a post-genome era" Feb 18-21, 2019, Hobart, Tasmania, Australia.

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Jetton, R.M. 2019. Industry-academia cooperation in forest health: a perspective from Camcore. Meeting on Forest Health Industry-Academia Cooperation, February 20, 2019, Gainesville, FL.

Jetton, R.M., K.M. Potter, A.R. Campbell, C.D. Nelson, V.D. Hipkins, and J.R. Rhea. 2019. Phylogeny and population genetics of eastern and Carolina hemlock. Tennessee Hemlock Conservation Partnership, February 7, 2019, Cumberland Mountain State Park, TN.

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Mayfield, A. and R. Jetton. 2019. Silviculture: Can it Help the Hemlocks? Hemlock Research Open House, Mountain Research Station, 5 Sep 2019, Waynesville, NC.

Mayfield, A.E., III, R.M. Jetton, and C.F. Miniat. 2019. Let There Be Light: Exploring silvicultural release as a management tool against the hemlock woolly adelgid. Coweeta Hydrologic Laboratory, Brown Bag Seminar, 12 Feb 2019, Otto, NC.

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Wagner, K., J.J. Riggins, R. Jetton, J. Hartshorn, D. Avtzis. 2019. Optimizing Forest management practices to minimize economic impact of *Sirex noctilio*. East Texas Forest Entomology Seminar, Nacogdoches, Texas, May 8-10th, 2019

Wagner, K., J.J. Riggins, R. Jetton, J. Hartshorn, D. Avtzis. 2019. Optimizing Forest management practices to minimize economic impact of *Sirex noctilio.* Biochemistry, Molecular Biology, Plant Pathology and Entomology Teaching Seminar, Starkville, Mississippi, March 1st, 2019

Whittier, W.A., Jetton, R.M., and Mayfield, A.E. 2019. Silvicultural Strategies to Improve the Sustainability of Eastern Hemlock. 20th Biennial Southern Silvicultural Research Conference. March 12-14, 2019. Shreveport, LA. USA

Whittier, W.A., Jetton, R.M., and Mayfield, A.E. 2019. Hemlock Gene Conservation Efforts. New York State Park Plant Materials Program. August 29, 2019. Syracuse, NY. USA.

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Whittier, W.A. 2019. Seed Collection Strategies. SASRI Annual Meeting. October 22, 2019. Asheville, NC. USA

Whittier, W.A. 2019. Camore's role in tree conservation in the Eastern United States. T.C. Henderson Grade School. December 16, 2019, Toxaway, NC. USA.

## Conference Posters

Crane, B.S., Whittier, W.A., Jetton, R.M., and Potter, K.M. 2019. Camcore and the Forest Service National Forest System, A Ten Year Partnership in Tree Conservation. Forest Restoration Alliance Open House. September 5, 2019. Waynesville, NC. USA.

Ibarra, L., Acosta, JJ., Balocchi, C., De Veer, C., Hodge, G (2019). Quantitative genetics of hybrid population of Eucalyptus nitens x Eucalyptus globulus: Genetics parameters and implications for breeding strategies. 35th Southern Forest Tree Improvement Conference (SFTIC). 3-6 June 2019, Lexington, KY.

Isik F, Wegryzn J, Eckert A, Sniezko R, Acosta JJ (2019). Developing SNP Arrays for Forest Trees (Conifer SNP Consortium). IUFRO Forest Tree Biotechnology Conference, 23-28 June 2019, Raleigh, NC.

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Tambarussi, E.V., Pereira, F.B., Acosta, J.J., Vencovsky, R (2019). Status (Ns) and Variance Effective (Ne) numbers as useful parameters for breeding and conservation genetics programs. In: IUFRO Tree Biotechnology Meeting, June 2019, Raleigh, USA

Thomas, A., B. Smith, A. Whittier, J. Frampton, and R. Jetton. 2019. Towards adelgid-tolerant Christmas trees. 60th Southern Forest Insect Work Conference, July 23-26, 2019, Savannah, GA.

Wagner, K., J.J. Riggins, R. Jetton, J. Hartshorn, D. Avtzis. 2019. Analyzing impacts of drought and forest management practices on invasive *Sirex noctilio.* Entomology Society of America, St. Louis, Missouri, November 18th, 2019

Wagner, K., J.J. Riggins, R. Jetton, J. Hartshorn, D. Avtzis. 2019. Impacts of global drought and forest management practices on *Sirex noctilio.* International Union of Forest Research Organizations, Pretoria, South Africa, November 5th, 2019

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Whittier, W.A. Jetton, R.M., Mayfield, A.E., Mudder, B., Tait, A.R. 2019. Silvicultural Strategies to Improve the Sustainability of Eastern Hemlock. 20th Biennial Southern Silvicultural Research Conference. March 12-14, 2019. Shreveport, LA. USA.

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**Back Cover**: Control pollination work in the SKC *P. tecunumanii* seed orchard in La Cumbre. This work is for the Camcore *P. tecunumanii x P. greggii* hybrid breeding project.

**Front Cover:** Mondi's research staff measure wood quality traits in a eucalypt species trial in the Msibi Moohoek plantation near Piet Retief, Mpumalanga. In the foreground, Ian Jones and Ben Magagula are using the TreeSonic acoustic tool to measure wood stiffness in an *E. grandis x E. nitens* tree. The other workers are using the Resistograph and another TreeSonic tool.