camcore

2016 Annual Report

NC STATE UNIVERSITY

2016 CAMCORE ANNUAL REPORT

International Tree Breeding and Conservation

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EXECUTIVE SUMMARY

1. In 2016, Camcore expanded its genetic base of *E. grandis*. We acquired unimproved family seed collections from 84 families and 8 provenances distributed across much of the natural range of the species. We also received generous donations of 130 advanced-generation *E. grandis* families from Smurfit Kappa Colombia, and Mondi, Sappi Forests, and SAFCOL from South Africa. These 130 families have been selected for an array of traits such as growth, disease tolerance, cold tolerance, and sawtimber characteristics.

2. In 2017, Camcore will expand its genetic base of *E. globulus* with selections made from over 100 families in a 1st generation progeny test planted at high elevation (2550 m) in the department of Cundinamarca, Colombia (4°N latitude). This material is being donated by Smurfit Kappa Colombia, Tekia, and the Colombian National Corporation of Forestry Research (CONIF).

3. The full-sib crossing for the *P. patula* x *P. tecunumanii* hybrid breeding project has been completed. Seed harvesting from previous years of crossing has begun, and we are developing plans for seed distribution and test establishment. Also in 2016, full-sib crossing for the *P. tecunumanii* x *P. greggii* breeding project began, with *P. greggii* pollen from Brazil and Colombia used to cross with *P. tecunumanii* in Colombia.

4. Low-elevation *P. tecunumanii* is susceptible to *Dothistroma* leaf blight, and in certain environmental conditions the disease can be severe. Analysis of a number of 2nd generation progeny tests of low-elevation *P. tecunumanii* in Colombia demonstrated that tolerance to *Dothistroma* is under strong genetic control.

5. We completed multiple-site analyses for 1st generation progeny tests of *E. pellita* and *E. dorrigoensis*, and for 2nd generation *P. tecunumanii* and *P. maximinoi*. Genetic parameter estimates and BLUP genetic gain predictions for volume growth were calculated. Selections of all of these species will be made in 2017.

6. Work on the pine hybrid wood quality project continued, with sampling done in tests in Argentina, Brazil and South Africa. Sampling of the 1st hybrid trial series is complete. In 2018, we will begin sampling the 2nd series, which contains different hybrid combinations.

7. In a study on the wood properties of four eucalypt species in Uruguay, it was clear that *E. dunnii* had excellent wood properties compared to *E. grandis*, *E. benthamii*, and *E. dorrigoensis*. For many important traits (density, MOE, cellulose content, lignin content, and S:G ratio), *E. dunnii* was the top-ranked species of the four.

8. It has been observed that *E. dunnii* has a tendency to accumulate high contents of calcium and phosphorus in the wood, and this may cause problems in kraft pulp mills. A very good NIR model was found to predict calcium content from woodmeal scans ($R^2 = 0.96$), but the model for phosphorus was less satisfactory ($R^2 = 0.45$).

9. Camcore is participating in a collaborative project to develop a pine SNP chip that will be useful for molecular breeding applications. The project involves scientists from NC State University, the University of Connecticut, Virginia Commonwealth University, USDA Forest Service, the University of Pretoria and many others.

10. Progeny of full-sib families of *P. taeda* produced by Arauco Argentina and Bosques del Plata were assessed for 29 SSR loci, and the markers used to predict the coancestry among progeny. Expected coancestry (from the pedigree) and the estimated coancestry (from the markers) showed very good agreement. This suggests that pedigree reconstruction could be used to extract genetic information from commercial plantations.

11. Camcore's domestic (USA) gene conservation programs continue to expand. In 2016, conservation collections were made from 7 species in 28 provenances, including a new project with ash (*Fraxinus*). The conservation work with hemlock (*Tsuga*) has expanded to include research on restoration silviculture, looking at the effects of canopy structure, deer exclusion, fertilization, competition control, and sunlight.

12. Camcore ended 2016 with 26 active and 5 associate members. Two new members joined the program at the end of 2016, and will be members effective for 2017: Miro Forestry Ghana, and Miro Forestry Sierra Leone. Miro has 10,000 ha under lease in Ghana, and 21,000 ha in Sierra Leone. Miro will work with tropical *Eucalyptus* and *Corymbia* species in both countries, and will also plant teak in Ghana.

RESUMEN EJECUTIVO (Español)

1. En el 2016, Camcore expandió su base genética de *E. grandis*. Adquirimos semilla no mejorada de 84 familias y 8 procedencias distribuidas a lo largo de la mayor parte del rango natural de la especie. También recibimos la generosa donación de 130 familias de generaciones avanzadas de *E. grandis* de Smurfit Kappa Colombia en Colombia y Mondi, Sappi Forests y SAFCOL en Sudáfrica. Estas 130 familias han sido seleccionadas por un conjunto de características tales como crecimiento, tolerancia a enfermedades, tolerancia al frío y madera para aserrío.

2. En el 2017, Camcore expandirá su base genética de *E. globulus* con selecciones hechas de más de 100 familias en un ensayo de primera generación plantado a alta elevación (2500 m) en el departamento de Cundinamarca, Colombia (4° Latitud N). Este material está siendo donado por Smurfit Kappa Colombia, Tekia, y La Corporación Nacional de Investigación y Fomento Forestal (CONIF).

3. Se concluyeron los cruzamientos de hermanos completos del proyecto de mejoramiento del híbrido *P. patula x P. tecunumanii*. Se inició la colecta de semillas de los cruces en los dos años previos y se están desarrollando los planes para la distribución de esta semilla y el establecimiento de los ensayos. En 2016, se iniciaron los cruzamientos para el proyecto del híbrido entre *P. tecunumanii* x *P. greggii* en Colombia, utilizando polen colectado en Brasil y Colombia.

4. *P. tecunumanii* de baja elevación es susceptible al tizón de la hoja causado por *Dothistroma*, y en ciertas condiciones ambientales la enfermedad puede ser severa. El análisis de varios ensayos de progenie de segunda generación de *P. tecunumanii* de baja elevación en Colombia demostró que la tolerancia al *Dothistroma* está bajo fuerte control genético.

5. Se completaron los análisis de múltiples ensayos de progenie de primera generación de *E. pellita y E. dorrigoensis*, así como también para ensayos de segunda generación de *P. tecunumanii y P. maximinoi.* Se calcularon estimaciones de parámetros genéticos y predicciones de ganancia genética BLUP para crecimiento en volumen. Se realizarán selecciones de todas estas especies en el 2017.

6. Continúan las actividades del proyecto de calidad de madera en híbridos de pino con muestreos en Argentina, Brasil y Sudáfrica. Se completó la toma de muestras en los ensayos de la primera serie. En el 2018 empezaremos el muestreo de la segunda serie, la cual contiene diferentes combinaciones de híbridos.

7. En un estudio de las propiedades de la madera de cuatro especies de eucaliptos en Uruguay, estuvo claro que el *E. dunnii* posee excelentes propiedades de la madera comparado con el *E. grandis, E. benthamii* y *E. dorrigoensis*. En muchas de las características importantes (densidad, MOE, contenido de celulosa, contenido de lignina, y relación S:G), E. dunnii demostró ser la especie con más alto rango de las cuatro.

8. El *E. dunnii* tiene la tendencia a acumular altos contenidos de calcio y fósforo en la madera, lo cual puede causar problemas en las plantas productoras de pulpa kraft. Se desarrolló un modelo NIR de muy buena calidad para predecir el contenido de calcio a través de escaneo de aserrín ($R^2 = 0.96$), sin embargo, el modelo desarrollado para fósforo resultó menos satisfactorio ($R^2 = 0.45$).

9. Camcore está participando en un proyecto colaborativo para desarrollar un chip de SNPs para pinos que será útil para aplicaciones en mejoramiento molecular. El proyecto involucra a científicos del NC State University, la Universidad de Pretoria, la Universidad de Connecticut, y muchos otros.

10. Progenies de familias de hermanos completos de *P. taeda* producidas por Arauco Argentina y Bosques del Plata, fueron evaluadas en 29 microsatélites, donde los marcadores fueron usados para predecir el parentesco entre la progenie. El parentesco esperado (del pedigrí) y el parentesco estimado (de los marcadores) fueron similares. Esto sugiere que la reconstrucción del pedigree podría ser usada para extraer información genética de plantaciones comerciales.

11. Los programas de conservación de genes domésticos (USA) de Camcore se continúan expandiendo. En el 2016 se realizaron colectas de conservación de 7 especies en 28 procedencias, incluyendo un nuevo proyecto con *Fraxinus* sp. El trabajo de conservación con el abeto (*Tsuga*) se ha expandido para incluir investigación en la silvicultura de restauración, observando los efectos de la estructura de la copa, exclusión de venados, fertilización, control de competencia y luz solar.

12. Camcore terminó el 2016 con 26 miembros activos y 4 miembros asociados. Dos empresas se afiliaron al programa a finales del 2016, las cuales serán miembros efectivos para el 2017: Miro Forestry Ghana y Miro Forestry Sierra Leona. Miro posee 10,000 ha bajo arrendamiento en Ghana y 21,000 ha en Sierra Leona. Miro trabajará con especies tropicales de *Eucalyptus* y *Corymbia* en ambos países, y también plantará teca en Ghana.

RESUMO EXECUTIVO (Português)

1. Em 2016, a Camcore expandiu a base genética de *E. grandis.* Foram compradas sementes não melhoradas de 84 famílias de 8 procedências que representam a ocorrência natural desta espécie. A Camcore também recebeu doações de 130 famílias de gerações avançadas de melhoramento de *E. grandis* da Smurfit Kappa da Colômbia e das empresas Mondi, Sappi Forests e SAFCOL da África do Sul. Estas 130 famílias foram selecionadas, levando-se em consideração uma ampla gama de características como crescimento, tolerância a doenças, tolerância a geadas como também características para madeira serrada.

2. Em 2017, a Camcore irá expandir a sua base genética de *E. globulus*, com seleções de mais de 100 famílias, procedentes de um teste de progênie de 1ª geração estabelecido a uma altitude de 2550 m na região de Cundinamarca, Colômbia a 4 °N de latitude. Este material está sendo doado pelas empresas Smurfit Kappa da Colômbia, Tekia e pela Corporação Nacional Colombiana de Pesquisa Florestal (CONIF).

3. Os cruzamentos para o projeto de produção de híbridos de *P. patula x P. tecunumanii* foram finalizados. A coleta de sementes híbridas de cruzamentos efetuados em 2016 já iniciou e estamos desenvolvendo os planos para a distribuição e posterior estabelecimento e implantação dos testes deste material. Também em 2016, já iniciamos o projeto para a produção de híbridos de *P. tecunumanii x P. greggii*. Pólen de *P. greggii* e *P. tecunumanii* do Brasil e Colômbia já estão sendo aplicados em flores femininas de *P. tecunumanii* na Colômbia.

4. O *P. tecunumanii* de baixa altitude é susceptível a *Dothistroma* e em algumas condições ambientais esta doença pode ser grave. Análises de vários testes de progênies de *P. tecunumanii* de 2ª geração na Colômbia, demonstram que a tolerância a *Dothistroma* está sob forte controle genético.

5. Finalizamos as análises de vários testes de progênies com material de 1ª geração de *E. pellita* e *E. dorrigoensis* como também conluímos as análises com material de 2ª geração de *P. tecunumanii* e *P. maximinoi.* Estimativas para parâmetros genéticos e predições de ganhos genéticos (BLUP) foram calculados para os respectivos testes acima mencionados. A seleções nestes testes serão ainda realizadas em 2017.

6. Continuamos com os trabalhos nos testes sobre a qualidade da madeira nos híbridos de *Pinus*, com amostragens sendo conduzidas na Argentina, Brasil e África do Sul. Finalizamos as amostragens nos testes com híbridos da 1ª série. Em 2018, iniciaremos as amostragens nos testes com híbridos de *Pinus* da 2ª série, que contemplam diferentes híbridos.

7. Em um estudo sobre a qualidade da madeira em 4 espécies de eucaliptus no Uruguai, concluiu-se que o *E. dunnii* apresenta excelente propriedades da madeira quando comparado com *E. grandis, E. benthamii*, e *E. dorrigoensis.* O *E. dunnii* obteve os melhores valores para as características avaliadas como (densidade, MOE, celulose, lignina e relação S:G).

8. O *E. dunnii* apresenta uma tendência em acumular altas concentrações de cálcio e fósforo na madeira, oque pode ocasionar problemas em fábricas de papel Kraft. Um ótimo modelo com NIR foi desenvolvido para a predição de cálcio em amostras de madeira (R^2 = 0.96), porém o mesmo modelo não foi satisfatório para fósforo (R^2= 0.45).

9. A Camcore está participando de um projeto cooperativo com o objetivo de desenvolver SNP em *Pinus*, e que terá aplicações em programas de melhoramento a nível molecular. Este projeto involve cientistas da Universidade da Carolina do Norte – USA, Universidae de Connecticut, Universidade da Virgínia, Serviço Florestal Americano-USDA, Universidade de Pretória e outros.

10. Testes de progenies de irmãos completos de *P. taeda* da Arauco e Bosques del Plata na Argentina foram avaliados para 29 SSR loci e os marcadores foram utilizados na predição da coancestria entre as progênies. A esperada coancestria do pedigree e a estimada coancestria dos marcadores apresentaram alta correlação. Isto sugere que a reconstrução do pedigree poderia ser utilizado para extrair informações genéticas de plantios operacionais.

11. Os projetos de conservação genética da Camcore continuam expandindo. Com este propósito, em 2016, coletamos 7 espécies de 28 procedências, incluindo um novo projeto com ash (*Fraxinus*). O projeto de conservação com hemlock (*Tsuga*) expandiu e agora contempla pesquisas em silvicultura, com o objetivo de avaliar a estrutura de dossel, impactos na fauna, fertilização, controle de competição e interceptação da irradiação solar.

12. A Camcore finalizou o ano de 2016 com 26 membros ativos e 5 membros associados. Duas empresas entraram na Camcore no final de 2016 e serão efetivados como membros em 2017: Miro Forestry Ghana e Miro Forestry Sierra Leone. Miro possui 10.000 ha de terras arrendadas em Ghana e 21.000 ha em Sierra Leone. Miro irá trabalhar com espécies de Eucalyptus tropicais e espécies de *Corymbia* nos dois países, como também plantará *Teca* em Ghana.

MUHTASARI WA TAARIFA KUU (Kiswahili)

1. Camcore ilipanua kizazi cha koo za *E. grandis* mnamo mwaka wa 2016. Tulipata mbegu kutoka familia 84 ambazo azikuboreshwa kutoka maeneo 8 tafauti ambapo hizo mbegu upatikana. Tulipata misaada wa kujitolea 130 ya uzao wa juu wa E. grandis kutoka sehemu zifuatazo Smurfit Kappa Colombia, Mondi, Msitu ya Sappi na SAFCOL Afrika Kusini. Hizi familia 130 zilichanguliwa kutokamana na ubora na maumbile yake ya ukuaji mwema, uvumilivu wa magonjwa, uvumilivu wa baridi kali na ubora wa maumbilie mema ya kutoa mbao.

2. Mwaka huu wa 2017 Camcore itapanua kiazi na koo za miti ya *E. globulus*. Familia zaidi ya 200 zatachanguliwa kutoka kizazi cha pili kilicho jaribiwa kwenye mwinuko wa mita 2550 kutoka baharini katika kitengo cha Boyaca nchini Columbia (40K Latitudo). Hizi mbegu zi michango ya kujitolea kutoka kwa Smurfit Kappa Columbia, Tekia, na Shirika la Kitaifa la Utafiti wa Msitu wa Columbia (CONIF).

3. Mnamo mwaka wa 2016, mradi wa kuunganisha kizazi cha *P. patula x P. tecunumanii* kwa kiasi kikubwa ulikamilika. Miti iliyo unganishwa miaka miwili iliyopita imeanza kuzaa na mbegu inaokotwa, kwa hivyo tunatengeneza mipango ya kusambaza hiyo mbengu na kuijaribu kuikuza. Na pia mwaka wa 2016 mradi wa kuunganisha kikamilifu miti ya *P. tecunumanii na P. greggii* ulianza ambapo chembe chembe za poleni za *P. greggii* kutoka Brazil zilitumiwa kuunganisha mbegu ya uzazi ya *P. tecunmanii* kutoka Colombia.

4. Ugojwa wa jani doa la *Dothistroma* hushika *P. tecunumanii* katika miinuko ya chini na kwa mazingira mengine huenda hali ikawa mbaya sana. Uchunguzi waonyesha kuwa kizazi cha pili chaonyeasha kuwa miinuko ya chini, *P. tecunumanii* ya Colombia ilionyesha usitahimilifu wa *Dothistroma* kwa koo sitahimilifu.

5. Tumekamilisha uchambuzi wa matokeo ya kizazi cha kwanza katika maeneo tafauti ya *E. pellita* na *E. dorrigoensis* na kizazi cha pili cha *P. tecunumanii* na *P. maximinoi.* Makadirio ya vigezo vya koo na BLUP ilihesabiwa. Mwaka wa 2017 ndio uchaguzi huo wa miti utafanywa.

6. Kazi katika mradi wa masuriama ya msonobari yenye mbao bora uliendelea ambapo sampuli za majaribio zilifanyiwa Argentina, Brazil na Africa Kusini. Sampuli za majaribio ya kizazi cha kwanza yamekamilika, na mwaka huu wa 2018 tutaanza sampuli ya kizazi cha pili ambacho kina muungano wa vizazi tafauti.

7. Katika mradi wa masomo ya kuangalia maumbile na miundo tafauti tafauti ya miti ya migamu kutoka Uruguay uliendelea. Ilionekana wazi kuwa *E. dunnii* ilikuwa na mbao bora ukilinganishwa na *E. grandis, E. benthamii* na *E. dorrigoensis.* Kwa vile vigezo muhimu kama (uzito, MOE, mirabaraba, gamu, S:G ratio) *E. dunnii* ilioorodheshwa ya kwanza kati miti yote minne.

8. *E. dunnii* ina mwelekeo wa kurundika kiwango kikubwa cha kalisi na fosforasi katika mbao zake ambacho chaweza tatiza mitambo ya mbao za Kraft. Miuondo mizuri ya NIR ilionekana kukadiria kiwango cha kalisi katika mchujo wa msago wa miti (R^2 = 0.96). Lakini kiwango cha fosforasi hakikutosholeza (R^2= 0.45).

9. Camcore inashiriki katika mradi wa ushirikiano kuunda chenga cha SNP cha msonobari ambacho kitakuwa muhimu kwa nyanja za uzalishaji. Mradi utashirikisha watafiti kutoka ratiba ya NC State Tree Improvement, Forest Molecular Genetics Program katika chuo kikuu cha Pretoria, Chuo Kikuu cha Connecticut na wengineo.

10. Uzalishaji mkamilifu wa familia za *P. taeda* uliletwa na Arauco Argentina na Bosques del Plata zilipimwa na 29 SSR loci na vigezo kutumiwa kukadiria utafauti kati ya uzao. Matarajio kati ya uzao yalikadiriwa na kaonyesha kukubaliana. Hii inaonyesha kuwa kuuwiana kwake kwaweza kutumiwa kutoa habari za genetiki kwa mashamba ya mauzo.

11. Taratibu za Camcore za uhifadhi wa chembe chembe katika USA zinazidi kupanuka kila kuchao. Katika uhifadhi wake wa mwaka wa 2016 kulikuwa miti aina saba (7) kutoka maeneo ishirini na nane (28) ikiwa pamoja na mradi mpya wa ash (*Fraxinus*). Kazi ya uhifadhi wa hemlock (*Tsuga*) imepanuliwa kuongezea utafiti wa kuboresha upanzi wa miti na kuangalia madhara ya tandarua ya miti, utengwaji wa kalungu, kurutubisha, kudhibiti mashindano na jua.

12. Camcore ilikamilisha mwaka wa 2016 na wanachama 26 na washirika 4. Wawili walijiunga mwisho wa mwaka 2016 na watakuwa wanachama rasmi kuanzia 2017: Miro Forestry Ghana na Miro Forestry Sierra Leone. Miro ina hecta 10,000 za kuleasi huko Ghana, na hecta 21,000 Sierra Leone. Miro itafanya kazi na miti ya migamu ya tropiki na *Corymbia* katika inchi zote mbili na pia itapanda miti wa mtiki katika inchi ya Ghana.

Message From the Director

Camcore completed its 36th year in 2016, another productive and busy year. Our mission is to be a world leader in the conservation and genetic improvement of tropical and subtropical forest tree species to provide economic, ecological and social benefits for the current and future generations. Practically, this means we work to provide our members with genetically improved material from a diverse array of species, with known silvicultural characteristics and wood properties. All our members cooperate and work together to test species, provenances and families. Our policy that all Camcore genetic material be available to all members ensures that everyone will have the ability to adapt and respond quickly to threats and changes, whether these are economic or biological in nature. Over the past ten years, we have seen a significant change in South African forestry: *Pinus patula* and *P. radiata*, planted commercially in South Africa for over one hundred years, are very susceptible to an introduced pathogen *Fusarium circinatum*, and the industry is responding by shifting to alternate varieties such as *P. maximinoi*, *P. tecunumanii*, and the *P. patula* x *P. tecunumanii* hybrid. The shift was possible because of the hard work done by the South African Camcore members to develop these genetic resources, long before it was apparent that they would be needed.

Our work with pine hybrids over the last 15 years continues to pay huge benefits. To date, we have planted 89 pine hybrid trials, where the hybrids are being tested as "species" or "variety" bulks, and we have begun a third phase of hybrid trials of this kind with some new combinations. We have age 3-, 5- and/or 8-year data from 52 of those trials. A number of hybrids, such as *P. patula* x *P. tecunumanii*, *P. greggii* x *P. tecunumanii*, and *P. caribaea* x *P. tecunumanii*, have shown great potential. We have begun two collaborative pine hybrid breeding projects, one with *P. patula* x *P. tecunumanii*, and one with *P. tecunumanii* x *P. greggii*, focused on the production of approximately 300 full-sib hybrid families. This would be very time-consuming and expensive for a single company, but is very feasible when done in community.

In addition to the pine hybrids, in 2016 we distributed seed from the collaborative *Eucalyptus* hybrid breeding project. From 8 to 25 full-sib families of 10 different hybrids were produced by participating members, and we hope to see clonal trials of these hybrids established over the next few years. Most of these hybrids included *E. grandis* or *E. urophylla* as one of the parents.

Camcore has the world's largest genetic base of *E. urophylla*, but our genetic base of *E. grandis* was more limited. As a result, in 2016 we acquired 84 families of *E. grandis* from native stands from 8 provenances, including several provenances at the northern end of the species range (17° to 19°S). We also acquired some improved seed orchard bulks from very productive sources in Victoria (30 to 34°S).

In addition to the acquisition of those *E. grandis* resources, several of the oldest Camcore member companies agreed to donate seed from a number of improved families of *E. grandis* to the Camcore community. Smurfit Kappa Colombia (SKC) agreed to donate 50 families, Mondi Forests 40 families, and Sappi and SAFCOL will each donate 20 families. These improved families (mostly 1st generation families, with a few 2nd and 3rd generation) become Camcore genetic material, meaning that the seed can be distributed to other Camcore members. This is a wonderful example of the collaborative spirit that marks our program. In the long run, a strong Camcore program will benefit all of our members. Many, many thanks to SKC, Mondi, Sappi and SAFCOL!

Finally, all of us on the Camcore staff want to express our thanks to all of our members. We appreciate your contributions in test establishment, maintenance and measurement, your work in hybrid breeding, and your help with the various research projects. Most of all we appreciate the enthusiasm and passion that all you forest managers and researchers bring to your work. This spirit of camaraderie permeates throughout the program, and makes it a pleasure to come to work each day. Community, collaboration, camaraderie: this is Camcore. We look forward to another productive year in 2017.

Gary Hodge, Director

2016 Camcore Membership

Active & Associate Members

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

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

Chile
- Arauco Bioforest 1991
- CMPC Forestal Mininco 1991

China
- Guangdong Academy of Forestry (Associate) 2013

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

Guatemala
- Grupo DeGuate (Associate) 2006

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

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

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

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

Tanzania
- Green Resources AS - Tanzania 2013

United States of America
- WestRock (Associate) 2010
- USDA Forest Service (Associate) 2006

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

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

Honorary Members

Belize
- Ministry of Natural Resources

El Salvador
- Centro Nacional de Tecnología Agropecuaria (CENTA)

Guatemala
- Instituto Nacional de Bosques (INAB)

Honduras
- Universidad ESNACIFOR

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

Nicaragua
- Instituto Nacional Forestal (INAFOR)

The 2016 Annual Meeting in Brazil

The 2016 Olympic Games were not enough excitement for Brazil so our Camcore companies offered to host this year's Annual Meeting. It's no surprise that long-term members Klabin and WestRock turned in a gold-medal performance in planning and executing this team event filled with field trips, presentations, and many interesting discussions indoors and out. In early December, 35 representatives from 21 organizations in 11 countries converged on the coastal town Florianópolis, Santa Catarina for committee meetings and technical sessions. In addition to reports on Camcore research, we were given presentations by guest speakers Dario Grattapaglia of EMBRAPA and long-time Camcore associate Teotônio de Assis. Other than the meetings, the main entertainment was a small cyclone that knocked out power in the area for half a day.

The first bus trip was to Otacílio Costa, Santa Catarina, for a full day of field visits to Klabin research projects. In the research nursery, heated beds within the greenhouse keep minimum temperatures above 20º C and allow production of subtropical eucalypts. Next stop: Azulão Farm to see a 5-year-old Camcore pine hybrid trial. From this second series of crosses, the *Pinus greggii* x *P. tecunumanii* is emerging as the winner in growth with a mean DBH of 16 cm and an estimated MAI of 30 m^3/ha/yr. At the same location, we visited a 5-year-old *Eucalyptus dunnii* clonal plantation and a 2-year-old *E. benthamii* progeny trial, both with impressive growth. The next stop was the TECHS study, Tolerance of *Eucalyptus* Clones to Hydric and Thermal Stresses. This is a very ambitious project where clones are tested in a wide range of spacing and rainfall. Rainfall is controlled by channeling water offsite with a system of plastic gutters above ground to catch the rain and move it away from the site.

The next two days, WestRock was host for numerous field stops, starting with a tour of the Formiga Farm Somatic Embryogenis trial where we heard an overview of loblolly pine breeding at the company. The best clone has a mean DBH of 30 cm at age 10, with a potential MAI of 75 m^3/ha/yr! We then toured a 5-year-old *E. dunnii* clonal trial, and a 1.7-year-old Camcore *E. benthamii* trial that was growing very well, with 95% survival and a mean DBH of 6.6 cm. The last stop for the day was the 5-year-old 2nd series pine hybrid trial at Canivete. After overnighting in Canoinhas, including a wonderful WestRock-hosted meal, we drove to the São Miguel da Roseira tract. We heard about eucalypt breeding at the company while admiring an 8-year-old *E. benthamii* seed production area. The company has done a lot of research with spacing and rotation age and some of their clones are able to produce over 70 m^3/ha/yr. The last stop was the 8-year-old pine hybrid trial where several crosses have a mean DBH of 20 cm and are competitive with improved loblolly.

Regiane Estopa gives a presentation on Klabin's breeding program for *Eucalyptus dunnii*. This planting at the Azulão Farm in Santa Catarina is 5 years old.

Ricardo Paim of WestRock gives an overview of the company's Loblolly pine breeding. The trial is 10 years old and is planted with clones produced by somatic embryogenesis.

The final field day was again hosted by Klabin, this time starting in Telêmaco Borba, Paraná. The first stop was a trial of *P. maximinoi* at Imbauzinho. This provenance-progeny trial planted in 1990 is now used as a seedling seed orchard. Selections from this planting provided seed for a 2nd generation trial that we visited next. At age 3, the F2 *P. maximinoi* families had a mean DBH of 11.7 cm and were growing better than the loblolly controls. The next stop was a 1990 progeny test of *P. tecunumanii*; this species doesn't grow as well as *P. maximinoi* in Klabin's areas, but has great potential as a hybrid partner. After a quick look at a eucalypt clonal plantation, we visited both 8- and 5-year-old pine hybrid trials. These trials have results similar to the WestRock trials. Both WestRock and both Klabin pine hybrid trials were sampled for wood quality this year and the group spent much time inspecting the crosses in the four trials and discussing the various issues related to hybrid pines. A washed out bridge prevented us from visiting the *Eucalyptus* and *Corymbia* species trials. We finished up the day visiting Klabin's indoor breeding orchard where we had a demonstration of controlled pollination before leaving for Curitiba.

The farewell banquet in Curitiba was fantastic, as expected, and included a great musical trio. Although this year's meeting was shorter than some in previous years, it was packed with interesting visits to both pine and eucalypt projects. Many thanks go to the two member companies and the primary planners: Ricardo Paim and Gisela Andrejow of WestRock and Fabricio Biernaski and Regiane Estopa of Klabin. Of course many other staff helped to give presentations, prepare tour sites, and perform the many tasks required to execute such a successful meeting. Many thanks and see you in Sweden in 2017!

A Klabin breeder performs controlled pollination in the company's indoor breeding orchard in Telêmaco Borba, Paraná.

The Camcore group poses in a eucalypt seed orchard in WestRock's Formiga Farm, Santa Catarina.

Developments in Camcore

Camcore staff made a number of member visits in 2016 to look at Camcore trials, to discuss breeding strategies and research questions, and to assist with ongoing Camcore research projects. Below is a brief summary of the visits and other developments.

Argentina

Juan Luis López and Juan José Acosta went to **Bosques del Plata** in October, where they participated in several field visits and interesting meetings with the company's research and technology team and Forestry Manager Sergio Alvarez. The Camcore pine hybrid program is producing very promising results for the company. In the 1st series of trials planted and assessed by BDP, the *Pinus caribaea x P. tecunumanii* shows great commercial potential in areas with no frost. In the 2nd series of trials, *P. greggii x P. tecunumanii* is showing excellent growth in Argentina, and also in neighboring countries. Three hybrids that are growing very well in the 3rd series are *P. taeda x P. tecunumanii*, *P. greggii x P. tecunumanii* and *P. patula x P. tecunumanii*. All these hybrids are comparable to improved *P. taeda* controls. Bosques del Plata is participating in the cooperative-wide *P. tecunumanii x P. greggii* hybrid project that is being conducted in Colombia. Some of the *P. greggii* families growing in 3-year-old 2nd generation progeny trials are competing favorably with improved families of *P. taeda* that are planted operationally. In Camcore, we are helping BDP with BLUP analyses of *P. greggii* 1st and 2nd generation trials to select the best families and the best individuals. A clonal seed orchard and 3rd generation progeny trials will be established with this material.

Arauco Argentina is testing an array of *Eucalyptus* and *Corymbia* species, provenances, and progeny provided by Camcore. Some species like *E. urophylla x E. grandis*, *E. grandis*, *E. urophylla*, and *E. dunnii* are showing potential. *Pinus greggii x P. tecunumanii* and *P. caribaea x P. tecunumanii* tested in Camcore trials are growing better than *P. taeda* at 5 and 8 years of age in volume growth, and show great potential for operational plantings. Juan José Acosta and Juan López had the opportunity to give an update to Juan Schapovaloff and German Raute on the *P. tecunumanii x P. greggii* breeding project that is taking place in Colombia in which Arauco is participating. In two years, the company will have enough seed of this hybrid to establish several progeny trials. Another hybrid that is showing fast growth at early ages in Argentina is *P. taeda x P. tecunumanii*. Romeo Jump and Willi Woodbridge traveled in February to work with both Bosques del Plata and Arauco Argentina to collect wood samples from 8-year-old hybrid pine trials. Working with a team of about 10 staff members from each company, a total of 600 trees were sampled for TreeSonic and Resistograph measurements. Shavings and cores were also extracted and sent to Raleigh for analysis. The company's crews did a great job in marking the trees before the trip and working long days in the field to complete the sampling.

Left to right, Matias Martin, Juan Luis López, Raúl Schenone, Raúl Pezzuti, and Santiago Marchesi in a Bosques del Plata *Pinus taeda* silviculture trial in la Fortaleza farm in Corrientes, Argentina.

Brazil

In March, Juan Luis López visited **Klabin** in Paraná. Juan and Fabricio Biernaski made preliminary plans for the Camcore annual meeting in Brazil. It was a successful meeting and is described on pages 7-8 of this report. Klabin is interested in finding more efficient ways to measure wood density to rank families for selection. Juan gave a

Fabricio Biernaski (Klabin) uses the Resistograph to estimate density in a 5-year-old pine hybrid trial at Monte Alegre, Telêmaco Borba, Brazil.

demonstration in a Camcore pine hybrid trial on how to use the Resistograph. Juan and Fabricio visited other hybrid trials in the area and Klabin is taking part in the tree breeding project of *P. tecunumanii* x *P. greggii* South that has high potential in Brazil. Klabin will send pollen of *P. greggii* from 18 selections in its seed orchard in Santa Catarina. Smurfit Kappa Colombia started making the crosses in October and has a goal of 300 crosses using 50 selected clones of each species.

Juan Luis also visited **WestRock** during his trip to Brazil. He had conversations with Ricardo Paim and his research team and forest manager, Ali Ayoub, regarding the organization of the annual meeting. Early and thorough planning was a key for the success of the meeting. WestRock is also participating in the breeding project with *P. tecunumanii* x *P. greggii* South, contributing pollen from 19 selected trees from their *P. greggii* clonal seed orchard in Santa Catarina. Some lots of pollen were collected and sent to Camcore and will be sent to Smurfit Kappa Colombia for the crosses with the *P. tecunumanii* mother trees. The research team in WestRock is very excited about the potential of this hybrid, not only because it is growing faster than *P. taeda*, but also because its wood properties are comparable. In August, Willi Woodbridge traveled to both Klabin and WestRock to continue work in the hybrid wood quality project. Eight-year-old trees were sampled for TreeSonic and Resistograph measurements. Shavings and cores were also extracted and sent to Raleigh for analysis. Work was also done in a younger trial of the 2nd series of hybrids at WestRock. In total, about 500 trees were sampled.

Chile

Gary Hodge visited Chile in May, and spent time with **Arauco Bioforest**. Indoor discussions focused on breeding and testing strategies to support the Arauco clonal program with *P. radiata*. The idea is to optimize the crossing strategy to increase the probability of developing and identifying new clones superior to those that are already in production. We also discussed the development of genomic selection strategies for *P. radiata*, and breeding strategies for Arauco's *E. globulus* x *E. nitens* hybrid breeding program. We visited some Camcore trials of cold-tolerant eucalypts, including *E. benthamii*, *E. dorrigoensis*, and *E. badjensis*. All three species are growing well, but interestingly, the *E. badjensis* appeared to be the best in terms of growth and vigor. In many other regions where these cold-tolerant species have been tested, *E. badjensis* does reasonably well, but has clearly been in third place behind *E. benthamii* and *E. dorrigoensis*. *Eucalyptus badjensis* has been reported to have higher pulp yields than *E. benthamii*, so if the species is competitive in growth, it may be attractive for pulp producers.

Gary also spent time with **CMPC Forestal Mininco**. We discussed the increasing threat of *Fusarium circinatum* to *P. radiata* in Chile. The Servicio Agrícola y Ganadero (SAG) is the Chilean governmental body responsible for control of

Philipp Bilabel of Arauco Bioforest in a 5-year-old trial of *E. badjensis* in Chile.

introduced diseases or pests that impact agriculture and forests. SAG has increased its *Fusarium* monitoring in forest tree nurseries, and when it finds infected trees, it will order the entire nursery bed to be destroyed. CMPC has been making numerous hybrids with *P. radiata*, such as *P. radiata* x *P. tecunumanii*, *P. oocarpa*, and *P. pringlei* to try to introduce *Fusarium* resistance. CMPC also completed a number of *E. nitens* x *E. pellita* crosses to contribute to the Camcore eucalypt hybrid project. We also discussed wood property research, with a focus on NIR models. In 2013 and 2014, Camcore worked on a large project to transfer our global pine NIR model to member-owned spectrometers. This transfer project used 200 samples from six different pine species, but no samples of *P. radiata* (see Annual Report 2014). During the 2016 visit, we developed a project with CMPC to expand that wood sample set with approximately 120 additional samples of *P. radiata*.

Colombia

Tekia is evaluating the possibility of strengthening its clonal program for teak and gmelina; they are planning to start with an intensive selection of superior individuals in their operational plantations. Juan José Acosta visited the company in February, and with Tekia's management and research staff, they reviewed the company's tree improvement program and discussed future activities. Camcore continues to help Tekia with the refinement of its nursery techniques. During our technical visit, we discussed several experimental designs to evaluate containers and substrates and rooting hormones for seedling and cutting production. Juan José and Tekia's research group also conducted a study to evaluate the genetic control of heartwood percentage in teak.

Gary Hodge visited **Forestal Monterrey Colombia (FMCo)** in March. The focus of the visit was to plan activities to identify new operational clones of *Gmelina arborea* for plantation establishment, and to create a new breeding population to turn over the next generation and position the program for long-term gains. In 2016, we completed a combined BLUP analysis of 11 clonal trials representing two populations, one derived from FMCo plantation selections and one from Camcore provenance - progeny tests from Myanmar and Thailand. Based on the results, a number

Diana Pérez and Gabriel Castellar of Forestal Monterrey in their seed orchard of *Pachira quinata* located in Zambrano, Colombia.

of new operational clones were selected from the Camcore populations. FMCo will also make open-pollinated seed collections in 2016 and 2017 from their entire genetic base of gmelina, representing a Colombia landrace (the FMCo population), Myanmar, Thailand, and India (Camcore collections), and some additional material from Venezuela. We also visited the FMCo nursery and discussed opportunities for research that might improve efficiency and plant quality. FMCo has done a very good job establishing a gmelina conservation park. This is a unique and valuable planting, there is no other gmelina conservation park within Camcore, and perhaps the world. FMCo also continues to work on its breeding program of *Pachira quinata* (formerly *Bombacopsis quinata*), and the company has a seed orchard of this species which will soon be producing commercial amounts of seed.

In December, Juan José Acosta visited **Smurfit Kappa Colombia** to present results of a genetic analysis of a very large disease dataset recorded by the SKC team. The data came from a set of low-elevation *Pinus tecunumanii* provenance-progeny tests for which phytosanitary information was recorded. The summary of these findings appears later in this report in the article titled "Genetics of Pine Diseases in Colombia". During his visit, Juan José also trained SKC's research staff to conduct this type of analysis and provided the R and SAS programs needed. Additionally, Juan José and the program leaders of forest health and tree breeding had a phone converstation with Robert Jetton about the eucalypt disease screening study that is being conducted at SKC.

Guatemala

Juan Luis López and a team from **Grupo DeGuate** visited two 2nd generation progeny trials of *P. tecunumanii* and *P. maximinoi* on two sites in July. These trials had been planted with seeds sent to the National Institute of Forests in Guatemala (INAB) eight years ago. Juan gave recommendations on criteria that should be used to make a genetic thinning to convert the two sites into seedling seed orchards. With Willi Woodbridge's help, Grupo DeGuate made the selections and the thinning. These are the first seed orchards of the two species ever established in Guatemala to produce improved seeds for commercial plantations.

Honduras

In May, Robert Jetton and Juan Luis López traveled to Honduras for a week-long visit with Camcore honorary member **Universidad ESNACIFOR**. The purpose of the trip was to see and learn about the *Dendroctonus* bark beetle outbreak that has been ongoing since 2014 and has caused severe levels of tree mortality in more than 600,000 ha of the country's native *P. oocarpa*, *P. tecunumanii*, *P. maximinoi*, and *P. patula* forests. Robert and Juan were hosted by faculty member Oscar Leverón who arranged a field tours to see bark beetle damaged areas, and meetings with Emilio Esbeth (Director, Universidad ESNACIFOR), Misael Leon Carvajal (ICF Executive Director), and Jacobo Paz (Minister of Agriculture for Honduras). They made recommendations for bark beetle monitoring, management, and research and discussed options for forest restoration following collapse of the bark beetle outbreak.

Honduras minister of Agriculture Jacobo Paz and, Emilio Esbeih and Oscar Leverón of Universidad ESNACIFOR meet with Camcore's Robert Jetton and Juan Luis López to discuss protection of the country's natural pine forests.

Juan Luis López, Josue Cotzojay, and Elmer Gutiérrez of Camcore and Henry Lemus with Grupo deGuate make Camcore selections in a 2nd generation *Pinus maximinoi* trial.

Kenya

Gary Hodge visited the Kenya Partnership in August, spending time with researchers from both the Kenya Forest Research Institute (KEFRI) and the Tree Biotechnology Programme Trust (TBPT). There is much excitement over the potential of new Camcore species for the highland regions of the country where typically *P. patula* has been planted. Pure species *P. tecunumanii*, *P. maximinoi*, and the *P. patula* x *P. tecunumanii* hybrid all demonstrate substantially better growth than *P. patula*. Much of this visit focused on how to scale up operational production of these new varieties for the country. KEFRI has a number of *P. patula* seed orchards that could be used to begin production of hybrid seed, which could then be multiplied through cuttings. We visited a very nice establishment of a 2nd generation *P. tecunumanii* progeny test at the Turbo research station. But in the short term, Kenya will need to bring in *P. tecunumanii* pollen from other sources, and

Ebby Chagala (right) and Mathews Mauya standing by a nice *Pinus patula x P. tecunumanii* tree in a pine hybrid trial planted by KEFRI in Kenya.

Camcore will continue to work with KEFRI and TBPT to try to provide this pollen in order to begin hybrid breeding. TBPT has also developed a potted breeding orchard of *E. urophylla* selections located in Nairobi. This orchard is already beginning to produce flowers, and will be an excellent resource to begin developing the skills for eucalypt breeding, and eventually to participate in Camcore eucalypt hybrid breeding.

Mexico

In late February, Juan José Acosta visited **Uumbal**. Camcore is guiding the company's work with a strategy for intense screening of F2 *Pinus elliottii* x *P. caribaea* var. *hondurensis* hybrid material. During 2016, we calculated breeding values for early growth for hundreds of clones for which resin quantity and quality will be evaluated by micro-tapping. Eight new Camcore breeding trials were established by Uumbal's research and development team. With those studies, the company has significantly increased its genetic base and is also evaluating the commercial potential of alternative species. *Pinus maximinoi* and *P. oocarpa* are showing promise for the highlands of Xicotepec de Juárez in the state of Puebla. In Las Choapas, Veracruz, *P. tecunumanii* low elevation tests are exhibiting great economic potential. Their initial development is very good and in some cases, better than *P. caribaea*, the commercially planted species.

Carlos Gioia and Guadalupe Pérez of Uumbal and Juan José Acosta of Camcore inspect a six-month-old Camcore progeny test of *P. tecunumanii* LE.

Juan Ramón Aguilar (Right) and Erick Morales (Left) in a four-month-old Camcore provenance and progeny test of *Eucalyptus urophylla*.

In March, Juan José Acosta visited **Proteak**. During the last few years, Proteak's research and development group has established six new Camcore tree breeding studies with which the company intends to evaluate the commercial potential of *Eucalyptus camaldulensis* in terms of volume per hectare, wood quality and plant disease resistance, as well as to broaden the genetic base of *E. urophylla*, the primary species currently planted. Camcore also helped Proteak with the identification of 114 selections of *E. urophylla* and presented a detailed plan explaining the activities required to establish a clonal seed orchard and several clonal tests using the selections.

Mozambique

Juan Luis López visited **Green Resources Mozambique** in October. The research team at GRM has done a great job establishing and managing a large number of Camcore trials that provide a broad genetic base that will help produce gains in productivity of pine and eucalypt species. Camcore will make selections from pine trials in provenance-progeny trials in 2017. Seed orchards and 2nd generation progeny trials can be established with these selections, and family forestry can be implemented with rooted cuttings of this genetic material. Juan will provide training on mass selection and vegetative propagation of eucalypts in 2017 as preparation for the implementation of a clonal program of *E. urophylla* x *E. grandis*. The company owns a large area planted with the hybrid where mass selection will provide the initial clones for this program.

Camcore continues to help **Florestas de Niassa** with its tree breeding program for pines and eucalypts in Lichinga, Mozambique. A new pine hybrid trial was established with a number of combinations with great potential for the region. *Pinus maximinoi* and *P. tecunumanii* are growing well in the trials and some selections will be made with Camcore's help in 2017. Several families in a 2nd generation trial of *P. caribaea* var. *hondurensis* are growing well at 800-900 m altitude. This species, as well as the hybrid with *P. tecunumanii*, are very promising at this elevation. *Corymbia maculata* is producing very straight trees and growing very fast, so it has potential for the pole industry in Mozambique. *Eucalyptus longirostrata* is also showing promise with fast growth and high survival, competing with the hybrid of *E. urophylla* x *E. grandis* that is planted commercially. FDN will take part in the 2-day course on mass selection and vegetative propagation to be conducted by Juan in Mozambique in 2017.

Custodio Pedro (left) and José Manteiga in a recently planted pine hybrid trial at Florestas de Niassa, Mozambique.

South Africa

Juan José Acosta visited **Sappi** twice in 2016. In May, he trained Sappi's research team in R programing in a three-day course held at their new forestry office with 14 students attending. In August, a variety of activities and discussions were conducted with Sappi's breeding group. Juan José led a hands-on workshop about NIR modeling and the use of Camcore's NIR pipeline. We talked about the utility of the Resistograph for breeding and operational applications, and had interesting discussions about the progress and future of genomic selection for *E. dunnii* and GU hybrids. Another topic was the establishment of "sentinel trials" to monitor diseases in eucalypts. In addition, we visited some trials that are helping Sappi to screen and rank a large pool of GN clones developed in house. Sappi will identify consistently snow-tolerant clones that will be intensively tested in cold zones and will serve as the core of the next generation of industry clones.

As part of the pine hybrid wood quality project, Romeo Jump traveled in July to work with **SAFCOL**, **Mondi** and **MTO** to take measurements and collect wood shavings and cores from trees in three different trials. Selected eight-year-old trees were measured with TreeSonic and Resistograph equipment. Staff from each company made great efforts to mark the selected trees before Romeo's visit. The staff also helped enormously with the fieldwork, sample preparation and shipment to Raleigh. We appreciate their hard work.

Gary Hodge visited **SAFCOL** (formerly Komatiland Forests) in August. The SAFCOL research team continues to make great progress in its internal breeding programs. We saw very good development of the advanced-generation *P. patula* clonally-replicated breeding seed orchard. A clonal BLUP analysis will be done in 2017, and the orchard thinned to the best clones. The company continues to use the TreeSonic to assess all genetic trials in order to help select for timber strength. Camcore will assist in analysis of this data in 2017.

Lizette de Waal, Leonard Mabaso, and John Crawford-Brunt of York Timbers discuss management of *Pinus tecunumanii* pollen with Gary Hodge.

There is excellent growth in their 8-year-old full-sib *P. patula* x *P. tecunumanii* progeny trials, and SAFCOL is expanding operational production with the best full-sib families. Finally, SAFCOL will provide logs from a 15-year-old *P. patula* x *P. tecunumanii* trial for a large sawtimber study to be done in collaboration with York Timbers and Merensky. SAFCOL scientist Christiaan Smit is taking the lead in organizing the study. This is another great example of the Camcore community working together.

Gary and Juan Luis López visited **York Timbers** in August prior to York hosting the Camcore Africa Regional Meeting. York has done a tremendous job establishing a *P. tecunumanii* seed orchard at Goodgeloof from Camcore 2nd generation selections. Many trees in the orchard are already producing large amounts of pollen, and this orchard will be very useful for the production of good *P. patula* x *P. tecunumanii* hybrids, as well as high-quality *P. tecunumanii* seed. York has company trials of some *P. patula* x *P. tecunumanii* (pollen-mix) that are 5 years old and can be analyzed to identify good *P. patula* hybrid mothers. As mentioned above, York will collaborate with SAFCOL on a *P. patula x P. tecunumanii* sawlog study, comparing the hybrid and pure *P. patula* for MOE, MOR, and many other timber traits.

MTO hosted Juan Luis López from Camcore in August. Juan met with several foresters and discussed issues about plantation forestry including genetics and propagation methods, wood properties, advantages and disadvantages of various pine species, and forestry financial models. It was a great opportunity to exchange ideas and to show Camcore research results. The company has made great efforts to plant and evaluate many Camcore provenance-progeny trials, building a large genetic base for several species. Having an extensive source of alternative species will give the company options to replace *P. radiata*, another species that is suffering significant mortality in young plantations due to *Fusarium circinatum*. Some pine hybrids are showing great commercial potential in the Cape region, such as *P. patula* x *P. tecunumanii* and *P. tecunumanii* x *P. caribaea*.

During his Camcore technical visit to **PG Bison** in the southern Cape, Juan Luis made some recommendations for the management of Camcore trials. Several genetic trials have been established by the company and some alternative species and hybrids are showing commercial potential. *Fusarium circinatum* continues to be a threat to *P. radiata* with significant incidence and severity in some plantations and trials. *Pinus patula* x *P. tecunumanii* LE and HE, *P. patula* x *P. oocarpa*, and *P. tecunumanii* HE x *P. oocarpa* show high survival and growth in the trials and are candidates to replace *P. radiata*. Building a genetic base of the pure species and making selections of the best trees and families will be the way to obtain great hybrids, and Camcore is helping the company with this project. Seed collections of *P. greggii* var. *australis* from selected trees and families of 1st generation Camcore progeny trials will be used for the establishment of 2nd generation progeny trials. PG Bison is collecting seeds that will be used by the company and some other Camcore members for the establishment of these trials.

Gary also spent two days in October with **Merensky** discussing research and breeding projects. The company is currently planting about 10% of its pine plantations with *P. patula* x *P. tecunumanii*, with a primary product objective of sawtimber. Regarding the collaborative SAFCOL – York – Merensky sawtimber project, one of the traits of interest to Merensky is the stability of the timber (e.g., twisting and warping) during kiln drying. In its breeding program for *E. grandis* sawtimber, Merensky is in the 4th generation of improvement, and has made great strides in reducing the splitting that is typical of many eucalypt species. Another trait of interest for eucalypt sawtimber production is “brittle heart”. In 2017,

Workers at Mondi perform controlled pollination in a *Pinus patula* seed orchard near Hilton, Kwazulu-Natal province, South Africa.

Merensky will also test the Resistograph to see if it can be used to select for brittle heart in eucalypts. As part of the Eucalypt Hybrid Project, the company has planted Seedling-to-Clone selection blocks of two hybrids (*E. grandis* x *E. benthamii*, and *E. grandis* x *E. pellita*) at Tzaneen.

Gary Hodge visited **Mondi** in October. Indoor discussions focused on the advantages and disadvantages of genomic selection, and how internal company breeding strategies might be structured to take advantage of anticipated future developments in this technology. We also outlined a special project to transfer the Camcore NIR models for mixed eucalypt species and *E. dunnii* to the Mondi Bruker spectrometer. Mondi is expanding its commercial production of *P. patula* x *P. tecunumanii*, and is working hard to optimize large -scale crossing operations in its *P. patula* seed orchard, as well as hedge management techniques to maximize the seedling-to-cutting multiplication rate. As part of the Eucalypt Hybrid Project, Mondi is responsible for Seedling-to-Clone selection blocks of *E. grandis* x *E.* nitens, that are planted at Mountain Home research station and is growing very nicely.

Tanzania

Gary Hodge visited **Green Resources Tanzania** (GRT) in May. Growth of *P. tecunumanii* and *P. maximinoi* progeny tests is very good. These tests are only 2 years old, but the early results clearly indicate that these species will outperform *P. patula*. This matches our expectations about what species would grow well based on climate, latitude and elevation, so we recommend that GRT expand commercial plantings of these more tropical species as much as possible in the next five years. In 2016, Camcore completed a BLUP analysis of GRT-Camcore *E. grandis* progeny test data and identified 50 advanced-generation selections for clonal testing. We expect these clones to average about 35% more volume gain (at age 4 years) than the local commercial material. GRT also has good trials of *E. urophylla* and *E. pellita* which can be used to broaden their genetic base, and provide future hybrid partners.

Prosper Wilbright and Simon Bayo in a *Eucalyptus grandis* trial at Green Resources in Uchindile, Tanzania.

Uruguay

Juan Luis López and Robert Jetton traveled to Uruguay in September for annual technical visits to **Montes del Plata** and **Weyerhaeuser**. The primary purpose of these visits was to collect data for wood properties studies of *Eucalyptus dorrigoensis*. At Montes del Plata, measurements were taken with the Resistograph and TreeSonic and wood shavings were collected from the five-year-old *E. dorrigoensis* provenance-progeny trial at La Rosada. Time was also spent in the office reviewing the BLUP analysis for volume growth and gain of *E. dorrigoensis* in Uruguay, and reviewing Camcore phytosanitary projects in Uruguay. At Weyerhaeuser, Resistograph and TreeSonic data

Paola Molina of Weyerhaeuser and Robert Jetton of Camcore by a hybrid of *Pinus greggii x P. tecunumanii* in Ivraoga Farm, Uruguay.

Alvaro Gonzalez from Smurfit Kappa Venezuela in a 2-year-old Camcore *E. pellita* progeny trial in Tacamajaca Farm, Portuguesa, Venezuela.

and wood shavings were collected from the five-year-old *E. dorrigoensis* provenance-progeny trial at Ivyraoga. The same data were also collected from *E. benthamii*, *E. grandis*, *E. dunnii*, and *E. dorrigoensis* in an 18-year-old species trail at Buena Union. Robert also spent time with personnel from Weyerhaeuser and INIA (Insituto Nacional Investigación Agropecuaria) to review and discuss progress with Camcore pathogen screening studies with *Coniothyrium* and *Eucalyptus* rust.

Venezuela

Smurfit Kappa Venezuela has made great progress on its *E. urophylla* tree breeding program. On his visit in March, Juan Luis López saw one clonal and one 2nd generation trial that have been planted with Camcore selections made in 1st generation progeny trials. The inclusion of these selections in the operational program will greatly increase the productivity of the company's commercial plantations. Camcore is working with SKV on a research project to develop a prediction NIR model of pulp yield based on wood chemical composition. SKV is doing the pulping study with several clones with known chemical composition. Camcore will develop the model to predict the pulp yield from NIR scan data once it obtains the pulp yield data from the lab.

Terranova de Venezuela (Masisa) has made great progress in the *Eucalyptus* program. The company has 3-year-old trials of *E. urophylla*, *E. brassiana*, and *E. camaldulensis* at two different locations. Other trials were established last year with *E. pellita* and drought-tolerant species. These species are showing commercial potential in challenging environmental conditions of poor, deep, sandy soils and limited annual rainfall. The company continues to advance its pine breeding program. The forestry team will establish an indoor seed orchard (controlled temperature) of *P. caribaea* to try to overcome the flowering challenges that the species and its hybrids experience in tropical Venezuela. In his visit in March, Juan Luis gave some recommendations on the vegetative propagation program of pines using rooted cuttings.

Terranova's research team with Juan Luis López in a 4-year-old progeny trial of Camcore *Eucalyptus urophylla* in Monagas, Venezuela.

Regional Technical Meetings

Three regional meetings were held by Camcore members in 2016, one at Forestal Monterrey and Tekia in northern Colombia, one at Montes del Plata in Uruguay, and one at York Timbers in South Africa. The regional meetings provide a great way to gather all members in a region to discuss common projects, get updates on Camcore research programs, and visit host members' field studies.

This year at Forestal Monterrey and Tekia, participants from Colombia and Venezuela had the opportunity to meet each other and share information from their own research programs. Field visits were hosted by both companies, and we saw vegetative propagation of *Gmelina arborea, Tectona grandis* and *Pachira quinata,* progeny tests, clonal trials, and clonal seed orchards. *Eucalyptus camaldulensis* and *E. urophylla* trees in Tekia trials display very good growth and form, and have definite commercial potential in the region.

In the meeting in Montes del Plata, several eucalypt species and progeny trials were growing well in the field. *Eucalyptus benthamii* and *E. dorrigoensis* appear to be good alternatives to *E. dunnii*, the species planted operationally. During the meeting, a decision was made to start researching wood properties at the family level in 5-year-old eucalypt species trials. As part of the Camcore technical visit in September, two trials of *E. dorrigoensis* were sampled, one at each company. Results on genetic parameters for wood traits will be obtained in 2017. An interesting visit was made to Montes del Plata's nursery where the group had the chance to see the Ellepot system used to produce nearly 20 million seedlings per year. Research on grafting and rooting cuttings of *E. dunnii* was also seen in the nursery.

Southern Latin America Meeting in Uruguay.

York Timbers was the host of the Africa regional meeting in Sabie, Mpumalanga, where representatives of Camcore members in South Africa, Kenya, Mozambique and Tanzania were present. The progress on pine and eucalypt breeding and conservation programs by members in Africa was reviewed and field trials were visited. During the office sessions, three research projects of interest were presented: "The use of field and artificial freezing studies to assess frost tolerance in natural populations of *Pinus oocarpa*" by Lizette de Waal from York, "Alternative pines for the Cape Timber growing regions" by André van der Hoef from MTO, and "The identification of markers associated with traits of interest in *P. patula*, *P. tecunumanii* and their hybrid" by Kitt Payn of Mondi. Two pine hybrid trials were visited at York, as well as a plywood plant. Genetic trials of *P. maximinoi*, *P. tecunumanii* and *E. grandis* x *E. urophylla* were visited at Sappi. On the last trip to SAFCOL, we visited 8-year-old trials of *P. maximinoi* and *P. tecunumanii* and a Camcore conservation park.

Northern Latin America Meeting in Colombia

Southern Africa Meeting

New *Eucalyptus grandis* Genetic Resources

Eucalyptus grandis is one of the most important commercial forestry species in the world. The species is grown for both pulp and sawtimber in many countries throughout South America, Africa, and Asia. In very tropical environments, *E. grandis* is sometimes susceptible to various insects (e.g., *Leptocybae invasa*) and diseases (e.g., *Puccinia psidii*). In cool temperate climates, *E. grandis* sometimes suffers frost damage. Breeding programs targeted for these kinds of environments often use *E. grandis* as a hybrid partner, crossed with a more tropical species like *E. urophylla* to bring in disease resistance, or with a cold-temperate species like *E. nitens* to bring snow and frost resistance.

For the past 20 years, Camcore has been expanding our collection of *Eucalyptus* genetic resources. Our initial focus was a range-wide collection of *E. urophylla* (62 provenances, 1116 mother trees, followed by provenance-progeny collections of *E. pellita* (6 provenances, 99 families), and *E. dorrigoensis* (4 provenances, 36 families), *E. longirostrata* (4 provenances, 45 families), and *E. badjensis* (3 provenances, 55 families). We have also acquired a number of other eucalypt species, some as family collections, but many as provenances and/or seed orchard bulks. In total, the Camcore eucalypt genetic base covers 37 species representing 210 provenances and seed orchard sources. However, only a small proportion of this was *E. grandis*, represented by 4 seed orchard bulks. In 2016, we sought to expand the Camcore genetic base of *E. grandis*, and we are very excited about what is now available to our members.

First, we purchased a large collection of unimproved family seed collections from CSIRO, Australia (8 provenances, 84 families). These collections represent a very large portion of the native range of *E. grandis*, from around 17° to 26° S latitude (Table 1, Figure 1). Noteworthy is that the most northerly provenances in the native range are well represented here, with 3 provenances and 33 families. These provenances have not typically been well tested in tree improvement programs

Figure 1. Natural range of *E. grandis*, and locations of Camcore seed collections. Dark red circles indicate the natural distribution of the species, yellow circles represent unimproved provenance and family collections, green circles indicate improved seed orchard bulk collections.

Table 1. Location details for *E. grandis* provenance-progeny and seed orchard bulk seed acquisitions.

Provenance	State	Type	Latitude	Elev (m)	Fams
Copperlode	Queensland	provenance-progeny	16° 58' S	425	10
Tinaroo Creek Road	Queensland	provenance-progeny	17° 05' S	1050	8
Mt Spec SF Paluma	Queensland	provenance-progeny	18° 56' S	850	15
Finch Hatton Gorge	Queensland	provenance-progeny	21° 05' S	200	10
Woondum	Queensland	provenance-progeny	26° 18' S	80	10
Mapleton	Queensland	provenance-progeny	26° 36' S	300	10
Connondale	Queensland	provenance-progeny	26° 40' S	560	10
Mt Lindsay	Queensland	provenance-progeny	28° 21' S	340	11
Coffs Harbour Orchard	New South Wales	seed orchard	30° 08' S	100	bulk
SPA Koorlong	Victoria	seed production area	34° 17' S		bulk
SSO Coleambally	New South Wales	seedling seed orchard	34° 49' S	150	bulk

around the world, so it will be interesting to see what advantages these populations might offer breeders. We also purchased 3 seed orchard bulks, improved material from southerly sources in latitudes 30° to 34°S (Table 1, Figure 1), that have shown good performance in many locations around the world.

We were also very pleased to receive donations of improved *E. grandis* families from Smurfit Kappa Colombia, and Mondi, Sappi Forests, and SAFCOL from South Africa. All of these organizations have been Camcore members for many years (from 28 to 36 years). These organizations have had their own internal *E. grandis* breeding programs, and are currently working with 3rd to 5th generation improved material. All of these companies have agreed to donate some of their older material (1st to 3rd generation families) to the Camcore program (Table 2). The array of families is quite diverse.

- Smurfit Kappa Colombia: 50 families selected for tropical environments and pulp production; 1st to 3rd generation material.
- Mondi: 40 families selected for adaptation to the cool temperate regions of Kwazulu-Natal province; 1st and 2nd generation material.
- Sappi: 20 families selected for disease resistance and adaptation to droughty, tropical sites in coastal Zululand; 1st and 2nd generation material.
- SAFCOL: 20 families selected for sawtimber traits in the Mpumalanga province; 1st and 2nd generation material

Hugo España (Smurfit Kappa Colombia) in a 3-year-old study of *E. grandis*, in Restrepo, Valle del Cauca, Colombia

In total, we received 130 advanced-generation families from these four members, and these obviously add tremendous value to our *E. grandis* genetic base. As other Camcore members test and use these materials in our collaborative testing and breeding efforts (both pure species and hybrids), the entire program will be strengthened. These donations are very generous, but also reflect an understanding on the part of some of our oldest members that a strong Camcore will, in the long-run, benefit everyone in the program. Many thanks to our friends at Smurfit Kappa Colombia, Mondi, Sappi, and SAFCOL!

Table 2. Details of *E. grandis* seed donations to Camcore: improved family seedlots from advanced generation breeding programs.

Donor	Country	Type	Latitude	Elev (m)	Fams
Smurfit Kappa Colombia	Colombia	1st gen families 2nd gen families 3rd gen families	2° to 4° N	1000 to 2000	20 15 15
Mondi	South Africa	1st gen families	24° to 26° S	900 to 1500	40
Sappi	South Africa	1st gen families	27° to 28° S	50 to 200	20
SAFCOL	South Africa	1st gen families	23° to 25° S	900 to 1500	20

New *Eucalyptus globulus* Genetic Resources

Camcore has an interest in continuing to acquire as many genetic resources as possible from different species. In 2016, an offer was made by Tekia, Smurfit Kappa Colombia, and the Colombian National Corporation of Forestry Research and Extension (CONIF) to donate some very valuable *E. globulus* material to Camcore. The information below describing the origin of this genetic material was taken from "Genetic parameters and comparison between native and local landraces of *Eucalyptus globulus* Labill. ssp. *globulus* growing in the central highlands of Colombia" by Salas et al. 2014.

In 1983, the National Institute of Renewable Natural Resources in Colombia (INDERENA) established a provenance-progeny trial near Bogotá (La Florida) with selected families from the natural forests in Australia and commercial plantations in Colombia. The main purpose of this trial was to expand the genetic base and to support a tree breeding program with the species in the country. The original seed used to establish the La Florida trial were collected from 106 Australian mother trees (open pollinated families) and 52 Colombian selections (Table 3). The mother trees in Australia were selected at several sites in Tasmania at latitudes between 39º and 43º S. The site attributes at La Florida where *E. globulus* is well adapted are 2550 meters elevation, 785 mm mean annual precipitation, latitude 4º 44' N and longitude 74º 09' W. The trial in La Florida was thinned at age six years and converted to a single-tree plot design by leaving only the best tree in each 5-tree family plot in each replication. Some years later, seeds were collected from the open-pollinated trees and were used to establish three 2nd generation progeny trials in the department of Boyacá, Colombia. Some remaining seed from this collection was offered to Camcore and will be used to establish 2nd generation progeny trials by several Camcore members in different countries. Camcore will make the best use of this valuable contribution from its two members in Colombia and CONIF. This is a great opportunity for Camcore members to establish future clonal and hybrid trials with the best trees selected in the progeny trials in areas where *E. globulus* has potential.

Lina Arango and Yair Díaz of Tekia in the 4-year-old 2nd generation *E. globulus* progeny trial at 2900 m elevation in Boyacá, Colombia.

Table 3. *Eucalyptus globulus* families and provenances from Tasmania and Colombia planted by INDERENA in La Florida provenance-progeny trial

Race	Location	Mother trees
Furneaux Group	South Flinders Island	5
King Island	King Island	5
NE Tasmania	Jericho Pepper Hill Seymour St. Helens	5 5 10 6
SE Tasmania	Chanel Rheban Uxbridge	10 10 5
Southern Tasmania	Bruny Island Geeveston Denison	10 10 5
Recherche Bay	Leprena	10
Western Tasmania	Henty River Macquary Harbour	5 5
Colombian Landrace	Boyacá Cundinamarca Nariño	11 35 6

Reference: Salas M, Nieto V, Perafán L, Sánchez A, and Borralho N. 2014. Genetic parameters and comparison between native and local landraces of *Eucalyptus globulus* Labill. ssp. *globulus* growing in the central highlands of Colombia. Annals of Forest Science (2014) 71:405-414.

Eucalyptus Breeding Update

Since 1996, Camcore has been working continuously on our *Eucalyptus* breeding program, with the objectives to provide our members with a suite of species to help them diversify their genetic base, to select material that is more resistant to disease, drought or frost, and to identify new species that can be used as hybrid partners and to increase productivity. Among the many species for which we have made collections, there are a number that have shown very good commercial potential in different regions of the world. Two of those species are *Eucalyptus dorrigoensis* and *E. pellita*. In this update, we discuss genetic analyses we made for a set of first generation studies of these two species.

Eucalyptus dorrigoensis

Distribution of provenance-progeny trials of *E. dorrigoensis* began in 2010. *E. dorrigoensis* is a cold-tolerant and fast-growing species that is closely related to *E. benthamii*. Both of these species have very restricted native ranges, and there is a very narrow genetic base of these species in breeding programs around the world. Camcore collections of *E. dorrigoensis* include 4 provenances and 36 families from Eastern Australia: Sandy Hill (14 Families), Tyringham via Dorrigo (5 Families), Clouds CK Armidale (9 Families) and Paddy Land SF (8 Families). With this genetic material, 17 trials (Table 4) were established by our members in Brazil (4 trials), Chile (5), South Africa (4) and Uruguay (4). Growth information at 3, 4 and 5 years of age was used to calculate genetic parameters. Single-site analysis across all tests indicated that provenance effect was not significant, so we combined data sets by country and used models without provenance to estimate variance components and to calculate genetic parameters, including narrow-sense heritabilities (h^2), and type B genetic correlations (r_{Bg}) which measure genotype by environment interaction (GxE).

Very low heritability values were found for volume in Brazil and South Africa (h^2=0.055 and h^2=0.045, respectively). These low heritability values reflect a high to moderately high amount of GxE (r_{Bg}=0.19 for Brazil and r_{Bg}=0.54 in South Africa). Heritability estimates for Chile and

Table 4. Mean values for survival, total height (HT), diameter at breast height (DBH) and volume in *Eucalyptus dorrigoensis* progeny tests.

TestID	Company	Country	Age	Survival (%)	HT (m)	DBH (cm)	Volume (m^3)
65-26-01J1	Klabin	Brazil	4	86.1	16.8	14.1	0.123
65-26-01J2	Klabin	Brazil	4	86.6	16.1	14.2	0.112
65-27-01F1	WestRock	Brazil	3	91.3	12.8	10.9	0.057
65-27-01F2	WestRock	Brazil	3	83.7	8.1	7.9	0.022
65-21-01A1	Arauco Bioforest	Chile	5	82.3	7.6	10.0	0.027
65-21-01A2	Arauco Bioforest	Chile	3	98.7	4.6	6.3	0.007
65-21-01A3	Arauco Bioforest	Chile	5	92.5	8.4	8.8	0.024
65-41-01B1	CMPC	Chile	3	89.5	5.0	6.1	0.006
65-41-01B2	CMPC	Chile	3	95.1	7.9	9.6	0.024
65-18-01C	Mondi	South Africa	3	48.7	12.1	11.8	0.054
65-18-02C	Mondi	South Africa	3	70.1	12.8	11.2	0.051
65-55-01E	PG BISON	South Africa	3	96.1	6.1	6.7	0.011
65-63-01I	YORK	South Africa	3	77.5	11.7	11.1	0.049
65-11-01G	Weyerhaeuser	Uruguay	4	76.2	14.8	15.4	0.115
65-11-02G	Weyerhaeuser	Uruguay	4	88.5	19.0	17.4	0.190
65-54-01D	MDP	Uruguay	5	93.6	13.5	13.9	0.084
65-54-02D	MDP	Uruguay	5	90.6	15.3	14.4	0.104

Uruguay were somewhat higher (h^2 = 0.11 for Chile and h^2 = 0.17 for Uruguay), with estimates that are more typical for forest tree growth traits. There was still a high level of GxE in Chile (r_{Bg}=0.38), while in Uruguay, relatively little GxE was observed (r_{Bg}=0.75). Despite the low heritablity estimates and high GxE, there are still opportunities to make genetic gain from selections within each country.

Eucalyptus pellita

Camcore began working with *E. pellita* in 2009. Our *E. pellita* population contains six provenances and about 100 families: Bupul (15 families), Caruk (21), Jagebob (22), Kweel (13), Muting (3), and Okaba (25), which were collected in Papua Indonesia and Papua New Guinea. *Eucalyptus pellita* can also be a valuable hybrid partner, as it can bring tolerance to various leaf diseases. The pure species has shown very good early growth in coastal Mexico, Tanzania and Mozambique. For this analysis, we used growth data at 2, 3, and 4 years of age to calculate genetic parameters in 11 trials established by our members (Table 5) in Colombia (2), South Africa (6), Mozambique (1) and Mexico (2). As in *E. dorrigoensis*, single-site analysis indicated that provenance effect was not significant, so this effect was not included in our models. Results presented here correspond to the combined analysis of all tests across all countries, excluding test 64-02-01I2 (SKC with high mortality) and 64-10-02C (SAFCOL for which single-site heritability was zero). Heritability values for HT, DBH and volume ranged between h^2 = 0.146 and 0.168, with a low to moderate GxE (r_{Bg} = 0.55 to 0.68) (Table 6). We also ran combined-site analyses by region (Africa vs Latin America), climate zones, and elevation and latitude ranges, however these did not improve or change results.

2nd generation selections

For both species, we calculated family BLUPs, and in 2017 we will provide lists of selection candidates to our members. We would like to advance the breeding cycle as quickly as possible, moving both of these species into the second generation. To complement this process, we will conduct wood studies during the next few years, assessing wood properties of the top families selected for growth. We have already started on this work for *E. dorrigoensis* with our members in Uruguay.

Table 6. Genetic paramter estimates for heritability (h^2), type B genetic correlation (r_{Bg}) and genetic coefficient of variation (GCV, %) for *Eucalyptus pellita* progeny tests.

Trait	h^2	r_{Bg}	GCV
HT	0.15	0.55	0.05
DBH	0.15	0.62	0.06
VOL	0.17	0.68	0.16

Table 5. Mean values for survival, total height (HT), diameter at breast height (DBH) and volume in *Eucalyptus pellita* provenance-progeny tests.

TestID	Company	Country	Age	Survival (%)	HT (m)	DBH (cm)	Volume (m^3)
64-02-01I1	SKC	Colombia	4	0.7797	14.2389	13.1855	0.0837
64-02-01I2	SKC	Colombia	3	0.4636	5.9787	5.4292	0.0085
64-10-01C	SAFCOL	S. Africa	3	0.6015	7.5751	9.3642	0.0245
64-10-02C	SAFCOL	S. Africa	3	0.7183	8.5119	10.2407	0.0317
64-18-01E	Mondi	S. Africa	4	0.8505	8.4071	10.3552	0.0304
64-18-02E	Mondi	S. Africa	4	0.9025	10.0159	9.4457	0.0287
64-49-01F	Merensky	S. Africa	3	0.9004	11.5014	9.2030	0.0348
64-49-02F	Merensky	S. Africa	3	0.7778	10.9448	8.6564	0.0288
64-59-01A2	Green Resources	Mozambique	3	0.9940	5.7338	5.2992	0.0067
64-67-01B	Proteak	Mexico	2	0.8240	9.1987	9.7106	0.0290
64-67-02B	Proteak	Mexico	4	0.7606	17.1455	14.1531	0.1220

Pine Breeding Update

Camcore was formed in 1980, with a focus on conservation and testing of the pine species of Central America and Mexico. Over the past 36 years, we have collected and tested 40 species and varieties in trials throughout South America and southern and eastern Africa. Almost every species offers some kind of interesting advantage, with tolerance to disease or cold or drought, or some wood property of interest. The five pine species that have most clearly demonstrated commercial potential are *P. tecunumanii*, *P. maximinoi*, *P. greggii*, *P. patula*, and *P. caribaea*. We have planted 2nd generation trials of all of these species, but are farthest along with *P. tecunumanii* and *P. maximinoi*. Both of these species are very fast growing, and have excellent wood properties. In addition, our pine hybrid studies have shown that *P. tecunumanii* is an excellent hybrid partner, combining well with a number of different species, including *P. patula*, *P. greggii*, and *P. caribaea*. In this report, we will briefly summarize the results of multiple-site 2nd generation progeny test analyses of *P. tecunumanii* and *P. maximinoi*.

Pinus tecunumanii

The families in these 2nd generation tests were derived from open-pollinated seed collected from selected trees in thinned 1st generation provenance-progeny tests of *P. tecunumanii* in Colombia and South Africa. The 2nd generation tests were typically planted in a randomized complete block design, with 6 replications and 6-tree row plots. Tests were measured for growth at ages 3, 5 and 8 years. In this analysis, we had data from Colombia, South Africa, and Mozambique. High elevation (HE) and low elevation (LE) provenances were kept separate in the 1st generation testing program, and these populations were also analyzed separately in this study. HE families survived and grew poorly in Mozambique and were deleted from this combined analysis. For the genetic parameter estimates, the LE data from Mozambique were combined with the South Africa data.

Growth Results

Growth means for the different countries are presented in Table 7. Very good growth was seen in Colombia, with the 5-year height approximately 11.5 m and 8-year height approximately 18 m for both the HE and LE populations. In Colombia (latitude 3° to 4°N), *P. tecunumanii* HE is planted from 2100 to 2400 m elevations, and the LE population is planted from 1700 to 2100 m. In South Africa and Mozambique, growth was also quite good, with a mean 5-year height of 8.1 m and 9.0 m respectively.

Genetic Parameter Estimates

For Colombia, ages 3, 5, and 8 years were analyzed. For South Africa and Mozambique, ages 5 and 8 were treated as a single trait, as this provided better convergence of the estimates. Genetic parameter estimates for volume growth are presented in Table 8.

In Colombia, heritability estimates for volume in the HE population were quite high at ages 3 and 5 years (h^2 = 0.46 and 0.35, respectively), but these decreased to a more typical value of h^2 = 0.21

Table 7. Growth results for 2nd generation P. *tecunumanii* progeny tests in Colombia, Mozambique and South Africa. Variables *n* = number of tests, *HT* = height, *DBH* = diameter at breast heigh, *VOL* = volume

Variety	Country	3 years				5 years				8 years			
		n	HT (m)	DBH (cm)	VOL m³)	n	HT (m)	DBH (cm)	VOL (m³)	n	HT (m)	DBH (cm)	VOL (m³)
HE	Colombia	5	6.5	9.5	0.0195	5	11.7	16.6	0.105	5	18.0	21.1	0.262
HE	South Africa	13	4.4	6.4	0.0069	13	8.1	12.8	0.045	10	13.2	19.2	0.158
LE	Colombia	11	7.1	10.4	0.0268	6	11.5	15.7	0.097	3	18.4	19.6	0.229
LE	Mozambique	2	3.6	3.5	0.0021	2	9.0	11.2	0.039	0	.	.	.
LE	South Africa	13	4.4	6.2	0.0069	13	8.1	12.3	0.042	10	13.1	18.1	0.140

Table 8. Genetic paramter estimates for heritability (h^2), type B genetic correlation (r_{Bg}) and genetic coefficient of variation (GCV, %) for 2nd generation progeny tests of *Pinus tecunumanii* High-elevation (HE) and Low elevation (LE) populations in Colombia and southern Africa.

HE = High Elevation P. tecunumanii				
Country / Region	**Trait**	**h^2**	**r_{Bg}**	**GCV**
Colombia	VOL3	0.46	0.89	28.9
Colombia	VOL5	0.35	0.87	25.5
Colombia	VOL8	0.21	0.67	19.9
SAF Cape	VOL3	0.31	0.93	44.4
SAF Cape	VOL58	0.05	0.16	10.9
SAF Cool	VOL3	0.09	0.39	22.1
SAF Cool	VOL58	0.17	0.63	20.9
SAF Warm	VOL3	0.10	0.20	19.8
SAF Warm	VOL58	0.12	0.29	16.9
LE = Low Elevation P. tecunumanii				
Country / Region	**Trait**	**h^2**	**r_{Bg}**	**GCV**
Colombia	VOL3	0.16	0.60	17.3
Colombia	VOL5	0.15	0.72	16.7
Colombia	VOL8	0.12	0.65	15.7
SAF Cape	VOL3	0.09	0.46	20.1
SAF Cape	VOL58	0.14	0.50	15.8
SAF Cool	VOL3	0.04	0.12	14.5
SAF Cool	VOL58	0.15	0.38	17.4
SAF Warm + MOZ	VOL3	0.10	0.48	19.2
SAF Warm + MOZ	VOL58	0.24	0.69	22.7

by age 8. In other regards, the genetic parameter estimates from Colombia were fairly typical for both HE and LE populations. Heritability was higher for the HE population, e.g., for age 8 volume, h^2 = 0.21 vs 0.12 for the HE and LE populations, respectively. GxE was moderate, with r_{Bg} ranging between 0.65 and 0.89.

In South Africa and Mozambique, there were very high levels of GxE in both the HE and LE populations. It was necessary to divide the South Africa data into three regions: Cape, Cool and Warm, classified by latitude and elevation (with the Mozambique tests grouped into the Warm region). Using this classification, heritability estimates for VOL58 in the LE population were reasonable, with h^2 = 0.14 to 0.24, and r_{Bg} = 0.38 to 0.69. The HE population had slightly lower heritability estimates and slightly higher levels of GxE for VOL58, with h^2 = 0.05 to 0.17, and r_{Bg} ranging from 0.16 to 0.63. However, even with the somewhat low heritability estimates, the GCV values indicate substantial potential to make genetic gain.

It is important to note the possible impact of hybridization with *P. patula* on these results. Recall that the 2nd generation *P. tecunumanii* seed was open-pollinated seed collected in thinned 1st generation tests. In both Colombia and South Africa, the 1st generation *P. tecunumanii* tests are surrounded by thousands of hectares of commercial *P. patula*. We know that there has been some natural hybridization, and that the 2nd generation families of *P. tecunumanii* contain both pure *P. tecunumanii*, and some percentage of *P. tecunumanii* x *P. patula* hybrids (Camcore Annual Report 2014). The HE population has a higher level of hybridization and more variation among OP families in the proportion of hybrids than does the LE population, so this may have contributed to the higher levels of GxE we are observing in the HE population.

Pinus maximinoi

As with the *P. tecunumanii*, the families in these 2nd generation tests were derived from open-pollinated seed collected in thinned 1st generation provenance-progeny tests. The 2nd generation test design was 6 replications and 6-tree row plots, and tests were measured ages 3, 5 and 8 years. In this analysis, we had 3-year-data from Argentina and Uruguay (which were grouped together) and from Mozambique, and 3-, 5-, and 8-year data from Colombia and South Africa.

Growth Results

Growth means for the different countries are presented in Table 9. Very good growth was seen in Colombia, with mean 5-year height equal to 9.9 m and 8-year height of 16.1 m. In South Africa, growth was also quite good, with a mean 5-year height of 8.7 m and 15.2 m respectively. In both countries, the growth of *P. maximinoi* and *P. tecunumanii* was roughly equivalent, but since the species were planted in separate tests and different regions, more definitive statements are not possible. Based on limited number of data sets, age 3 growth in Mozambique appears comparable to South Africa and Colombia, with somewhat less growth at age 3 in Argentina-Uruguay.

Table 9. Growth results for 2nd generation *P. maximinoi* progeny tests in Argentina and Uruguay, Colombia, Mozambique and South Africa.

Variables *n* = number of tests, *HT* = height, *DBH* = diameter at breast heigh, *VOL* = volume

Country	3 years				5 years				8 years			
	n	HT (m)	DBH (cm)	VOL m³)	n	HT (m)	DBH (cm)	VOL (m³)	n	HT (m)	DBH (cm)	VOL (m³)
Argentina - Uruguay	4	3.3	2.6	0.0008	0	.	.	.	0	.	.	.
Colombia	13	5.2	7.5	0.0118	9	9.9	15.0	0.0814	6	16.1	22.3	0.2668
Mozambique	4	5.0	5.4	0.0075	1	9.7	11.9	0.0443	0	.	.	.
South Africa	10	4.6	5.9	0.0074	8	8.7	12.2	0.0462	5	15.2	19.6	0.1858

Table 10. Genetic parameter estimates for heritability (h^2), type B genetic correlation (r_{Bg}) and genetic coefficient of variation (GCV, %) for 2nd generation progeny tests of *Pinus maximinoi*.

P. maximinoi				
Country / Region	**Trait**	**h^2**	**r_{Bg}**	**GCV**
Arg-Uruguay	HT3	0.35	0.82	15.9
Colombia	VOL3	0.15	0.53	21.2
Colombia	VOL5	0.17	0.74	18.6
Colombia	VOL8	0.11	0.55	15.2
Mozambique	VOL3	0.16	0.67	27.0
South Africa	VOL3	0.06	0.34	17.5
South Africa	VOL5	0.06	0.29	11.2
South Africa	VOL8	0.10	0.44	14.4

Isaac Mapunda and Platiel Chilaue (Green Resources, Mozambique) in 3.5 -year old *Pinus maximinoi* 2nd generation progeny trial. On the left with Isaac is *P. maximiminoi* family, on the right with Platiel is a *P. tecunumanii* control Both species are performing very well in Mozambique.

Genetic Parameter Estimates

In Colombia, age 3-, 5-, and 8-year volume heritabilities range from h^2 = 0.11 to 0.17, very comparable to heritatbility estmates for *P. tecunumanii* LE (Table 10). However, in South Africa, the heritability estimates for all three ages are somewhat low (h^2 = 0.06 to 0.11), with fairly high levels of GxE (r_{Bg} = 0.29 to 0.44). We attempted to examine regional classification as was done with the *P. tecunumanii* (e.g., region = Cape, Warm, Cool). However, no classification was found that partitioned the GxE effectively. There are fewer tests in the *P. maximinoi* data set than the *P. tecunumanii* LE and HE data sets, and this probably limited our ability to discern GxE patterns. In Mozambique, age 3 volume had moderately high heritability (h^2 = 0.16), and in Argentina-Uruguay, age 3 height had a very high heritability (h^2 = 0.35). All results suggest that good genetic gains can be made from selection in all regions.

Outlook

The genetic parameter estimates reported here should be regarded as somewhat preliminary. There are some additional tests in other countries, and for several of the current trials we are waiting for age 5 and age 8 measurements. However, it is clear that there are good opporunities to make genetic gains for growth. In 2017, we will generate candidate tree selection lists for all tests of *P. tecunumanii* and *P. maximinoi* with at least age 5 data, inspect the candidates in the field, and finalize some new 3rd generation selections of these species. Regarding the *P. tecunumanii* selections, it will also be critical to do some further molecular marker work to know if we are selecting pure *P. tecunumanii* or *P. tecunumanii* x *P. patula* hybrids.

Camcore Pine Hybrid Projects

Pine Hybrids - New Alternatives

Camcore members have made great efforts to identify pine hybrids with potential for commercial plantation forestry. For 14 years, the members have been working on a number of research activities related to this project. More than 50 different crosses between species have been made, large amounts of seeds have been produced, true hybrids have been verified with genetic markers, seeds have been distributed, hedges have been grown in the nurseries, and rooted cuttings have been distributed among members to establish trials. In 2016, ten more trials were planted by members in Mozambique and South Africa, making a total of 89 trials; 32 in Latin America and 57 in Africa. The assessment of these trials at 3, 5 and 8 years of age is providing abundant and excellent information in terms of survival and volume growth in diverse environmental conditions. Based on evaluations at those ages, *Pinus greggii* var. *australis* x *P. tecunumanii* high elevation, *P. caribaea* x *P. tecunumanii* low elevation, *P. elliottii* x *P. caribaea*, *P. patula* x *P. pringlei*, *P. patula* x *P. tecunumanii* low elevation and *P. taeda* x *P. tecunumanii* are showing great results in South American countries. In South Africa, the results show that *P. patula* x *P. tecunumanii* low elevation, *P. patula* x *P. tecunumanii* high elevation, *P. patula* x *P. oocarpa*, *P. elliottii* x *P. caribaea*, and *P. caribaea* x *P. tecunumanii* low elevation have the best volume growth and highest survival in the trials. Based on these results, *P. tecunumanii* appears to be an excellent hybrid partner with other pine species, bringing high survival, great growth and wood properties, and *Fusarium* (pitch canker) resistance, especially with the low-elevation *P. tecunumanii*. As part of the evaluation of the pine hybrids, Camcore is assessing wood properties of the standing trees in the trials. This project is described in detail elsewhere in this report.

P. patula x P. tecunumanii breeding

Among the pine hybrids planted in the trials, *P. patula* x *P. tecunumanii* has consistently shown great growth and survival in many places in South Africa. This hybrid has better *Fusarium* resistance and better wood properties than *P. patula*. In the Camcore annual meeting in Chile in 2012, it was decided to begin a tree breeding program among South African members for this hybrid. The objective was to produce seeds of 300 full-sib families to be tested in progeny trials. A collaborative project like this allows the participating members to produce the hybrid seeds at a lower cost, test a larger number of hybrid families, and make more gain. All seven South African members and Green Resources Mozambique are supporting this program, with crosses made by Sappi in its *P. patula* clonal seed orchard at Lions River in Howick, KwaZulu-Natal. Overcoming the

Johan Vermaak and Bongani Noludwe of PG Bison inspect a 6-year-old *P. patula x P. tecunumanii* hybrid.

challenges created by two heavy hail storms in 2013 and 2014, the Sappi team was able to finish the 300 crosses in 2015. Seeds from the 2013 and 2014 crosses have been collected already and the remaining seeds will be collected in 2017. Hybrid hedges will be grown in the nursery to multiply the number of rooted cuttings required to establish the progeny trials. Forty-three females of *P. patula*, 53 males of *P. tecunumanii* high elevation and 44 males of *P. tecunumanii* low elevation were used in the mating plan to obtain the 300 families.

P. tecunumanii x P. greggii breeding

In South America, several hybrid trials in Argentina, Brazil, Colombia and Uruguay have shown excellent results in growth and survival of *P. greggii* var. *australis* x *P. tecunumanii* high elevation. This pine hybrid is competing very well with commercial improved material planted in the region, *P. taeda* in the southern part of South America and *P. maximinoi* and *P. tecunumanii* in Colombia. Some of the good traits of this hybrid are the frost resistance of *P. greggii*, and the fast growth, great wood properties, and *Fusarium* resistance of *P. tecunumanii*. In the Camcore annual meeting in Texas in 2015, eight members decided to pursue a tree breeding program with this hybrid, making the crosses in Colombia. Last year, Camcore created a plan to implement this project. Pollen collections from 19 *P. greggii* selections from WestRock, 18 from Klabin, and 13 from Smurfit Kappa Colombia were started. All these selections are currently producing flowers in clonal seed orchards of the three companies. Smurfit Kappa Colombia already started making crosses with pollen of *P. greggii* in several *P. tecunumanii* clonal seed orchards where 50 clones will be used as mother trees, 25 clones each of high and low elevation. The objective is to make 300 controlled crosses to produce seeds of 300 full-sib families that will be used to plant hedges and establish progeny trials through rooted cuttings. Seven Camcore members are taking part in this project: Arauco Argentina and Bosques del Plata in Argentina, Klabin and WestRock in Brazil, Smurfit Kappa in Colombia, Uumbal in Mexico, and Weyerhaeuser in Uruguay.

Isolated flowers of *P. tecunumanii* for crosses with *Pinus greggii* in the Smurfit Kappa Colombia clonal seed orchard in Restrepo, Valle.

Future opportunities

Another pine hybrid showing excellent growth and survival at 3 years of age is *P. taeda* x *P. tecunumanii*. This hybrid is competitive with the best families of *P. taeda* in Bosques del Plata, Argentina and may be a great alternative to *P. taeda* in southern South America. Members in Argentina, Brazil, Uruguay and South Africa should consider initiating a breeding program with this hybrid, using selections of *P. taeda* from the genotype x environment (GxE) interaction study conducted by Camcore a few years ago. Companies who did not take part in the GxE study might contribute some of its own *P. taeda* material to participate in this breeding project.

Genetics of Pine Diseases in Colombia

Introduction

Smurfit Kappa Colombia (SKC) is a paper, packaging, and solid wood company that manages over 68,000 ha of forests located in the Colombian Andes in six departments and 36 municipalities. Its lands are grouped into three management zones: North, Central, and South. Pines are planted on approximately 58% of total productive area, and several species, including *Pinus maximinoi*, *P. patula*, *P. tecunumanii* high and low elevation (HE and LE) are matched to sites based on species adaptability and productivity. A set of 2nd generation *P. tecunumanii* LE progeny tests with 42 families was established by the SKC research team. Along with growth, the incidence, severity and impact of several diseases is being evaluated. With this study, we hope to develop a standard methodology to evaluate diseases in tree breeding tests, estimate genetic parameters, understand disease evolution over time, and estimate the effects of diseases on productivity.

Three study sites (one per zone) were planted during the first half of 2011. Detailed information about the study sites is presented in Table 11. Diameter at breast height (DBH) and total height (HT) were measured at three and five years of age. Five fungal diseases were assessed for all trees every six months starting when the studies were 12 months old (Table 11). We evaluated the incidence and the severity of each pathogen, using a categorical system, summarized here and depicted in Figure 2.

Incidence: The height of the tree crown was divided into quarters, and the incidence of a given disease was defined as the number of quarters affected:

- 0: No incidence of the disease
- 1: Incidence in one quarter (1-25 %)
- 2: Incidence in two quarters (26-50 %)
- 3: Incidence in three quarters (51-75 %)
- 4: Incidence in four quarters (76-100 %)

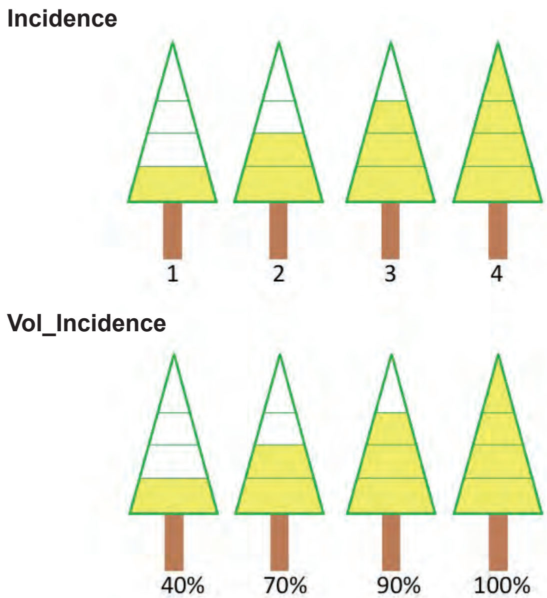
Severity: Intensity of the attack:

- 1: Low severity
- 2: Medium severity
- 3: High severity

To understand how the diseases progress over time, and to define which diseases should be analyzed in detail, frequency plots for each disease, site, and time were created using custom-made R scripts (Figures 3 and 4). Incidence and Severity assessments were combined into three indices: Index1 = Incidence + Severity; Index2 = Incidence*Severity; and Index3 = Vol_Incidence*Severity, where Vol_Incidence represents the estimated cumulative proportion of the total crown volume (Figure 2). We used mixed models to calculate variance components and to estimate genetic parameters for all indices and growth data. We also calculated the Best Linear Unbiased Predictors (BLUPs) for each family. All calculations were made using PROC VARCOMP and PROC MIXED in SAS version 9.4.

Table 11. Description of study sites.

Site	Libano (North)	Aguaclara (Central)	San José (South)
Camcore ID	16-02-X11A1	16-02-X11A2	16-02-X11A1
Established	June 2011	May 2011	May 2011
Latitude	4° 43' 19'' N	3° 41' 29''N	2° 35' 3'' N
Longitude	75° 35' 45'' W	76° 33' 57'' W	76° 35' 7'' W
Elevation (m.a.s.l)	2118	1748	1790
Precipitation (mm)	3793	1082	2292
Ages at evaluation (months)	12, 18, 24, 30, 39, 42, 48, 54, 65	12, 18, 24, 36, 43, 48, 55	12, 18, 24, 30, 36, 42, 48, 54
Diseases evaluated	*Dothistroma septosporum, Fusarium circinatum, Mycosphaerella dearnesii, Phytophthora spp, and Diplodia pinea.*		



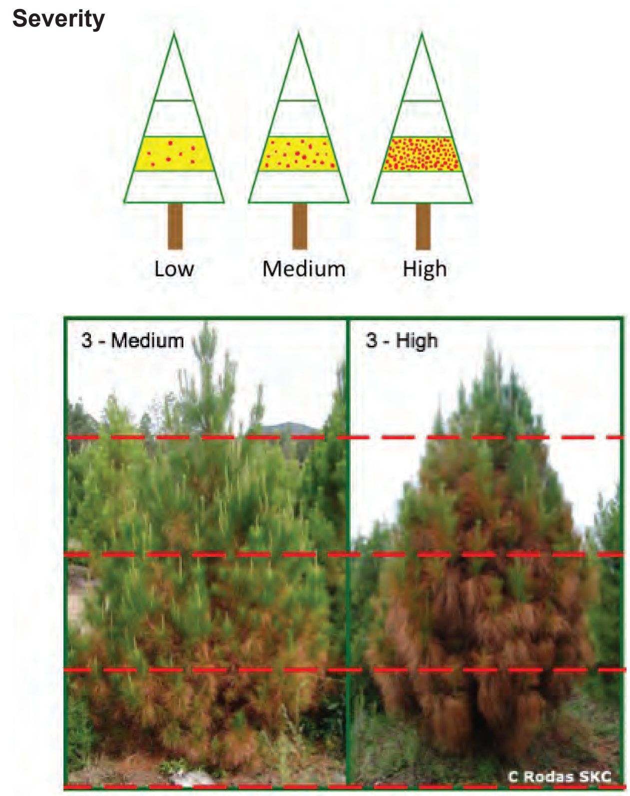


Figure 2. Categorical evaluation of Incidence, Vol_Incidence, and Severity. In the photo, the tree on the left has an Incidence = 3 (51-75 %) and medium severity, the tree on the right has the same Incidence = 3 (51-75 %), but with a much higher severity.

Results and Discussion

Initial descriptive analysis of incidence values across sites indicates that only a few diseases were affecting the trials. For Aguaclara (Central zone) and San José (South zone), we found that only *Mycosphaerella dearnesii* was present. However, only a small fraction of trees was affected, and at a low incidence, between the second and third year of age (Figure 3). No trees with incidence greater than 50 % were observed. Due to the low levels of variation observed in these study replications, the estimation of variance components, genetic parameters, BLUPs and GCA values was not feasible.

For Libano (North zone), the only disease affecting the trees is *Dothistroma septosporum.* This disease was consistently expressed during evaluation periods and as shown in Figure 4, there is a good distribution of the incidence categories over time. Note also that there are two assessment ages (18 and 54 months) for which any genetic variance in tolerance that may exist would be masked by extremely low incidence. We know that those months were excessively dry, and presumably the fungal activity was reduced.

Heritability values of infection indices across assessment ages were equivalent for all indices: h^2_b=0.204 for Index1, h^2_b=0.200 for Index2, and h^2_b=0.202 for Index3. So, hereinafter, we will only present the results for Index3 since it represents a standardized estimation of the infection caused by *Dothistroma septosporum* on each tree. With the Libano data set, we calculated genetic parameters for growth and for Index3 for each age (Table 12). Excluding 18- and 54-month measurements for which rainfall was very low, observed heritability values for Index3 were similar to or higher than the ones observed for growth traits; their values ranged between 0.224 and 0.328, which indicates that the response to *Dothistroma septosporum* infection is under a good level of family control.

To evaluate the average performance of the half-sib families, we calculated general combining abilities (GCA) for each of the female parents. In Table 13, we present the top and the bottom 10 families ranked by GCA of standardized volume at 5 years of age (GCA_stvol5). The top-ranking families are progeny of Camcore selections and have an average GCA 25.6% higher than the study mean, whereas the bottom-ranking families have an average GCA 22.3% lower than the study mean and include the two control lots: unimproved material from Yucul and Arcadia, SKC's first seedling seed orchard with a low level of improvement. Note that the top families for volume have negative GCA values for the infection score Index3, which indicates that volume growth increases when fungal infection decreases. Specifically, the top performing family for growth at five years (16-162) has GCA_stvol5 = +49.7%, and consistently has less serve infection acoss measurement ages, with an average GCA_Index3 = -8.1. In comparison, the worst growing family (16-205) has GCA_stvol5 = -30.7%, and it consistently has more severe infection, with average GCA_Index3 = 5.1% (Table 13). In fact, across this population (42 families + 2 controls), there is a strong relationship between *Dothistroma* tolerance and volume growth on this site. The correlation of GCA predictions for Index3 with GCA_stvol5 is negative at all ages, and is particularly strong at ages 24, 30, 39 and 42 months, with r = -0.76, -0.83, -0.78, and -0.75, repectively. The negative values indicate that less *Dothistroma* infection is associated with higher volume. To illustrate, assume that all families are ranked based on GCA_Index3 (age 30 months); in this case, the 10 most-susceptible families have a mean GCA_stvol5 = -17.4%, while the 10 most-tolerant families have a mean GCA_stvol5 = +20.3%.

Summary and Outlook

This study allowed us to develop a new protocol to evaluate the effects of diseases on tree breeding tests and to discover that in this population at the Libano Farm site, the response to *Dothistroma septosporum* attack is highly heritable. Infection intensity is governed by family structure, and growth and *Dothistroma* tolerance are highly correlated. This indicates that on SKC land in the North zone of Colombia, selection for one trait will bring associated improvement in the other trait. SKC will be able to identify *P. tecunumanii* families that are tolerant to *Dothistroma* for deployment to sites with high risk of infection from the fungus.

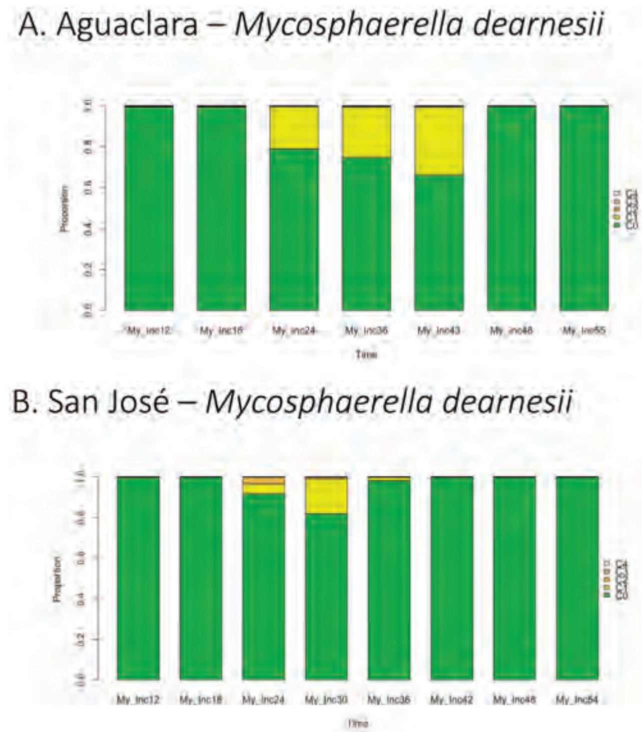


Figure 3. Incidence of *Mycosphaerella dearnesii* at Aguaclara (A) and San José (B) Farms. Colors represent the proportion of trees in each incidence category: green=C0, no incidence; yellow=C1, incidence of 1-25%; orange=C2, incidence of 26-50%; brown=C3, incidence of 51-75%; and white=C4, incidence of 76-100%.

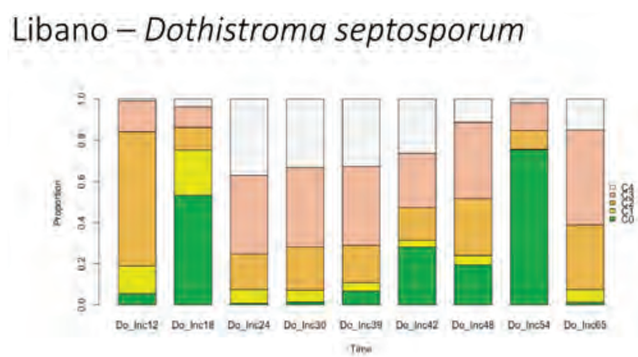


Figure 4. Incidence of *Dothistroma septosporum* at Libano Farm. Colors represent the proportion of trees under each incidence category: green=C0, no incidence; yellow=C1, incidence of 1-25%; orange=C2, incidence of 26-50%; brown=C3, incidence of 51-75%; and white=C4, incidence of 76-100%..

Table 12. Genetic parameters: estimated variance components and heritabilities for Index3 (standardized infection of *Dothistroma septosporum*) over age, and for standardized volume at 3 and 5 years.

Trait_age	vfam	vplot	verr	vphen	h2b
Index3_12	20.49	70.45	183.42	274.36	0.224
Index3_18	7.44	178.93	164.35	350.72	0.064
Index3_24	38.51	166.44	304.98	509.94	0.227
Index3_30	69.67	324.16	316.53	710.37	0.294
Index3_39	40.12	207.28	221.06	468.46	0.257
Index3_42	97.59	381.39	414.21	893.19	0.328
Index3_48	36.84	183.84	256.07	476.76	0.232
Index3_54	8.29	244.35	217.64	470.28	0.053
Index3_65	17.89	108.41	254.74	381.04	0.141
stvol3	408.731	1631.272	4109.794	6149.796	0.199
stvol5	551.034	1314.747	4120.551	5986.332	0.276

Table 13. General combining ability (GCA) for Index3 and growth traits. Families are ranked by GCA_stvol5. Top performing families highlighted in green, bottom ones in pink.

Family	GCA_12	GCA_24	GCA_30	GCA_39	GCA_42	GCA_48	GCA_65	GCA_ stvol3	GCA_ stvol5
16-162	0.25	-8.92	-12.62	-8.73	-12.51	-8.19	-5.89	43.16	**49.67**
16-204	-6.44	-7.06	-7.60	-4.53	-11.65	-7.73	-4.32	28.93	42.66
16-164	-1.70	-6.20	-10.40	-5.97	-7.04	-0.71	-1.06	20.74	37.32
16-153	0.53	-2.44	-3.30	-4.17	-4.83	-2.40	-3.52	15.63	23.90
16-189	-3.24	-5.57	-10.27	-10.40	-12.80	-3.74	-3.76	8.95	22.23
16-146	-5.77	-4.46	-9.29	-5.54	-13.40	-1.30	-1.83	11.99	21.19
16-142	-1.62	-3.69	-5.70	-2.49	-3.96	-3.34	-0.10	20.55	17.05
16-183	-4.74	-1.02	-2.32	-0.23	-4.99	-2.63	0.22	16.80	16.42
16-174	0.33	-0.30	-1.75	1.73	3.68	-2.63	-1.33	8.20	13.54
16-203	0.50	-1.25	-6.41	-4.86	-1.81	0.32	-0.76	23.69	12.04
16-167	-5.65	5.04	7.21	2.39	2.33	-0.55	1.10	-11.56	-16.74
16-156	-1.61	-0.78	0.89	1.21	-0.07	-4.02	-2.01	-9.67	-17.10
Yucul*	0.90	8.44	6.54	2.76	12.17	9.50	1.33	-16.51	-17.19
16-185	4.66	2.26	5.06	3.91	3.63	2.73	3.04	-17.51	-20.32
16-188	4.89	9.33	12.13	5.96	8.75	5.06	2.39	-16.89	-22.17
16-170	6.81	3.64	8.99	6.50	8.93	5.58	0.57	-18.09	-22.30
16-192	1.40	8.15	10.49	9.41	9.84	5.73	3.37	-11.46	-23.41
16-166	6.36	2.03	3.59	5.14	8.33	0.79	4.44	-17.82	-25.60
Arcadia*	5.63	3.36	4.41	2.85	13.33	4.60	6.33	-24.66	-27.48
16-205	2.04	5.36	6.90	6.09	6.06	4.03	5.01	-18.76	**-30.70**

* Control lots: Yucul: unimproved material. Arcadia: seedling seed orchard

Wood Properties of Four Eucalypt Species in Uruguay

In 2016, we conducted a study to compare the wood properties of four eucalypt species in Uruguay. This is the first of what we hope will be many years of experiments characterizing the wood properties of eucalypt species across a wide range of environments around the world.

Materials and Methods

A species trial was planted by Weyerhaeuser Company in the state of Rivera, Uruguay, in December of 1998. The trial contains four species: *E. dunnii*, *E. grandis*, *E. benthamii*, and *E. dorrigoensis*. The test details and environmental conditions are shown in Table 14. The test was 18-years-old when wood samples were taken in 2016. Standing trees were sampled with the IML Resistograph to measure wood resistance (correlated with wood density), and sampled with the TreeSonic to measure acoustic velocity (which was converted to modulus of elasticity, MOE). In addition, wood shavings were taken, shipped to North Carolina, ground into wood meal and scanned with an NIR spectrometer to assess chemical properties. The Camcore global eucalypt NIR model was used to predict contents of different types of sugars and lignin. The Weyerhaeuser research team did a fantastic job, taking all the measurements of 123 trees in a single day: 31 trees of *E. benthamii*, 32 of *E. dorrigoensis*, 30 of *E. dunnii* and 30 of *E. grandis*.

Results and Discussion

Table 15 shows that the ranking of the species is very consistent; for essentially all of the wood properties, *E. dunnii* is first, followed by *E. grandis*, *E. benthamii* and *E. dorrigoensis*.

Table 14. Details of an 18-year-old eucalypt species trial in Weyerhaeuser, Uruguay.

Latitude	31° 15’ 53” S
Longitude	55° 39’ 00” W
Elevation	180 m
Max. mean annual temp.	30.1°C
Min. mean annual temp.	7.0°C
Frost events per year	5.2
Mean annual precipitation	1484 mm
Soils	Well-drained sandy loam.

For *E. dunnii*, mean MOE was 16.4 GPa, and this was 19%, 31% and 60% greater than that of *E. grandis*, *E. benthamii* and *E. dorrigoensis*. The lowest single-tree value of MOE for *E. dunnii* (13.1 GPa) is similar to the highest value for *E. dorrigoensis* trees (Figure 5). The results for resistance were similar to those for MOE. Mean resistance for *E. dunnii* was 1654, and this was 17%, 27%, and 39% greater than for *E. grandis*, *E. benthamii* and *E. dorrigoensis*, respectively.

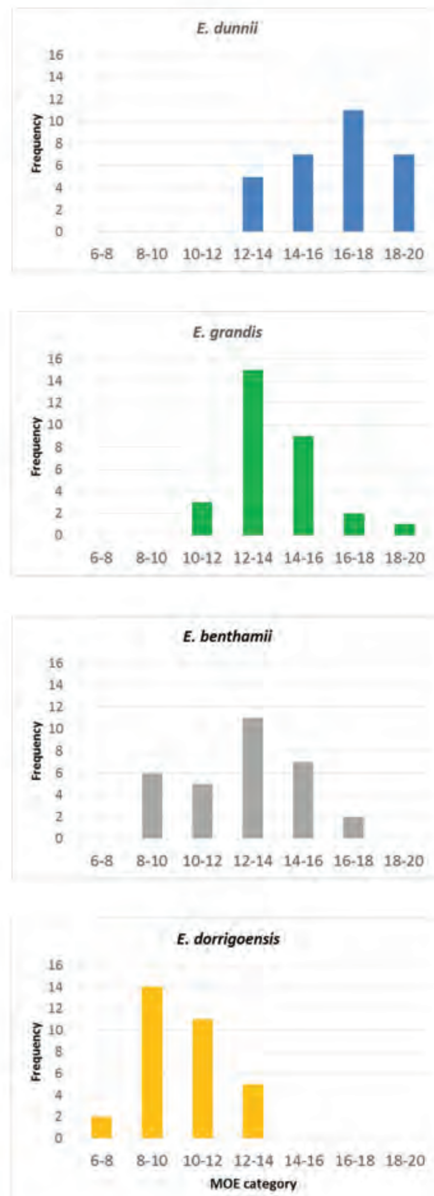


Figure 5. Distribution of modulus of elasticity (MOE) in standing 18-year-old trees of four eucalypt species at Weyerhaeuser, Uruguay.

Table 15. Resistograph resistance, modulus of elasticity (MOE), and chemical composition of 18-year-old trees of four eucalypt species in Weyerhaeuser, Uruguay.

Species	MOE	Resistance	Cellulose	Lignin	Klason lignin	S:G ratio
E. dunnii	16.4	1654	50.7	28.8	23.6	4.03
E. grandis	13.8	1415	48.7	32.1	27.0	2.37
E. benthamii	12.5	1304	47.6	34.0	28.6	3.28
E. dorrigoensis	10.2	1190	46.9	35.2	29.8	3.43

Generally, *E. dunnii* is considered to have high density, so this high Resistance value relative to other eucalypt species is consistent with that. As with MOE, the *E. dunnii* trees with the lowest Resistance were similar to the trees of *E. dorrigoensis* with the highest Resistance.

Finally, in terms of pulp potential, *E. dunnii* has the best characteristics, with the highest cellulose, lowest lignin, and a high ratio of syringyl to guaiacyl lignin (S:G). *E. dunnii* has roughly a 2 to 4% advantage in cellulose, a 4 to 6% advantage in lignin, and S:G = 4.03, compared to S:G = 3.4 for *E. benthamii* and *E. dorrigoensis*, and S:G = 2.4 for *E. grandis*. S:G ratio was the only trait where the order of the species changed, and this was because *E. grandis* had the worst ratio (in terms of effects on pulp yield). The low S:G ratio would reduce, at least somewhat, the slight advantage that *E. grandis* has over *E. benthamii* and *E. dorrigoensis* in cellulose and lignin content.

From these results, it is clear that the quality of *E. dunnii* wood will probably be excellent for many products. Another interesting result is the comparison of *E. benthamii* and *E. dorrigoensis*, considered to be closely related species. Although the two species have quite similar chemical characteristics, their solid wood characteristics (as measured by MOE in standing trees and Resistance) seem to be quite different, with an advantage to *E. benthamii*.

These results will be compared to those from another planting of 5-year-old trees of these species on the same site. Wood samples from the younger trees are currently being processed and analyzed by Camcore in Raleigh. It will be interesting to see whether there are any changes in the ranking of the species, as well as in the mean values for the wood properties at the two ages.

Eucalypt Disease Screening Update

In 2015, Camcore began a project to screen eucalypt species for resistance or susceptibility to several pathogens of concern across our membership, specifically *Puccinia psidii*, *Botryosphaeria*, and *Teratosphaeria* (*Coniothyrium* canker). Screening efforts are being coordinated by Weyerhaeuser in Uruguay (in partnership with INIA) and Smurfit Kappa Colombia (SKC). In Uruguay, Weyerhaeuser and INIA established a field screening trial for *Coniothyrium* in March 2016 that includes 1,600 seedlings representing the 12 eucalypt species and resistant and susceptible control clones planted across 20 replicates on a one-hectare plot. The first data are being collected at the time of this writing and should be delivered to Camcore soon. INIA and Weyerhaeuser also started their *P. psidii* laboratory screening study with all 12 eucalypt species in December 2016 with data delivery to Camcore expected in early 2017. We are excited to receive this data and thank Jorge Martinez and Paola Molina (Weyerhaeuser) and Sofia Simeto, Pilar Gasparri, and Robert Scoz (INIA) for their excellent work on this project.

Seed import issues have delayed the start of screening studies for *P. psidii* and *Botryosphaeria* at SKC in Colombia, but the phytosanitary issue was resolved and SKC finally received the seed in late December 2016. Robert Jetton and Juan José Acosta (Camcore) are working with Nhora Izaza and Carlos Rodas (SKC) to develop a plan to complete these screening projects in 2017 and 2018. Once completed, Camcore will continue working with SKC to screen our eucalypt genetic material against additional pathogens of concern, including *Certocystis, Chrysoporthe,* and *Cylindrocladium*. The work in Colombia is being conducted in collaboration with FABI, University of Pretoria in South Africa.

Pine Hybrid Wood Properties

Introduction

Camcore members initiated a cooperative international pine hybrid breeding program in 2002 and have created more than 40 different interspecific combinations. The goal of the project is to test these pine hybrids and determine their commercial potential based on adaptability to different environments, growth, and stem form, compared to the pure pine species currently in use.Since 2007, our members have planted 89 pine hybrid trails with 23 verified hybrids in Africa and Latin America. Growth data has allowed Camcore to identify hybrids of high interest to our members. Among the best are *Pinus greggii* x *P. tecunumanii* in Latin America and *P. patula* x *P. tecunumanii* in Africa. In 2014, our technical committee decided to sample trees in a subset of those studies to characterize the hybrids' wood properties in order to rank them and compare their wood to that of pure species. During the last two years, we have sampled eight trials: two from Smurfit Kappa Colombia (reported in the 2015 Annual Report) and this year, two in Argentina, two in Brazil and two in South Africa. This article presents the results from these six trials.

Materials and Methods

General information and location of the study sites are presented in Table 16. At each site, there were from 6 to 15 treatments including hybrids and pure species controls. For each treatment, we randomly selected 30 trees from the dominant and codominant trees. If a given control species was represented by more than one genetic source, for example *P. taeda* first generation and *P. taeda* second generation, average species values are presented. From each selected tree, field measurements and wood samples were taken at breast height to assess the following wood traits:

Cellulose and lignin content: We used hand drills to collect wood shavings from just inside the bark to just short of the pith. Samples were oven dried and shipped to NC State University where they were ground and scanned on a FOSS 6500 NIR spectrometer. We used our Global Pine NIR model to predict lignin and cellulose percentages.

Extracting wood shavings for NIR analysis. The yellow paint mark indicates where Resistograph readings have already been taken.

Modulus of Elasticity (MOE): In its simplest form, MOE characterizes wood stiffness, and is a good overall indicator of strength. We estimated MOE using the TreeSonic. This tool measures the acoustic wave propagation time in the stem of standing trees. With this time and the distance between two sensors, the stress wave velocity is calculated. This value correlates well with MOE and yield strength of wood.

Table 16. Hyprid pine trials sampled in 2016.

TestID	Member	Country	Date Planted	Latitude	Longitude	Elev. (m)	Precip. (mm)	Treat ments
98-45-H01B1	Arauco	Argentina	Nov-2007	26° 02' S	54° 37' W	195	1965	10
98-48-H01A1	BDP	Argentina	Nov-2007	27° 58' 56" S	56° 0' 47" W	127	1657	10
98-26-H01C2	Klabin	Brazil	Jan-2007	24°13' 56" S	50° 36' 04" W	836	1368	6
98-27-H01A2	WestRock	Brazil	Dec-2008	29° 59' 55" S	50° 11' 11" W	790	1556	6
98-10-H01A2	SAFCOL	South Africa	Oct-2008	25° 08' 36" S	30° 52' 15" E	1610	1300	15
98-52-H01B2	MTO	South Africa	Apr-2009	34° 2' 27" S	23° 10' 29" E	236	945	11

Santiago Marchesi of Bosques del Plata, Argentina uses the TreeSonic to estimate MOE of a hybrid pine tree.

Density: We used the IML Resistograph to obtain the density profile of the trees. The Resistograph system measures the resistance of a thin needle drill that is inserted under constant drive into the wood. While drilling, the required energy is measured; this resistance is directly proportional to the density of the tree.

Statistical analysis for this project included fitting a generalized linear model (GLM) for all traits (percentage cellulose, percentage lignin, resistance, and MOE) on each site. If statistically significant differences among treatments were found, pairwise comparisons (differences) were made between the treatments' LSMEANS. Confidence intervals (CI) for the mean response of each trait were also calculated and plotted. All analyses were made using R version 3.3.1.

Romeo Jump of Camcore samples a hyprid pine tree with the Resistograph.

Results and Discussion

Across all tests and traits, we found that the variation associated with treatments (species and hybrids) was statistically significant, which indicates that there are true differences between treatment means. To identify the magnitude of the differences, we calculated pairwise differences between treatment Least Squares Means (LSMEANS). In this discussion, we are presenting detailed results only for Brazil, as an example. However, Tables 17, 18, and 19 summarize the results found in all three countries.

The two members in Brazil, WestRock and Klabin, had the same number of treatments; however, each company used its own commercial *P. taeda* as control lots. In terms of cellulose and lignin percentages, we noted that in WestRock, the hybrids having *P. patula* as a mother (PATxPRI, PATxGRS and PATxELL) have the highest percentage cellulose and the lowest percentage lignin; hybrids having *P. elliottii* as mothers (ELLxTEH, ELLxCAR) have the lowest percentage cellulose and the highest percentage lignin. WestRocks's control treatment (*P. taeda*) has intermediate values for both cellulose and lignin (Figure 6). The treatment responses at Klabin were similar to those at WestRock with just a few differences: the cellulose percentage was higher for ELLxCAR than for ELLxTEH; and Klabin's *P. taeda* showed an intermediate value for cellulose and a low value for lignin (Figure 6).

For both companies, the hybrids PATxGRS and PATxELL showed the uppermost values for modulus of elasticity; intermediate values of this trait were observed for PATxPRI and ELLxCAR, and ELLxTEH exhibited the lowest value for MOE. Interestingly, the commercial controls of each company showed different responses. WestRock's *P. taeda* had high values of MOE, whereas *P. taeda* from Klabin showed an intermediate value (Figure 7). We also evaluated treatment differences for resistance using the Resistograph. Our results showed that Resistograph readings are correlated with core density values, but if we want to use Resistograph data to calculate density, there may be sites or species effects that affect the predictions (see "Resistograph Profiles – Converting to Density " later in this report).

Table 17. Treatment means[1] for percentage cellulose.

Hybrid	Arauco	BDP	Klabin	West Rock	MTO	SAF-COL
TELxCAR					41.8	40.4
TEHxOOC					42.2	42.3
PATxPRI	42.9	41.9	43.6	43.6		42.5
PATxGRS	42.8	42.5	44.3	43.9	43.3	43.6
PATxELL	42.6	42.2	44.2	43.7		42.3
PATxTEL					42.4	42.9
PATxTEH					42.6	42.7
PATxOOC					42.2	41.8
CARxTEL	41.8	42.6				40.4
CARxOOC	41.4	42.0				40.7
ELLxTEH	42.2	42.1	42.6	41.2		
ELLxCAR	42.2	42.5	43.5	41.4	40.8	40.2
P. elliottii					40.4	39.9
P. maximinoi					42.6	
P. radiata					43.3	
P. tecunumanii	42.6	42.8				
P. taeda	42.6	42.2	43.6	42.4	41.6	41.5
P. oocarpa	41.2	42.0				
P. patula						43.3
P. pseudostrobus						43.2

[1] For each test site, green shading is the upper half of the treatment means (higher cellulose), and red shading the lower half (lower cellulose).

Table 18. Treatment means[1] for percentage lignin.

Hybrid	Arauco	BDP	Klabin	West Rock	MTO	SAF-COL
TELxCAR					27.3	28.6
TEHxOOC					27.0	27.2
PATxPRI	28.9	29.1	28.9	27.3		27.1
PATxGRS	28.5	28.0	28.4	26.7	26.1	25.6
PATxELL	28.7	28.7	28.5	27.1		26.7
PATxTEL					26.6	26.8
PATxTEH					26.7	26.6
PATxOOC					26.5	27.4
CARxTEL	29.8	28.3				28.5
CARxOOC	30.2	28.8				28.2
ELLxTEH	29.5	28.8	29.7	29.5		
ELLxCAR	30.2	29.1	29.4	29.6	28.0	28.8
P. elliottii					29.1	29.0
P. maximinoi					27.1	
P. radiata					25.0	
P. tecunumanii	28.8	27.9				
P. taeda	28.3	28.0	28.5	28.1	27.5	27.3
P. oocarpa	29.8	28.1				
P. patula						26.4
P. pseudostrobus						26.0

[1] For each test site, green shading is the lower half of the treatment means (lower lignin), and red shading the upper half (higher lignin) .

To summarize our findings across countries, we present treatment LS means for each trait in Tables 17, 18, and 19. Cellulose means are shown in Table 17, lignin means in Table 18 and MOE means in Table 19. In each table, the cell color indicates whether a treatment is in the top-better half (green) or the bottom-worse half (red). A single column compares treatments on one site, and readers can examine the overall perfromance of a hybrid or species by looking across rows.

For example, the hybrids that yield the highest percentage cellulose in WestRock are PATxPRI, PATxGRS and PATxELL (Table 17). Those hybrids also have the lowest percentage lignin (Table 18). Note also that PATxGRS consistently performs well, since it is green across all sites for percentage cellulose and lignin (Tables 17, 18), and green for MOE in all countries but Argentina (Table 19).

This project is an ongoing effort. To date, we have completed the evaluation of the selected tests from the first hybrid series. During the next few years, we will evaluate studies from the second and third series with different hybrids.

Table 19. Treatment means[1] for MOE.

Hybrid	Arauco	BDP	Klabin	West Rock	MTO	SAF-COL
TELxCAR					10.5	7.9
TEHxOOC					11.7	12.1
PATxPRI	7.8	8.1	11.1	12.6		9.5
PATxGRS	7.2	8.3	14.2	14.5	12.4	10.9
PATxELL	8.8	9.7	13.9	14.5		10.0
PATxTEL					12.8	11.1
PATxTEH					12.0	9.9
PATxOOC					9.8	8.9
CARxTEL	10.3	10.9				6.6
CARxOOC	8.6	9.0				7.3
ELLxTEH	11.0	10.6	10.0	10.4		
ELLxCAR	10.9	12.0	13.0	13.3	8.2	6.9
P. elliottii					9.5	8.0
P. maximinoi					12.2	
P. radiata					8.9	
P. tecunumanii	12.2	12.1				
P. taeda	9.3	12.2	11.9	14.9	10.7	8.3
P. oocarpa	9.7	10.1				
P. patula						11.0
P. pseudostrobus						8.2

[1] For each test site, green shading is the upper half of the treatment means (higher MOE), and red shading the lower half (lower MOE).

Figure 6. LSMEANS Confidence intervals in Brazil. Graphs on top show the CI for percentage cellulose (Klabin left, WestRock right). Graphs on bottom depict CI for percentage lignin (Klabin left, WestRock right).

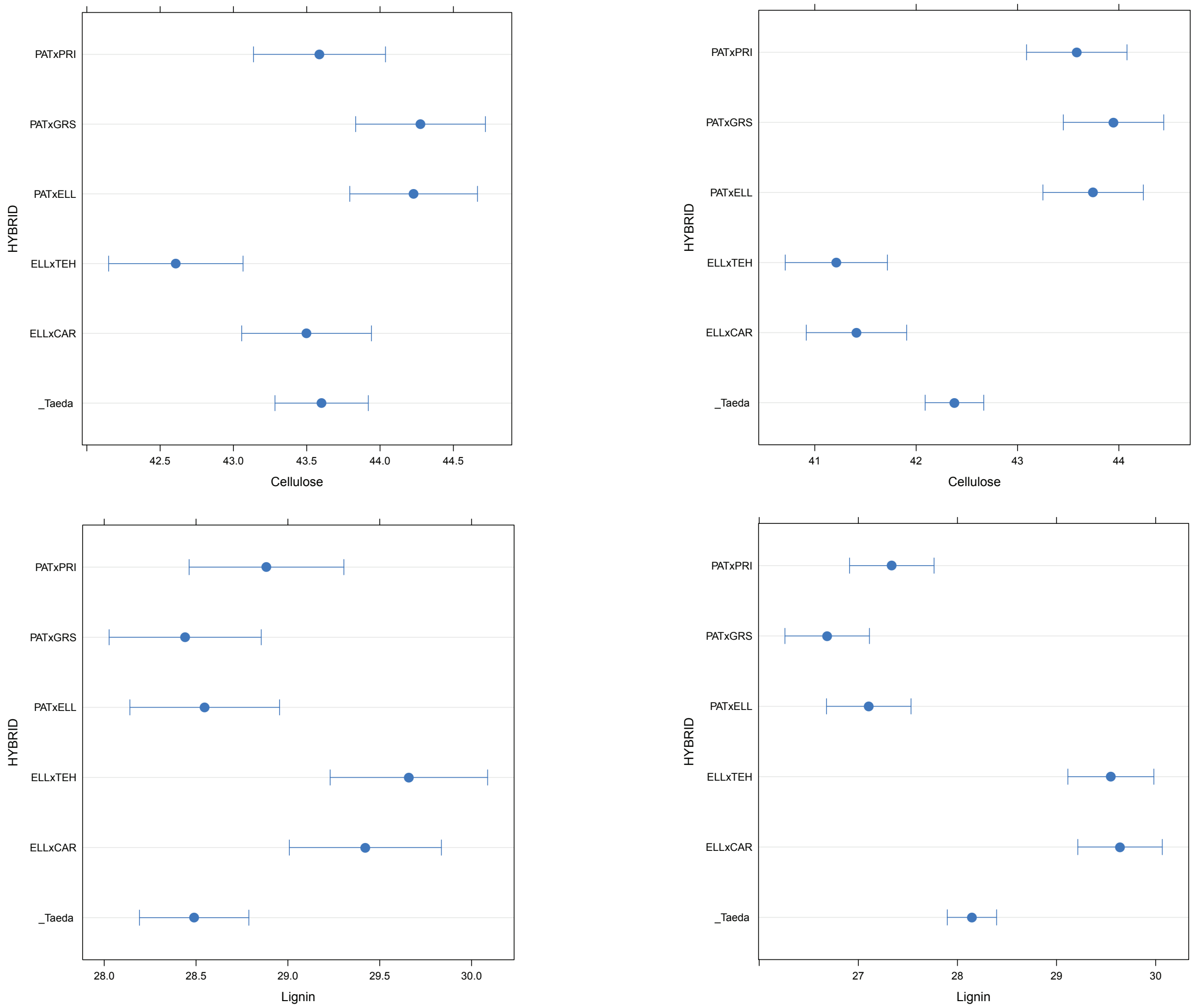
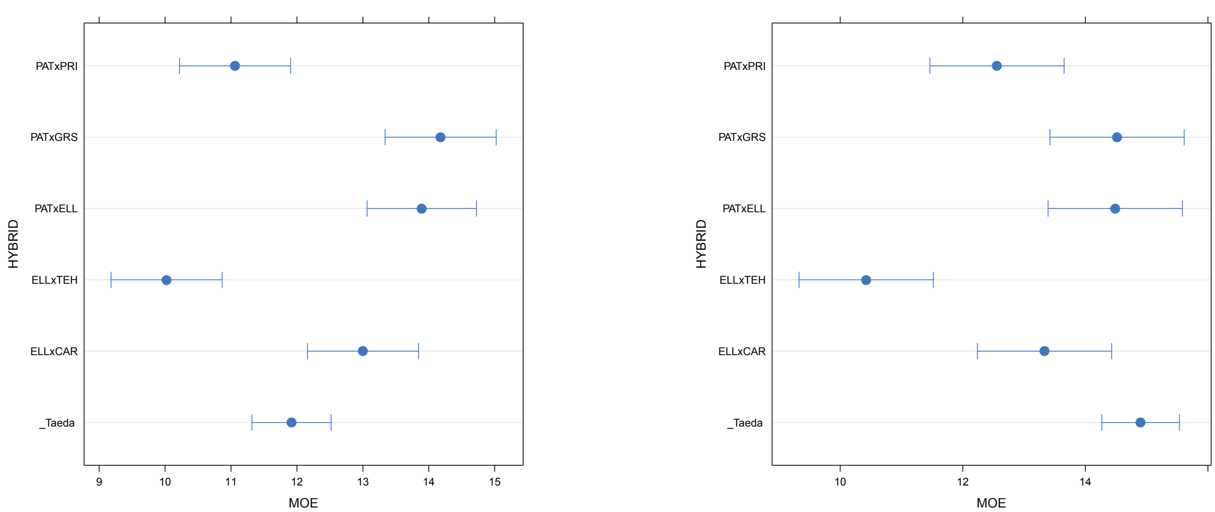


Figure 7. LSMEANS Confidence Intervals for MOE in Brazil (Klabin left, WestRock right).



Resistograph Profiles – Converting to Density

We have used the IML Resistograph extensively over the past 15 years in various Camcore research projects. The Resistograph is a machine that pushes a thin needle-like drill through a standing tree and records the resistance encountered by the needle as it passes through the wood. Camcore members have found this tool to be very useful, but would like to be able to convert Resistograph resistance readings into absolute density values.

We are very confident that resistance and density are correlated. For example Gantz (2000) studied the use of the Resistograph in four species: *Pinus radiata* and *Eucalyptus globulus* in Chile, and *P. caribaea* and *E. urophylla* in Venezuela. He compared bark-to-bark resistance readings with X-ray density measurements of increment core samples. In general, the phenotypic correlation for mean profile resistance and mean core density was moderate, ranging from r = 0.42 to 0.76. Mean resistance was highly heritable in all four species, with single-site heritability (h^2_b) ranging from h^2_b = 0.30 to 0.57, and genetic correlations near unity for three of the four species (though estimated with a relatively small data set). Other studies have examined the correlation of pith-to-bark resistance and density, and found very strong relationships, on the order of r ≈ 0.90 in spruce (*Picea abies*, Rinn et al. 1996, Holzforschung 50: 303-311), and r ≈ 0.80 in eucalypts (*E. urograndis*, Lime at al. 2007, Scientia Forestalis 75:85-93).

In 2015, Camcore began a long-term project to study the wood properties of pine hybrids. In this study, we wanted to use the Resistograph to characterize the density of the different hybrids Typically, 6 to 9 hybrids per site have been sampled, and Resistograph readings were taken on 25 to 30 trees per hybrid per site. On each site a small number of trees were also sampled with increment cores, and gravimetric density was measured. We hoped to develop a general calibration to convert resistance to density, and we thought that this equation might vary depending on site factors such as climate, elevation, time of year, average moisture content of the trees, etc. But we also thought that, on a particular site or in a particular region, the linear relationship between resistance and density would be the same for all pine species. However, with our most recent data set, we compared resistance and density measurements for *P. taeda* controls and all subtropical pine hybrids in a set of four studies in Argentina and Brazil (Figure 8). There seems to be a difference in slope for the *P. taeda* and the hybrids, and the data suggests that a given resistance might correspond to a higher density for a subtropical hybrid sample than for a *P. taeda* sample.

It is important to note that this should still be considered a preliminary result – the data are "noisy", with different sites, different sets of species and hybrids on each site, etc. But at this point, we are working under the following assumptions:

1. There is a very strong linear relationship between resistance and density for all pine species and hybrids.
2. The slope of the relationship between resistance and density may differ among species.

This means that the Resistograph can be used in a breeding program to compare families and clones of the same species or hybrid type, and it will work very well to rank genotypes, estimate genetic parameters, etc. But for comparisons among species, we may have to rely more on traditional kinds of density measurements, e.g., increment cores or discs, and gravimetric or X-ray densitometry. For our future work in the Camcore pine hybrid studies, it means we will be buying some new increment borers and taking many more increment core samples. At least it is good exercise!

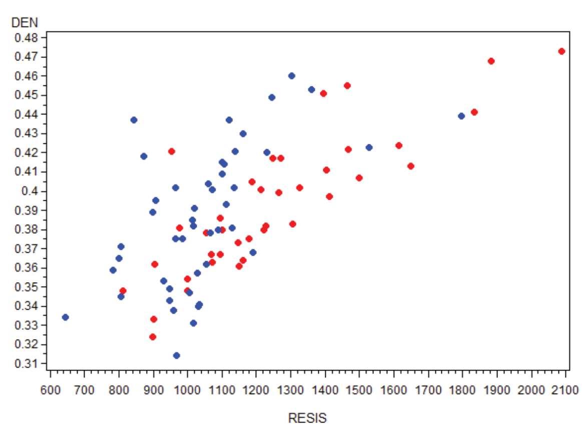


Figure 8. Scatter plot of mean resistance and core density for *P. taeda* (T, blue circles) and sub-tropical pine hybrids (X, red circles) across four sites in Brazil and Argentina.

Sterile Transfer of Genetic Material

Background

Camcore is in the business of tree improvement. We work in many countries, with many species and hybrids. In order for our members to reap the maximum benefit from our work together, we must be able to exchange genetic material across international borders, and this genetic material could take the form of seed, pollen, or even vegetative material from tested pine or eucalypt clones. As just one example, with our new *P. tecunumanii* x *P. greggii* project, we are doing full-sib breeding, crossing *P. greggii* from Brazil with *P. tecunumanii* selections in Colombia. In 8 to 10 years, we will have identified the very best full-sib families, and our members from Brazil will want to import the top *P. tecunumanii* parents for their own orchards, and the Colombian members will want to import the top *P. greggii* parents for their own orchards. And our members in Argentina, Uruguay, and Chile will want the parents of both species!

Over the past 15 years, transfer of genetic material has become more and more difficult as plant import requirements become more burdensome. Several countries where Camcore works have recently amended their regulations and procedures for importing and exporting plant material. These countries are creating an integrated system that involves biodiversity protection agencies, quarantine-plant protection agencies, and customs agencies, making the process of sharing genetic plant material very challenging for both senders and recipients.

Sterile propagation using plant tissue (scions, meristems, shoots, etc.) cultured on a specific medium in strict aseptic conditions could be a reliable and less problematic method to transport plant material internationally. Sterile material has a higher level of acceptance among phytosanitary agencies worldwide because it is handled in controlled, aseptic environments. For this reason, sterile propagation is considered to be a phytosanitary-friendly way to transport and share plant genetic resources.

As a result of these developments, Camcore has plans to investigate various methods to produce propagules and plantlets of adult pine and eucalypt genotypes in a sterile environment. The objective is to develop propagation and shipping protocols that would comply with phytosanitary regulations and allow our members to efficiently share material. For our first effort in this direction, we have begun testing laboratory methods to be able to produce sterile pine scion and rooted cuttings *in vitro* using tissue culture techniques.

Pine Scion Sterilization and Grafting

A preliminary experiment was conducted in the summer of 2016. Twelve actively growing *Pinus taeda* scions were collected from an 8-year-old plantation at the Schenck Forest at NC State University. Scions are usually collected in dormant periods so these non-dormant samples were subjected to atypical handling conditions to test their resilience. After being collected, the scions were wrapped in damp paper towels, placed in plastic bags, and stored in a cooler at 5ºC for transport. The scion were then kept in a cold room at approximately 7ºC for 24 days to simulate the shipping process.

Potted rootstock of loblolly pine from Camcore's greenhouses was used for the grafting. They were approximately 2 years old and 4 feet tall. All trees were grafted in a laboratory 24 days after scion collection. To prepare for grafting, the

Table 20. Chemical treatments used to sterilze *P. taeda* scion prior to grafting.

Treatment	Chemical	Concentration (%)	Time (min)	Survival %
1	Liquinox	1	10	50
	C_2H_6O	95	1	
	NaClO	6	10	
2	Liquinox	1	10	50
	C_2H_6O	95	1	
	H2O2	7	15	

Scion of *P. taeda* being washed and sterilized.

scions were stripped to remove all of the needles from the stem. Prior to grafting, the scions were treated using one of two different treatments (Table 20). The scions were submerged in three chemicals, one at a time, inside a round Pyrex bottle placed on a shaker. After each submersion, scions were rinsed three times with distilled water.

After grafting, the entire union was wrapped with a grafting rubber so that only the terminal bud was exposed. Standard household canning paraffin was melted, kept at 80° C to 90° C, and applied with a paintbrush to completely cover the scion bud and grafting rubber. The material was then placed on a greenhouse bench where day/night temperatures were approximately 31ºC / 22ºC. The pots were watered as needed 3 to 4 times per week. The number of surviving grafts was determined 4 weeks after grafting; it was 50% for both chemical treatments. Success rates for loblolly grafting in the South are normally above 80% when using standard methods with dormant scion during the normal grafting season. Considering that the scions used for this study were harvested in a non-dormant state, stored for 24 days inside a cold room and subject to a fairly harsh chemical treatment to clean them, we are encouraged by the 50% survival in this experiment. It seems likely that we will be able to improve this rate in the future, as we optimize the collection, sterilization, and grafting procedures.

A followup study of sterile transfer techniques will be performed in Colombia or Guatemala in 2017. We will evaluate different chemical treatments to sterilize scions of *P. tecunumanii* and *P. maximinoi*. The sterilization process will be performed using laboratory protocols to ensure asepsis of the scion. Once sterile, the material will be placed inside shipping coolers for several days, resembling the time the material would spend during shipment. After this, the scions will be grafted onto rootstock of the same species.

Outlook

As mentioned above, this work is just the first effort in what will likely be a long-term project, and we anticipate a number of years in research and protocol development. In the midterm, we will investigate methodology to produce sterile rooted cuttings of pine, eucalypts and teak, and we currently have hedges of all three genera growing in the greenhouse. But it is very important to remember that the success of this project will depend not only on our science and technology, but also on our relationships with national phytosanitary institutions. It is important that the forest industry in every country work hard with personnel in these organizations so that they understand the importance of genetic material transfer, and help us by putting in place import requirements that allow this to be done in a safe and efficient manner.

Hedges of *P. tecunumanii*, *E. urophylla* and *E. benthamii*, and *Tectona grandis* in the NC State greenhouse. The hedges will be used to try to produce rooted cuttings under sterile conditions.

NIR Models for Ca and P content in *Eucalyptus* Wood

Camcore has done much work over the past few years developing NIR models to predict wood chemistry traits for wood of *Eucalyptus*. Specifically, we have good global models to predict lignin, S:G ratio, glucose, xylose, and other minor sugars. These models are "global" in the sense that they are based on multiple species (*E. urophylla*, *E. dunnii*, *E. globulus*, and *E. nitens*), and we believe that they will be useful to extrapolate to a wide range of other eucalypt species, for example, to rank selection candidates for wood chemistry traits.

We will continue to expand our eucalypt wood property work in the future. One project that is on-going is Juan Pedro Posse's PhD research on the genetic control of wood properties of *E. dunnii*. This species is a very important commercial species for cool temperate regions around the world, including in South Africa, Brazil and Uruguay. *Eucalyptus dunnii* offers a number of advantages: fast growth, high density, and moderate cold tolerance, and is a major component of the species portfolio of the two Camcore members in Uruguay, Weyerhaeuser and Montes del Plata. Juan Pedro's research involved more than 1642 samples of *E. dunnii* and some *E. grandis* and *E. grandis* x *E. camaldulensis* controls, and the idea was to use the Camcore global NIR models to predict wood chemistry for genetic parameter analysis.

There have been reports in the literature that *E. dunnii* wood accumulates a higher concentration of nutrients (e.g., N, P, K, Ca, and Mg) than other eucalypt species. In particular, high levels of calcium (Ca) would be a problem for pulp producers. Calcium, phosphorus and magnesium are considered "Non-Process Elements" in the pulp mill, and can have various negative effects in kraft mill operations, including increased lime kiln fuel use, reduced filtration efficiency, reduced lime mud settling, increased scaling of heat exchangers, fouling and corrosion in the recovery boiler, and increased use of bleaching chemicals. Calcium is highly alkali insoluble, so it can cause scaling problems in digester screens and heating surfaces, evaporator heating surfaces and bleaching wash equipment. Reducing Ca content of *E. dunnii* wood might be a breeding objective for some *E. dunnii* programs.

Juan Pedro's wood samples offered an opportunity to investigate if we could develop useful NIR models to predict Ca content of *E. dunnii*, and if this trait were under genetic control. We also took the opportunity to look at P content, with the same objectives.

Materials and Methods

Woodmeal samples from a total of 122 *E. dunnii* trees representing 62 families and 12 provenances were selected. The samples were stratified across a range of glucose, xylose and lignin content and S:G ratios in order to ensure that the calibration data set covered the range of variation in these other important traits. In addition, control tree samples were included from 6 *E. grandis* and 3 *E. grandis* x *E. camaldulensis* clones (GC). For convenience, these 9 samples will be referred to as "*E. grandis* controls".

Chemical analysis was conducted by the Soil Testing Lab, NC Dept of Agriculture and Consumer Services. Both calcium (Ca) content and phosphorus (P) content were assessed. Data are expressed in mg/kg (equivalent to ppm).

NIR scanning was done with a Foss 6500, and reflectance was measured across wavelengths from 1100 to 2500 nm. Our R-NIR pipeline was used to transform spectral data using SNV + Savitzky-Golay 2nd derivative (7 points), and outlying spectra were deleted. PLS modeling was done with SAS® Proc PLS, with cross-validation done using a "leave-one-out" methodology.

Results and Discussion

As expected, the lab samples of *E. dunnii* had higher Ca and P content than did the *E. grandis* controls. The 122 *E. dunnii* samples had a mean Ca content of 2045 ± 94 mg/kg, compared to 1489 ± 189 mg/kg for the 9 controls. For phosphorus, the *E. dunnii* had a mean P content of 219.7 ± 19.9 mg/kg compared to 167.4 ± 51.7 mg/kg for the *E. grandis* controls. The standard errors on the controls are largely due to the difference in sample size (122 *E. dunnii*, 9 controls). However, it seems clear that on average, *E. dunnii* accumulates around 1/3 more of these "non-process elements" than do *E. grandis* and *E. grandis* hybrids. Specifically,

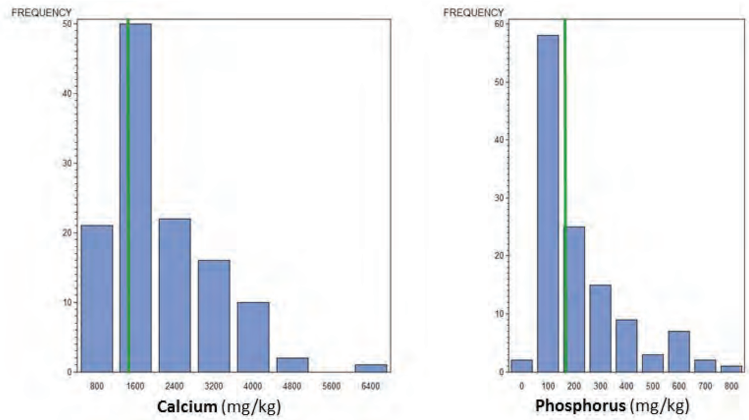


Figure 9. Distribution of calcium and phosphorus content in 122 wood samples of *Eucalyptus dunnii*. The green line indicates mean Ca and P content of 9 samples from control lots of *E. grandis* and *E. grandis* hybrids.

the *E. dunnii* had 37% more Ca and 31% more P than the *E. grandis* controls. The distribution of Ca and P content of these 122 *E. dunnii* samples shows that a large proportion of the population has values similar to *E. grandis*, but there is a substantial tail of the distribution with very high Ca and P contents (Figure 9).

Results for NIR models are presented in Figure 10. Briefly, the NIR model for Ca was excellent, but the NIR model for P has, at best, moderate utility. For Ca, model R^2 was 0.96 with the standard error of cross validation (SECV) of ± 195 mg/kg, approximately 10% of the trait mean. For P, model R^2 was 0.45, with a SECV = ±126 mg/kg, approximately 58% of the trait mean. Ca content of these samples was much higher than P content, by a factor of 10. It seems possible that the P measurements from the lab might be less precise than those for Ca, and less precise lab values will have a negative impact on NIR model fit.

Summary and Outlook

These initial results suggest that there is substantial phenotypic variation in Ca and P content among *E. dunnii* wood samples. An excellent NIR model for Ca content could be used to select against high Ca content. The next step is to use this model to further investigate phenotypic variation and genetic control in the entire population of 1642 samples (62 families and 12 provenances) of *E. dunnii*. It may be possible to improve the P model, and also to develop models for other non-process elements, such as magnesium, if these are of concern for some mill processes.

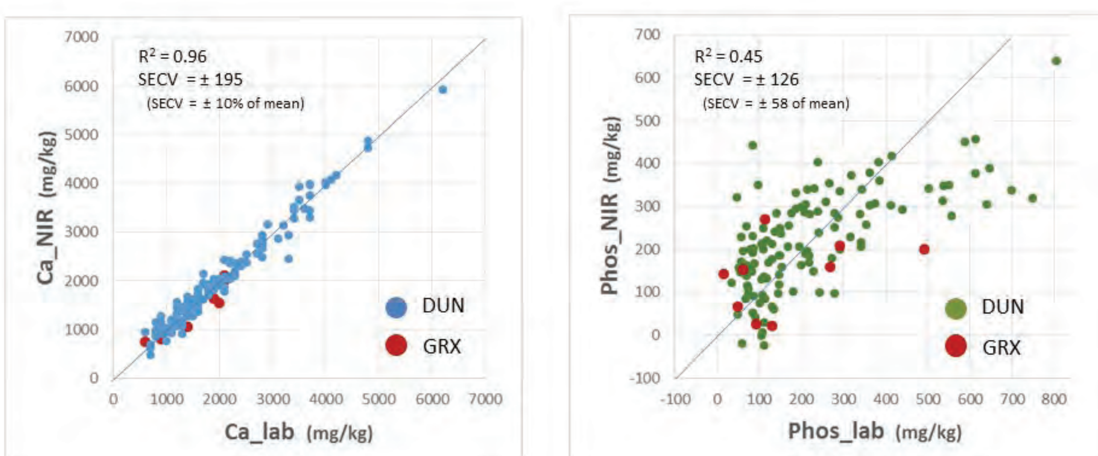


Figure 10. NIR calibration models for calcium and phosphorus content in 122 wood samples of *Eucalyptus dunnii* (DUN) and 9 samples from control lots of *E. grandis* and *E. grandis hybrids* (GRX, red dots).

Pedigree Reconstruction with Molecular Markers

The rapid development of molecular genetics tools over the last 10 to 15 years has opened up a number of possibilities to use this technology in breeding programs. Most prominent is the opportunity to incorporate genomic selection in a breeding program in order to reduce the number and/or size of progeny tests. This technology is already widely used in animal breeding programs, and is an area of intense research in the tree breeding community. Camcore is actively collaborating with other forest genetics programs to work toward developing this capacity for some of our most important pine species (see article "Pine SNP Chip Development" in this Annual Report). Another possible application of molecular markers is in the area of pedigree reconstruction, which may permit breeders to recover useful genetic information from commercial forest plantations.

In 2014, we worked with Milan Lstiburek of the Czech Agricultural University to investigate the efficacy of recovering genetic information (essentially progeny test information) from commercial forest plantations. The results of that simulation study were presented in the 2014 Annual Report, and published in the journal *Tree Genetics and Genomes* (Lstiburek et al. 2015), and full details of the approach can be read there. Briefly, the idea is to measure and genotype a moderately -sized random population in a plantation. Molecular markers would be used to create a pedigree matrix of relationships among all the trees, and with this pedigree plus phenotypic information, we effectively have a “progeny test” (on a single site or on multiple sites). The breeder would also screen a very large candidate population to find a small set of extremely good phenotypes. These highly selected phenotypes would also be genotyped with the molecular markers, to determine if they came from good families in the “progeny test”. In summary, the process would identify good progeny from good families, and simulation results indicate that the approach can make very good genetic gains. The approach would be particularly useful in the initiation of a tree improvement program for a new species starting from commercial or pilot plantations.

The success of this “breeding without breeding” approach depends on the accuracy of pedigree reconstruction. The simulation study assumed 100% accuracy in reconstructing the pedigree matrix. The objective of the current study was to examine the accuracy of pedigree reconstruction for a realistic case study with a population of *P. taeda*.

Materials and Methods

The study was conducted using full-sib families of *P. taeda* which were part of the breeding programs of Arauco Argentina and Bosques del Plata, Argentina. Most of these full-sib families were derived from Florida-source *P. taeda*, with some lower coastal plain Louisiana. There were a total of 38 parents, 36 full-sib families, and 341 progeny that were sampled. Foliage was collected and sent to the Forest Molecular Genetics Programme at the University of Pretoria (South Africa), where DNA was extracted and analyzed using micro-satellite (SSR) markers. There were 29 SSR loci studied. Pedigree reconstruction was done using the program CoAncestry (Wang 2011), which calculates a coefficient of relationship for all pairs of parents and progeny.

Results and Discussion

SSR marker information

The SSR marker data was generally of very good quality, although some loci returned better data than others. On average, there was 7.9% missing values (no genotype data at a particular locus for a given tree), but this ranged from near zero to 55.1%. The median value was 3.2% missing values, so the mean was heavily influenced by a few loci that gave lower quality results. The number of alleles per locus ranged from 2 to 15, with mean = 8.3 alleles and median = 7 alleles. Expected heterozygosity (H_e) for the 29 loci ranged from H_e = 0.08 to 0.89, with mean H_e = 0.65 and median H_e = 0.675.

Coancestry Estimation

There were 38 parents and 303 progeny included in the pedigree reconstruction analysis. There were a total of 57,970 pairs of individuals, for which we know the true genetic relationship, and the expected coefficient of relationship (E(r)) (Table 21). Figure 11 presents the distribution of estimated coefficient of relationship ($\hat{r}$) as calculated by the CoAncestry program for parent-offspring (PO) and parent-unrelated offspring pairs (PU). As expected, for the 563 parent-offspring pairs, the distribution of $\hat{r}$ values centers on 0.50. Unless there were crossing or identification errors, every true PO pair would have an E(r) of 0.50. Some variation of the calculated $\dot{r}$ would be expected, as the program must deal with estimated allele frequencies, missing values, etc. There was a moderately small proportion of PO pairs with low values of $\hat{r} < 0.25$; these might be crossing or identification errors, or may simply be poor estimates of the true r. Perhaps these would be closer to $\hat{r} = 0.50$ with a bigger marker dataset.

Figure 12 presents the distribution of $\hat{r}$ as calculated by the CoAncestry program for all unrelated (UN), half-sib (HS) and full-sib (FS) progeny pairs. The three distributions all center on the correct E(r) for their relationship type. The HS and FS distributions are relatively

Table 21. Relationship, expected coefficient of relationship, and number of pairs for the *P. taeda* pedigree reconstruction study.

Relationship	Code	E(r)	# pairs
Parent-offpsring	PO	0.50	563
Parent-unrelated offspring	PU	0	11,654
Full-sib	FS	0.50	1350
Half-sib	HS	0.25	2791
Unrelated	UN	0	41,612

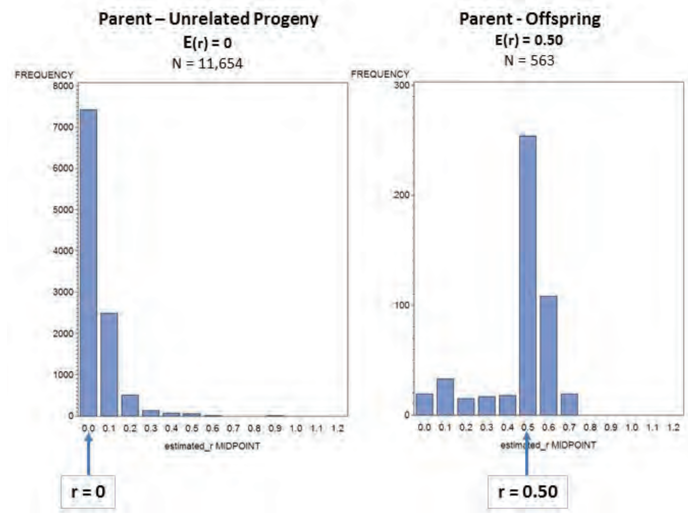


Figure 11. Distribution of estimated coefficient of relationship is calculated from SSR markers using the CoAncestry program for parent-offspring and parent-unrelated offspring. Blue arrow indicates the expected coefficient for relationship for that class.

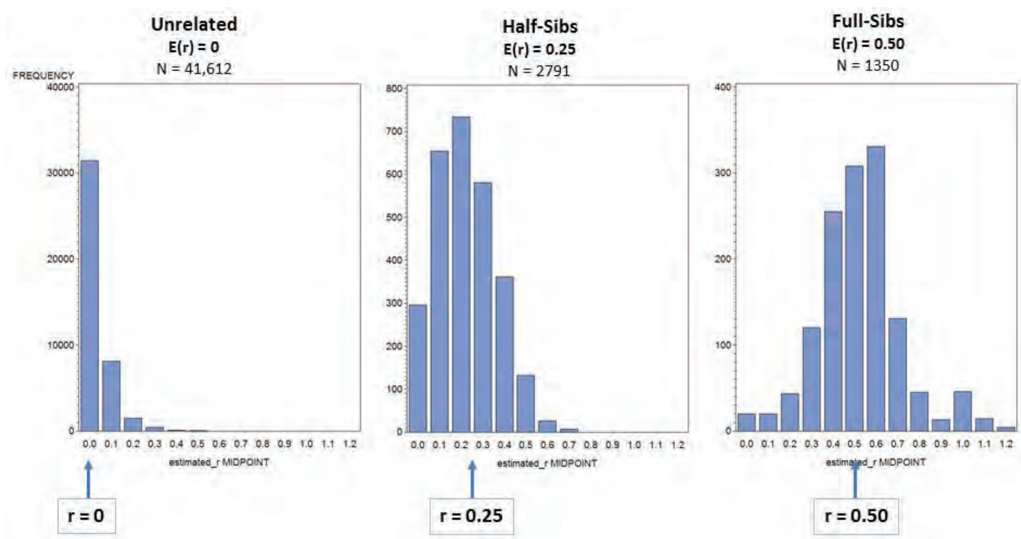


Figure 12. Distribution of estimated coefficient of relationship as calculated from SSR markers using the CoAncestry program for all UN, HS and FS progeny pairs. Blue arrow indicates the expected coefficient for relationship for that class.

Figure 13. Comparison of known pedigree relationship and estimated pedigree relationship for 43,753 progeny pairs of *P. taeda*. Classification was based on estimated coancestry calculated with SSR markers from 29 loci[1].

29 Loci		Classified by Markers			
		FS	HS	UN	Total
Pedigree Relationship	FS	1147 *85%*	178 *13%*	25 *1.9%*	1350
	HS	524 *19%*	1805 *65%*	462 *17%*	2791
	UN	165 *0.4%*	5735 *14%*	35712 *86%*	41612
	Total	1836	7718	36199	45753

[1]Progeny pairs with $\hat{r} \leq 0.08$ were classified as unrelated (UN); pairs with $0.08 < \hat{r} \leq 0.35$ were classified as half-sib (HS); and pairs with $\hat{r} > 0.35$ were classified as full-sib (FS).

wide, which is to be expected due to Mendelian sampling. This effect can be seen clearly by comparing the Parent-Offspring plot in Figure 11, with the Full-Sib (FS) plot in Figure 12 Both distributions are centered on E(r) = 0.50, but the PO distribution is narrow and the FS distribution is wide. This is because every offspring received exactly ½ of its alleles from the parent (regardless of which alleles it received). However, any given FS progeny pair may have many alleles in common (e.g., a high r), or few alleles in common (a low r), simply by random allelic sampling during meiosis. But across a large population of FS progeny, the average r will be very near 0.50.

Pedigree Reconstruction

In a real-world application of pedigree reconstruction for recovery of genetic information, it is unlikely that parental genotype data would be available. Rather, the breeder would be estimating a pedigree matrix only for the progeny in the plantations. In this case, the estimated coancestry values $\hat{r}$ for all progeny pairs could be used directly in a REML-BLUP pedigree matrix. This might be appropriate if $\hat{r}$ were estimated with several thousand SNP markers distributed evenly throughout the genome. Alternatively, a breeder might wish to use the $\hat{r}$ to classify a progeny pair as unrelated or half-sib or full-sib, and then use the appropriate E(r) for that class in the REML-BLUP pedigree. This might be preferable if $\hat{r}$ is estimated with a relatively small number of loci, while the trait of interest is likely to be controlled by many hundreds of genes located throughout the genome.

For the 43,753 progeny pairs in this study, each pair was classified as unrelated (UN), half-sib (HS), or full-sib (FS), based on the $\hat{r}$ calculated from the SSR markers: pairs with $\hat{r} \leq 0.08$ were classified as UN; pairs with $0.08 < \hat{r} \leq 0.35$ were classified as HS; and pairs with $\hat{r} > 0.35$ were classified as FS. Figure 13 shows the comparison of the known classification and the marker-based classification using all 29 loci to estimate $\hat{r}$. For the known FS pairs, 85% were classified as FS by the markers, with 13% classified as HS, and 1.9% classified as UN. For known UN pairs, 86% were classified as UN by the markers, with 14% classified as HS, and 0.4% classified as FS. For known HS pairs, 65% were classified as HS, with roughly equal percentages classified by the markers as FS (19%) or UN (17%).

Summary and Outlook

These data are still undergoing some analysis, and final results will be published in a refereed journal. However, the preliminary results presented are very encouraging, and indicate that pedigree reconstruction with molecular markers is fairly accurate. This suggests that a real world application of the "breeding-without-breeding" approach to recover genetic information in plantations would be successful. Since we have parental data for this study, the marker data will be examined further to see if crossing or identification errors can be identified, and the results improved. Future work may also focus on modified simulation studies incorporating the kind of variability and errors seen in this study to examine the impacts on potential genetic gains.

Acknowledgements

Many thanks to both Arauco Argentina and Bosques del Plata for their generous contribution of the genetic material, and the work in collecting samples. Thanks also to Zander Myburg and Melissa Reynolds and the rest of the staff at FMG, University of Pretoria for their work on the SSR markers.

Camcore Seed Collections 2016

Ex situ conservation of genetic resources continues to be one of the main objectives of Camcore. Dwindling populations of different pine species in several countries of Central America make the conservation of this genetic material urgent. Many types of degradation and destruction have been persistent causes of forest shrinking and fragmentation on these sites, including frequent forest fires, periodic attacks by *Dendroctonus* bark beetles, illegal logging, competition with agricultural crops, resin extraction, and others. Camcore has agreements with government organizations to allow us to make seed collections every year. The purpose is to maintain our seed supply so that we can establish genetic trials and conservation banks. Seeds from these plantings can be used to reintroduce genetic material and reestablish the original forests that have recently disappeared or have been severely degraded. Seeds collected from the natural forests are also used by Camcore members that are starting tree breeding programs to establish genetic trials and to expand the genetic base of the species.

In 2016, Elmer Gutiérrez and Josué Cotzojay, Camcore field coordinator and tree climber in Guatemala, respectively, made collections of seeds in selected trees of *Pinus caribaea*, *P. maximinoi*, and *P. tecunumanii* in one population in Guatemala and six populations in Honduras (Table 22).

Different criteria are used for planning these seed collections: the current seed inventory in the Camcore cold room in Raleigh, conservation status of the population and the species, performance of the provenances in established genetic trials, accessibility, and seed availability. Elmer and Josué contact government representatives in advance to let them know their collection plans. They also ask permission from the stand owners, and work with local people to help them find the best trees.

Camcore climber Josué Cotzojay collecting cones from a *Pinus tecunumanii* tree in Culmí, Honduras.

So far, Camcore, together with INAB in Guatemala, Colegio de Postgraduados and Universidad Autonoma Agrícola Antonio Narro in Mexico, has been able to establish eight 2nd generation reintroduction trials with seeds collected in Colombia and South Africa from trees that were established from seeds collected more than 20 years ago. Four trials have been planted with *P. maximinoi* and one with *P. tecunumanii* in Guatemala, while two have been planted with *P. patula* and one with *P. greggii* in Mexico.

Table 22. Summary of seed collections completed in Central America in 2016.

Country	Species	Provenance	Conservation Status	Latitude	Longitude	Trees
Guatemala	*P. tecunumanii*	La Soledad	Endangered	14^o 50’	90^o 13’	12
Honduras	*P. tecunumanii*	Campamento	Vulnerable	14^o 29’	86^o 42’	18
Honduras	*P. tecunumanii*	Culmí	Vulnerable	15^o 10’	85^o 32’	18
Honduras	*P. tecunumanii*	Los Planes	Vulnerable	14^o 46’	87^o 50’	20
Honduras	*P. maximinoi*	Tatumbla	Vulnerable	13^o 58’	87^o 05’	20
Honduras	*P. maximinoi*	Yuscarán	Vulnerable	13^o 54’	86^o 52’	20
Honduras	*P. caribaea*	Marañón	Vulnerable	15^o 22’	88^o 05’	20

Seed Acquistion: Bulk Pine Seedlots

In 2016, Camcore purchased a number of pine bulk seedlots of *Pinus taeda*, *P. elliottii* and *P. elliottii* x *P. caribaea* hybrid for distribution to members. These seedlots are described briefly here.

***P. taeda*, improved, Argentina**

This seed was purchased from INTA, the national research institution of Argentina. There are two seed orchard bulks of *P. taeda*, one composed primarily of Marion Co., Florida selections, and one composed of Livingston Parish, Louisiana selections. There are many reports from the USA and from the southern hemisphere that these sources show very fast growth. Both orchards are 1.5 generation clonal seed orchards. In other words, the clones in these orchards are all 1st generation parents, but they are the top parents from a large population of progeny-tested 1st generation parents. After field progeny testing on 7 sites, the best parents were regrafted in improved 1st generation orchards, often called 1.5 generation orchards.

***P. taeda*, improved, Florida Division of Forestry**

This seed was purchased from the Florida Division of Forestry, a bulk collection of seed from the 2nd generation seed orchard, selected for fast growth and resistance to fusiform rust, caused by *Cronartium fusiforme*, a native pathogen in the southeast US.

***P. elliottii*, improved, Florida Division of Forestry**

There are two bulk seedlots of *P. elliottii* collected from 2nd generation orchards. One orchard was selected for fast growth, and one was selected for resistance to pitch canker (caused by *Fusarium circinatum*).

***P. elliottii x P. caribaea* var. *hondurensis*, F2 seed, Australia**

P. elliottii x *P. caribaea* is a well-known hybrid that shows excellent growth in tropical and subtropical regions. This seed was purchased from HQ Plantations in Australia. The 2011 Annual Meeting was held in Australia, so many Camcore members had the opportunity to see this material when we visited what was then Forestry Plantations Queensland. This is bulk seed collected from a seed orchard of F1 *P. elliottii* x *P. caribaea* parents, so is open-pollinated F2 seed. The Australian breeders have good evidence that the F2 seedlots perform very similarly to F1 seed produced by control crossing.

The idea of these seed acquisitions is to plant species trials and/or pilot plantations with the material, as an inexpensive way to expand genetic diversity and maintain genetic resources of species with some commercial potential. Species tests can be established to compare new varieties to the local commercial options. If some of these species seedlots perform well, the member can then purchase commercial seedlots for large-scale operational plantations from the vendors. For members who already have an interest in a species, pilot plantations can be used to expand the genetic base, establishing these materials across a number of environments, which can later (if necessary) serve as a base for selection. Additionally, such pilot plantations would serve well as material for "breeding without breeding" (i.e, pedigree reconstruction and recovery of genetic information). Regarding these seedlots in particular, all of them can be of use to Camcore members.

Regarding *P. taeda*, a number of Camcore members have internal plantation and breeding programs, but most of these are based primarily on Atlantic Coastal Plain selections from North Carolina, South Carolina and Georgia. The *P. taeda* seedlots represent sources from Florida and Louisiana in the southern-most part of the *P. taeda* natural range.

Some Camcore members still use *P. elliottii* as a commercial species, particularly in South Africa. The species is generally not as fast growing as other options, but it is a very robust species which shows excellent survival across many environments. In addition, many Camcore members have interest in *P. elliottii* as a hybrid partner, so the high-growth or *Fusarium*-resistant sources may be of value.

Finally, a number of Camcore members have active *P. elliottii* x *P. caribaea* hybrid programs. Other members know that the hybrid is a good commercial option, but they do not have their own seed orchards or breeding orchards to produce commercial seed. In the short- to mid-term time frame, this F2 seed might be a very good option to produce commercial *P. elliottii* x *P. caribaea*.

Domestic Species Conservation in the USA

Since 2003, Camcore has been collaborating with the USDA Forest Service to conserve the genetic resources of threatened and endangered tree species native to the United States. Originally known as the "hemlock project" and focused on two species, the program has grown to include seed collections and research projects on 10 species and is now referred to as the Camcore Domestic Conservation Program. Our work here is primarily focused in the eastern half of the country, includes species threatened by invasive insects, shifting management objectives, land use change, and climate change, and has all been accomplished with more than $1 millon in grant funding from the USDA Forest Service.

We had a productive seed collection year for the program in 2016. Overall, seed was collected from 154 mother trees representing 21 provenances and nine species (Table 23). Seeds were collected from 6 provenances and 38 mother trees of Carolina hemlock (*Tsuga caroliniana*), and 5 provenances and 18 mother trees of eastern hemlock (*T. canadensis*). Both species have suffered widespread decline and mortality due to the invasive insect pest hemlock woolly adelgid (*Adelges tsugae*). The genetic resources secured by Camcore represent more than 900 mother trees (Table 24) distributed from New England south to Georgia, and will play an important role in the eventual restoration of these tree species to their native habitats.

Andy Whittier (Camcore) collecting seed cones of Atlantic white cedar in the Appleton Bog population in Maine.

The domestic program established its first conservation seed orchard of Carolina hemlock in western North Carolina in 2008. For the past two years, this planting has been producing seed, and we have been able to collect and process seed from 83 trees over the past two years. This seed is currently undergoing viability testing, and we hope to use it to expand our conservation plantings of the species in the years to come.

In addition to our ongoing work with the hemlocks, we continued our seed collection efforts for a number of other species in 2016. Seeds representing seven Table Mountain pine (*Pinus pungens*) mother trees were collected from the Wisemans View population in western North Carolina. We were able to complete our seed collections of Atlantic white cedar (*Chamaecyparis thyoides*) in the northern-most seed zone of the species in New England with a five-provenance and 50-mother-tree collection in Maine, New Hampshire, Massachusetts, and Connecticut. Despite a rather poor seed year across the southern Appalachian mountains, we were also able to add to our genetic resources for Fraser fir (*Abies fraseri*) and red spruce (*Picea rubens*), adding a single mother tree from one population of Fraser fir and 10 mother trees from two populations of red spruce. Altogether, our work with these four species has provided genetic material from more than 700 mother trees (Table 24) to the USDA Forest Service to use in various reforestation efforts.

Our newest domestic seed conservation project at Camcore is focused on ash (*Fraxinus*) species that are threatened by a highly invasive and destructive beetle called the emerald ash borer (*Agrilus planipennis*). This was the first year of population explorations and seed collections for these species, and we are off to a solid start. So far we have been able to collect seed from three species representing 30 mother trees distributed across seven populations (Table 23). This was aided by collections of Carolina ash by our USDA Forest Service colleagues from the two bayou sites in Louisiana. Expanding our ash seed collections will be a primary focus of the Domestic Conservation Program in 2017.

In addition to our seed collection projects, we continued work on related research projects in 2016, specifically our eastern hemlock restoration field study and our conservation assessment of natural populations of Carolina hemlock (see boxes for updates on these two projects). We also had the opportunity to share our domestic conservation work at several regional, national, and international meetings. Robert Jetton was invited to give

Seeds of blue ash *(Fraxinus quadrangulata)* at Bledsoe Creek State Park, Tennessee. Dispersed by wind, each single-wing samara carries one seed.

Table 23. Summary of seed collections completed by the Camcore Domestic Conservation Program in 2016.

Country	Species	Provenance	Latitude	Longitude	Elev (m)	Trees (#)
USA	*T. carolinana*	Babel Tower	35.9250	-81.9126	1007	10
USA	*T. carolinana*	Bynum Bluff	35.9393	-81.9166	908	10
USA	*T. carolinana*	Caesars Head	35.1059	-82.6262	978	6
USA	*T. carolinana*	Camp Creek	35.9806	-81.9270	1048	1
USA	*T. carolinana*	DuPont Forest	35.1904	-82.6113	771	1
USA	*T. carolinana*	Wisemans View	35.9042	-81.9051	1048	10
USA	*T. canadensis*	Babel Tower	35.9272	-81.9120	950	1
USA	*T. canadensis*	Caesars Head	35.1056	-82.6270	974	1
USA	*T. canadensis*	DuPont Forest	35.1772	-82.6169	785	10
USA	*T. canadensis*	Jones Gap	35.1256	-82.5740	427	3
USA	*T. canadensis*	Wisemans View	35.9041	-81.9054	1052	3
USA	*P. pungens*	Wisemans View	35.9038	-81.9052	1053	7
USA	*C. thyoides*	Appleton Bog	44.3336	-69.2681	90	10
USA	*C. thyoides*	Bolton Lakes	41.8298	-72.4161	215	10
USA	*C. thyoides*	Loverens Mill	43.0732	-72.0250	348	10
USA	*C. thyoides*	Marconi	41.9110	-69.9794	7	10
USA	*C. thyoides*	Mashpee	41.5901	-70.4887	13	10
USA	*A. fraseri*	Black Mountain	35.7773	-82.2598	2012	1
USA	*P. rubens*	Black Mountain	35.8000	-82.2558	2004	3
USA	*P. rubens*	Whittier NC	35.3426	-83.3536	1270	7
USA	*F. americana*	Cedars of Lebanon	36.0849	-86.3234	191	2
USA	*F. americana*	Vesta Cedar Glade	36.0767	-86.3959	187	1
USA	*F. quadrangulata*	Cedars of Lebanon	36.0920	-86.3320	209	2
USA	*F. quadrangulata*	Couchville Cedar Glade	36.1039	-86.5331	165	8
USA	*F. quadrangulata*	Long Hunter	36.0765	-86.5210	152	2
USA	*F. quadrangulata*	Bledsoe Creek	36.3764	-86.3520	139	5
USA	*F. caroliniana*	Black Bayou	32.9918	-94.0268	57.6	5
USA	*F. caroliniana*	Saline Bayou	32.0839	-92.9030	38.4	5

oral presentations at the USDA Interagency Research Forum on Invasive Species, the North Carolina Hemlock Woolly Adelgid Symposium, the Southern Appalachian Forest Entomology and Pathology Seminar, the East Texas Forest Entomology Seminar, the USDA Forest Service Tree Gene Conservation meeting in Chicago, and the North American Forest Insect Work Conference. Andy Whittier provided a keynote address on the Atlantic White Cedar gene conservation project at the 2016 AWC Symposium in Plymouth, MA, and presented a poster on our hemlock restoration project at the Tree Gene Conservation meeting in Chicago. Overall our work continues to be well received, and Camcore's reputation as a leader in tree gene conservation in the United States is growing.

Table 24. Summary of seed collections completed by the Camcore Domestic Conservation Program for all domestic species 2003-2016.

Species	Year Initiated	Provs (#)	Mother Trees
T. caroliniana	2003	24	168
T. canadensis	2005	76	750
P. pungens	2010	41	269
C. thyoides	2012	35	255
A. fraseri	2014	11	130
P. rubens	2015	14	93
F. americana	2016	2	3
F. quadrangulata	2016	4	17
F. caroliniana	2016	2	10
F. texensis	2016	0	0
F. profunda	2016	0	0
F. pennsylvanica	2016	0	0

Carolina Hemlock Conservation Assessment

Carolina hemlock (*Tsuga caroliniana*) is a tree species native to the southern Appalachian mountains of the United States that is threatened by an invasive insect called the hemlock woolly adelgid (*Adelges tsugae*). Camcore has been collaborating with the USDA Forest Service (USFS) since 2003 to conserve the genetic resources of the species so that reforestation efforts can take place once effective adelgid management strategies are in place. Although we have been working on this project for a number of years now, the full extent of the Carolina hemlock distribution has never been mapped, and the full impact of the adelgid on isolated populations has never been documented. This information is critical to the successful conservation of the species. In 2015, Camcore received a 3-year grant from the USFS Evaluation Monitoring program to generate this important data. The objectives of the project are to delineate and census all populations of Carolina hemlock, quantify the levels of hemlock woolly adelgid infestation and related tree decline and mortality in each population, and establish long-term monitoring plots in a subset of representative stands to document the progression of hemlock woolly adelgid infestation, patterns of tree decline, and stand responses to the loss of Carolina hemlock. Camcore Research Forester Andy Whittier has taken on responsibility for the data capture and analysis for this project, and he has spent much of the last year in the woods collecting data. So far he has mapped nearly all of the 138 potential populations in our database, and he has found that population size ranges from as few as 2 living trees to more than 1500, and overall tree health ranges from poor (< 10% of trees surviving) to excellent (> 90% of trees surviving). There are no discernable trends in population health relative to geography, elevation, or latitude; and sites that had previously received imidacloprid treatments for hemlock woolly adelgid infestations are generally in better health than those receiving no treatment or releases of biological control agents. Within chemically treated sites, tree health declined with increased distance from trails and roads.

Dillon Dunn (Camcore), Bryan Mudder, Bud Mayfield (USDA Forest Service), and Andy Whittier (Camcore) in one of the hemlock restoration study plots.

Research on Silvicultural Options for Hemlock Restoration

Since 2014, Camcore has been collaborating with the USDA Forest Service (USFS) Southern Research Station on a field study to evaluate different silvicultural options for restoring eastern hemlock (*Tsuga canadensis*) to southern Appalachian cove forests. Eastern hemlock is a keystone tree species in these forest ecosystems, and it is dying in large numbers due to infestation of an exotic insect called the hemlock woolly adelgid (*A. tsugae*). Camcore has been collaborating with the USFS since 2005 to conserve the genetic resources of eastern hemlock at risk due to the adelgid. While the gene conservation effort continues and research on adelgid management strategies progresses, it was important to begin evaluating the best silvicultural strategy for reintroducing this tree species to ecosystems that have been fundamentally altered by its loss. This project, in collaboration with USFS Research Entomologist and Project Leader Albert E. (Bud) Mayfield, is considering the effects of canopy structure, deer exclusion, fertilization, and competition control on the establishment, survival, and early growth of planted eastern hemlock seedlings. Field operations for this study are being coordinated by Camcore Research Forester Andy Whittier. So far this project has produced a tremendous amount of data on tree growth and survival, competing vegetation, and wildlife activity all of which we are currently sorting through and preparing for analysis. A complete update will be prepared for the 2017 Camcore Annual Report, with submission of peer-reviewed manuscripts to follow.

Changes in Camcore

Adriana Marin, the planning and research manager in Smurfit Kappa Venezuela relocated to Colombia where she works at Smurfit Kappa Colombia in the forest research department. Adriana was replaced by **Gerardo Balza** who is now in charge of forest research and by Carlos Lucena in charge of planning.

André van der Hoef, who had been working for many years with MTO in the Cape, South Africa moved to northwest Africa and took a position as the research director for Miro Forestry Ghana and Sierra Leone. Miro Forestry has joined Camcore in 2017 with two memberships, one for each country where they operate.

Charles Bosworth, Co-founder and Director of Business Development in Miro Forestry Company in London, will be the member of the Camcore advisory board for the company.

Darren Lapp, head of forestry in Florestas de Niassa, Rift Valley, left FDN to work with another large group in Africa that owns a forestry project in Angola. Our best wishes for Darren in his new job.

Marynor Ortega was hired by Proteak to take over the research manager position from **Juan Ramón Aguilar.** Juan Ramón assumed new responsibilities as nursery manager for the company. We welcome Marynor and wish the best for Juan Ramón.

Eric Morales, who had been assisting the research manager in Proteak, left the company in March 2016. **Secundino Torres**, a new employee at Proteak, replaced Eric to help Marynor with tree genetic improvement activities.

Marcelo García left Green Resources Mozambique in February and was later replaced by **William Prado**. William had left the company in 2015 and came back as the forest manager in 2016.

Geoff Galloway retired from Sappi in December 2016 but will keep helping the research department part time. Congratulations to Geoff for his long commitment to the company and best wishes in his new activities. **Nonsikelelo Mhlongo** took over Geoff's duties as a new research officer for Sappi.

Lebo Mphahlele, previously working with SAFCOL, has now been employed by Sappi to take the position of Kgosi Mongwaketsi, who left the company. We wish Lebo a lot of success in her new challenges in research at Sappi.

Raesetje Kupa from SAFCOL, who finished her BSc in Forestry from Stellenbosch, replaced Lebo Mphahlele and will be supervised by Bonnita Meyer, who is now more involved in Camcore activities at the company.

Marius du Plessis, after working for several years in Mondi, left the company to work for Sinar Mas in Indonesia as the Research and Development Director, starting in June 2016. Sinar Mas will be an active member of Camcore in January 2017 and we will have Marius as a member of the Camcore advisory board.

Moacyr Fantini, Forest Manager at Montes del Plata, made the decision to leave the company in Uruguay in August 2016 and moved to work for another forestry company in Brazil. Our best wishes for Moacyr in his new endeavors.

Philip Cox is the new forestry research manager, for MTO, replacing **Cassie Carstens**. Cassie will serve full time as MTO's planning manager. Thanks to Cassie for being the contact with Camcore for several years and welcome to Philip in his new position.

Simon Bayo left Green Resources Tanzania and was replaced by **Isaac Mapunda** who has been working with the company for several years. Isaac will take care of the genetic improvement program with Camcore.

R Statistical Software Shortcourses

During 2016, Camcore offered several training sessions for our members in the R programming language. R is a free software environment for statistical computing and graphics. It compiles and runs on a wide variety of UNIX platforms, Windows and MacOS. In addition, R has a system of add-on packages that makes it extremely easy for users to increase functionality and share their developments with the R users' community. The training sessions were led by Juan José Acosta with the objective of teaching the basis of good programming using R. We tried to understand how R works and how to use it as a daily tool. Here is an overview of the course:

1. Introduction and preliminaries
2. R Objects: variables, vectors, matrices and arithmetic
3. Working with databases (data frames)
4. Logical operators, if statements and for loops
5. Graphical applications and basic functions
6. Loading packages
7. Getting help

To date, over 80 students from the following members have attended these Camcore courses:

- Colombia, September 2014 (SKC)
- NC, USA, February, 2015 (Camcore staff)
- Mexico, March 2016 (Proteak and Uumbal)
- South Africa, April 2016 (Mondi and Sappi)
- Uruguay, June 2016 (Montes del Plata, Weyerhaeuser, Bosques del Plata, Klabin)
- Arkansas, USA, June 2016 (Weyerhaeuser)
- South Africa, July 2016 (Mondi, Sappi, York, MTO, Merensky, KLF, ICFR, FMG, NCT)

North Carolina State University and Camcore offered a three-part workshop on R Basics, Quantitative Genetics, and Genomic Selection in South Africa. This symposium was offered to members of the South African tree improvement community, and was presented by Dr. Juan José Acosta and Dr. Fikret Isik. This workshop was hosted by ICFR, Sappi, and Mondi, and was also supported by the Forest Molecular Genetics Research Programme (FMG), University of Pretoria, and the Forestry Sector Innovation Fund.

Participants from Proteak and Uumbal in the R course in Mexico.

Participants from Mondi in the R course in South Africa.

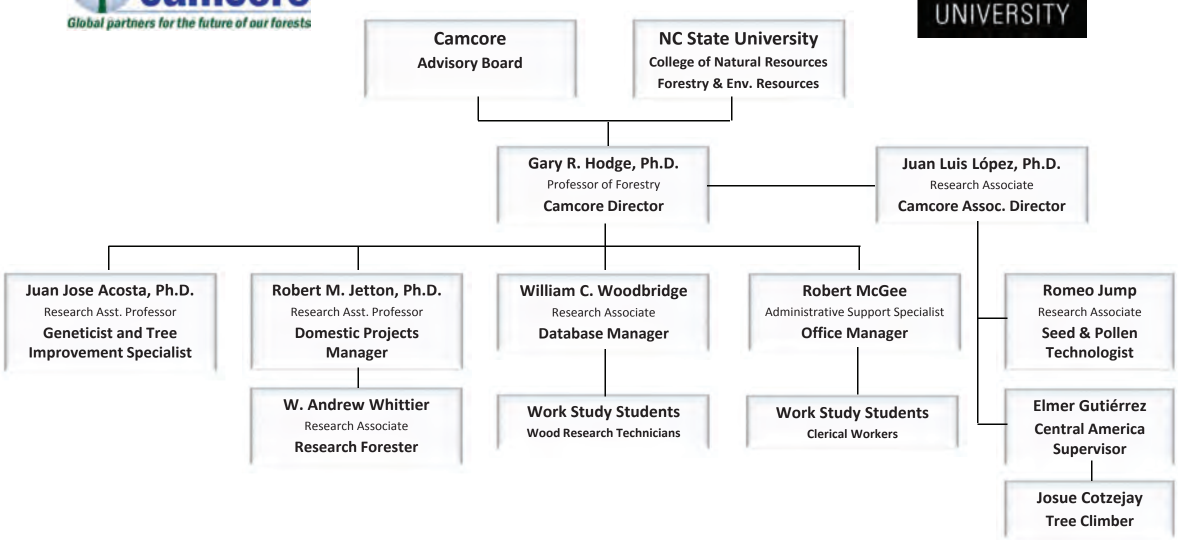
Pine SNP Chip Development

Having a single nucleotide polymorphism (SNP) tool with high throughput for pines would greatly enhance both basic and applied genetic research. In 2016, a group of scientists: Fikret Isik (NC State University, Principal Investigator), Jill Wegrzyn (University of Connecticut), Andrew J. Ecker (Virginia Commonwealth University), Richard A. Sniezko (United States Forest Service, Dorena Genetic Resource Center) and Juan José Acosta (Camcore, NC State University), received a large grant to develop a pine SNP chip. This chip will facilitate genotyping with high marker density, high genotype call accuracy and reproducibility. In addition, genotyping would be at low cost, with fast data generation, and most importantly, be fully accessible to the pine breeding community.

This project involves the discovery, annotation and validation of SNPs from millions of potential loci through existing large-scale *Pinus taeda* genomics projects. SNP loci will be filtered based on sequencing metrics and tested for population genetic parameters and selected loci will be uploaded to the TreeGenes database for free public access. To bring the tree breeding community together, we will establish the PineSNPchip consortium. Our goal is to include SNP loci from additional pine species in the development of the SNP chip; consequently, a higher volume of genotyping samples will allow us to negotiate better prices with genotyping centers.

At Camcore, we are collaborating with Dr. Zander Myburg (Forest Molecular Genetics Programme, University of Pretoria) to ensure that many SNPs on the final chip will be useful for our tropical pines. Currently, we are combining transcriptome information for *P. patula* and *P. tecunumanii* generated at FMG with target sequence capture methods to discover and validate polymorphisms on *P. tecunumanii*, *P. patula*, *P. oocarpa*, and *P. greggii*.

Camcore Personnel



Publications and Papers

Publications

Brantley, S.T., A.E. Mayfield III, R.M. Jetton, C.F. Miniat, D.R. Zietlow, C. Brown, and J.R. Rhea. 2017. Elevated light levels reduce hemlock woolly adelgid infestation and improve carbon balance of infested eastern hemlock seedlings. Forest Ecology and Management, In press.

Bucholz, E., J. Frampton, R. Jetton, D. Tilotta, and L. Lucia. 2017. Effect of different headspace concentrations of bornyl acetate on fecundity of green peach aphid and balsam woolly adelgid. Scandinavian Journal of Forest Research, In press.

de Waal, L., R.G. Mitchell, G.R. Hodge and P.W. Chirwa. 2017. The use of field and artificial freezing studies to assess frost tolerance in natural populations of Pinus oocarpa Southern Forests, in press.

Extension and Outreach Publications

Jetton, R.M. and W.A. Whittier. 2016. The Camcore-USDA Forest Service cooperative ash (*Fraxinus* spp.) genetic resource conservation program: project background and seed collection guidelines. Camcore Forestry Bulletin No. 20. N.C. State University, Raleigh, NC.

Conference Papers and Abstracts

Jetton, R.M., W.A. Whittier, G.R. Hodge, W.S. Dvorak, and J.R. Rhea. 2016. The role of genetic resource conservation in the restoration of forests after invasion by exotic forest pests. Proceedings of the North American Forest Insect Work Conference. p. 51 (Abstract).

Brantley, S.T., A.E. Mayfield III, R.M. Jetton, C.F. Miniat, D.R. Zietlow, C. Brown, and J.R. Rhea. 2016. Elevated light levels reduce HWA infestation and improve carbon balance in eastern hemlock seedlings. Proceedings of the North American Forest Insect Work Conference. p. 94 (Abstract).

Lapham, M., C. Miniat, A. Mayfield, R. Jetton, D. Zietlow, S.T. Brantley, and R. Rhea. 2016. Shade and hemlock woolly adelgid (HWA) infestation affect eastern hemlock (*Tsuga canadensis*) nutrient content. Proceedings of the North American Forest Insect Work Conference. pp. 104-105 (Abstract).

Jetton, R.M., W.A Whittier, W.S. Dvorak, G.R. Hodge, B.S. Crane, and J.R. Rhea. In press. Overview of the Camcore (NC State University) and USDA Forest Service cooperative gene conservation program for threatened and endangered tree species native to the southern United States. Proc. of Gene Conservation of Tree Species – Banking on the Future. (Abstract).

Potter, K.M., L. Campbell, S.A. Josserand, C.D. Nelson, and R.M. Jetton. In press. Population isolation results in low genetic variation and high differentiation in Carolina hemlock (*Tsuga caraoliniana*), an imperiled Southern Appalachian conifer. Proceedings of Gene Conservation of Tree Species – Banking on the Future. (Abstract).

Whittier, W.A., R.M. Jetton, A.E. Mayfield III, A.R. Tait. In press. Silvicultural and integrated management strategies for restoring hemlock to degraded Southern Appalachian Forests. Proceedings of Gene Conservation of Tree Species – Banking on the Future. (Abstract).

Hastings, J., K. Potter, M. Megalos, F. Koch, and R. Jetton. In press. Using climate and genetic diversity data to prioritize conservation seed banking for imperiled hemlock species. Proceedings of the Twenty-seventh USDA Interagency Research Forum on Invasive Species. (Abstract).

Jetton, R., B. Crane, A. Whittier, and B. Dvorak. 2016. Genetic resource conservation of Table Mountain pine in the central and southern Appalachian Mountains. Proceedings of the Southern Forest Tree Improvement Conference. p. 27. (Abstract).

Conference Presentations

Jetton, R.M. 2016. Camcore and USDA Forest Service collaborative hemlock genetic resource conservation and restoration research. Forest Restoration Alliance Board Meeting, October 7, 2016, Asheville, NC.

Jetton, R.M., W.A. Whittier, G.R. Hodge, W.S. Dvorak, and J.R. Rhea. 2016. The role of genetic resource conservation in the restoration of forests following invasion by exotic forests pests. North American Forest Insect Work Conference, May 31-June 3, 2016, Washington, D.C.

Whittier, A., R. Jetton, G. Hodge, and B. Crane. 2016. Genetic resource conservation of Atlantic white cedar (*Chamaecyparis thyoides*) in the eastern United States. 2016 Atlantic White Cedar Symposium – Imperiled Ecosystems in a Shifting Climate, May 24-26, Plymouth, MA.

Jetton, R.M., W.A. Whittier, B.S. Crane, J.R. Rhea, W.S. Dvorak, and G.R. Hodge. 2016. Overview of the Camcore and USDA Forest Service cooperative gene conservation program for threatened and endangered tree species native to the southern United States. Gene Conservation of Tree Species Workshop – Banking on the Future, May 16-19, 2016, Chicago, IL.

Lopez, J.L., W.S. Dvorak, and G.R. Hodge. 2016. Camcore: Thirty-five years of Mesoamerican pine gene conservation. Gene Conservation of Tree Species Workshop – Banking on the Future, May 16-19, 2016, Chicago, IL.

Hastings, J., K. Potter, F. Koch, M. Megalos, R. Jetton. 2016. Using climate and genetic diversity data to prioritize conservation seed banking for imperiled hemlock species. Gene Conservation of Tree Species Workshop – Banking on the Future, May 16-19, 2016, Chicago, IL.

Jetton, R.M. 2016. Research needs for *Dendroctonus frontalis* in Honduras. Escuela Nacional de Ciencias Forestales (U-ESNACIFOR), May 5, 2016, Seguatepeque, Honduras.

Jetton, R.M. 2016. Research needs for *Dendroctonus frontalis* in Honduras. Instituto de Conservacion Forestal (ICF), May 4, 2016, Tegucigalpa, Honduras.

Jetton, R.M. 2016. Genetic resource conservation: a tool for forest health management. East Texas Forest Entomology Seminar, April 21-22, 2016. Nacogdoches, TX.

Jetton, R.M. 2016. A very brief introduction to entomology and insects in forest ecosystems. North Carolina State University EcoVillage, March 31, 2016, Raleigh, NC.

Whittier, W.A., Jetton, R.M., Hodge, G.R., Rhea, R., Crane, B. 2016. Gene Conservation of Threatened Tree Species. Oral presentation at the Second Blue Ridge Parkway Science and Research Symposium, March 25, 2016, Asheville, NC.

Lapham, M., C. Miniat, A. Mayfield, R. Jetton, D. Zietlow, S.T. Brantley, and R. Rhea. 2016. Shade and hemlock woolly adelgid (HWA) infestation affect eastern hemlock (*Tsuga canadensis*) nutrient content. Southern Appalachian Forest Entomology and Pathology Seminar, March 3-4, 2016, Crossnore, NC.

Jetton, R.M., W.A. Whittier, A.R. Tait, A.E. Mayfield III, and J.R. Rhea. 2016. Gene conservation, silviculture, and conservation assessment: research towards hemlock restoration. North Carolina Hemlock Woolly Adelgid BioControl Forum, February 24-25, Montreat, NC.

Miniat, C.F., K.J. Elliott, T. Cofer, P. Clinton, S.T. Brantley, D. Zeitlow, R. Jetton, M. Lapham, A. Mayfield, R. Rhea, P.V. Bolstad, W.T. Swank, and J.M. Vose. 2016. Hemlock research at Coweeta. North Carolina Hemlock Woolly Adelgid BioControl Forum, February 24-25, Montreat, NC.

Conference Posters

Brantley, S.T., A.E. Mayfield III, R.M. Jetton, C.F. Miniat, D.R. Zietlow, C. Brown, and J.R. Rhea. 2016. Elevated light levels reduce HWA infestation and improve carbon balance in eastern hemlock seedlings. North American Forest Insect Work Conference, May 31-June 3, 2016, Washington, D.C.

Lapham, M., C. Miniat, A. Mayfield, R. Jetton, D. Zeitlow, S.T. Brantley, and R. Rhea. 2016. Shade and hemlock woolly adelgid (HWA) infestation affect eastern hemlock (Tsuga canadensis) nutrient content. North American Forest Insect Work Conference, May 31-June 3, 2016, Washington, D.C.

Miniat, C., S.T. Brantley, D. Zeitlow, A. Mayfield, R. Rhea, R. Jetton, and P. Arnold. 2016. Physiological responses of eastern hemlock to biological control and silvicultural release: implications for hemlock restoration. North American Forest Insect Work Conference, May 31-June 3, 2016, Washington, D.C.

Whittier, A., R.M. Jetton, A.E. Mayfield II, and A.R. Tait. 2016. Silvicultural and integrated management strategies for restoring hemlock to degraded southern Appalachian forests. Gene Conservation of Tree Species Workshop – Banking on the Future, May 16-19, 2016, Chicago, IL.

Potter, K.M., L. Campbell, S.A. Josserand, C.D. Nelson, and R.M. Jetton. 2016. Population isolation results in high inbreeding and differentiation in Carolina hemlock (*Tsuga caroliniana*). Gene Conservation of Tree Species Workshop – Banking on the Future, May 16-19, 2016, Chicago, IL.

Lapham, M., C. Miniat, A. Mayfield, R. Jetton, D. Zietlow, S.T. Brantely, and R. Rhea. 2016. Shade and infestation affect eastern hemlock nutrient content. North Carolina Hemlock Woolly Adelgid BioControl Forum, February 24-25, Montreat, NC.

Zietlow, D., S.T. Brantley, C. Miniat, A. Mayfield, R. Jetton, and R. Rhea. 2016. Silvicultural treatments to preserve and restore eastern hemlock. North Carolina Hemlock Woolly Adelgid BioControl Forum, February 24-25, Montreat, NC.

Hastings, J., K. Potter, M. Megalos, F. Koch, and R. Jetton. 2016. Using climate and genetic diversity data to prioritize conservation seed banking for imperiled hemlock species. Twenty-seventh USDA Interagency Research Forum on Invasive Species, January 12-15, 2016, Annapolis, MD.

Graduate Programs and Training

Andy Whitter, Research Forester with Camcore's Domestic Conservation Program, is nearing completion of his M.S. degree project entitled "Nutrient interactions and deficiency symptoms in teak raised in growth chambers." On completion of this thesis he will compile a document detailing how different nutrient deficiencies are exhibited in seedlings and will provide this to Camcore members working with teak.

Juan Pedro Posse, Research Manager with Weyerhaeuser, Uruguay, passed his PhD preliminary exam, and has finished all of his coursework at NC State University. He has also completed all laboratory measurements and finished the data analysis on his project investigating genetic control of wood properties in *Eucalyptus dunnii*. Juan Pedro returned to Uruguay in December 2016, and resumed his normal duties with Weyerhaeuser. He plans to complete the PhD dissertation in 2017.

Martha Salas, Research Geneticist with Smurfit Kappa Colombia, is working on her M.S. degree at NC State University, supported by the Camcore stipend. Her project will investigate the genetic control of wood chemical properties in a clonal population of *Eucalyptus grandis*.

University Committees and Service

Gary Hodge and **Juan José Acosta** served on the NCSU-CNR team to develop long-term strategies for the Center for Industry Research Programs. The Center is an umbrella structure within the University of North Carolina system, containing Camcore, the NC State Tree Improvement Program (*P. taeda* breeding), the Forest Productivity Cooperative, (nutrition and silviculture), and the Southern Forest Resource Assessment Consortium (economics). The goal of the Center is to leverage the influence of these programs to gain greater support within the university for our work with forest industry.

Gary Hodge also reviewed manuscripts for *Tree Genetics* and *Genomes, New Forests, Southern Forests,* and *Applied Spectroscopy*, and spoke about forestry and plant breeding to four classes of 7th and 8th graders at the Triangle Math and Science Academy career day.

Juan José Acosta served as the leader of the organizing committee for the Applied Course in Tree Breeding which would be taught during the first quarter of 2017 in Cali, Colombia. The course is open to the Colombian forestry community, and instructors from NCSU, Universidad Nacional de Colombia and Smurfit Kappa will participate. Juan José also reviewed manuscripts for *Southern Forest* and for *Tree Genetics and Genomes*.

Robert Jetton, continues to serves as a Manuscript Editor for *Southeastern Naturalist*, was Guest Editor for a special gene conservation issue of *New Forests*, and reviewed manuscripts for *Environmental Entomology, Forest Science,* and the *New Zealand Journal of Forest Science*. He is currently Chair-elect of the Southern Forest Insect Work Conference and will assume the role of Chair in August 2017.

Andy Whittier, Research Forester, continuted to serve on the SASRI (Southern Appalachian Spruce Restoration Initiative) steering committee.

Robert McGee served on numerous committees in the CNR including the Financial Efficiencies Implementation Team, the Human Resources Implementation, and the CNR Senior HR Generalist Search Commitee. At the University level, he served as Project SAFE Ally, the NCSU GLBT Center, and on the NCSU Transportation Appeals Board.

CAMCORE BOARDS AND COMMITTEES

Seed cones of Carolina hemlock *(Tsuga caroliniana)* in the Linville Gorge area of the Pisgah National Forest in North Carolina. Camcore has made gene conservation collections for 10 native tree species in the United States, including Carolina hemlock.

Front Cover: Menzi Lukhele of SAFCOL in a 9-year-old full-sib progeny test of *P. patula x P. tecunumanii* near Sabie, South Africa. This hybrid has shown excellent growth and adaptability across a wide range of sites and environmental conditions in southern and eastern Africa.