camcore

Global partners for the future of our forests

NC STATE UNIVERSITY

2015 Annual Report

2015 CAMCORE ANNUAL REPORT

International Tree Breeding and Conservation

Department of Forestry and Environmental Resources
College of Natural Resources
North Carolina State University
Raleigh, North Carolina 27695-8008, USA

Telephone:	919.515.6424
Fax:	919.515.6430
Email:	info@camcore.org
Gary R. Hodge	grh@ncsu.edu
Juan Luis Lopez	jllopez@ncsu.edu
Juan José Acosta	jjacosta@ncsu.edu
William C. Woodbridge	woodbridge@ncsu.edu
Romeo Jump	rjump@ncsu.edu
Robert M. Jetton	rmjetton@ncsu.edu
W. Andrew Whittier	wawhitti@ncsu.edu
J. Robert McGee	rmcgee@ncsu.edu
Elmer A. Gutiérrez	egutierrez3161@gmail.com
Web:	www.camcore.org

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EXECUTIVE SUMMARY

1. In 2015, Camcore celebrated its 35th Anniversary with 27 active members, 6 associate members and 7 honorary members in 18 countries.

2. The Camcore *Eucalyptus* program continues to grow. As of 2015, members have established 370 tests, including 88 species-site trials and 282 progeny tests of 15 species. Around the cooperative there is increasing interest in cold-tolerant eucalypts. The most promising species are *E. benthamii* and *E. dorrigoensis*, which are doing well in Argentina, Brazil, Chile, Uruguay, and South Africa.

3. We have initiated a eucalypt disease screening project in conjunction with Smurfit Kappa Colombia, and Weyerhaeuser and INIA in Uruguay. We will screen 12 species for three important diseases: *Puccinia psidii, Botryosphaeria*, and *Teratosphaeria* (Coniothyrium canker).

4. We distributed seeds from full-sib families of nine *Eucalyptus* hybrids to participating organizations, as part of the Camcore Eucalypt Hybrid Project. In 2016, we will begin planning for a second phase of eucalypt hybrid crossing that we hope will involve all members of the program with some interest in eucalypts.

5. Camcore members have produced 23 verified pine hybrids, and established 82 trials with pine hybrid bulks in 8 countries. Results from the first two series of pine trials have identified a number of hybrids that are growing better than commercial species *P. patula, P. taeda, P. elliottii,* and *P. radiata.* Trials of the third series of hybrid bulks will be planted in 2016. In 2015 we began a long-term project to study the wood properties of these pine hybrids. For the next several years, we plan to sample approximately two to four tests per year using the same protocols in various countries.

6. Two collaborative pine hybrid breeding efforts are underway. The first is focused on *P. patula* x *P. tecunumanii*, and involves mainly organizations in southern Africa. This project completed its third year of crossing, involving 43 *P. patula* mothers and 97 *P. tecunumanii* males. The second project involves seven members in Argentina, Brazil, Colombia, Uruguay, and Mexico, and will focus on *P. tecunumanii* x *P. greggii*.

7. A study on the genetic control of wood properties in *P. taeda* showed high heritability for density and timber strength (modulus of elasticity), and moderate heritability for lignin and cellulose content. There was very little genotype x environment interaction for these four traits across two sites in Argentina and Brazil.

8. Camcore has developed a number of excellent NIR models for wood chemical properties of eucalypts, including glucose content, lignin content, syringyl-guayacyl lignin ratio, and xylose content. The models are based on *E. urophylla, E. dunnii, E. globulus* and *E. nitens*, have very high R^2 from 0.92 to 0.99, and should be sufficiently robust to extrapolate to other species.

9. Very good NIR models for wood chemistry were developed with spectra taken with the handheld microPhazir spectrometer. The machine was tested on samples of both pine and eucalypts. For the pines, we tried both woodmeal samples (like those used in the Camcore laboratory NIR), and solid wood samples. Woodmeal samples gave slightly better models than solid wood samples (R^2 = 0.93 vs 0.83, respectively). For eucalypts, only solid wood samples were scanned, but these gave quite good results for lignin, glucose, and xylose content ($R^2 \approx 0.90$).

10. Preliminary results from a study on the genetic control of heartwood percentage in teak indicates that the trait is under genetic control, and is strongly and positively correlated with growth rate. This means that teak breeders can select primarily (or solely) for growth rate, and make associated genetic gain in percentage of heartwood produced.

11. The Camcore USA domestic gene conservation program continues to expand. Our species portfolio now includes Atlantic white cedar, Table Mountain pine, Fraser fir, red spruce, and in 2015, we added four rare species of ash (genus *Fraxinus*), Carolina ash, pumpkin ash, Texas ash, and blue ash. Our hemlock program has expanded beyond gene conservation into research on ecological modeling, nursery production, and silvicultural options for species restoration. Our hemlock work was highlighted in *Science* magazine, one of the premier scientific journals in the world.

RESUMEN EJECUTIVO (Español)

1. En 2015, Camcore celebró su trigésimo quinto aniversario con 27 miembros activos, 6 miembros asociados y 7 miembros honorarios en 18 países.

2. El programa de *Eucalyptus* de Camcore continúa creciendo. Al 2015, los miembros habían establecido 370 ensayos, incluyendo 88 ensayos de especie-sitio y 282 ensayos de progenie de 15 especies. En la cooperativa hay creciente interés en eucaliptos tolerantes al frío. Las especies más promisorias son *E. benthamii* y *E. dorrigoensis*, a los cuales les está yendo bien en Argentina, Brasil, Chile, Uruguay, y Sur Africa.

3. Hemos iniciado un proyecto de muestreo de enfermedades de eucaliptos en conjunto con Smurfit Kappa Colombia, y Weyerhaeuser e INIA en Uruguay. Muestrearemos 12 especies para tres enfermedades importantes: *Puccinia psidii, Botryosphaeria,* y *Teratosphaeria* (Cáncer Coniothyrium).

4. Distribuimos semillas de familias de hermanos completos de nueve híbridos de Eucalyptus a las organizaciones participantes, como parte del proyecto de híbridos de eucaliptos de Camcore. En el 2016, empezaremos a planear la segunda fase de cruces de híbridos de eucaliptos que esperamos involucre a todos los miembros del programa con algún interés en las especies del género.

5. Los miembros de Camcore han producido 23 híbridos de pino verificados y han establecido 82 ensayos de híbridos en 8 países. Los resultados de las dos primeras series de ensayos han identificado un número de híbridos de pino que están creciendo mejor que las especies comerciales *P. patula, P. taeda, P. elliottii,* y *P. radiata.* Los ensayos de la tercera serie de híbridos se plantarán en el 2016. En el 2015 empezamos un proyecto de largo plazo para estudiar las propiedades de la madera de estos híbridos de pino. Para los próximos años, estamos planeando tomar muestras de cuatro ensayos por año, utilizando los mimos protocolos en varios países.

6. Dos proyectos colaborativos de mejoramiento genético de híbridos de pino están en ejecución. El primero está enfocado en *P. patula* x *P. tecunumanii*, e involucre muchas organizaciones en el sur del Africa. Este proyecto completó su tercer año de cruzamientos, incluyendo el uso de 43 madres de *P. patula* y 97 padres de *P. tecunumanii.* El segundo proyecto involucra siete miembros en Argentina, Brasil, Colombia, Uruguay y México y se enfocará en *P. tecunumanii* x *P. greggii.*

7. Un estudio sobre control genético de las propiedades de la madera en *P. taeda* mostró alta heredabilidad para densidad y resistencia de la madera (módulo de elasticidad), y heredabilidad moderada para contenido de lignina y celulosa. Hubo muy poca interacción genotipo x ambiente para estas cuatro características en dos sitios en Argentina y Brasil.

8. Camcore ha desarrollado varios modelos excelentes de NIR para las propiedades químicas de eucaliptos, incluyendo contenido de glucosa, contenido de lignina, relación de lignina siringil-guayacyl, y contenido de xilosa. Los modelos están basados en *E. urophylla, E. dunnii, E. globulus* y *E. nitens*, tienen un alto R^2 de 0.92 a 0.99, y deberían ser suficientemente robustos para extrapolar a otras especies.

9. Se desarrollaron modelos NIR muy buenos para química de la madera con espectros tomados con el espectrómetro portátil microPhazier. La máquina fue ensayada con muestras de pinos y eucaliptos. Para los pinos, ensayamos muestras de aserrín (como aquellas usadas en el NIR del laboratorio de Camcore), y muestras de madera sólida. Las muestras de aserrín dieron modelos ligeramente mejores que con las muestras sólidas ($R^2 = 0.93$ vs 0.83). Para eucaliptos, solamente fueron escaneadas muestras sólidas, pero estas dieron muy buenos resultados para lignina, glucosa, y xilosa ($R^2 \approx 0.90$)

10. Resultados preliminares de un estudio de control genético del porcentaje de duramen en teca indican que la característica está bajo control genético, y está fuertemente correlacionada positivamente con la tasa de crecimiento. Esto significa que los mejoradores de teca pueden seleccionar primeramente (o únicamente) por tasa de crecimiento, y obtener una ganancia genética en porcentaje asociada con el duramen producido.

11. El programa doméstico Camcore de conservación de genes en los Estados Unidos continúa expandiéndose. Nuestro portafolio de especies ahora incluye Atlantic white cedar *(Chamaesyparis thyoides)*, Table mountain pine *(Pinus pungens)*, Fraser fir *(Abies fraseri)*, red spruce *(Picea rubens)*, y en el 2015, agregamos cuatro epecies raras de ash (género *Fraxinus*), Carolina ash, pumpkin ash, Texas ash, y blue ash. Nuestro programa con hemlock se ha expandido más allá de la conservación de genes hacia la investigación en modelación ecológica, producción en viveros, y opciones silviculturales para la restauración de las especies. Nuestro trabajo con hemlock fue resaltado en la revista científica *Science*, una de las publicaciones científicas de más alta categoría en el mundo.

RESUMO EXECUTIVO (Português)

1. A Camcore celebrou em 2015 o seu 35º aniversário, tendo 27 membros, 6 membros associados e 7 membros honorários localizados em 18 países.

2. O Programa de *Eucalyptus* da Camcore demonstra um desenvolvimento contínuo. Em 2015, os membros estabeleceram 370 estudos; sendo 88 testes de espécies e 282 testes de progênies de 15 espécies. Dentro da Camcore existe um interesse crescente em espécies de eucalyptus tolerantes ao frio. As espécies mais promissoras até o presente momneto são: *E. benthamii* e *E. dorrigoensis*.

3. Com Smurfit Kappa Colombia, Weyerhaeuser e INIA no Uruguay, iniciamos um projeto de diagnose de *Puccinia psidii, Botryosphaeria* e *Teratosphaeria* (Coniothyrium canker) em 12 espécies de eucalyptus.

4. Distribuímos sementes de 9 espécies híbridas de Eucalyptus para nossos membros como parte do Projeto de Desenvolvimento de Híbridos de Eucalyptus. Em 2016, estaremos planejando uma segunda fase deste projeto, efetuando novos cruzamentos híbridos e esperamos envolver todos os membros da Camcore com interesse neste projeto.

5. Os membros da Camcore produziram 23 híbridos de pinus e estabeleceram 82 testes em 8 países. Os resultados dos primeiros estudos, identificaram híbridos com maior crescimento que espécies comerciais de *P. patula, P. taeda, P. elliottii* e *P. radiata.* Estudos com a terceira série de híbridos serão estabelecidos em 2016. Durante 2015, começamos um projeto de longo prazo com o objetivo de estudar as propriedades da madeira destes híbridos. Nos próximos anos, planejamos amostrar aproximadamente 2 testes por ano usando os mesmos protocolos nos diferentes países.

6. Dois novos projetos cooperativos estão sendo desenvolvidos com foco no desenvolvimento de híbridos de *Pinus.* O primeiro tem como objetivo o desenvolvimento de híbridos de *P. patula* x *P. tecunumanii* com empresas da África. Este projeto completou o terceiro ano, envolvendo 43 mães de *P. patula* e 97 pais de *P. tecunumanii.* O segundo projeto cooperativo abrange 7 empresas na Argentina, Brazil, Colombia, Uruguay e México e terá como foco *P. tecunumanii x P. greggii*.

7. Um estudo no controle genético das propriedades da madeira em *P. taeda* demonstrou haver alta herdabilidade para densidade e resistência (MOE) e moderada herdabilidade para conteúdo de lignina e celulose. Também foi demonstrado baixa interação genótipo x ambiente para estas 4 propriedades em 2 sítios na Argentina e Brasil.

8. A Camcore desenvolveu excelentes modelos de NIR para propriedades químicas de *Eucalyptus*, incluindo conteúdo de glicose, lignina, relação syringyl-guayacyl e xilose. Os modelos foram desenvolvidos para *E. urophylla, E. dunnii, E. globulus* e *E. nitens*, apresentam R^2 de 0,92 até 0,99 e devem ser suficientemente robustos para serem extrapolados para outras espécies.

9. Ótimos modelos de NIR para propriedades químicas da madeira foram também desenvolvidos utilizando-se do modelo portátil microPhazir. Este equipamento foi testado em amostras de *Pinus* e *Eucalyptus.* Em *Pinus*, utilizamos amostras de madeira moída (como aquelas utilizadas no laboratório da Camcore para análise de NIR) e amostras de madeira sólida. Amostras de madeira moída demonstraram melhores resultados quando comparadas com resultados provenientes de amostras de madeira sólida (R^2 =0,93 vs 0,83 respectivamente). Para *Eucalyptus,* somente amostras sólidas de madeira foram escaneadas, porém resultando em bons resultados para conteúdo de lignina, glicose e xilose (R^2 = 0,90).

10. Resultados preliminares de um estudo do controle genético do percentual de cerne em *Teca,* indica que esta característica é controlada genéticamente como também é fortemente correlacionada com a taxa de crescimento. Isto significa que os melhoristas de *Teca* podem selecionar unicamente para crescimento e associar ganhos genéticos em percentuais a quantidade de cerne produzido.

11. O Programa de Conservação Genética da Camcore continua a expandir. A nossa lista de espécies agora inclui Atlantic white cedar *(Chamaesyparis thyoides)*, Table mountain pine *(Pinus pungens)*, Fraser fir *(Abies fraseri)*, red spruce *(Picea rubens)* e em 2015, adicionamos 4 espécies raras de ash (gênero *Fraxinus*), Carolina ash, pumpkin ash, Texas ash, e blue ash. O nosso programa de hemlock expandiu além de conservação genética para mais pesquisas em modelagem ecológica, produção de mudas em viveiro e manejo silvicultural para a recuperação da espécie. Nosso trabalho com hemlock foi mencionado na revista *Science*, uma das melhores revistas científicas do mundo.

MUHTASARI WA TAARIFA KUU (Kiswahili)

1. Mwaka 2015, Camcore ilisherehekea mwaka wake wa 35 pamoja na wanachama27, washirika 6 na 7 waliotunikwa heshima kwenye nchi 18.

2. Mradi wa mikaratusi wa Camcore bado unaendelea. Mwaka wa 2015, wanachama walithibitisha majaribio 370 baina yao yakiwa pamoja na mahala 88 penye aina tofauti ya mikaratusi na majaribio 282 ya mazao kutoka aina 15. Utafiti wa aina ya mikaratusi inaoweza kuota kwenye baridi umezidi. Aina zenye mafanikio zaidi ni *E. benthamii* na *E.dorrigoensis,* zinazoota vyema Argentina, Brazil, Chile, Uruguay na Afrika Kusini.

3. Tumeanzisha mradi wa kuchunguza maradhi ya mikaratusi pamoja na Smurfit Kappa Colombia, na Wayerhaeuser na INIA humo Uruguay. Tutatafiti aina 12 ya mikaratusi kuangalia maradhi tatu muhimu: *Puccinia psidii, Botryosphaeria* na *Teratosphaeria* (Coniothyrium canker)

4. Tuligawa mbegu kutoka aina za familia tisa za mikaratusi mahaluti, kama mpango wa Camcore Eucalypt Hybrid Project. Mwaka 2016, tutaanza mpango wa awamu ya pili ya kuunganisha mikaratusi mahaluti. Tunayo imani kuwa awamu hii itahusisha wanachama wote wa mradi huu wenye maslahi na mikaratusi.

5. Wanachama wa Camcore wameota mizao 23 iliyothibitishwa kuwa mahaluti ya msindano, na pia walianzisha majaribio 82 ya msindano mahaluti kwenye nchi 8. Matokeo ya mifululizo mbili ya kwanza ya majaribio inaonyesha aina kadhaa ya mahaluti yanaota vyema zaidi kuliko aina zinazowamba za kibiashara za *P. patula, P.taeda, P.elliottii* na *P. radiata.* Majaribio ya mfululizo wa tatu ya mahaluti yatapandwa 2016. Mwaka wa 2015, tulianza miradi ya kuchunguza sifa za msindano mahaluti. Miaka ijayo, tutapanga kuchukua sampuli mara mbili kila mwaka tukitumia itifaki inayotumika kwenye nchi kadhaa.

6. Miradi mbili ya kuota mihaluti ya msindano inaendelea. Wa kwanza unaangalia *P. patula* x *P. tecunumanii*, na unahusisha mashirika kadhaa kwenye nchi za kusini mwa Afrika. Mradi huu umemaliza mwaka wake wa tatu wa kuota mahaluti kutoka miti 43 ya kike ya *P. patula* na miti 97 ya mume ya *P. tecunumanii*. Mradi wa pili unahusisha wanachama nane nchini Argentina, Brazil, Colombia, Uruguay na Mexico na utaangalia *P. tecunumanii* x *P. greggii*.

7. Uchunguzi wa kudhibitisha adili ya jeni ya *P. taeda* ulionyesha sifa kuu ya umiliki wa wiani na nguvu wa kuni (thamini ya ustahimilivu), na umiliki wa lignina na seluosi. Kulikuwa na tofauti ndogo kati ya jeni na mazingira kuhusiana kwenye hizo sifa nne nchini Argentina na Brazil.

8. Camcore inaendelesha mifano kadhaa bora ya NIR ya kutumika kwenye utafiti wa kuni kemia ya mikaratusi, kwa mfano sukari, lignina, uwiano kati ya siringili-guayasili kwenye lignina, na zilosi. Mifano haya yana msingi kwenye *E. urophylla, E. dunnii, E. globulus* na *E. nitens* na yana R^2 ya juu kutoka 0.92 mpaka 0.99, na yatakuwa mizuri zaidi kuendelesha mapato kwenye aina zingine za miti.

9. Mifano kuu zaidi ya kuni kemia yaliundwa kwa namna ya spectra kipimwa na microPhazir spektromita ya mkono. Mashine hii ilipima sampuli ya miti ya sindano na mikaratusi. Kwa mti wa sindano, tulitumia sampuli mbili za miundo msingi ya massa (kama yenye inayotumika kwenye maabara ya Camcore NIR) na kuni. Sampuli za miundo msingi ya massa zilikuwa sampuli kuu kuliko kuni (R^2 = 0.93 kulinganishwa na 0.83). Sampuli za kuni pekee zilitumiwa kwa mikaratusi, lakini sampuli hizi zilotoa matokeo mazuri ya lignina, sukari na zilosi.

10. Matokeo ya asili ya utafiti wa kipima asilimia ya ng'arange kwa namna ya kupima jeni yanaonyesha kuwa adili hii imo kati ya maumbile ya nyenzo, na inawasiliana, kwa namna nguvu na halisi, na kiwango cha kuota. Matokeo haya yanamaanisha kuwa wekezaji wa teak wanaweza kuchagua miti kutumia kiwango cha kuota, na kuwasilisha faida ya jeni kwa asilimia ya ng'arange watakaopata.

11. Mradi wa Camcore USA wa kuhifadhi jeni za miti kienyeji unaendelea. Jalada letu la aina za miti sasa lina Atlantic Mwerezi Mweupe, Msindano wa Table Mountain, Fraser Fir, Spruce Nyekundu na, mwaka 2015, tuliongeza aina nne nadra za Kijivu (familia *Fraxinus*), Kijivu ya Carolina, Kijivu boga, Kijivu yaTexas na Kijivu Samawati. Mradi wetu wa mbaruti umeenea zaidi ya kuhifadhi jeni. Mradu huu sasa unachunguza mifano ya mazingira bora, kuota miche na mifano ya udongo ili kuwezesha urejeshaji wa aina za miti. Kazi yetu ya mbaruti iliangazwa kwenye jarida la *Science*, mmoja wao wa jarida kuu ya sayansi duniani.

Message From the Director

In 2015, Camcore celebrated its 35th Anniversary, and it was marked both by change and continuity. Camcore was born in 1980, with four members and a hopeful but uncertain future. Thirty-five years later, we ended 2015 with 27 active members, 6 associate members and 7 honorary members in 18 countries. This is a testament to the vision and commitment of many research and forestry managers of our member companies, as well as the leadership of Bill Dvorak, our founding director. Bill retired in August 2014, so 2015 was my first full year as Director. It has been a learning experience, and perhaps the most important lesson was that I still have much more to learn!

Camcore's work covers four broad areas: breeding and tree improvement, species characterization, research and technology development, and gene conservation. In 2015, we saw exciting developments in all categories.

There is increasing interest in finding species and varieties of pines and eucalypts suited for cooler climates. Pure species *P. greggii* is performing very well across a range of sites, particularly in the 2nd generation Camcore trials. We also see great potential for *E. benthamii* and *E. dorrigoensis* on cooler sites in southern Latin America and southern Africa. These species even have some potential in certain parts of the southeastern USA coastal plain, as we saw in some WestRock trials in Texas during our Annual Meeting.

We continue to work on breeding and testing both pine and eucalpyt hybrids. We completed the third year of breeding for the *P. patula* x *P. tecunumanii* project, a crossing effort involving 43 patula and 77 tecunumanii parents. Another exciting development was an agreement among a number of Latin American members to begin a collaborative breeding project with the *P. tecunumanii* x *P. greggii* hybrid. This project will begin in 2016, and was motivated by the outstanding performance of the *P. greggii* x *P. tecunumanii* hybrid in Camcore trials. Finally, in 2015, we distributed seed from our collaborative *Eucalyptus* hybrid project. Full-sib families of 8 hybrids were sent to participating members, and in 2016 propagation for clonal testing will begin.

We continue to work hard in the development of new technologies for use in our breeding programs, particularly in the area of wood quality. We have learned that the microPhazir handheld NIR spectrometer is very effective, and can be used to predict wood chemistry of both pines and eucalypts. One very interesting result is that the microPhazir can be used with wood meal samples (similar to those used in with the lab NIR), but we have also developed very good models with solid wood samples. We have learned that we can efficiently transfer our NIR models from our lab to company-owned machines (including the microPhazir). We have developed very good multiple-species models for eucalypt wood chemistry, similar to the global models we have for pines.

We also continue to study the genetic control of important wood properties. We completed work on a study of 60 *P. taeda* families planted on sites in Brazil and Argentina. We initiated a study on the genetic control of heartwood production in teak. And we began a long-term project to characterize the wood properties of various pine hybrids: the first sites in Colombia were sampled in 2015, and additional sites in Brazil, Argentina, and South Africa will be sampled in 2016.

Over the past 12 years, we have been funded by the USDA Forest Service to work on gene conservation projects with a number of species in the USA, including hemlock, Atlantic white cedar, Table mountain pine, red spruce, and Fraser fir. In 2015 we began a project with ash (*Fraxinus* spp.). These domestic gene conservation efforts continue to garner very favorable attention for Camcore in the scientific community and popular press.

Finally, commitment to the program among the Camcore membership remains strong. Even in a tight financial year, 24 of the 27 members sent representatives to one of our three Regional Meetings and/or the Annual Meeting. The spirit of collaboration and collegiality that we have in Camcore is unsurpassed. Our work together in breeding, testing and research leverages the work done by any one member, multiplying the benefits many fold. I look forward to the Camcore family celebrating many more anniversaries together.

Many thanks for your support,

Gary Hodge, Director

2015 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
- Suzano Pulp and Paper 2011

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
- Komatiland Forests, Ltd 1983
- Merensky Pty Ltd 2004
- Mondi South Africa 1988
- PG Bison Holdings Pty Ltd 2006
- Sappi Forests 1988
- York Timbers 2010

Tanzania
- Green Resources AS - Tanzania 2013
- Private Forestry Programme (Assoc.) 2015

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 2015 Annual Meeting in Texas

This year marked Camcore's 35th anniversary as a global leader in the breeding and conservation of forest genetic resources for the benefit of industry, society, and the environment. To celebrate this anniversary and other program milestones, Camcore gathered in Texas in November for the 35th Camcore Annual Meeting hosted by WestRock, ArborGen, the USDA Forest Service, and Camcore staff. This year's meeting was attended by 42 participants and five spouses, all who enjoyed eight days of informative field visits, technical sessions, cultural visits, and cuisine unique to the region, all mixed with a healthy dose of fun. This was Camcore's sixth annual meeting in the United States with the five previous meetings being held in 1980 (North Carolina), 1984 (Washington), 1985 (North Carolina), 2000 (Southeast), and 2005 (North Carolina).

The meeting began in Houston where the opening business meeting, technical committee meeting, and first technical session were held. The technical session featured a keynote address from Texas State Forester Tom Boggus who provided an overview of the forestry sector in Texas. There were also invited presentations from Executive Vice President of the Texas Forestry Association Ron Hufford on the role his organization plays in Texas forestry, Chris Edgar from the Texas A&M Forest Service on the forestry inventory, analysis, and information portal utilized by foresters in Texas, and NC State University Professor Emeritus Bob Kellison who reviewed the history of native hardwood and eucalypt plantation forestry in the southeastern United States.

The following day the meeting moved deep into the piney woods of eastern Texas and western Louisiana for a whirlwind two-day field tour. The first day started with stops at WestRock *Eucalyptus benthamii* and *E. amplifolia* plantations where, at the latter, the only thing bigger than the trees were the mosquitos! After getting back on the bus and everyone receiving a healthy dose of calamine lotion, we were treated to a fried catfish lunch and nursery tour hosted by IFCO at the company's DeRidder, LA seedling production facility. Here meeting participants had the opportunity to learn about and see IFCO's large-scale containerized seedling production system that produces millions of *Pinus taeda, P. elliottii,* and *P. palustris* seedlings annually on raised benches under pivot irrigation. The final stop for the day was at an impressive 3-year-old *E. benthamii* plantation established by WestRock near Jasper, TX that illustrated to everyone the excellent work the company has done in the selection and breeding of cold-hardy eucalypt genotypes suitable for plantation forestry along the United States Gulf Coast. The day ended with a wonderful dinner hosted by WestRock at the Rayburn Country Resort that featured a selection of creole dishes typical of the region.

The 2015 Camcore Annual meeting attendees gathered at the Bastrop State Forest.

Field tours continued the next day with stops designed to give participants a sense of the production, manufacturing, and historical aspects of forestry in the region. The highlight of the day was the stop at the Texas Electrical Cooperatives' pole manufacturing plant in Jasper. Here we learned about the entire manufacturing process for wooden electrical transmission poles, from the selection and grading of trees in the plantation, to the milling and preservation of the raw material into finished poles, and finally the sale and shipment of the finished product. ArborGen hosted stops at one of their *P. taeda* varietal trials and their Livingston Seed Orchard where they produce MCP crosses, and Campbell Global provided an overview and tour of their bareroot nursery facility in Jasper. The day also included several field stops hosted by the USDA Forest Service on the Angelina National Forest where participants had the opportunity to learn about the ecology, breeding, and restoration of longleaf pine, *P. palustris,* the species that historically dominated the forests of the Atlantic and Gulf Coastal Plain regions of the United States, but whose populations declined dramatically in the late 1800s and early 1900s due to overharvesting, wildfire suppression, and the rise of *P. taeda* as the preferred species for commercial forestry in the region.

The following day found the Camcore Annual Meeting in College Station, TX where the second technical session was held in a beautiful conference facility at the Thomas G. Hildebrand Equine Complex on the campus of Texas A&M University. In addition to research updates from Camcore staff and company representatives, the session included invited presentations from Tom Byrum, Fred Raley, and associated faculty about the breeding and research activities of the Western Gulf Forest Tree Improvement Program, and Texas A&M faculty member Steve Hague on the cotton industry and cotton breeding in Texas. During breaks for coffee and lunch, participants had the opportunity to watch practice sessions of the 11-time national collegiate champion Texas A&M equestrian team. The day ended with a winery tour and dinner at the nearby Messina Hof Winery.

The third and final technical session was held the next morning at the USDA ARS Pecan Breeding and Genetics Research Center near College Station where Camcore staff and company representatives gave a final set of research updates. Following these final talks the group was treated to a presentation and hay wagon tour of the pecan breeding facility by center director Dr. L. J. Grauke and his staff. It was interesting to learn that pecan tree breeders face many of the same challenges as forest tree breeders related to gene conservation, propagation, breeding and deployment strategies, and market volatility. Following a short drive and lunch on the bus, participants experienced one last field tour hosted by the Texas A&M Forest Service at Bastrop State Forest. Bastrop is the center of diversity for what is known as the Lost Pines of Texas. The Lost Pines stand is the westernmost natural population of *P. taeda* and is known for its high level of drought tolerance. Catastrophic wildfires in 2011 and again in 2015, just prior to our visit, destroyed much of the population. The bus tour and field stops in Bastrop focused on the effects of the fire and efforts to restore the population with genetic resources conserved by the Western Gulf Forest Tree Improvement Program.

The 2015 Annual Meeting closed in Austin. In addition to the final business meeting, participants also had opportunities to explore the scenery and culture of one of the finest cities in the United States. The farewell dinner hosted by Camcore featured a country music band and a meal of Texas barbequed brisket and sausage complete with traditional fixings. As is our tradition, the Camcore staff handed out small gifts of thanks to our meeting hosts WestRock, ArborGen, and the USDA Forest Service in recognition of an excellent trip. The Camcore staff and members also took this opportunity to honor Gary Hodge and Bill Dvorak. We thanked current director Gary Hodge for 20 years of dedicated work to the program and for accepting the challenge of taking over as director. Director Emeritus Bill Dvorak was also in attendance, and as a group, Camcore took the opportunity to honor and thank him for his 34 years of tireless service as the founding director of the program. We all departed Texas with strengthened partnerships and a renewed appreciation for Texas, its people, and the excellent forestry research being conducted by our hosts in the region.

Developments in Camcore

Camcore staff made a number of member visits in 2015 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

Gary Hodge visited Argentina in July, and spent time with both Camcore members there.

Arauco Argentina (AA) is planning to expand their eucalpyt planting and breeding efforts, and to support this they have planted a full array of Camcore species and provenance tests. We saw encouraging growth from a number of species, including the *Eucalyptus urophylla* x *E. grandis* hybrid, and *E. pellita*. Late in 2015, the company planted a series of progeny trials with *Corymbia* species. We also visited the pine hybrid trials, where the *Pinus greggii* x *P. tecunumanii* hybrid continues to show great growth potential, and it compares nicely with the normal commercial species, *P. taeda*. We also saw some *P. taeda* x *P. tecunumanii* hybrids that were doing well. These hybrids were actually made by AA, with Florida-source *P. taeda* as the mother.

At **Bosques del Plata (BDP)**, *Pinus greggii* appears to have great potential as an alternate pine species. Second-generation progeny tests showed substantial genetic gains over the unimproved material in the 1st generation trials, and the best 2nd generation families of *P. greggii* are competitive with the best *P. taeda* families for early volume growth. The species should also offer improved juvenile wood quality, and show better rooting. To further investigate the potential of *P. greggii*, BDP will begin developing hedges of the six best 2nd generation families for the establishment of pilot plantations over the next several years. The *P. greggii* x *P. tecunumanii* hybrid also shows good potential for BDP.

Finally, both companies continue to provide great support to Camcore research efforts. In 2015, they provided DNA samples from *P. taeda* full-sib crosses for a project on molecular markers and pedigree reconstruction (see article in this Annual Report).

Outstanding growth of a 5-year-old block plot of *P. greggii* x *P. tecunumanii* in the Camcore pine hybrid trial at the Motosierristas (Arauco Argentina) site. This hybrid may have potential for Arauco Argentina and other companies in southern Latin America.

Brazil

Juan Luis Lopez and Juan José Acosta visited **WestRock** Brazil in July. Several *Eucalyptus* species provided by Camcore are showing great commercial potential in the trials. For example, *E. benthamii, E. dorrigoensis*, and *E. badjensis* are showing much better frost resistance than *E. dunnii.* The company is expanding its current genetic base with new species that will also serve to produce hybrids. Camcore pine hybrid trials are providing interesting results with hybrids that compete well with *P. taeda. Pinus greggii* var. *australis* x *P. tecunumanii* high elevation is growing very fast in all the hybrid trials established in Brazil.

Camcore continues to help **Klabin** manage its tree breeding program. New seeds of *P. maximinoi* and *E. urophylla* will be sent to the company to test new families and sources and to expand its genetic base. *Pinus* greggii x *P. tecunumanii* shows great potential in the area of Paraná. Camcore offered to help Klabin develop and build research models on Genomic-Wide Selection with its elite breeding population of eucalypts. A practical tool developed by Camcore for quick analysis of NIR data was made available to Klabin during the technical visit made by Juan José Acosta and Juan Lopez in July.

Waldemar Veiga (WestRock) and Juan Luis Lopez (Camcore) with a 4.6-year-old hybrid between *P. patula* and *P. tecunumanii* high elevation.

Chile

Gary Hodge and Juan Lopez visited **CMPC Forestal Mininco** in April. We discussed the CMPC *E. nitens* x *E. globulus* breeding program. The company has an extensive clonal testing program with more than 1000 clones in trials (NG hybrids, and G x NG backcrosses). We visited the Camcore species trials, where the species with the most potential were *E. benthamii*, *E. badjensis*, and *E. macarthurii*. We also discussed the Global Pine NIR Model Transfer Project, and outlined a small project to bulk up the *P. radiata* samples in the study. CMPC also contributed some 400 wood samples of *E. globulus* and *E. nitens* for the Global Eucalypt NIR project.

Gary Hodge also spent some time with **Arauco Bioforest** discussing their *P. radiata* breeding strategy, focusing on strategies to generate new families and new clones for their clonal and somatic embryogenesis program (SE). Currently, the commercial *P. radiata* plantations are being established with 100% tested clones from the SE program, thus the breeding and testing strategy must focus on generating material that will produce genetic gain with that deployment option.

CMPC and Arauco both participated in the Camcore eucalypt hybrid project, and they are receiving seed from a number of hybrids of *E. grandis* with a cold tolerant species (*E. benthamii*, *E. dunnii, E. smithii, E. globulus*). Both companies are still working on completing crosses for this project, CMPC with *E. nitens* x *E. pellita*, and Arauco Bioforest with *E. globulus* x *E. camaldulensis*.

Colombia

In March, Juan José Acosta traveled to **Smurfit Kappa Colombia (SKC)** to take wood samples in pine hybrid trials, as the first effort in a long-term research project (see full article later in this report). They used the IML-Resistograph to evaluate density differences between hybrids and the TreeSonic acoustic tool to measure wood stiffness. Wood shavings and increment cores were also extracted. Wood shavings were used to make predictions for lignin and cellulose based on the Camcore Global NIR model; cores were used to develop a linear model for prediction of wood density based on wood resistance.

In December, Gary Hodge and Robert Jetton visited **Smurfit Kappa Colombia (SKC)**. Robert spent time with Carlos Rodas to discuss forest pathology monitoring and research, and to plan the Camcore eucalpyt species disease screening project (see article in this Annual Report). Gary spent time with Byron Urrego and Nhora Isaza discussing *E. pellita* and *E. urophylla* breeding strategies, the eucalypt hybrid testing strategy, and the *P. maximinoi* and *P. tecunumanii* 2nd generation testing program. SKC has also had some difficulties maintaining long-term health of *P. maximinoi* and *P. tecunumanii* hedges using the sandbed system in their nursery. The hedges do well during the first year, but then begin to decline. We outlined a research study to look at frequency of harvest, nutrition, and hedge size / spacing to try to optimize hedge health and cutting production.

Tekia is exploring the use of eucalypts as a source of energy for its cement plants in Colombia. Early results of progeny trials show that *E. urophylla* and *E. camaldulensis* have commercial potential. Camcore is studying heritability and genotype x site interaction of teak heartwood and volume growth in Colombia, Mexico and Guatemala. During the technical visit to Tekia in March, Juan Lopez and Juan José Acosta gave

Camilo Alberto Ramirez (Tekia) and Juan José Acosta (Camcore) in a 3.5-year-old teak progeny trial in Carmen de Bolívar, Colombia.

instructions for thinning two teak progeny trials as part of this study. In 2015, we sent teak seeds from four provenances in Laos to Tekia for the establishment of additional provenance-progeny trials.

The optimum development of the tree breeding strategy with *Gmelina arborea, Bombacopsis quinata* and several species of eucalypts is part of Camcore's ongoing mission with **Forestal Monterrey** in Colombia. Juan Lopez and Juan José Acosta recommended that the company emphasize the establishment of an indoor seed orchard to develop and manage controlled-pollination techniques in *Gmelina arborea;* this will be an important step forward for the tree breeding program. Now that the company has decided to continue planting *B. quinata*, Camcore recommended the use of vegetative propagation using rooted cuttings. More eucalypt trials will be sent by Camcore when the company expands its land base to areas with potential for this genus.

Guatemala

Reintroduction studies established in association with the National Institute of Forests (INAB) are in the process of being converted to seedling seed orchards. Camcore helped **Grupo DeGuate** in Guatemala with the data analysis and selection of the best trees and families in a 2nd generation *P. tecunumanii* study in the department of Jalapa. Grupo DeGuate will start producing genetically improved seeds of this species for commercial plantations and 3rd generation studies. Juan Lopez, Romeo Jump, Elmer Gutiérrez and Josué Cotzojay took part in the thinning and measurement of two progeny trials in the teak genetic parameters study in June.

Kenya

Juan José Acosta and Juan Lopez visited the Kenya members in September. Camcore has been helping the partnership of the **Kenya Forest Research Institute (KEFRI)** and the **Tree Biotechnology Programme Trust (TBPT)** to develop a tree breeding program with eucalypts, pines, teak and *Gmelina* by providing genetic material, giving strategic guidance, designing experiments, and analyzing data. The hybrid of *Pinus patula* x *P. tecunumanii* low elevation is showing great commercial potential in two different regions of the country, Turbo and Maguga, in two Camcore trials at 3.5 years of age. During this visit, we had the opportunity to meet and talk with Dr. Ben N. Chikamai (director of KEFRI), and Dr. Bernard Kigomo (Senior Deputy Director, Research & Development). Both of them reaffirmed KEFRI's commitment to forestry research and the importance of their strategic alliance with Camcore.

Good growth in the KEFRI-TBPT 4-year-old progeny test of *P. tecunumanii* at the Turbo research station in the Rift Valley ecoregion in Kenya.

Mexico

Gary Hodge and Juan José Acosta visted **Uumbal** in February. Field stops included tests established in the states of Puebla and Veracruz and Uumbal's new nursery facilities. Camcore proposed a method to accelerate the clonal screening of F_2 hybrids to evaluate their quantity and quality of resin. In April, Juan José made a short visit to a pine resin processing plant in Nuevo León and the quality control laboratory in Monterrey. The purpose of this visit was to understand which resin properties are the most important to the mill so that they can be considered during the selection of the best genotypes for Uumbal's breeding program.

Gary Hodge and Juan José Acosta visited **Proteak** in February. During their visit, they began a study to determine whether the percentage of heartwood in teak is genetically controlled and how variable this trait is under different environments. They also visited the nursery and several Camcore studies and operational plantings established by the company's research team. First generation provenance-progeny tests of *E. pellita* looked great compared to nearby operational plantations of *E. urophylla*. *Eucalyptus pellita* has good potential for the company's breeding program and can be used as a pure species or as a hybrid parent.

Ramón Aguilar and Erick Morales (Proteak) with some very nice *E. urophylla* identified in Camcore trials.

Mozambique

In September, Juan Luis Lopez and Juan José Acosta visited the plantation project of **Florestas de Niassa** (FDN) in Lichinga, Mozambique. The main commercial hardwood species planted is *E. urophylla* x *E. grandis* and for softwoods, *P. maximinoi* and *P. tecunumanii*. Camcore is providing FDN genetic material of these and other alternative species for the establishment of genetic trials in the region. Some of the species showing potential at this point are *E. dunnii*, *E. pellita*, and *E. longirostrata.* FDN will need to continue to refine its species-site matching and develop its own improved populations to make the company competitive in plantation forestry.

Camcore is very committed to helping **Green Resources Mozambique** (GRM) develop an effective tree breeding program with eucalypts and pines. Juan Lopez and Juan José Acosta visited the project in Lichinga in September. They made recommendations on how to obtain good quality information from the trials for data analysis. Camcore will run a BLUP analysis for *P. maximinoi* and *P. tecunumanii* to start making selections in the GRM progeny trials. The implementation of a clonal program of *E. grandis* x *E. urophylla* will help the company be more competitive.

South Africa

Gary Hodge visited **Komatiland Forests (KLF)** in August. In 2015, KLF experienced a number of hail and frost events that damaged some 2nd generation Camcore trials of *P. patula*, *P. elliottii* and *P. maximinoi*. In any operational breeding program, some losses of these kinds are unavoidable. But this points out the advantage of Camcore membership and collaboration in genetic testing. We share the work and the risk, so that everyone benefits and has access to important genetic material. Despite these challenges, KLF continues to make good progress in their breeding programs. Camcore helped KLF with the 5-year BLUP analysis of their *P. patula* x *P. tecunumanii* and *P. elliottii* x *P. caribaea* F_1 progeny tests, and we recommended full-sib crosses to make for commercial production. Crosses were made, seed was collected, and hedges established. In 2016, 8-year data will be available from the *P. patula* x *P. tecunumanii* F_1 tests, for re-analysis prior to full commercialization of those families.

Gary also visited with **York Timbers** in August. York continues to increase its emphasis on planting the *P. patula* x *P. tecunumanii* hybrid, which made up nearly 50% of its 2015 planting program. In addition to working with the Camcore pine hybrid program, York has a very strong internal breeding and testing effort with an array of hybrids. Some other hybrids which look to have commercial potential include *P. patula* x *P. oocarpa*, and *P. greggii* S x *P. tecunumanii*. A very nice surprise was the impressive growth of *P. greggii* S x *P. herrerae*, a hybrid that we have not seen before. It would be good to repeat this cross and begin to test it more widely. York's *P. tecunumanii* seed orchard at Goedgeloof is developing nicely, and York was able to contribute some pollen to the Camcore *P. patula* x *P. tecunumanii* crossing program. York's major focus is pine sawtimber, but they have some interest in eucalypts, with idea of veneer or MDF as a product. As a result, York will participate in the Camcore eucalypt hybrid testing project in South Africa.

Gary Hodge and Juan Lopez visited **PG Bison (PGB)** in August, prior to the Regional Meeting. PGB has established five Camcore pine hybrid trials, and both *P. patula* x *P. tecunumanii* and *P. patula* x *P. oocarpa* show great commercial potential when compared to pure species. Several *P. greggii* Camcore trials have been thinned in recent years to obtain improved seeds of the species for commercial plantations and second generation progeny trials, and seed collections are in process. PGB will make some seed collections of *P. greggii* (S) by family for Camcore 2nd generation progeny trials. PGB has done a great job with the conservation parks of the Mexican species *P. arizonica, P. englemannii,* and *P. cooperi*. The NE Cape is one of the few locations in the program where these cold-tolerant, long-rotation species are well adapted, so the provenance-progeny tests have been thinned and converted into conservation parks. Finally, PGB continues to investigate the potential of eucalypts on the NE Cape, where *E. dorrigoensis*, *E. benthamii*, and *E. badjensis* are showing potential.

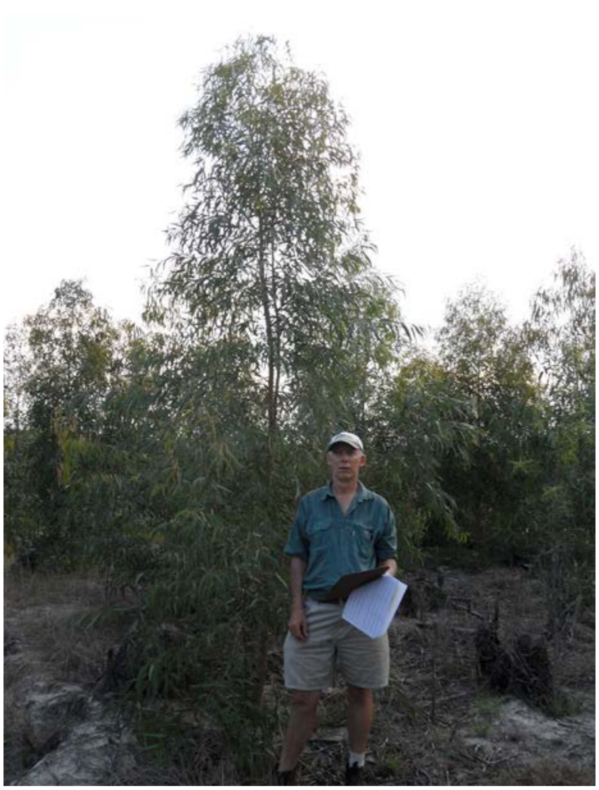
Ilse Botman (PG Bison) at the Glen Cullen site in the northern Eastern Cape, South Africa, in a 23-year old *P. cooperi* trial which has been 50% thinned for conversion into a conservation park.

John Crawford-Brunt, Leonard Mabaso, and Lizette DeWaal (York Timbers) in a plot of *P. greggii* var *australis* x *P. herrerae* (age 5 years) at Klipkraal, Mpumalanga, South Africa. This hybrid is growing very well, with growth similar to *P. patula* x *P. tecunumanii* and *P. greggii* x *P. tecunumanii*. *P. herrerae* is not as well studied or as well tested as other MesoAmerican pine species.

Gary Hodge and Juan Lopez also visited **Merensky** and their land holdings in southern KZN and the northern Eastern Cape. As with PGB, Merensky is thinking about opportunities with cold-tolerant eucalypts in this region, but for a product objective of sawtimber. We visited a *E. nitens* progeny test, planted on a site that experiences several frosts each year. We observed some frost damage in the *E. nitens*, but the survival was high. There were some *E. badjensis* on the same site that were doing quite well. It will be important to begin progeny testing *E. badjensis*, *E. benthamii*, and *E. dorrigoensis* for this region. We also visited a pine hybrid trial, and many of the patula hybrids (with *P. tecunumanii* LE, *P. tecunumanii* HE, *P. greggii* S, and *P. oocarpa*) are doing very well compared to the improved *P. patula* controls. Since the product objective is sawtimber, Merensky places a high priority on form characteristics, particularly straightness and broken tops. In 2nd generation trials of *P. tecunumanii*, Merensky has observed large family differences for broken tops at age 8, with some families having less than 10%, and some close to 70% broken tops.

Gary Hodge and Juan José Acosta visited **Sappi.** Indoor discussions with the Sappi research team included a wide array of topics: development and refinement of NIR models, a research project to investigate the potential of genomic selection, pine breeding and the Sappi breeding strategies for *E. dunnii* and the *E. grandis x E. urophylla* (GU) program. Much of the discussion about GU focused on reducing the time required for the clonal testing cycle. We also visited some progeny tests and species trials in Zululand, where one of the highlights was the one-year-old *Corymbia citriodora* progeny test. Growth and survival was very good. We also noted a tremendous amount of

Absalom Nkosi (Mondi) next to a plot of an outstanding family of *E. dorrigoensis* in a 3 ½ year-old progeny trial in Mpumalanga, South Africa.



Geoff Galloway (Sappi) in a one-year-old progeny test of *Corymbia citriodora* in Zululand, KwaZulu-Natal, South Africa.

foliage morphological variation: width and length of the leaves varied widely, some families had very glabrous leaves, others had very pubescent leaves. There is much interest in the *Corymbias* – they add genetic diversity to our hardwood programs, which may be very valuable as most programs around the world are reporting more and more disease and insect problems with eucalypts.

Following the Regional Meeting in August, Gary Hodge and Juan José Acosta visited **Mondi.** The visit focused on Mondi's cool temperate eucalypt program in southern Mpumalanga. The primary commercial species there are *E. dunnii* and *E. grandis* x *E. nitens* (GN) hybrids. The Mondi breeding team has developed an efficient scheme to produce and test GN and *E. dunnii* clones, but we looked for opportunities to make some marginal improvements in the process. We also visited a number of Camcore eucalypt species trials and provenance-progeny tests. As in other locations, *E. benthamii* and *E. dorrigoensis* demonstrate good potential, with good growth and very good frost resistance. Frost resistance for the GN hybrid is still an issue. At one test site near Belfast (latitude 27°S), which had experienced severe frosts, GN hybrids suffered much damage and dieback, and the majority of the trees had multiple stems. In contrast, the *E. dunnii* and the *E. benthamii* showed no damage from the frost. Mondi has already begun a clonal seed orchard of *E. benthamii* and *E. dorrigoensis*, and will be able to add selections of these species from Camcore trials.

The MTO-Camcore pine hybrid trial (age 6 years) at Kruisfontein, Western Cape, South Africa.
Left: a plot of *P. patula* x *P. tecunumanii* hybrid with good survival.
Right: André van der Hoef in plot of *P. radiata* with very low survival, and remaining trees infected by *Fusarium.*

Gary Hodge visited **MTO/group** at the end of August. The company has been primarily focused on pine sawtimber with some 35,000 ha in the Cape, but in 2015 MTO expanded by acquiring 46,000 ha of plantation land in the lowveld of Mpumalanga and Limpopo. The company is now referred to as MTO/group, with two forestry divisions, MTO/cape and MTO/lowveld, which will focus on pines and eucalypts, respectively. With the expansion into eucalypts, MTO will become more involved in Camcore's eucalypt breeding and testing programs. The 2015 visit was in the Cape, focused on pines, and we visited a number of 2nd generation *P. tecunumanii* and *P. maximinoi* trials, and hybrid trials. The most important new development is difficulty in establishing new plantations of *P. radiata*. Over the past 5 years, foresters are observing very high levels of mortality, presumably due to *Fusarium.* The good news is that *P. maximinoi*, *P. tecunumanii*, and the *P. patula* x *P. tecunumanii* hybrid all are demonstrating very good survival and growth in the Cape. MTO has done a good job establishing tests of these species, and should be able to shift commercial production to these new varieties. The company has made numerous selections in Camcore trials, and is grafting and rooting the material for establishment into seed orchards.

Tanzania

Establishment of genetic trials with seeds sent by Camcore continues to be an important part of the tree improvement program at **Green Resources Tanzania** (GRT). During their visit to GRT in 2015, Juan Lopez and Juan José Acosta gave recommendations on the establishment and management of the trials. The trials of *E. grandis* and *E. urophylla* include some superior individuals and families that will make great selections for parents for the hybrid between these species. These selections will produce very useful clonal trials and greatly improved commercial plantations. Similar results are being obtained with the *P. maximinoi* and *P. tecunumanii* progeny trials.

Uruguay

Gary Hodge and Robert Jetton visited **Weyerhaeuser** in June. Second-generation families of *P. greggii* are showing excellent growth potential in trials and continue to outperform the *P. taeda* controls. We were also impressed with the performance of the *P. greggii* x *P. tecunumanii* hybrid at Weyerhaeuser. *Pinus maximinoi* is also growing and surviving well in Uruguay, but it does not show the same potential as *P. greggii* or the *P. greggii* x *P. tecunumanii* hybrid. Among the eucalypts, several cold-tolerant species are also doing very well in various Camcore trials at Weyerhaeuser, including *E. benthamii*, *E. dorrigoensis*, and *E. badjensis* that all show good survival, growth, and form. During this visit, Gary and Robert also reviewed and made plans for two important forest health research projects with the Weyerhaeuser research team, the *Thaumastocoris* impact study and the eucalypt pathogen screening project. Forest health and plantation security are important issues for Camcore now and in the future and we are pleased that Weyerhaeuser is contributing to the program in this area.

Simon Bayo (Green Resources Tanzania) in a newly established *P. tecunumanii* progeny test.

Gary Hodge and Juan Luis Lopez visited **Montes del Plata (MdP)** in December. MdP has done a great job with a number of Camcore species trials and progeny tests. Across all sites, the best survival and growth was observed in *E. benthamii* and *E. dorrigoensis*, and it is clear that these species have commercial potential in the region. The primary commercial species for MdP has been *E. dunnii*, and compared to that species, both *E. benthamii* and *E. dorrigoensis* have much better frost resistance. At a minimum, this will offer MdP the logistical advantage of extending their normal planting season into the early winter, and be assured of good survival. In addition, however, both species appear to have faster growth, at least on some sites, and they may offer some fiber property advantages. Another factor is that *E. dunnii* has been reported to have higher calcium contents in the wood than is found in other eucalypts (specifically, *E. grandis* and *E. globulus*). High calcium content could have a significant negative impact in a pulp mill. We have an opportunity to study genetic variation in wood calcium content in *E. dunnii*, using a large population sampled by Juan Pedro Posse (Weyerhaeuser, Uruguay), who is working on his PhD at NC State University.

Venezuela

Terranova de Venezuela is planting new studies of *Eucalyptus,* sent by Camcore, to look for species with faster growth than *Pinus caribaea* for plantations in the eastern plains of Venezuela. New trials of *E. pellita*, 2nd generation *E. urophylla* and drought-hardy eucalypt species will be planted soon to complement existing trials of *E. brassiana* and *E. camaldulensis* planted in 2013. These latter species are showing survival of over 90% and acceptable levels of growth at early ages.

Juan Lopez visited **Smurfit Kappa Venezuela** (SKV) in February. He recommended that the company increase productivity through the use of wood density and pulp yield as selection criteria in the tree improvement program with eucalypts. SKV sent wood samples of 60 *E. urophylla* selections to be tested with the Camcore NIR models for wood chemistry (lignin, cellulose, and sugars). Wood density will be measured by Camcore in the laboratory and a pulping study will be conducted by the company pulp mill with some of the selected trees. The *E. urophylla* selections will be used for the establishment of clonal trials and 2nd generation studies.

Cristián Montouto and Monica Heberling (Montes del Plata) in a Camcore progeny test of *E. dorrigoensis* (age 4.5 years) at La Rosada farm, Uruguay. On the left is *E. dunnii*, on the right is an outstanding family of *E. dorrigoensis*.

Regional Technical Meetings

Camcore continues to hold regional technical meetings in Africa, northern South America and southern South America. At these meetings, representatives of Camcore members gather to share ideas, technical knowledge and experience. It is a great opportunity for breeders and managers to discuss objectives and strategies for Camcore projects that companies in the region have in common. This year the hosts of the regional meetings were Sappi and Mondi in South Africa, Smurfit Kappa in Colombia, and Klabin in Brazil. At all three meetings there was an update on Camcore accomplishments including the pine and eucalypt research projects and a presentation by Juan José Acosta on the utility of molecular markers in applied breeding programs.

The northern South America meeting was hosted by Smurfit Kappa Colombia, and three members from Colombia, one from Venezuela, and one from Mexico took part. Representatives had the opportunity to learn about the genetic programs at Smurfit Kappa. Updates on the Camcore teak and gmelina programs, wood properties of pine hybrids, and other research projects in Camcore were presented to the group. There was a field tour the second day to La Suiza farm in Restrepo, Valle, with visits to a *P. tecunumanii* seed orchard, a pine hybrid trial, a *Eucalyptus* species trial, a study of nutrient deficiency in eucalypts, the phytosanitary lab, and the nursery.

In the southern South America meeting, hosted by Klabin, attendance was also good, with two members each from Argentina, Brazil, Chile and Uruguay. Juan Lopez and Juan José Acosta from Camcore attended this meeting. We proposed the development of a cooperative breeding project with *P. tecunumanii x P. greggii,* whose reciprocal hybrid has shown great results in Camcore pine hybrid trials. The project will begin in 2016, and seven members will participate. In the field trip near Telêmaco Borba in Paraná state, interesting discussions were held on the pine progeny trials, pine seedling seed orchards, pine and eucalypt hybrid trials, and a clonal plantation of eucalypts.

Southern Latin America Meeting.

The meeting in South Africa had good attendance with participants from six South African members, one member from Kenya, and one from Tanzania. Gary Hodge, Juan Lopez and Juan José Acosta from Camcore all attended. Several research projects were discussed, including the *P. patula* x *P. tecunumanii* breeding project, 2nd generation seed collections and distribution, wood assessments in pine hybrids, status of conservation of genetic material from Camcore, and results from Camcore pine hybrid studies in South Africa. The field tour visited holdings of Mondi, Sappi, KLF and MTO including several genetic trials and conservation parks, a clonal seed orchard located in the Kwambonambi area, and Mondi's new nursery.

Northern Latin America Meeting.

Southern Africa Meeting

Eucalyptus Breeding Update

Eucalyptus breeding and testing at Camcore started in 1996 with seed collections of *E. urophylla*. in Indonesia. As of 2015, Camcore has distributed to its members around the world more than 200 trials of this species, testing 62 provenances and 1104 families that have provided valuable information on growth and wood quality. In 2015, we published a meta-analysis paper for *E. urophylla* in which we analyzed genetic variation for stem volume growth at provenance and within-provenance levels (see publications and paper in this report). The analysis was carried out on a large trial series of 125 provenance-progeny tests in five countries.

In 2008, Camcore started a major expansion of its work with *Eucalyptus*, collecting and testing genetic material of tropical, subtropical and temperate *Eucalyptus* and *Corymbia* species. Figure 1 is a summary of the total number of tests sent by Camcore to its members. Note that we have expanded our suite of species and diversified our genetic base so that members can select material that is more resistant to diseases, drought or frost, and identify new species that can be used as hybrid partners and increase their productivity.

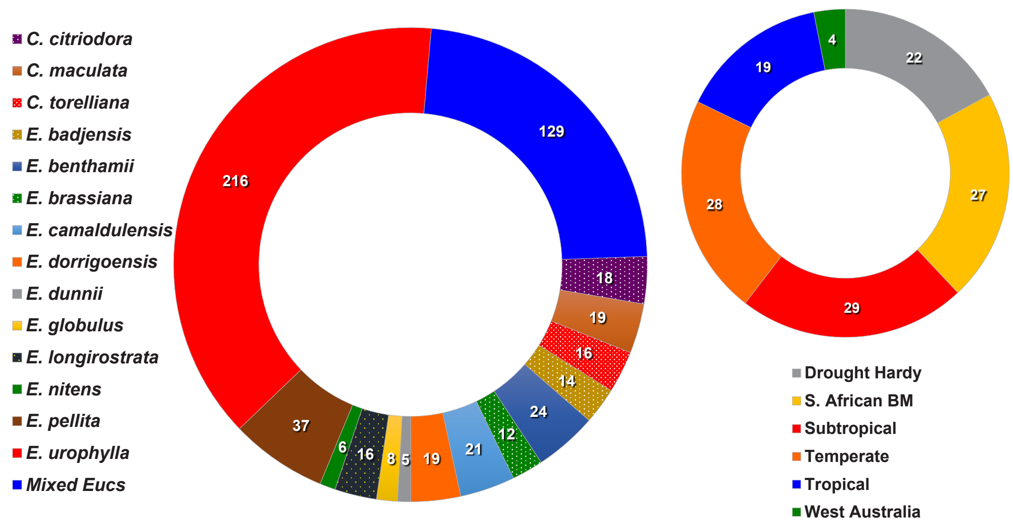


Figure 1. *Eucalyptus* and *Corymbia* trials sent to Camcore members as of December 2015. The right circular plot is a detailed breakdown of the mixed *Eucalyptus* species trials (the blue section on the left plot)

During the last few years, Camcore members have made great efforts in the establishment, maintenance, and measurement of *Eucalyptus* and *Corymbia* trials. In 2015 we sent several sets of seed for establishment of at least 12 provenance and progeny trials to our members in Mexico, Mozambique and Venezuela (Table 1). We also started a disease-screening project for 12 *Eucalyptus* species in Colombia and Uruguay (see article in this report), and we are very close to establishing an exciting series of trials of *Eucalyptus* hybrids over a wide environmental range with members in Brazil, Chile, Colombia, South Africa, Uruguay and Venezuela (see article in this report).

Table 1. *Eucalyptus* trials sent to Camcore members during 2015

Species[1]	Member	Provs.	Families
Eucalyptus urophylla	Green Resources Moz.	35	60
Eucalyptus brassiana	Green Resources Moz.	8	24
Eucalyptus camaldulensis	Proteak	3	24
Eucalyptus urophylla 2nd. Gen	Masisa	2	25
Eucalyptus pellita	Masisa	6	45
Eucalyptus mixed (Drought hardy)	Masisa	4	4
Species	**Member**	**Species**	
Eucalyptus spp. Disease screening	Weyerhaueser	12	
	Smurfit Kappa Colombia	12	

Eucalypt Hybrid Project Update

In 2011, a group of Camcore members agreed to participate in a cooperative Eucalypt Hybrid Breeding Project. The objectives of this project were to create full-sib families of a wide array of eucalypt hybrids and assess their potential in different environments. When this project began, Camcore had a strong genetic base for *Eucalyptus urophylla* and we had just begun to expand our genetic base with other *Eucalyptus* species. For this reason, participants in the project used their proprietary genetic material as hybrid parents, and different crosses were assigned to members based on availability of parents. The idea was to produce hybrids with potential in any geographic region or climate, and the goal was to produce 20 full-sib families of each hybrid. The rationale was that this would be sufficient to test the commercial potential of the hybrid, explore the patterns of genetic variation, and provide a genetic base for the selection of progeny or clones from hybrids that demonstrated commercial potential.

By the end of 2015, hybrid seeds for the following crosses were successfully produced, collected and distributed (Table 2): *E. grandis* x *E. pellita*, *E. grandis* x *E. benthamii*, *E. grandis* x *E. brassiana*, *E. grandis* x *E. dunnii*, *E. grandis* x *E. globulus*, *E. grandis* x *E. nitens, E. grandis* x *E. smithii*, *E. urophylla* x *E. brassiana* and *E. urophylla* x *E. pellita*. We are very pleased with the results of this first eucalypt hybrid crossing program. In 2016, members will begin test establishment and we are confident that we will find some very interesting hybrid combinations and genotypes.

This project is one of a kind and demonstrates a major benefit of Camcore's cooperative work: sharing the cost, workload, and results. As of 2015, Camcore has built a substantial genetic resource of eucalypt species (see article "*Eucalyptus* Breeding Update" in this report). These new eucalypt genetic resources have been distributed widely among all Camcore members, putting us as a group in a very strong position to move forward. We are excited about the future Phase 2 of the Eucalypt Hybrid project.

Table 2. Distribution of hybrid full-sib families for the Camcore Eucalypt Hybrid Project.

Member	Hybrid	FS families
Arauco-Bioforest	*E. grandis x E. globulus*	17
	E. grandis x E. dunnii	13
	E. grandis x E. benthamii	10
	E. grandis x E. smithii	26
CMPC Forestal Mininco	*E. grandis x E. globulus*	17
	E. grandis x E. dunnii	12
	E. grandis x E. benthamii	10
	E. grandis x E. smithii	26
Smurfit Kappa Colombia	*E. grandis x E. brassiana*	24
	E. urophylla x E. brassiana	26
	E. grandis x E. globulus	17
	E. urophylla x E. pellita	11
	E grandis x E. pellita	19
Smurfit Kappa Venezuela	*E. urophylla x E. pellita*	11
	E grandis x E. pellita	19
South Africa:	*E. urophylla x E. brassiana*	30
• Komatiland	*E. grandis x E. globulus*	17
• Merensky	*E grandis x E. pellita*	20
• Mondi	*E. grandis x E. dunnii*	12
• Sappi	*E. grandis x E. benthamii*	9
• York Timbers	*E. grandis x E. nitens*	20
	E. grandis x E. smithii	26
WestRock Brazil	*E. grandis x E. globulus*	17
	E. grandis x E. dunnii	12
	E. grandis x E. benthamii	11
	E. grandis x E. smithii	26
Weyerhaueser	*E. grandis x E. globulus*	17
	E grandis x E. pellita	19
	E. grandis x E. dunnii	13
	E. grandis x E. benthamii	12

Pine Hybrid Project Update

As part of the long-term Pine Hybrid Project, Camcore members have produced 23 verified pine hybrid crosses and established 82 trials in 8 countries: Argentina, Brazil, Colombia, Kenya, Mozambique, Uruguay, South Africa and Tanzania. A number of companies served as Regional Coordinators, which involved receiving the hybrid seeds, producing rooted cuttings from hedges, and distributing the hybrid plants to the different member companies within the country. In South Africa, regional coordinator Mondi also sent cuttings to Mozambique, Kenya and Tanzania. Three series of different hybrid seeds have been shipped to the members, the first in 2005, the second in 2007, and the third in 2011. Some of the trials established in these countries have been measured at 1, 3 and 5 years of age, giving results on volume growth that show the commercial potential of different hybrids. At five years, the hybrids from the first series with the best potential in Argentina and Brazil are *P. elliotii* x *P. caribaea*, and *P. caribaea* x *P. tecunumanii* low elevation (Figure 2). At three years, the most promising hybrid in the second series is *P. greggii* var. *australis* x *P. tecunumanii* high elevation (HE) (Figure 3). All of these hybrids are growing much faster than the *P. taeda* controls, the commercial species planted in the region.

In parts of South Africa at low elevations, where *P. elliottii* is the commercial species, a number of hybrids appear to offer superior growth. For example, in one MTO trial, *P. elliottii* x *P. caribaea*, *P. patula* x *P. tecunumanii*, *P. patula* x *P.*

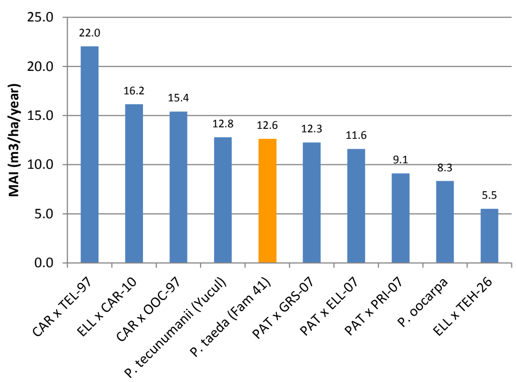


Figure 2. Mean annual increment of pine hybrids at Bosques del Plata (Argentina) at 4.5 years of age.

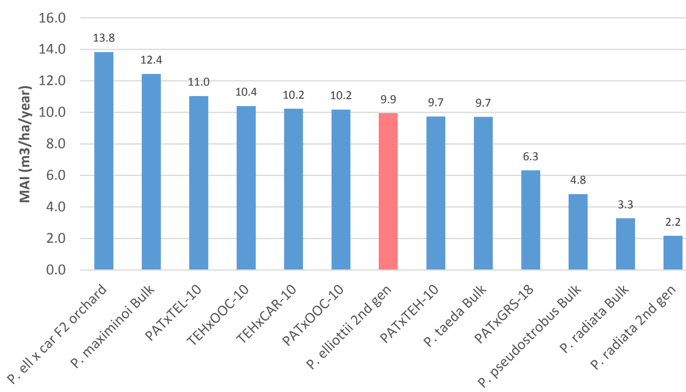


Figure 4. Mean annual increment of different taxa in a Camcore pine hybrid trial at MTO (South Africa), five years old, at elevations where *P. elliottii* is the commercial species.

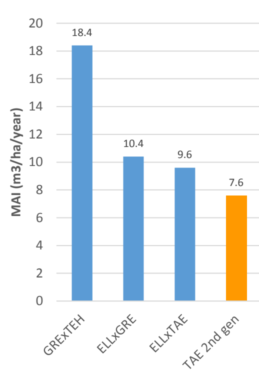


Figure 3. Mean annual increment of pine hybrids at Klabin, (Brazil) at 3 years of age. Notice the excellent mean annual increment of *P. greggii* x *P. tecunumanii* compared to improved *P. taeda* and other hybrids.

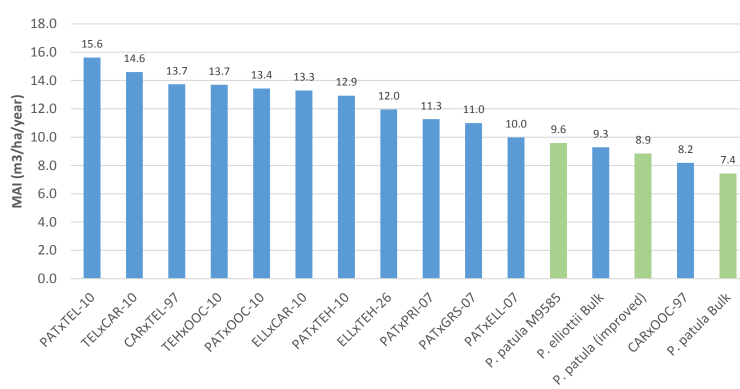


Figure 5. Mean annual increment of different taxa in a Camcore pine hybrid trial at Mondi (South Africa) at 5 years of age, at elevations where *P. patula* is the primary commercial plantation species.

oocarpa, *P. tecunumanii* x *P. caribaea*, and *P. tecunumanii* x *P. oocarpa* all have better volume than the improved *P. elliottii* controls (Figure 4).

Throughout much of South Africa where *P. patula* is planted commercially, the growth of the *P. patula* x *P. tecunumanii* hybrid, particularly with the low elevation (LE) *P. tecunumanii*, is much greater than *P. patula.* Other hybrids with commercial potential under similar environmental conditions are *P. caribaea* x *P. tecunumanii* LE, *P. patula* x *P. oocarpa*, *P. elliottii* x *P. caribaea*, *P. tecunumanii* HE x *P. oocarpa*, and *P. patula* x *P. tecunumanii* HE (Figure 5).

More trials will be planted by Camcore members in 2016 with the third series of hybrids shipped in 2015. Additional seed collections were made from crosses performed in 2013 by Bosques del Plata in Argentina, CMPC Forestal Mininco in Chile, Klabin in Brazil, and Sappi and York in South Africa.

Camcore *P. patula* x *P. tecunumanii* Hybrid Breeding

In the annual meeting held in Chile in 2012, many Camcore members, mainly from South Africa, agreed to embark on a cooperative breeding program of *P. patula* x *P. tecunumanii* using Camcore selections. The main objectives of the program were to 1) produce 250 full-sib families of the hybrid to be tested in progeny trials and 2) select the best families and best individuals in the progeny trials for operational deployment in commercial plantations.

The project is being implemented in the *P. patula* clonal seed orchard at Lions River, Howick, part of the Sappi Shaw Research Centre. Pollen collections and controlled crosses began in 2013, and 53 crosses were made that year. These activities continued with 111 new crosses in 2014 and 135 in 2015. Forty-three females of *P. patula* have been crossed with 53 males of *P. tecunumanii* HE and 44 males of *P. tecunumanii* LE. Two hail storms damaged the seed orchard, one in 2013 and another in 2014, causing losses of over 60% of the cones. With the number of crosses completed so far, it is very likely that the target of 250 full-sib families will be reached in 2016. The seeds produced will be sent to regional coordinators to grow hedges for vegetative propagation and distribution of rooted cuttings for the establishment of the progeny trials. Before seed distribution to the regional coordinators, verification of true hybridity will be made using molecular markers on seedlings. Crosses between the parents of the best families selected from the trials at eight years of age will be repeated for seed production. Again, these seeds will be used to grow hedges in the nursery to produce cuttings at a commercial scale for plantation establishment.

Sappi team and the equipment used to make crosses and collect cones in the *P. patula* clonal seed orchard at the Shaw Research Centre.

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

Based on results from the Camcore pine hybrid trials at four years of age, the hybrid between *P. greggii* var. *australis* and *P. tecunumanii* HE has shown excellent growth and adaptation in Argentina, Brazil, Colombia, and Uruguay. Some advantages of this hybrid include frost resistance acquired from the *P. greggii*, tolerance to *Fusarium circinatum* from the *P. tecunumanii*, and superior wood and pulp properties coming from both species. Because of these multiple advantages and a high potential, some Camcore members from Latin America made the decision at the 2015 Camcore annual meeting in Texas to start a cooperative breeding program with this hybrid.

Logistical and biological reasons led to a decision to develop the project using the reciprocal hybrid: *P. tecunumanii* x *P. greggii*. The objectives of this breeding project are the same as those of the *P. patula* x *P. tecunumanii* in South Africa. The crosses to obtain the 250 full-sib families will be made using 50 female trees in a *P. tecunumanii* clonal seed orchard at Smurfit Kappa Colombia with pollen collected from 44 selected trees of *P. greggii* by Camcore. Seven members will participate in the project: Arauco Argentina and Bosques del Plata in Argentina, Smurfit Kappa in Colombia, Klabin and WestRock in Brazil, Weyerhaeuser in Uruguay, and Uumbal in Mexico.

Fabricio Biernaski (Klabin) in a block of 5-year-old *P. greggii* x *P. tecunumanii* in Paraná, Brazil.

Clonal seed orchard of low-elevation *P. tecunumanii* on the La Suiza farm, Valle del Cauca, Colombia (Smurfit Kappa Colombia).

Tectona grandis and *Gmelina arborea* Update

In 2015 Camcore continued sending seeds of teak and gmelina to its members for the establishment of new Camcore provenance-progeny trials in Colombia and Mexico. Proteak in Mexico received the teak seeds in time for planting this year and the company established two new Camcore trials with four provenances from Laos and one or more provenances from each of Indonesia, Bangladesh, Thailand, Colombia, Costa Rica, Guatemala, Venezuela and Mexico. The seeds sent to Tekia in Colombia were retained for several weeks in customs, delaying planting until 2016. Camcore also shipped two 2nd generation *Gmelina arborea* trials to Tekia with seeds collected from plantings in Smurfit Kappa Venezuela and Forestal Monterrey in Colombia.

The total number of teak trials planted by current Camcore members to date is ten: two by Grupo DeGuate, four by Proteak, and four by Tekia. The trials planted include genetic material from the four countries of origin, 2 countries where teak is naturalized, and 18 land races from seven countries where the species is planted commercially.

Results from a four-year-old Camcore provenance-progeny trial at Tekia, Colombia are presented in Figure 6. Seeds originally from Thailand and planted in Costa Rica by Grupo DeGuate are showing the greatest volume. Other sources from East Kalimantan in Indonesia and Smurfit Kappa Venezuela (a control lot) exhibit good performance in the study.

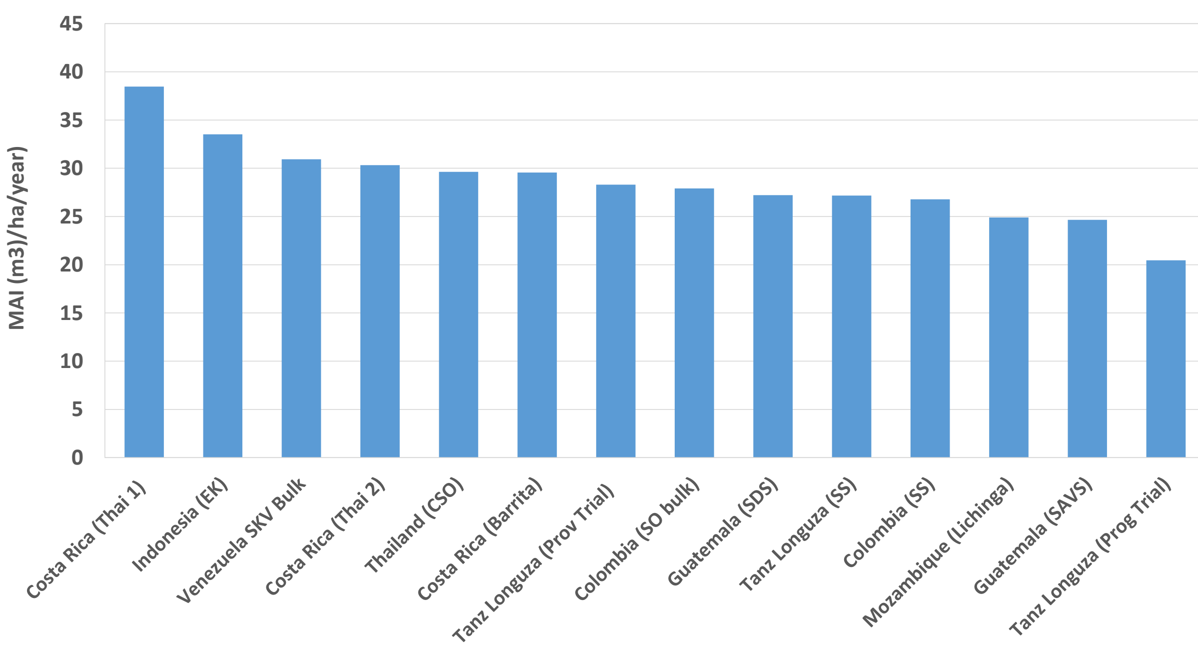


Figure 5. Teak volume growth (m^3/ha) of different sources of teak in a Camcore-Tekia trial in Colombia.

Genetic Control of Heartwood Production in Teak

Teak is grown for the production of high quality hardwood, and commands high prices in the world market. It is well known, however, that the price of teak wood in the market is highly influenced by the proportion of heartwood: the greater the heartwood, the higher the price. If heartwood percentage is under genetic control, it could be included as a selection criterion in breeding programs. This is of critical interest to Camcore members who grow teak, so for some time we have been looking for sutitable genetic tests where this could be studied.

Elmer Gutiérrez (Camcore) measuring heartwood diameter on teak logs with help from local workers at Valle Verde farm in Guatemala.

Materials and Methods

The testing strategy outlined in 2009 for Camcore teak trials called for the provenance-progeny trials to be thinned when trees start competing with each other after crown closure. The two Camcore trials in Guatemala, one in Retalhuleu (Valle Verde farm) and another in Izabal (Macho Creek farm) were thinned at 4.5 years of age. Taking advantage of the trees cut during the thinning, a study was designed to assess genetic parameters of diameter growth and heartwood proportion, including heritability and genotype x site interaction, as well as the genetic correlation between diameter growth and heartwood percentage at early ages. The two trials in Guatemala each have 65 families with 27 of these in common. Out of the six trees per family per plot, three were left standing and three were thinned. Using the felled trees, logs at 1.3 meters (DBH), 3 meters and 6 meters were cut. Using a ruler, log diameter (inside bark) and heartwood diameter were measured in two directions perpendicular to each other at both ends of the logs. The heartwood percentage was calculated as the ratio between the two diameters.

Results

Heartwood proportion was greater at the base of the tree and smaller at the top. In Valle Verde farm, the average heartwood was 43.5% at the stump and 20.7% at DBH, while in Macho Creek it was 22.6% at stump and 3.6% at DBH. It is important to note that the tree growth in Valle Verde was considerably greater than in Macho Creek. Heritability was calculated for heartwood percentage at breast height, and for the mean at the stump and breast height. As seen in Table 3, heritability for heartwood percentage at these heights was $h^2 = 0.11$ and 0.15 respectively. Similar values were obtained for the heritability of the growth trait "diameter inside bark". The family x site interaction was moderate, with a Type B correlation (r_{Bg}) varying between 0.37 and 0.51 for both traits. This means that there is some variation in the ranking of the families between sites. Perhaps most importantly, the genetic correlation between the heartwood percentage and the diameter inside bark was $r_g = 0.73$, which is relatively high. As a preliminary conclusion it could be said that by selecting trees with the best diameter growth, we are also selecting trees with the greatest heartwood proportion. The results of this study will be completed in 2016 when 2 more trials with different environmental conditions and families in Colombia will be measured the same way.

Table 3. Genetic parameters of teak heartwood proportion and diameter inside bark of trees from two Camcore progeny trials in Guatemala.

Trait	Location	h^2	r_{Bg}
Heartwood %	Base & DBH	0.15	0.51
	DBH	0.11	0.37
Diameter inside bark	Base & DBH	0.09	0.46
	DBH	0.15	0.49

Pine Hybrid Wood Properties

Introduction

Compared to pure species, pine hybrids may offer superior growth due to heterosis or "hybrid vigor", and may show better drought and frost tolerance, disease resistance, or wood properties. In 2002, Camcore started developing its pine hybrid program, with the idea of testing an array of pine hybrid bulks to determine their commercial potential. In a combined effort, Camcore members have attempted more than 40 different interspecific crosses. Since 2007, our members have planted 82 pine hybrid trials with 23 verified hybrids in Africa and Latin America. So far, we have good growth data that has allowed us to identify hybrids of great interest to our members, such as *Pinus patula* x *P. tecunumanii* in Africa and *P. greggii* x *P. tecunumanii* in Latin America. At the 2014 annual meeting in Guatemala, the technical committee approved a new phase of the hybrid project with the main objectives to do the following: 1) evaluate variation of wood properties among pine hybrids, 2) rank hybrids based on wood traits, and 3) compare hybrid wood properties to those of pure species.

Materials and methods

In March 2015, we evaluated trees on two sites on Smurfit Kappa Colombia's land. The first site, 8-year-old trial 98-02-H01A1, is located on Delicias farm close to the city of Armenia, Quindío and the second site is 5-year-old trial 98-02-H02A3 located on Los Chorros farm just outside the city limits of Popayán, Cauca. General information about each trial is presented in Table 4. At both sites, we randomly selected 35 trees per hybrid, with the exception of two hybrids TAExCAR and PATxPRI; only 22 trees were sampled for TAExCAR due to mortality and for PATxPRI, only 23 trees were labeled as true hybrids based on phenotypic identification made by Bill Dvorak in 2014. For each selected tree, field measurements and wood samples were taken at breast height to assess three wood traits using the methods described below.

- Cellulose/Lignin content: we used hand drills to collect wood shavings from just inside the bark to just short of the pith. Oven-dried wood shavings were shipped to North Carolina State University where samples were ground into woodmeal and scanned on a FOSS 6500 NIR spectrophotometer. Spectra generated for each sample were processed using Camcore's Global Pine NIR models to estimate lignin and cellulose content.

- Modulus of Elasticity (MOE): In its simplest form, MOE measures wood stiffness and is a good overall indicator of strength. We estimated MOE using the TreeSonic. This tool measures the time needed for stress waves to propagate between two sensors inserted into

Table 4. Description of sampling sites used for wood characterization of pine hybrids.

Site	Delicias	Los Chorros
Camcore ID	98-02-H01A1	98-02-H02A3
Established	Dec-2007	Nov-2010
Latitude	4˚ 64' N	2˚ 26' N
Longitude	75˚ 55' W	76˚ 33' W
Elevation (m.a.s.l)	2,140	2,206
Precipitation (mm)	3,900	2,100
Hybrids (Label)	*P. caribaea* X *P. oocarpa* (CARxOCC) *P. caribaea* X *P. tecunumanii* LE (CARxTEL) *P. patula* X *P. greggii* (PATxGRS) *P. patula* X *P. pringlei* (PATxPRI) *P. patula* X *P. tecunumanii* HE (PATxTEH)	*P. elliottii* X *P. greggii* (ELLxGRS) *P. elliottii* X *P. taeda* (ELLxTAE) *P. greggii* X *P. tecunumanii* HE (GRSxTEH) *P. taeda* X *P. caribaea* (TAExCAR)

the stem of a standing tree. With the measured time and known distance between the sensors, fiber direction velocity is calculated, which correlates very well with MOE and in turn, predicts wood strength.

- Density: We used the IML-Resistograph to obtain the radial density profile of the trees. This system measures the drilling resistance of a thin needle inserted into the bole. The energy required to drill through the entire stem is measured at small increments and this resistance is directly proportional to the density at each point of the stem.

Statistical analysis for this project included the fitting of a generalized linear model (GLM) for each trait (% cellulose, % lignin, resistance, and MOE). Significance of each model was evaluated and if variation between hybrids was found, pairwise comparisons (differences) were made between the hybrid's LSMEANS. Confidence intervals for the mean response of each trait were also calculated and plotted. All analyses were made using R version 3.2.1.

Results and Discussion

The variation associated with hybrids was significant (all P-values were less than 0.001), which indicates that there are statistical differences between hybrid means; these results were consistent for both sites and all traits. At Los Chorros, the hybrid ELLxTAE had the lowest values for resistance, MOE and percent cellulose and the highest percent lignin. Interestingly, the other hybrids (ELLxGRS, GRSxTEH and TAExCAR) have high values for resistance and MOE; moderate to high percent cellulose and low to moderate percent lignin (Table 5).

At Delicias, PATxTEH and PATxPRI showed the highest values for resistance and MOE, and had high cellulose and low lignin. PATxTEH was the best hybrid of the series with the highest resistance, MOE and percent cellulose and the lowest percent lignin. Hybrids that included *Pinus caribaea* were in the lowermost tail of the trait distribution (Table 6).

To study the relationship between Resistograph and density, we took increment cores from 50 trees per site, stratified across hybrids. In the lab, we measured specific gravity, and calculated the correlation between specific gravity (wood density) and resistance (from the resistograph). In Delicias, there was little or no relationship between wood density and resistance (r = 0.157, see Figure 7). This was an unexpected finding and we believe that it might be due to higher moisture content in the trees that could reduce the resistograph's ability to capture density differences between trees. As noted in Table 4, the annual rainfall on this site is almost twice as much as at Los Chorros.

Juan José Acosta (Camcore) using the IML-Resistograph to measure wood density.

Ovidio Orrego and Liliana Perafán (SKC) using the TreeSonic to measure wood stiffness.

Wilman Serna (SKC) taking wood shavings for NIR estimation of lignin and cellulose.

Contrary to results at Delicias, the coefficient of correlation in Los Chorros was very high (r = 0.899, see Figure 7). A strong linear relation between density and resistance was observed and we were able to fit a statistically significant linear model to these two variables.

This is the first set of hybrid trials for which we have characterized wood properties. In 2016 we will sample and measure two tests each in Argentina, South Africa and Brazil. Our goal is to evaluate at least 10 trials from our members in the next few years.

Table 5. LSMEANS and Confidence Limits for hybrids present on Los Chorros farm.

Hybrid	Resistance				Lignin %				Cellulose %				MOE			
	LSMEAN[1]		LCL[2]	UCL[2]	LSMEAN[1]		LCL[2]	UCL[2]	LSMEAN[1]		LCL[2]	UCL[2]	LSMEAN[1]		LCL[2]	UCL[2]
ELLxGRS	1008.9	B	978.6	1039.2	27.8	A	27.5	28.1	42.2	C	41.9	42.5	8.05	B	7.72	8.38
ELLxTAE	816.8	A	785.5	848.0	30.5	C	30.2	30.8	39.8	A	39.5	40.1	4.90	A	4.56	5.24
GRSxTEH	973.0	B	940.6	1005.3	29.8	B	29.5	30.0	41.5	B	41.1	41.8	7.63	B	7.27	7.98
TAExCAR	1024.5	B	984.9	1064.1	28.3	A	27.9	28.6	41.7	BC	41.3	42.0	7.53	B	7.10	7.96
PATxTEH	895.9	B	865.9	926.0	26.8	A	26.5	27.1	42.8	B	42.5	43.2	12.84	C	12.10	13.59

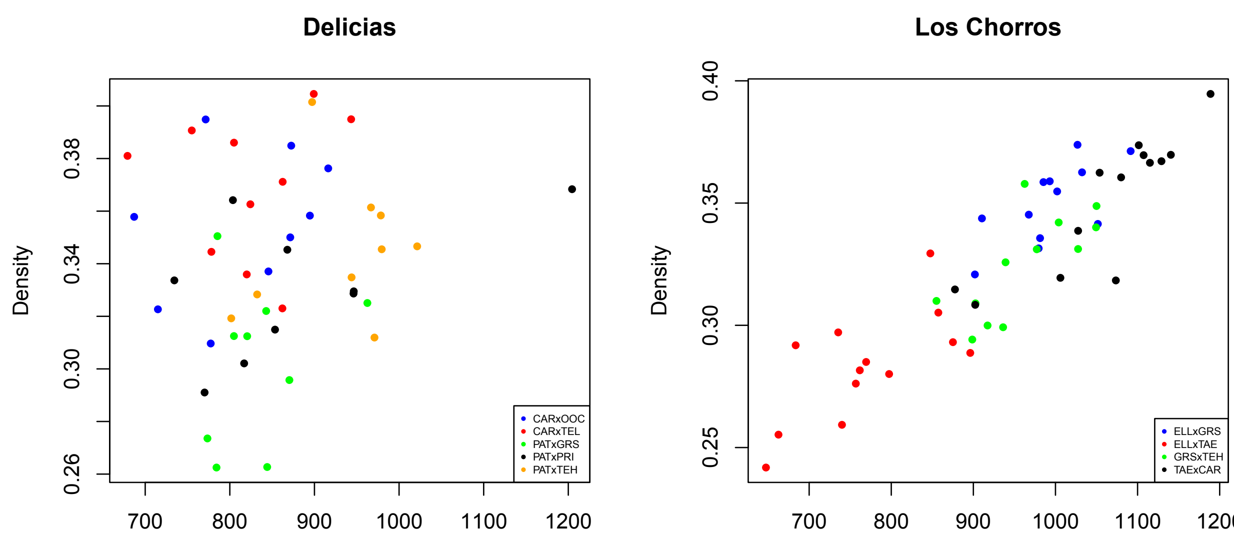
Table 6. LSMEANS and Confidence Limits for hybrids present on Delicias farm.

Hybrid	Resistance				Lignin %				Cellulose %				MOE			
	LSMEAN[1]		LCL[2]	UCL[2]	LSMEAN[1]		LCL[2]	UCL[2]	LSMEAN[1]		LCL[2]	UCL[2]	LSMEAN[1]		LCL[2]	UCL[2]
CARxOOC	805.5	A	775.4	835.6	28.7	D	28.4	29.0	39.5	A	39.1	39.8	6.97	A	6.23	7.71
CARxTEL	836.0	A	805.9	866.0	28.2	CD	27.9	28.5	39.6	A	39.3	40.0	7.52	A	6.78	8.26
PATxGRS	833.8	A	803.6	863.9	27.2	AB	26.9	27.5	42.7	B	42.4	43.1	10.22	B	9.47	10.97
PATxPRI	908.0	B	870.8	945.3	27.7	BC	27.3	28.1	42.3	B	41.8	42.7	11.34	BC	10.42	12.26
PATxTEH	895.9	B	865.9	926.0	26.8	A	26.5	27.1	42.8	B	42.5	43.2	12.84	C	12.10	13.59

[1] LSMEAN, hybrids with the same letter represent a nonsignificant subset.

[2] LCL (Lower Confidence Limit) and UCL (Upper Confidence Limit), both with alpha=0.05.

Figure 7. Scatter plots per site. X-axis is resistance, Y-axis is density.



Genetic Control of Wood Properties in *Pinus taeda*

Introduction

Camcore members in Argentina, Brazil and South Africa initiated a Genotype x Environment (GxE) interaction study for *Pinus taeda* and planted trials in 2006 and 2007. The objectives for this study were: to determine the size and patterns of GxE, and to exchange material of *P. taeda* among members to increase genetic diversity for all participants. Five-year data showed that there was relatively small GxE interaction among sites at both the provenance and family-within-provenance levels (Annual Report 2012). We found provenance differences, but very consistent rankings across sites. The best sources were Arauco and Bosques del Plata in Argentina and Inpacel in Brazil. Late in 2013, participating organizations of this study decided to evaluate the genetic variation of wood properties in this population and to rank the top half of the population (based on growth) for important wood traits.

Materials and methods

We evaluated two 8-year-old trials, one at Bosques del Plata (BDP), Argentina, and one at WestRock (WR), Brazil. All seven provenances were evaluated on each site and approximately half of the families from each site (between 57 and 60) were sampled in this study. The sampling protocols used were the same as described earlier in this Annual Report (see article "Wood Properties of Pine Hybrids"). The traits measured were: Modulus of Elasticity (MOE), density, and cellulose and lignin content predicted from NIR spectra. All measurements were taken at breast height. The following genetic parameters were estimated: single-site heritability (h^2_b), across-site heritability (h^2) and type B genetic correlation (r_{Bg}).

Results and Discussion

Results for MOE (measured indirectly with TreeSonic) and wood density (using IML-Resistograph) were presented in the 2014 Annual Report. Single-site heritability values for TreeSonic velocity (MOE) were h^2_b = 0.33 and 0.43 for the BDP and WR tests, respectively. For mean Resistance (functionally equivalent to mean density), single-site heritability estimates were h^2_b = 0.62 and 0.36 for the BDP and WR sites. All of these values are in line with expectations for wood traits, that is, moderate to high heritability. Combined-site analyses were done for both traits (Tables 7 and 8). For TreeSonic, across-site heritability was h^2 = 0.40 with zero GxE (r_{Bg} = 1.00). For Resistance, across-site heritability was h^2 = 0.35 with moderate GxE (r_{Bg} = 0.71).

Table 7. Single-site heritability (h^2_b) estimates for wood property traits of *P. taeda* grown in Brazil and Argentina.

Site	MOE	Density	Cellulose	Lignin
Argentina	0.33	0.62	0.02	0.12
Brazil	0.43	0.36	0.30	0.21

Table 8. Across-site heritability (h^2_b) and Type B genetic correlation (r_{Bg}) estimates for wood property traits of *P. taeda* grown in Brazil and Argentina.

Trait	h^2	r_{Bg}
MOE	0.40	1.00
Density	0.35	0.71
Cellulose (%)	0.17	1.00
Lignin (%)	0.16	0.95

Estimated single-site heritabilities for cellulose and lignin are presented in Table 7. Parameters for cellulose were h^2_b = 0.02 and 0.30 for the BDP and WR sites, respectively. For lignin, they were h^2_b = 0.12 and 0.21 for the BDP and WR trials, respectively. Across-site heritability (h^2) and type B genetic correlation (r_{Bg}) were calculated for both traits (Table 8). For cellulose, across-site heritability was h^2 = 0.17 with zero GxE (r_{Bg} = 1.00). For lignin, across-site heritability was h^2 = 0.16 with very small GxE (r_{Bg} = 0.95).

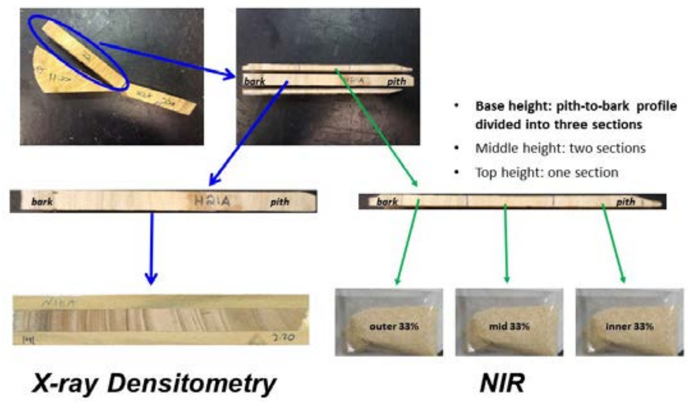
These results are consistent and support what we concluded for growth traits when these trials were 5 years old. Although there are provenance differences, ranks are very consistent across sites. As a consequence, low levels of GxE for wood properties were observed. This suggests that there is a great opportunity to exchange genetic material among members of Argentina, Brazil and Uruguay. Camcore members participating in this project can use this population to expand their genetic bases for *Pinus taeda* and create a joint breeding program for the species.

Within-tree Variation in Wood Chemistry in *E. globulus*, *E. nitens*, and *E. nitens* x *E. globulus*

Introduction

In recent years, much of our research work in Camcore has focused on characterizing different species, provenances and hybrids for their physical and chemical wood properties. In addition to variation among species, and among whole trees, there might be important variation at the within-tree level. For example, the pattern of pith-to-bark variation in temperate conifers is well known: in general, moving from pith to bark, we see increasing density, decreasing microfibril angle, increasing timber strength, and slight tendency for increasing cellulose and decreasing lignin.

In the 2014 Annual Report, we presented initial results on within-tree density variation in *E. globulus*, *E. nitens*, and the *E. nitens* x *E. globulus* hybrid. The wood samples for this study were provided by CMPC Forestal Mininco (Chile), and the study was motivated by questions about optimal rotation length for various species and product objectives. In 2015, we extended this study to look at within-tree variation in chemical properties. Here we present those results, and summarize earlier results with density.



Schematic of sampling methodolgy to measure within-tree variation in density and wood chemistry.

Materials and Methods

CMPC collected wood samples from 34 trees of three species: *Eucalyptus globulus*, 14 trees, age 15; *E. nitens*, 10 trees, age 20; and *E. globulus* x *E. nitens*, 10 trees, age 15. From each tree, 5-cm-thick disks were cut from the stem at 3 heights: base (breast height), top (height where diameter was 10 cm), and mid height (the midpoint of the other two). The disks were dried and shipped to Raleigh for processing.

Sections from each disk were cut with a band saw with the following protocol: from each base and mid-height disk, one radial wedge and 2 rectangular bark-to-pith sections were marked. From the top disk, a single bark-to-bark rectangular section was excised. The wedges are for gravimetric density measurements and the rectangular sections were for X-ray densitometer and NIR scanning. After more cutting, each disk yielded two rectangular bark-to-pith "planks" (for a total of 6 per tree), one plank for X-ray analysis and additional plank that was ground into wood meal for NIR scanning. The planks were glued onto wooden holders and resawn with a custom blade setup that produces 2-mm-thick sections that can be loaded into the densitometer. A total of 204 samples were scanned; 2 reps each of 3 disks from 34 trees.

The within-tree chemistry variation (pith-to-bark, and base-to-top) was measured as follows. Each tree provided two pith-to-bark samples at each height. The pith-to-bark planks from the base height were divided into 3 sections, the planks from the middle height were divided into two sections, and one half of the plank from the top was considered one section. The plank sections were then ground into woodmeal, and scanned with the laboratory Foss 6500 NIR. A very accurate two-species NIR model (based on *E. urophylla* and *E. dunnii*) was used to predict the following wood chemical properties: lignin, proportion of syringyl lignin, cellulose, and xylose. The NIR model had R^2 = 0.84 for glucose, and R^2 = 0.97 for the other three traits. Average values for the chemical properties were calculated for the different heights and positions in the tree.

Results and Discussion

Within-tree variation (pith-to-bark, top-to-bottom) for density and chemical properties is summarized in Figure 8. The density profiles for each variety are represented by three pith-to-bark lines, one at each height. Details of how these lines were calculated are presented in the 2014 Annual Report. The *E. nitens* profiles are slightly longer due to the fact that those samples were from age 20 trees, while the *E. globulus* and hybrid samples were from age 15 trees. The solid circles on the density graphs represent the mean density of the corresponding section that was analyzed for chemical properties. The chemical profiles are represented by six pie charts: three for the base, two for the middle, and one for the top. Each pie chart presents chemical content of glucose, lignin, xylose, and other components.

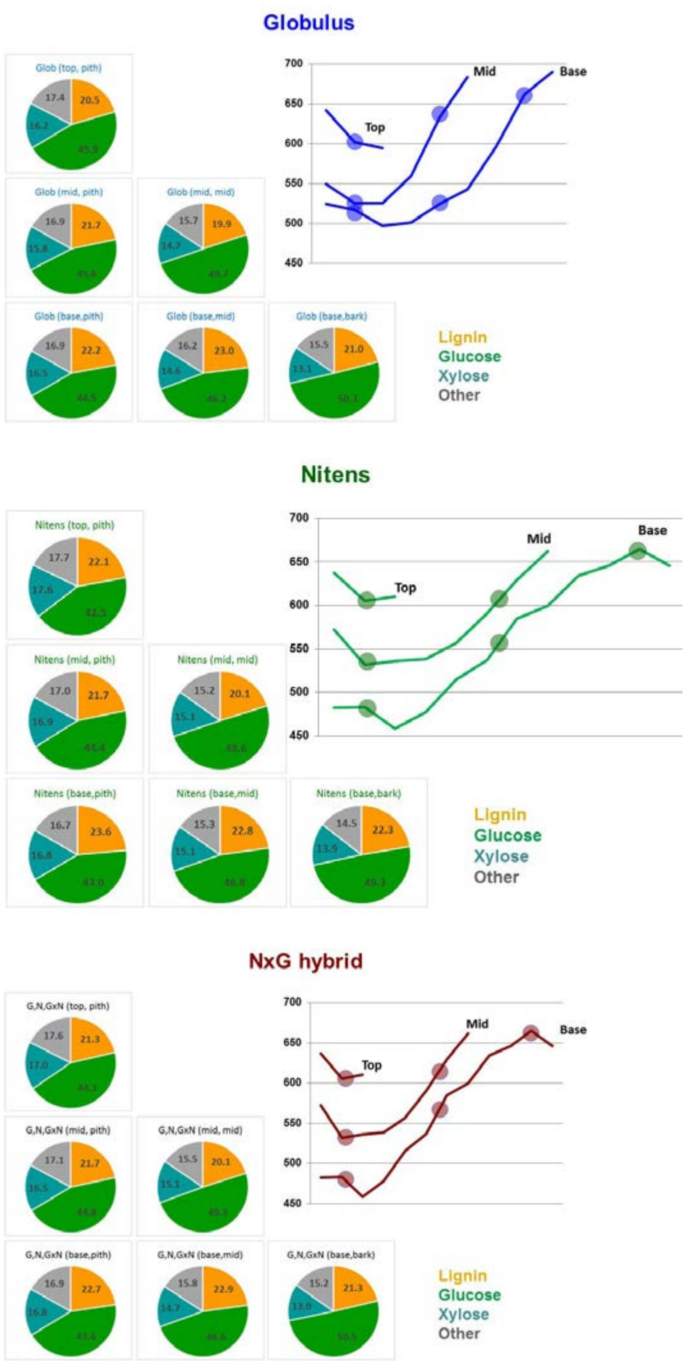


Figure 8. Within-tree variation (pith-to-bark, at three heights) in density (kg/m^3) and wood chemistry in *E. globulus*, *E. nitens* and *E. nitens* x *E. globululs* grown in Chile.

The density profiles show a very clear pattern that is consistent among the three varieties. First, density increases as one moves up the stem. For *E. globulus*, the density of the pith section increases from about 520 kg/m^3 at the base to just over 600 kg/m^3 at the top. For *E. nitens* and the hybrid, the pattern is very similar: the density of the pith section is around 480 kg/m^3 at the base, 540 kg/m^3 in the middle, and 610 kg/m^3 at the top. Second, at all heights, density decreases from the pith for 3 to 6 years, then steadily increases. This is clearly seen in the pith-to-bark curves for the base height and mid height for all three varieties.

The chemical profiles are more subtle than the density profiles, but they correspond nicely. Moving up the stem, lignin percentage decreases slightly, and glucose percentage increases slightly. For example, in *E. globulus*, the lignin content of the pith section decreases from 22.2% at the base height, to 21.7% at the middle height, to 20.5% at the top. For the same sections, glucose content increases from 44.5% to 45.6% to 45.9%. The other varieties show similar patterns. The change in chemical content with height is similar, but slightly more dramatic in the middle section of the pith-to-bark profile. For example, for *E. globulus*, the middle profile section of the base height had 23.0% lignin and 46.2% glucose, while the corresponding profile section of the middle height had 19.9% lignin and 49.7% glucose.

Syringyl lignin (S) is easier to remove in the pulping process than guayacyl lignin (G). The NIR models used in this study measure the proportion of syringyl lignin, calculated as S-pct = 100 x (S/(S+G)). Results for S-pct are not presented, but this value is related to lignin content. In general, as lignin content decreases, S-pct increases. Mean values for S-pct for *E. globulus* ranged from 82.0 to 84.2% depending on the location in the stem.

Mean values for S-pct for *E. nitens* were lower, from 78.0 to 82.2%. *Eucalyptus nitens* also generally had lower densities than *E. globulus*, so these data correspond with the fact that *E. nitens* is considered slightly less desirable than *E. globulus* as a pulping species. Interestingly, the hybrid seemed to be more similar to *E. nitens* in terms of its density profile, but more similar to *E. globulus* in terms of its chemical properties.

Summary and Conclusions

There is clear within-tree variation for both density and chemical properties. Although there can be significant variation between individual trees for important wood traits, the pattern of variation is consistent across trees and varieties. In general, moving from pith to bark, and from the base of the tree to the top, there can large changes in density, e.g., increases of around 200 kg/m^3. Glucose content increases moderately from pith-to-bark (around +6%) and slightly from base-to-top (around +2%). As glucose increases, lignin decreases and the proportion of desirable lignin (S-pct) increases. An understanding of these patterns could have an impact on optimal rotation age, harvesting practices, and woodyard procedures.

Update on *Eucalyptus* Pest and Pathogen Research

Introduction

Forest health and the impacts of forest insects and diseases on natural and planted forests continue to be topics of much concern among foresters worldwide. Of particular concern to many Camcore members is the growing list of pests and pathogens of eucalypts that continue to be introduced into many countries at an alarming rate and can affect seedlings and trees in both nurseries and plantations. The rise of insect and disease threats to the security of eucalypt plantations has coincided with the global increase in hectares planted to eucalypts and the growth of Camcore's eucalypt breeding program. Moving forward, it is paramount that Camcore and its members understand how our eucalypt genetic material interacts with pests and pathogens, identify the potential impacts on productivity, and develop integrated pest management strategies for those that pose a real threat. The following sections present updates on two projects currently underway in this important area of research.

Thaumastocoris Impact Study

In 2012, Camcore began a field study with Weyerhaeuser and INIA in Uruguay to evaluate the impacts of the eucalyptus bronze bug, *Thaumastocoris peregrinus*, on the productivity of plantations of *E. benthamii*, *E. grandis*, and a *E. grandis* x *camaldulensis* clone. Details on the experimental design were presented in the 2012 and 2013 Camcore Annual Reports and will not be restated here. Briefly, the objectives of this project are to develop an insect exclusion method that will allow for the measurement of tree height and diameter growth differences between bronze bug infested and uninfested trees, and then utilize the data on growth differences to determine the impacts of infestation on eucalypt productivity and potential economic losses at the mill. The goal is to determine if, for a particular tree species, the presence of actively feeding bronze bug populations warrants investment in pest management strategies such as biological or chemical controls. Insect exclusion is being achieved through stem injections of the neonicotinoid insecticide imidacloprid, and growth differences and bronze bug population densities for each species are being compared between paired insecticide-treated/untreated plots on higher and lower quality planting sites in trials distributed across the northern zone of Uruguay. The study is ongoing, but after 3 years of evaluation the following conclusions can be made. The insecticide injections were successful at introducing imidacloprid to the trees, however the residual activity of this insecticide in eucalypts appears to be very shortlived (approximately 1 year). Imidacloprid did reduce bronze bug populations in treated plots but did not completely exclude the insect. Where insect pressure is highest, in the *E. benthamii* field plots, early trends in diameter growth data suggest that the bronze bug may have a significant impact on productivity. Bronze bug densities have remained low in treated and untreated plots of *E. grandis* and the GC clone throughout the study and growth trends for these species are inconclusive. A more detailed report and journal manuscript on the early results of this study will be forthcoming.

Eucalyptus Pathogen Screening Project

At the 2014 Camcore Annual Meeting in Guatemala, the Camcore Technical Committee approved a new research project to screen Camcore eucalypt genetic material for resistance to pathogens of concern to members. The project is a collaboration between Camcore, Smurfit Kappa Colombia (SKC), and Weyerhaeuser and INIA in Uruguay, and the initial phase will test Camcore breeding material of *E. urophylla*, *E. pellita*, *E. brassiana, E. camaldulensis, E. grandis*, *E. dunnii*, *E. longirostrata*, *E. benthamii*, *E. dorrigoensis*, *E. badjensis*, *E. globulus*, and *E. nitens* against the pathogens *Puccina psidii, Botryosphaeria,* and *Teratosphaeria* (Coniothyrium Canker). Future phases will test the additional pathogens *Ceratocystis, Chrysoporthe,* and *Cylindrocladium.* Due to delays in the importation of seeds for the study into Colombia and Uruguay, this study is still in the planning phase, but we anticipate making significant progress in 2016. Seeds have arrived in Uruguay where seedlings are currently being grown for field and greenhouse screening of Coniothyrium and laboratory screening of *Puccinia psidii.* Seedling production is being coordinated by Paola Molina and Jorge Martinez Haedo from Weyerhaeuser and the screening schedule and protocols are being coordinated by Sofia Simeto and Guillermo Perez from INIA. The seed import permit for Colombia is still being processed, but plans are already in place at SKC so that work can start immediately when seed and seedlings are ready. Nhora Isaza and Carlos Rodas are coordinating the seedling production and pathogen screening, respectively, aspects of the project at SKC.

American Chestnut Rooting Study

In 2015, Camcore began collaborating with The American Chestnut Foundation (TACF) on research to develop a system for rooting stump sprouts of American chestnut *(Castanea dentata)* for breeding and deployment purposes. American chestnut is a tree that once dominated much of the forested area of the eastern United States before being driven to near extinction in the early 1900s by the exotic bark canker fungus *Cryphonectria parasitica*, commonly referred to a chestnut blight. TACF was founded in 1983 with the goal of restoring American chestnut to its native range through the development of blight-resistant genotypes utilizing a backcross breeding approach to transfer the blight resistance of Asian chestnut species into the American chestnut. During the past 33 years, TACF has made substantial progress towards reaching its goal of having blight-resistant genetic material ready for deployment into restoration plantings; however, much of the work along the way, including establishment of progeny trials and seed orchards, has been accomplished via seed rather than rooted cuttings. The development of methods for rooting cuttings will allow TACF to further streamline its breeding and deployment programs and allow for the capture of American chestnut genotypes resistant to *Phytophthora cinnamomi,* another exotic pathogen that threatens the species, while reducing the risk of this pathogen being introduced to breeding orchards. Our research on chestnut rooting is being conducted in collaboration with former Camcore Associate Director Jeff Donahue who currently serves as the Director of Operations for TACF's Meadowview Research Farm in Virginia. Three small pilot studies were conducted during the summer of 2015 testing the effects of several factors on the success of stump sprout rooting, including family, clone, cutting type (apical versus basal), and rooting compound formulation (liquid versus powder) and concentration. Results from these preliminary studies were promising and indicate several avenues for future research. We look forward to continuing our new relationship with TACF in 2016 and beyond.

Global NIR Models for *Eucalyptus* Wood Chemistry

Introduction

Camcore has done a great deal of work with NIR spectroscopy, mostly focused on the development of models to predict wood characteristics. NIR offers the breeder a fast, precise, and inexpensive method to assess wood properties for hundreds or thousands of trees in a breeding populations. We have NIR models for pine wood chemistry (lignin, cellulose) that are based on multiple species, age, and environments: "global" models that we believe are robust enough and precise enough that we can use them for screening pine wood samples from any pine species from anywhere in the world. We have also learned that we can effectively transfer these models to any member NIR machines, so that the screening can be done "in house".

Over the past five years, Camcore has been working to develop similar global NIR models for eucalypt species. The first phase was done in 2010, and was part of a larger project to study the wood property variation of *E. urophylla* provenances. The second phase was done in 2014, and added in samples of *E. dunnii* from Uruguay (part of Juan Pedro Posse's PhD research). The third phase expanded the model with samples of *E. globulus* and *E. nitens* from Chile (thanks to CMPC Forestal Mininco). In 2016, we plan to prepare a manuscript for publication which will fully detail all methods and results, but here we present a brief summary of the most important results.

Materials and Methods

Three sets of samples were used in this study: 50 samples of *E. urophylla*, 50 samples of *E. dunnii* from Uruguay, and 50 samples of *E. globulus* and *E. nitens* from Chile (41 and 9 samples, respectively). In each case, the 50 samples were pre-selected from a larger set of samples ranging from 400 to 1700 (described below).

All samples that were scanned with NIR were prepared and handled in the same way. Briefly, solid wood samples were ground into woodmeal using a Wiley mill. The samples were dried at 50˚C for 24 hours, then removed from the oven and allowed to come to room temperature. They were than scanned in a Foss 6500 NIR spectrometer using a spinning sample module. Reflectance readings were taken for NIR wavelengths from 1100 to 2500 nm, at 2 nm intervals.

Wetlab chemistry on all 150 samples was done by Shawn Mansfield at the University of British Columbia. The chemistry was done on the same 4-gram woodmeal samples that were scanned with NIR, using micro-analytical techniques which will not be described in detail here. The traits measured were: glucose, xylose, mannose, arabinose, galactose, and total sugar content; soluble lignin, insoluble lignin, and total lignin content, and S-G ratio. S-G ratios were converted into S-pct = 100 x S / (S + G), where S = syringyl lignin content and G = guayacyl lignin content. Final NIR models were developed using these wetlab values.

For each of the three species sample sets, pre-selection of the 50 sample subset for wetlab chemistry was done using the same approach. All samples in the large set were scanned with NIR, and a prior NIR model was used to make predictions of chemical traits. A principal component analysis (PCA) was also done on the spectral data set for the species. The 50 samples for wetlab chemistry were then selected to ensure good representation of the variation for predicted chemical variation, and for variation of the first two principal components of the spectral dataset. The total number of samples and the NIR model used for pre-selections are summarized below:

Pre-selection of E. urophylla samples

- Total number of samples = 1672
- Prior NIR models: three models for *E. urophylla*, *E. nitens*, *E. grandis*, trait = pulp yield, R^2 ranged from = 0.63 to 0.70

Pre-selection of E. dunnii samples

- Total number of samples = 400
- Prior NIR model: *E. urophylla*, traits = glucose, xylose, insoluble lignin, S-pct, R^2 ranged from = 0.92 to 0.98

Pre-selection of E. globulus and E. nitens samples

- Total number of samples = 438
- Prior NIR model: Combined *E. urophylla* + *E. dunnii*, traits = glucose, xylose, insoluble lignin, S-pct, R^2 ranged from = 0.84 to 0.98

NIR model development

Various transformations of the spectral datasets were investigated. Eventually, a single transformation (Multiplicative Scatter Correction + Savitzy-Golay 2nd derivative) was selected and used for all models. This transformation has generally given very good results with a variety of traits in both pines and eucalypts. Both single-species NIR models and multiple-species models were investigated. To examine how well these models might extrapolate to other species not included in the original model, we used a model developed on two species to predict wetlab chemical values for the third species.

Results and Discussion

In this report, we will focus on only four wood chemical traits: glucose, xylose, insoluble lignin and S-pct, and species means for the 50 wetlab samples are presented in Table 9. The globulus-nitens had the lowest lignin percentage (18.6%), highest glucose percentage (46.9%), and highest S-pct (84.1%), while the *E. urophylla* was at the other end of the scale, with highest lignin percentage (28.6%), lowest glucose percentage (46.2%), and lowest S-pct (74.3%). The dunnii was intermediate for all of these traits. Interestingly, the dunnii was not intermediate for xylose: dunnii averaged 15.1% xylose, compared to 11.7% for globulus-nitens and 12.0% for urophylla.

Single-Species NIR Models

It was possible to develop good NIR models for all four traits for all species sample sets (Table 9). For *E. urophylla*, model R^2 ranged from 0.92 to 0.98, with standard errors of cross validation (SECV) around ± 0.6% to ± 2.2%. For *E. dunnii*, model R^2 were slightly lower, ranging from 0.89 to 0.91, with SECV around ± 0.8% to ± 1.6%. The lower R^2 with lower SECV reflect a narrower range in variation among the *E. dunnii* samples for all of the four traits, compared to the other species. For the globulus-nitens set, model R^2 were very high, ranging from 0.96 to 0.99, and SECV were very low, ranging from ± 0.3% to ± 0.9%.

Combined-Species Model

Very good NIR models for all four traits were developed using the combined three-species dataset (Figure 9, Table 10). Models for lignin (R^2 = 0.98, SECV = ± 0.7%), S-pct (R2 = 0.97, SECV = ± 1.1%), and xylose (R^2 = 0.98, SECV = ± 0.4%) were excellent; the model for glucose (R^2 = 0.84, SECV = ± 1.3%) was very good.

Table 9. Means and single-species NIR model statistics for wood chemistry traits for three species datasets. Data based on a subset of 50 samples selected for wetlab chemistry from larger samplesets.

E. urophylla			
Variable	Mean	R^2	SECV
Insoluble Lignin (%)	28.6	0.98	1.1
S/(S+G) (pct)	74.3	0.99	2.2
Glucose (%)	46.2	0.92	1.3
Xylose (%)	12.0	0.94	0.6
E. dunnii			
Variable	Mean	R^2	SECV
Insoluble Lignin (%)	23.3	0.89	0.8
S/(S+G) (pct)	81.6	0.88	1.6
Glucose (%)	46.4	0.80	1.6
Xylose (%)	15.1	0.91	0.8
E. globulus + E. nitens			
Variable	Mean	R^2	SECV
Insoluble Lignin (%)	18.6	0.99	0.3
S/(S+G) (pct)	84.1	0.99	0.3
Glucose (%)	46.9	0.96	0.9
Xylose (%)	11.7	0.98	0.4

Table 10. Summary statistics for NIR models for wood chemistry traits with a combined-species dataset.

E. urophylla, E. dunnii, E. globulus, E. nitens			
Variable	Mean	R^2	SECV
Insoluble Lignin (%)	28.6	0.98	1.1
S/(S+G) (pct)	74.3	0.99	2.2
Glucose (%)	46.2	0.92	1.3
Xylose (%)	12.0	0.94	0.6

Model Extrapolation: AB2C

To get some indication of how well the combined three-species model might extrapolate to predict species not included in the calibration data set, we examined how well different two-species models predicted the third species. For convenience, this is designated as AB2C, where A and B are the species datasets in the calibration model,

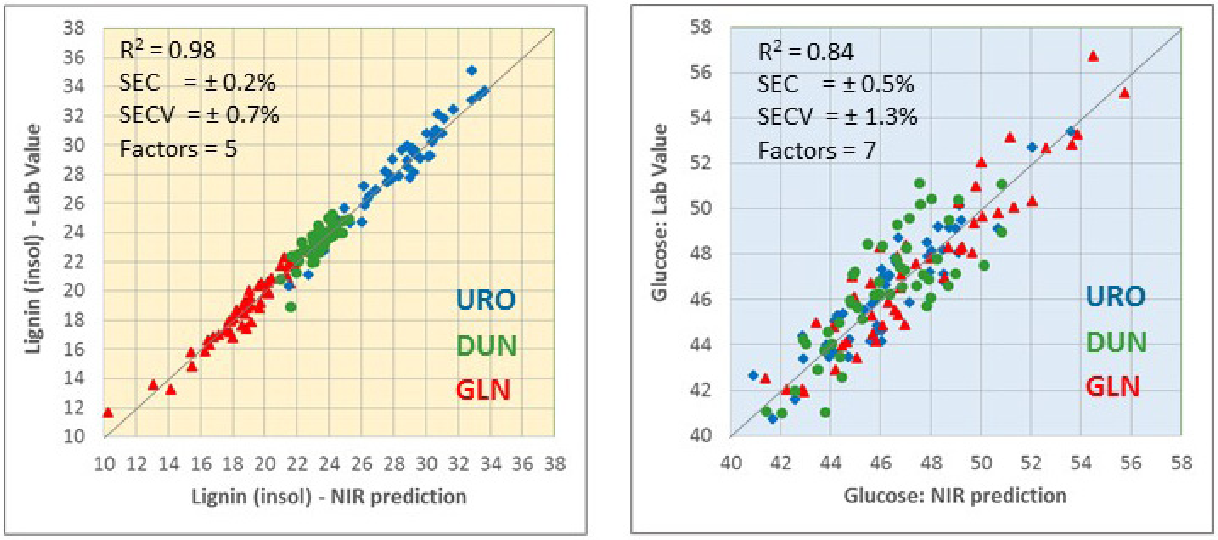


Figure 9. NIR models for insoluble lignin and glucose for a combined-species dataset containing 50 samples each of *E. urophylla*, *E. dunnii*, and *E. globulus* + *E. nitens*.

and C is the species to be predicted. Species datasets will be designated as U = urophylla, D = dunnii, and G = globulus-nitens. Table 11 presents the R^2 of calibration and prediction for each of the three combinations (UD2G, DG2U, and UG2D). The results can be summarized briefly as follows:

- UD2G worked very well for all four traits.
- DG2U worked moderately well for all four traits.
- UG2D worked moderately well for xylose and lignin, and very poorly for glucose and S-pct.

It is somewhat surprising that the extrapolation of a model calibrated with *E. urophylla* + *E. globulus-nitens* to *E. dunnii* performed so poorly (see UG2D statistics, Table 11), given that *E. dunnii* was intermediate between *E. urophylla* and *E. dunnii* for most traits. Perhaps there is something unusual about *E. dunnii* wood that affects the NIR spectra. As mentioned above, *E. dunnii* showed less variation for all traits than was observed in the other species; since the differences among dunnii samples is more subtle than in the other species, this may make it more important to have some dunnii samples in the calibration dataset. However, the models with *E. dunnii* in the calibration data set (UD2G and DG2U) extrapolated quite well to the third species.

It should also be noted that although the extrapolation may work very well in terms of R^2, and hence in terms of ranking individuals, the

Table 11. Summary statistics (R^2 of calibration and prediction) for extrapolation of two-species NIR models for wood chemistry traits to a third species.*

Variable	UD2G		DG2U		UG2D	
	R^2_{calib}	R^2_{pred}	R^2_{calib}	R^2_{pred}	R^2_{calib}	R^2_{pred}
Insoluble Lignin (%)	0.95	0.89	0.97	0.88	0.98	0.40
S/(S+G) (pct)	0.97	0.81	0.93	0.62	0.99	0.09
Glucose (%)	0.75	0.83	0.83	0.53	0.89	0.10
Xylose (%)	0.94	0.94	0.99	0.59	0.95	0.53

*U = urophylla, D = dunnii, G = globulus + nitens. Model designation is of the form AB2C, where species A and B are used to build a calibration model, and predictions are made for species C.

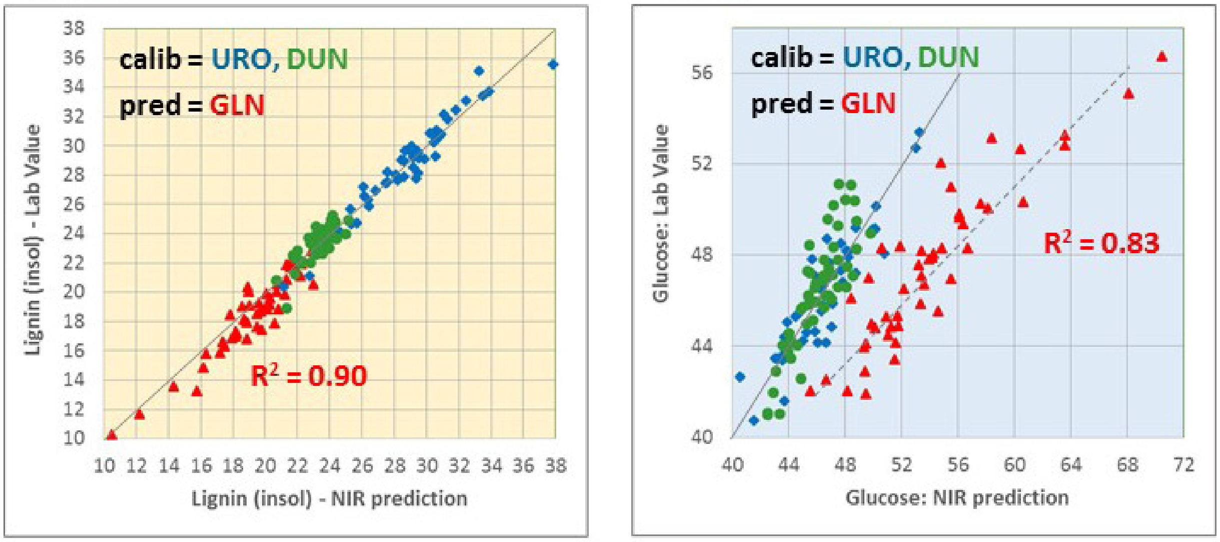


Figure 10. NIR Predicted and lab values for insoluble lignin and glucose with the UD2G extrapolation. Calibration dataset contained *E. urophylla* (URO) and *E. dunnii* (DUN), and that model was used to predict samples of *E. globulus* and *E. nitens* (GLN). For lignin, the predictions for the globulus-nitens samples (red) are precise and appear unbiased, for glucose the predictions are precise, but are biased upward.

predictions may be biased up or down from the actual wood chemistry values. For example, consider the case of UD2G for lignin and glucose (Figure 10). The predictions of lignin for the globulus-nitens dataset have a high $R^2 = 0.90$, and fall on the exact same line as the predictions for the calibration dataset of *E. urophylla* and *E. dunnii*. In other words, they are precise and unbiased. However, the predictions of glucose for the globulus-nitens dataset are biased upward (the predictions are higher than the lab values), and as a result they do not fall on the same line as the calibration dataset. Nevertheless, the correlation of the predictions and the lab values is quite good ($R^2 = 0.83$), and thus the UD calibration will provide a very good ranking of the globulus-nitens samples.

Conclusions and Outlook

Very good combined-species NIR models for important wood chemical traits have been developed. With the diversity of species used for the models, a wide range in variation is included in the calibration model, and it should be suitable for use to predict wood chemistry for most eucalypt species, with a degree of accuracy suitable for ranking candidates in a breeding program.

As opportunities develop to include additional species in the model, we will do that incrementally with a small number of samples from a new species. For example, if a project arises to study wood chemistry of *E. benthamii*, we would use the current model (urophylla + dunnii + globulus + nitens), and expand the calibration dataset with wetlab data on 10 to 15 *E. benthamii* samples.

Acknowledgements

Thanks to Weyerhaeuser Uruguay and to CMPC Forestal Mininco for contributing wood samples for this study, and to Shawn Mansfield and an army of unnamed graduate students at the University of British Columbia for their good work with the wetlab chemistry.

Utility of the Handheld microPhazir NIR Spectrometer: Models for Pine Wood Chemistry

Introduction

Over the past few years, Camcore has developed several NIR models to efficiently predict important wood properties. These NIR models are of great utility to our members' tree improvement programs since they can be used to screen many hundreds of genotypes rapidly and accurately. However, developing a robust NIR model is expensive and time consuming. Currently, some of our members have different desktop NIR instruments: Camcore, Bioforest-Arauco, and CMPC are using a Foss 6500, Mondi and Sappi use a Bruker, and Klabin uses a Shimadzu IR Prestige-21. Each NIR machine captures different wavelength information (wavelength range and capture interval). In the 2014 Annual Report, we presented results from a large project to transfer the Global NIR Pine models developed by Camcore to our associates. This report presents results from the same dataset, but examines whether the global models can be transferred to a handheld NIR instrument: the ThermoScientific microPhazir.

Materials and methods

Several pine species were sampled for this project: *P. greggii*, *P. maximinoi*, *P. patula*, *P. taeda*, *P. tecunumanii* and some *P. elliottii* hybrids. Wood wedges from breast height were collected at multiple geographic regions by our members Klabin, Mondi, Sappi and Weyerhaeuser. Samples were sent to Camcore for processing and distribution. Wedges were sliced to create "identical" samples for different members to scan (Figure 11). Each member received approximately 200 slices. Distribution of sliced wedges was done as follows: Camcore kept two sets of sliced wedges D and G, while CMPC, Klabin, Mondi, Sappi and Weyerhaeuser received a mix of slices A, B, C, E, F and Bioforest-Arauco received slice H. Each member (including Camcore) ground all its slices into woodmeal and scanned the samples using their own equipment and protocol. At Camcore, we took additional readings with the handheld NIR microPhazir instrument on slices D and G. First, for slice G of each sample, we scanned its transverse face at five non-overlapping points (Figure 11). Second, woodmeal from slices D and G were placed in a plastic bag and we scanned both sides of the bag twice (four NIR spectra per sample). For both sliced wedge and bagged woodmeal, mean NIR spectra were used for model building.

We took the following approach to transfer NIR models to other machines:

Figure 11. Schematic of wood processing and disctribution for the NIR Transfer Study, and the sampling with the handheld microPhazir NIR spectrometer. Sliced wedges were distributed among participants of this study. On the right, is the sampling procedure used for the handheld NIR instrument on wedges, and on woodmeal in plastic bags.

1. Camcore predicted lignin and cellulose using our Global Pine NIR models. Predictions were made with spectral data from the original NIR machine (Foss 6500). In other words, given that the original Camcore NIR model is very accurate for lignin and cellulose, we assumed that we had the correct "lab" values for lignin and cellulose percentage for the 200 samples. We used the average of the two NIR predictions for slices D and G as the correct "lab" value for each particular sample.
2. Spectra from all "secondary" machines were sent to Camcore for spectral comparison, data analysis, and model building.
3. We built models for all secondary machines, using partial least squares (PLS) methods. At this point, we used our members' NIR spectral data as predictors and Camcore "lab values" as response variables.

Results and Discussion:

Results for all desktop NIR instruments were presented in our 2014 Annual Report, so here we focus on results obtained for the microPhazir.

The process of building a reliable NIR model involves the use of mathematical pre-treatments (transformations) applied to the NIR spectra. The objective of applying those transformations is to remove "noise" (scattering of diffuse reflections associated with sample particle size) from the spectra in order to improve the subsequent regression. The most widely used transformation techniques can be divided into two categories: scatter-correction methods and spectral derivatives. In this study, we applied several transformations to all spectra. From the scatter-correction methods we used Multiplicative Scatter Correction (MSC), Standard Normal Variate (SNV) and De-trend (DT). From the spectral derivatives methods we used a second derivative of Savitzky-Golay smoothing with two different window sizes of 5 and 7 points (SG5 and SG7). We also created pairs of transformations (MSC_SG, SNV_SG and DT_SG).

An analysis pipeline was developed using R statistical software to easily apply all transformations and to identify local outliers based on density and distance. Transformed and outlier-free databases were used to fit NIR models. Tables 12 and 13 summarize the model statistics for each different data set. We also included the statistics of the fitted models using the untransformed data (Raw).

A desirable PLS NIR model is one that maximizes the coefficient of determination (R^2), minimizes the standard errors of cross-validation (SECV), and has a small number of projection factors. NIR models made with NIR spectra from wedges are displayed on Table 12. We obtained

Table 12. Summary statistics for NIR models based on spectra from the handheld microPhazir NIR, using predictions from the "Original" Camcore NIR model as lab values. NIR spectra come from sliced wedges (G) scanned on their transverse face.

Variable = lignin					Variable = cellulose				
Data	Factors	SECV	R^2	R	Data	Factors	SECV	R^2	R
Raw	10	0.529	0.830	0.911	Raw	10	0.516	0.813	0.902
SNV	7	0.460	0.832	0.912	SNV	7	0.505	0.797	0.893
MSC	7	0.460	0.832	0.912	MSC	7	0.503	0.795	0.892
DT	7	0.458	0.843	0.918	DT	6	0.504	0.795	0.892
SG5	3	0.487	0.818	0.905	SG5	3	0.541	0.778	0.882
SG7	3	0.485	0.803	0.896	SG7	4	0.531	0.792	0.890
SNV_SG5	4	0.484	0.828	0.910	SNV_SG5	4	0.546	0.789	0.888
SNV_SG7	3	0.498	0.788	0.888	SNV_SG7	7	0.521	0.829	0.911
MSC_SG5	4	0.484	0.828	0.910	MSC_SG5	4	0.546	0.789	0.888
MSC_SG7	3	0.498	0.788	0.888	MSC_SG7	7	0.521	0.829	0.911
DT_SG5	4	0.484	0.828	0.910	DT_SG5	4	0.546	0.789	0.888
DT_SG7	3	0.498	0.789	0.888	DT_SG7	7	0.522	0.829	0.910

Table 13. Summary statistics for NIR models based on spectra from the handheld microPhazir NIR, using predictions from the "Original" Camcore NIR model as lab values. NIR spectra come from woodmeal.

Variable = lignin					Variable = cellulose				
Data	Factors	SECV	R^2	R	Data	Factors	SECV	R^2	R
Raw	10	0.363	0.912	0.955	Raw	16	0.429	0.909	0.953
SNV	14	0.349	0.942	0.970	SNV	14	0.428	0.909	0.953
MSC	15	0.345	0.943	0.971	MSC	14	0.431	0.905	0.951
DT	11	0.346	0.932	0.965	DT	14	0.459	0.890	0.944
SG5	13	0.350	0.936	0.968	SG5	13	0.476	0.875	0.936
SG7	9	0.362	0.927	0.963	SG7	11	0.484	0.881	0.938
SNV_SG5	11	0.348	0.934	0.967	SNV_SG5	12	0.478	0.872	0.934
SNV_SG7	9	0.353	0.929	0.964	SNV_SG7	10	0.493	0.861	0.928
MSC_SG5	11	0.348	0.935	0.967	MSC_SG5	12	0.477	0.873	0.934
MSC_SG7	9	0.356	0.929	0.964	MSC_SG7	11	0.490	0.869	0.932
DT_SG5	11	0.347	0.935	0.967	DT_SG5	12	0.477	0.873	0.934
DT_SG7	9	0.351	0.930	0.964	DT_SG7	8	0.497	0.848	0.921

very good models for both lignin and cellulose. For lignin, R^2 ranged between 0.79 and 0.84, and SECV ranged between ±0.46% and ±0.53%. The transformations that generated the best models for this trait were combinations of SNV, MSC and DT with SG5, note that with a small number of factors (4) the SECV is minimized and the R^2 is very good. For cellulose, R^2 ranged between 0.78 and 0.83, and SECV ranged between ±0.50% and ±0.55%. Similarly, the best transformations for this trait were combinations of SNV, MSC and DT with SG7.

Fitted models for NIR spectra from woodmeal are presented in Table 13. Lignin and cellulose models are very good: R^2 ranged from 0.91 to 0.94 and SECV ranged from ±0.34% to ±0.36% for lignin, and R^2 ranged from 0.85 to 0.91 and SECV ranged from ±0.43% to ±0.50% for cellulose. As stated previously, the best transformation pairs were the combinations of SNV, MSC and DT with SG. Scatter-corrected data followed by spectral derivatives and outlier detection facilitates the creation of good predictive models. All fitted models using NIR spectra from two different sample types scanned with the handheld NIR instrument explained over 82% of the total variance observed. Those models also had a very small SECV (all lower than ±0.55%). Resulting models from woodmeal spectra yielded better R^2 values than models obtained from readings taken directly on the wedges, but it required an extra step to grind the samples.

Conclusions

The microPhazir NIR spectra can be used to develop very good NIR models for pine wood chemistry. The fact that we were able to develop very good models for two sample types (ground and unprocessed wedges) shows the usefulness of the handheld NIR instrument that can capture data quickly and precisely. The handheld NIR machine used here is also a good economic alternative because it may cost one third to one half the price of a desktop instrument. It is clear that using a good global NIR model to generate “pseudo" wetlab data is a quick and easy way to develop NIR models for different machines. Our method was rapid and inexpensive, and in addition, the pseudo lab data probably has less variation than laboratory data obtained using traditional wetlab chemical analyses. As a consequence, PLS models may show less error and may need fewer factors.

Utility of the Handheld microPhazir NIR Spectrometer: Models for Eucalypt Wood Chemistry

Introduction

In 2015, we examined the utility of the microPhazir handheld NIR spectrometer to measure wood chemistry properties for pine. Good models were obtained with NIR spectra on woodmeal, and on solid wood wedges (see article " Utility of the Handheld microPhazir NIR Spectrometer: Models for Pine Wood Chemistry" in this Annual Report). Here we report on a second project, using the microPhazir on solid wood strips of *E. globulus* and *E. nitens*.

Materials and methods

This project used samples of *E. globulus*, *E. nitens*, and the *E. globulus* x *E. nitens* hybrid that were collected by CMPC Forestal Mininco (Chile) for another project (see article "Within-Tree Variation in Wood Chemistry..." in this Annual Report). Briefly, there were samples from 34 trees, and from each tree, 5-cm-thick disks were cut from the stem at 3 heights: base (breast height), top (height where diameter was 10 cm), and mid height (the midpoint of the other two). For each tree, a total of 6 pith-to-bark sections were extracted from the disks, two pith-to-bark samples at each height. In total, there were 204 pith-to-bark planks. Each pith -to-bark sample was then processed for NIR scanning (Figure 12. The pith-to-bark planks from the base height were divided into 3 sections, the planks from the middle height were divided into two sections, and one half of the plank from the top was considered one section. Handheld microPhazir scans were taken from an adjacent pith-to-bark strip across the full length of the strip, on both the radial and transverse faces.

The plank sections were ground into woodmeal, and scanned with the laboratory Foss 6500 NIR, and "wetlab" values were predicted using a very accurate two-species NIR model (based on *E. urophylla* and *E. dunnii*) for the following wood chemical properties (lignin, proportion of syringyl lignin, cellulose, and xylose). The NIR model had R^2 = 0.84 for glucose, and R^2 = 0.97 for the other three traits. NIR models were then developed using the wetlab values for each section and the mean microPhazir spectrum for each section.

Results and Discussion

A number of transformations of the spectra were investigated. Results are reported here only for a single transformation which worked well for all models (SNV-SG5, Standard Normal Variate, + Savitzky-Golay 2nd derivative with a 5-point window).

Very good models were obtained for all four wood chemical properties (Table 14). For lignin, glucose and xylose content, all models had $R^2 \approx 0.90$, and SECV ≈ ±0.4%. For proportion of syringyl lignin (S/(S+G), model $R^2 \approx 0.70$, and SECV ≈ ±0.7%.

Although these models are not as good as those from the Foss 6500 laboratory machine, they are certainly good enough to be very useful in a breeding program. Given that the microPhazir scans at only 100 wavelengths, compared to 700 for the Foss 6500, this performance was very impressive.

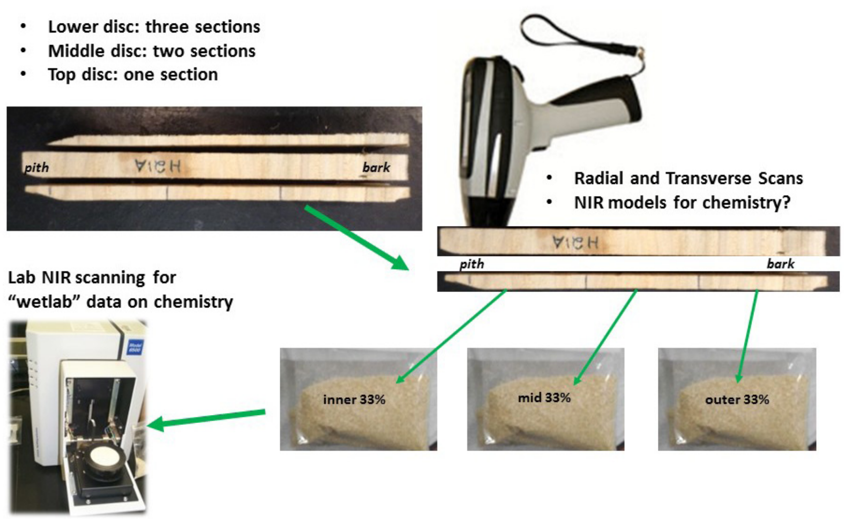


Figure 12. Schematic of sampling methodolgy to measure NIR spectra with the microPhazir.

Conclusions

It is clear that we can develop useful NIR models for wood chemistry using the handheld microPhazir. The microPhazir NIR is about one third to one half of the price of a laboratory machine. It is very fast, and depending on the project and the sampling scheme, the ability to use the handheld on solid wood samples may offer a significant time advantage.

Table 14. Summary statistics for NIR models based on microPhazir scans of radial and transverse faces of solid wood samples of eucalypts. Predictions from a lab NIR model were used as wetlab values.

MicroPhazir NIR models (Globulus, Nitens, Hybrid)				
Variable	Scan	Factors	R^2	SECV
Insoluble Lignin	Radial	11	0.90	0.44
Insoluble Lignin	Transverse	9	0.91	0.39
S/(S+G) (%)	Radial	7	0.69	0.74
S/(S+G) (%)	Transverse	7	0.74	0.69
Glucose (%)	Radial	6	0.90	0.37
Glucose (%)	Transverse	4	0.91	0.39
Xylose (%)	Radial	5	0.89	0.39
Xylose (%)	Transverse	6	0.89	0.38

Pedigree Reconstruction and "Breeding without Breeding"

In 2014, Gary Hodge and Milan Lstiburek (Czech Agricultural University) investigated the potential of using molecular markers to reconstruct pedigrees of a plantation population. The idea was to recover a post-hoc progeny test from an operational plantation. The study was done using computer simulation, and it demonstrated that a Breeding without Breeding (BwB) strategy could return about 80% to 95% of the genetic gains of a large full-sib family testing program (Lstiburek, Hodge, and Lachout 2015, in *Tree Genetics and Genomes*; see also 2014 Annual Report). In a sense, the BwB strategy allows a breeder to identify superior families and genotypes, and make genetic gain as if someone had established progeny tests years earlier.

Raul Schenone (Bosques del Plata, Argentina) with hedges from full-sib families of *P. taeda* that will be used in the BwB Pedigree Reconstruction Study.

An important assumption in this study was that the pedigree reconstruction with the molecular markers was 100% accurate. In fact, we don't know how accurate pedigree reconstruction with forest trees will be (99% accurate? 90% accurate? or less?), and we don't know how pedigree errors will affect the genetic gains. In 2016, we will begin working on a simulation model that can evaluate the impact of pedigree errors, and second, we will do a study on a population with a known pedigree to determine pedigree reconstruction accuracy.

The population we will study consists of full-sib families of Florida-source *P. taeda* in the breeding programs of Arauco Argentina and Bosques del Plata. We will sample 364 progeny of 40 parents mated to form 38 full-sib families. This will give us a total of 66,066 pairs of progeny, of which 1546 are full-sibs, 3304 are half-sibs, and 61,216 are unrelated. Foliage samples have been collected, and will be sent to the Forest Molecular Genetics program at the University of Pretoria in South Africa. The samples will be analyzed with 30 SSR markers, and pedigree reconstruction will be done assuming that the parental genotypes are unknown (as in a real-life application). However, since we are also sampling the parents, we will be able to confirm pedigree with near 100% accuracy. The results will let us know how accurate pedigree reconstruction using only progeny data will be, and thus provide better estimates of the potential genetic gains (and costs) of the BwB strategy.

Camcore Seed Collections 2015

Elmer Gutiérrez and Josué Cotzajay made collections of *P. tecunumanii* and *P. maximinoi* seed in seven natural populations: two in Guatemala and five in Honduras (Table 15). *Ex situ* conservation continues to be one of Camcore's main objectives. The conservation of genetic material from Central American countries is carried out through the establishment of genetic studies, conservation parks, and reintroduction studies on Camcore members' land. The conservation status of the natural pine stands where seeds are collected is assessed by Camcore staff with help from local people using the standards of the International Union for Conservation of Nature (IUCN).

Several factors affect the conservation status of natural tree populations, often fragmented and degraded, in Central American countries. Agriculture is usually competing with forest land use, especially on sites with deep soils and good physical properties. The felling of trees is common practice for the establishment of coffee, corn and other agricultural crops such as beans, tomatoes, potatoes, and cardamom. The lack of management of natural pine stands sometimes favors attacks by pests such as *Dendroctonus* bark beetles, which deplete large expanses of forest. Other factors with large impacts on forest decline are cattle raising, forest fires, illegal logging, resin extraction and other uses by the local communities.

A number of Camcore member studies have been converted to conservation. Other members are planting conservation parks to conserve genetic material collected by Camcore in Mexico and Central America. Two Camcore reintroduction studies with *P. patula* and one with *P. greggii* have been planted in Mexico with help from the Colegio de Postgraduados in Texcoco, Mexico and Universidad Autónoma Agraria Antonio Narro in Saltillo, Coahuila. Four reintroduction studies with *P. maximinoi* have been planted in Alta Verapaz and one of *P. tecunumanii* in Jalapa, Guatemala through the Instituto Nacional de Bosques (INAB). Some of these studies are being converted to seed production areas by thinning or rogueing and leaving the best families.

Josue Cotzojay (Camcore) climbing a *Pinus maximinoi* in Guatemala to collect seed for gene conservation.

Table 15. Summary of seed collections completed in Central America in 2015.

Country	Species	Provenance	Conservation Status	Latitude	Longitude	Trees
Guatemala	*P. maximinoi*	Cobán	Critically endangered	15° 22'	90° 23'	15
Guatemala	*P. maximinoi*	San Jerónimo	Critically endangered	15° 01'	90° 16'	11
Guatemala	*P. tecunumanii*	San Jerónimo	Critically endangered	15° 00'	90° 15'	14
Honduras	*P. maximinoi*	Dulce Nombre de Copán	Endangered	14° 50'	88° 51'	10
Honduras	*P. maximinoi*	Marcala	Vulnerable	14° 08'	87° 57'	15
Honduras	*P. tecunumanii*	La Esperanza	Vulnerable	14° 22'	88° 09'	15
Honduras	*P. tecunumanii*	San Esteban	Endangered	15° 17'	85° 40'	15
Honduras	*P. tecunumanii*	Villa Santa	Vulnerable	14° 12'	86° 17'	20

Hemlock Conservation and Restoration Update

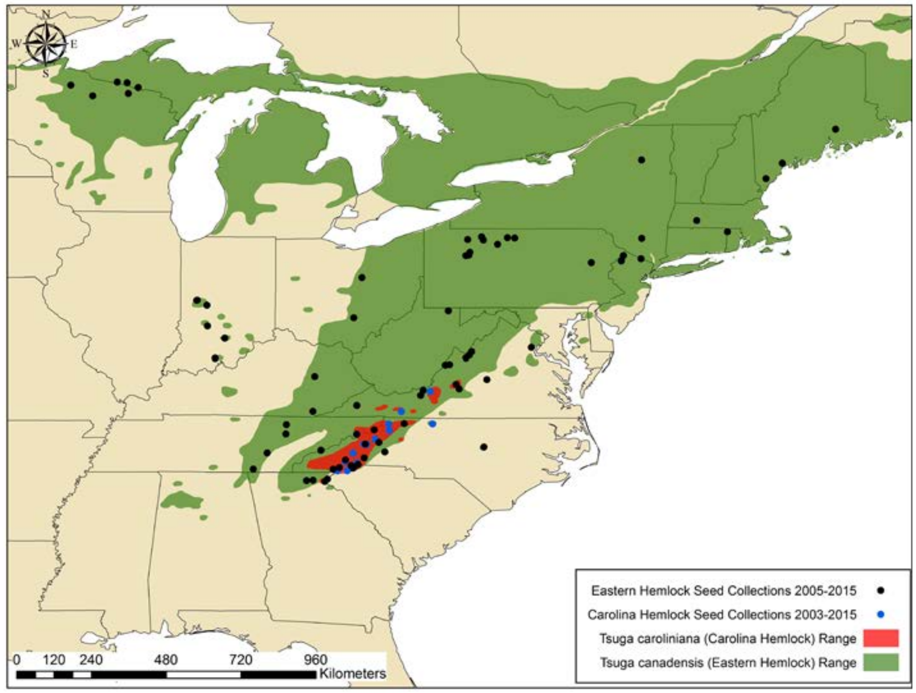


Figure 13. Map of range and collection sites of eastern and Carolina hemlocks.

This year was Camcore's 12th year of collaboration with the USDA Forest Service (USFS) on research projects related to the conservation and restoration of eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*T. caroliniana*). Both are ecologically important species native to the eastern United States and have experienced widespread decline due to infestations of an invasive insect pest named hemlock woolly adelgid, *Adelges tsugae* (HWA). Our work with hemlock has addressed a number of important topics including genetic resource conservation, population genetics, ecological modelling, host resistance screening, seed technology, nursery production, tree and insect responses to environmental conditions, conservation assessment, and silvicultural options for hemlock restoration, all accomplished with more than $1 million in grant funding from the USFS. Outputs from this work include 24 peer-reviewed and scientific publications and numerous oral and poster presentations at conferences and workshops that have provided information utilized among hemlock researchers worldwide. More than any of our other domestic conservation projects, our accomplishments with the hemlocks have helped Camcore to be recognized as a leader in the field of gene conservation and restoration of threatened and endangered tree species in the United States.

At the core of the hemlock program is our work on genetic resource conservation for the species. Our initial seed collections occurred in 2003 and have continued annually through 2015, resulting in the acquisition of material from 733 mother trees in 73 populations of eastern hemlock and 134 mother trees in 19 populations of Carolina hemlock (Figure 13). This represents the largest genetic resource that exists outside of natural stands for both species. Our genetic conservation work with hemlock also includes the establishment of conservation banks and seed orchards where we have attempted plantings in Brazil (WestRock), Chile (Arauco-Bioforest), and the United States (Camcore). Hemlocks are particularly difficult to produce in the nursery and establish in the field, so our results have been mixed, but we were pleased to see seed production this year in our Carolina hemlock orchard in the United States. This planting is at the NCSU Upper Mountain Research Station in western North Carolina. Cones were collected in September from 70 mother trees in the planting, and the seed is currently being processed in our lab in Raleigh and viability testing will occur in early 2016. This is a significant milestone, and we hope to replicate this with seed from other Camcore domestic conservation projects.

An important development in 2015 for our hemlock conservation and restoration research project, and the entire domestic conservation program in general, was the relocation of research forester Andy Whittier to Asheville, NC. Andy has been the lead field technician on the hemlock project since its inception in 2003, and he will continue in this role as a Camcore staff member based in Asheville. Through an agreement with the USFS Southern Research Station he is now housed in the same building as many of our key USFS collaborators, allowing Camcore to strengthen our

Carolina hemlock cone production in 2015 in the Camcore seed orchard at the Upper Mountain Research Station in western North Carolina.

relationship with the USFS and facilitate a higher level of research collaboration.

Among Andy's new duties in Asheville will be coordination of our two newest hemlock research initiatives. The first is a field study on silvicultural options for restoring eastern hemlock to Southern Appalachian forests, a collaboration with USFS SRS Research Entomologist Bud Mayfield. We first reported on this study in the 2014 Camcore Annual Report. The first round of tree health and growth data from this study has been collected and is currently being analyzed. The second project is a conservation assessment of Carolina hemlock in the Southern Appalachian Mountains. Funded through a $118,000 grant from the USFS Forest Health Monitoring Evaluation Monitoring Program, this study aims to delineate and census all known populations of Carolina hemlock, assess their current health status in relation to hemlock woolly adelgid infestation, and establish long-term monitoring plots to assess ecosystem changes over time as the adelgid infestation progresses. The data will be utilized to formulate adelgid management strategies and hemlock restoration activities across the range of Carolina hemlock. Both these projects are in their early stages, and Andy will have detailed updates ready for the 2016 Camcore Annual Report.

Camcore Hemlock Conservation and Restoration Projects Featured in *Science* Magazine

Forest health and the risks to the security of the world's forests posed by pests, pathogens and climate change are a topics of much concern among forestry professionals. Of particular concern are invasive insects and pathogens that continue to be introduced at unprecedented rates to countries worldwide and whose impacts can be catastrophic to both natural and planted forests. The importance of this topic is such that it was the focus of the August 21, 2015 issue of *Science* magazine. The issue contains a number of excellent and informative articles, including one by longtime Camcore friend and collaborator Mike Wingfield (and co-authors) about the need for a global strategy to address pest and pathogen problems that threaten the value and potential of plantation forests. Also in the issue appears an article by science writer Gabriel Popkin titled "Battling a Giant Killer" that provides and overview of ongoing research and development activities aimed at mitigating the impacts of the hemlock woolly adelgid *(Adelges tsugae)*, an invasive insect that has caused widespread decline and mortality of hemlock trees (*Tsuga* spp.) throughout the native forests of the eastern United States. This article cites two ongoing hemlock research projects being led by Camcore that are considered key components of the integrated effort to develop management strategies for the adelgid. These are the hemlock genetic resource conservation projects being conducted in collaboration with USDA Forest Service (USFS) Forest Health Protection and Entomologist Rusty Rhea, and the field study with USFS Southern Research Station and Research Entomologist Bud Mayfield on silvicultural options for restoring hemlock to Southern Appalachian forests. The inclusion of these projects in this article is a testament to Camcore's international reputation as a world leader in genetic resource conservation and the importance of our efforts, together with the USDA Forest Service, to conserve and restore threatened and endangered tree species native to the United States.

Genetic Conservation of Atlantic White Cedar

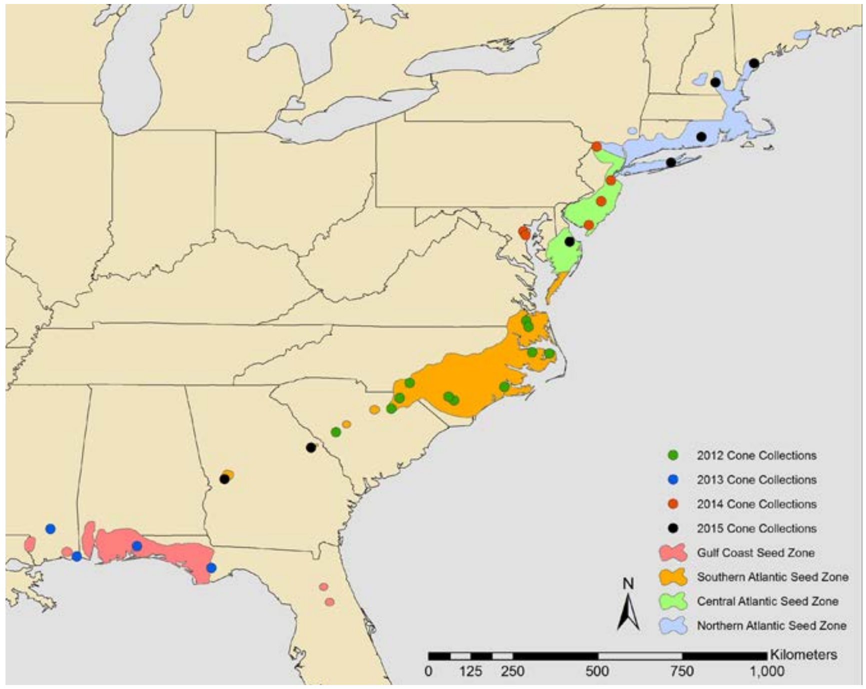


Figure 14. Map of range and collection sites of Atlantic White Cedar.

Atlantic White Cedar (AWC, *Chamaecyparis thyoides*) is a primarily coastal species found in the eastern United States from Maine south to the Gulf Coast states of Florida, Georgia, and Mississippi. Overharvesting, wetland drainage for agriculture and development, and wildfires have reduced natural AWC populations to 20 percent of the area they once occupied. Interest in this ecologically important species from USDA Forest Service Regional Geneticist Barbara Crane resulted in a $250,000 grant to Camcore to collect and conserve germplasm from throughout the range of the species.

Using the climatic mapping software FloraMap™, we divided the species range into four separate seed zones (Figure 14). In 2012 and 2013, we collected seed from the Southern Atlantic and Gulf Coast seed zones, respectively. In 2014, we collected from the Central Atlantic Seed Zone states of Maryland and New Jersey. The seed collection strategy for 2015 targeted populations in the Northern Atlantic seed zone and the under-sampled Central Atlantic zone, as well as two outlier populations in Georgia not yet sampled.

In July of 2015, 12 populations in the northern half of the range were explored. Unfortunately, cone production was fairly poor, but we decided to attempt a collection in this region in order to conserve some of this material before the project's conclusion. During the second week of October, we returned to five of the twelve explored northern sites and were able to collect seed from 35 new mother trees. We also collected seed in Georgia, from 25 trees in two populations located on opposite sides of the state. In total, we collected seed from 60 new mother trees on seven sites during the fall of 2015. Of the seven sites collected, four were on property owned by the Nature Conservancy, who graciously allowed our collections. In total, we have now conserved material from 205 trees in 28 populations spread across the four different seed zones.

Robert Jetton measuring an Atlantic White Cedar tree at Saco Heath Nature Preserve in Maine.

Beginning in early 2016, we will begin extracting and cleaning seed from the 2015 collections. Subsequent germination studies will tell us whether we will need to resample some of the collections in the northern portion of the range. Future seed sampling efforts will likely target additional sites in Maine, New Hampshire, Connecticut, Delaware, and Massachusetts.

In addition to seed, we are collecting foliage from populations visited throughout the range of the species. All foliage samples are sent to the USDA Forest Service National Forest Genetics Lab in California for a genetic diversity study to better understand patterns of genetic structure across the species' range.

Gene Conservation of Ash (*Fraxinus*)

In late 2015, Camcore began working on a new genetic resource conservation project in the United States focused on species of ash trees, members of the family Oleaceae and the genus *Fraxinus*. This genus is comprised of 43 species that are widely distributed across North America and Eurasia, occupying a diverse range of habitats from semi-desert to temperate climates and sea-level to subalpine elevations. The United States Geological Survey lists 16 species of ash that are found in the United States, six that occur in the southern region of the country where Camcore's work is focused. Two, green (*F. pennsylvanica*) and white (*F. americana*), are widely distributed. Four, Carolina (*F. caroliniana*), pumpkin (*F. profunda*), blue (*F. quadrangulata*), and Texas (*F. texensis*) have more limited distributions and are considered rare species.

Ash trees are an important source of hardwood timber that is valued for its hardness and resilience and is utilized for tool handles, furniture, baseball bats, and other products where wood of superior strength is important. They are also highly valued as landscape trees, planted widely for shade and ornamental purposes. From an ecological perspective, ash trees provide a number of ecosystem services including thermal cover, forage, and nesting sites for associated fauna, and have been widely utilized for the reclamation of surface mine sites in the coal producing regions of the United States.

Ash species native to North America face a significant threat from the emerald ash borer, *Agrilus planipennis* (EAB), an invasive wood boring beetle native to China that was introduced sometime before 2002. Since its first detection in 2002 in urban forests surrounding Detroit, EAB has spread to 25 US states and 2 Canadian provinces and has killed trees numbering in the tens of millions. Despite significant research and development efforts in chemical and biological control against EAB, the invasion continues unabated and its distribution is spreading at an alarming rate.

The best long-term solution to EAB and the restoration of lost ash forest resources is the breeding and deployment of EAB-resistant planting stock. Significant progress has already been made in understanding the mechanisms and genetic control of EAB resistance in ash species from China, and methods for breeding resistant genotypes through interspecific hybridization and other introgression methods are being investigated. Key to any resistance breeding and deployment program is access to genetically diverse and broadly adaptable breeding populations of the native ash species to be restored. Given the speed at which EAB continues to spread in North America and the number of trees already killed, it is critical that steps be taken immediately to conserve the genetic resources of native ash species so that they are available for future breeding and restoration efforts.

Camcore's work on ash genetic resource conservation is funded by a $42,000 grant from the USDA Forest Service (USFS), and is a collaboration with USFS Southern Region Geneticist Barbara Crane. The project will focus on the four rare ash species native to the southern region of the United States. The project objectives are to: 1) secure a genetically diverse and broadly adaptable collection of seeds for the four rare ash species occurring in the Southern Region. The goal is to collect seed from 200 mother trees per species sampled from 20 populations, 10 trees per population. 2) Place seed into seed banks at two locations to support research, breeding, and deployment activities aimed at species restoration. Half of all seed collected will reside at the USDA Forest Service Ashe Seed Facility in Brooklyn, MS. The other half of seeds collected will serve as a back-up collection and will reside in the Camcore Seed Bank at NC State University in Raleigh, NC. 3) Submit 500 seeds from each mother tree to the USDA National Center for Genetic Resource Preservation in Fort Collins, CO for long-term preservation. These objectives will be addressed in three project phases. Phase 1 will occur in 2016 and will focus on identifying suitable populations for seed collection for all four rare ash species in the south and initiating seed collections from populations of Carolina and pumpkin ash. Phase 2 is scheduled for 2017 and will focus on completing seed collections from target populations of all four of the rare ash species. If needed, Phase 3 will follow in 2018 and will focus on completing seed collections missed during years 1 and 2 due to poor seed production or other factors.

Genetic Conservation of Red Spruce and Fraser Fir

During the summer and fall of 2015, Camcore made substantial progress on our genetic resource conservation projects with Fraser fir *(Abies fraseri)* and red spruce *(Picea rubens)* conducted in conjunction with the USDA Forest Service. Historically, both species saw dramatic reductions in numbers due to overharvesting and severe wildfires. In the Southern Appalachian Mountains, both species are found very high elevations where they have experienced increased losses due to climate change and atmospheric deposition. Since the 1950's, Fraser fir has also been threatened by infestations of the exotic insect balsam woolly adelgid *(Adelges piceae)*.

Fraser fir trees on Clingmans Dome laden with cones.

When beginning our work with Fraser fir, we identified the seven known natural populations of the species. The two largest of these populations were further broken down into seven smaller subpopulations for a total of 12 populations spread across North Carolina, Tennessee, and Virginia From each of these populations Camcore is attempting to collect seed from between 10 to 20 trees. During June of 2015, Camcore visited seven natural populations of Fraser fir throughout the range of the species. Cone production at each of the sites ranged from low to moderate. At several of these sites, cone crops on some trees was excellent while the remaining trees had few to no cones. While more abundant cones would have been beneficial to our collections, overall we were happy with these crops.

From late August to early September, Camcore visited ten separate populations of Fraser fir. From nine of these ten sites we were able to collect cones from 99 new mother trees (Figure 15). The 2015 collection, combined with seed from 30 trees donated to Camcore in 2014 by the North Carolina Christmas Tree Growers Association Cooperative Seed Orchard brings our total to 129 individual mother trees conserved. Cone maturity varied across the sites with lower elevations typically maturing sooner. Even with this variation, collections were well timed with cone ripening, with maturation states ranging from dark purple to nearly shattering. Cones collected in 2015 were dried during the fall and winter of 2015 with seed extraction planned for early 2016.

In addition to collecting cones, we are sampling

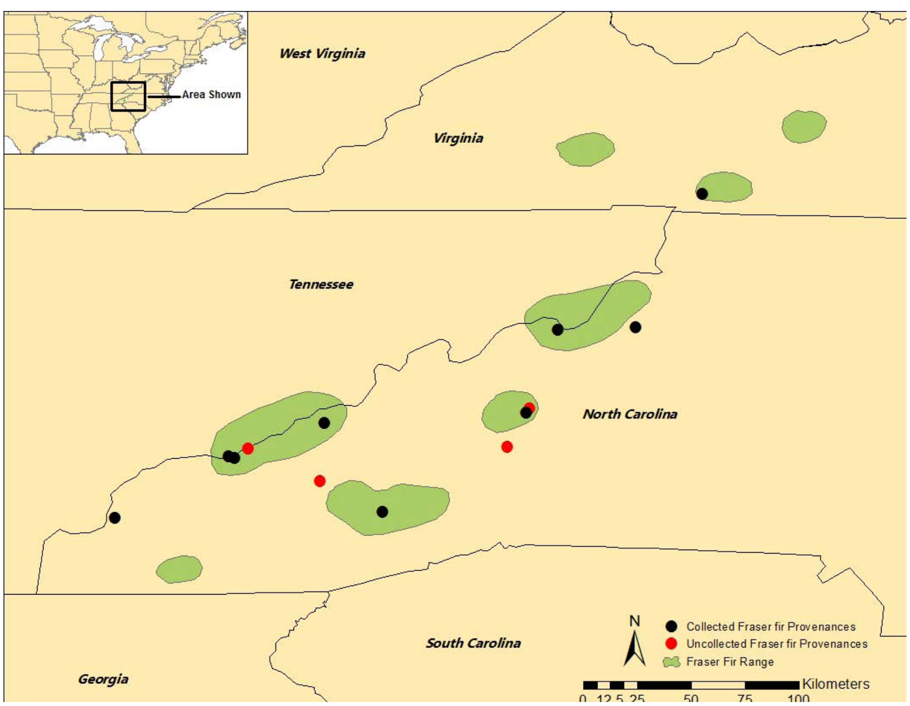


Figure 15. Map of range and collection sites of Fraser fir.

Red spruce trees at Dolly Sods Wilderness, West Virginia.

foliage from nearly all of our mother trees. Foliage samples have been sent to the National Forests Genetics Laboratory in Placerville, California where DNA will be extracted. Genetic information from this material will help us to better understand patterns of diversity of the species while allowing us to evaluate the effectiveness of our conservation efforts.

Overall we are pleased with the progress made on our work with genetic conservation of Fraser fir. In 2016 we are planning to resample some of the under-sampled sites and to apply for additional permits in order to collect from some of the populations which were missed in 2015.

Our work with red spruce in the southeastern United States has significant overlap with Fraser fir. Southern populations of red spruce are found only at the highest elevations in this portion of its range and coincide with Fraser fir habitat. Red spruce was present in six of the seven Fraser fir sites explored during the summer of 2015. An additional four red spruce populations farther north into Virginia and West Virginia were explored, for a total of ten sites. As with Fraser fir, 2015 was a decent year for cone production for red spruce. Eight of the ten sites explored had enough mother trees with cones to warrant a fall cone collection. During the month of October, we collected cones from 83 trees in 12 of the 13 red spruce sites visited (Figure 16). Seed extraction from the collected cones is slated for early 2016. Future collections of red spruce will focus on populations in the Black Mountains of North Carolina as well as sites in the under-sampled states of Virginia and West Virginia. Similar to the Fraser fir collections, we sampled foliage from each of the cone trees for eventual DNA extraction by the National Forests Genetics Laboratory.

Interest in our work with both Fraser fir and red spruce from different individuals and organizations in the southern Appalachian Mountains has led to opportunities for collaboration and potential seed exchanges. Of the 83 red spruce trees sampled, 10 were collected by volunteers with Warren Wilson College and the western North Carolina nonprofit Mountain True. In late October, Camcore attended the forth meeting of the Southern Appalachian Spruce Restoration Initiative (SASRI) in order to learn more about what other groups are doing with red spruce and to explain Camcore's work with the species. Following this meeting, Andy Whittier was invited to serve on the SASRI steering committee.

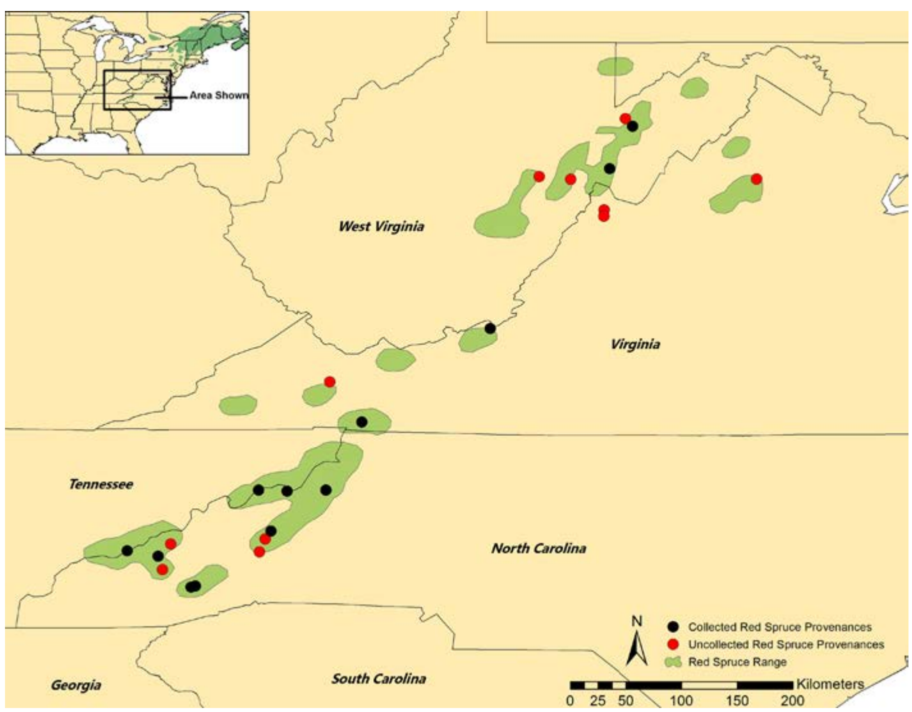


Figure 16. Map of range and collection sites of red spruce.

Changes in Camcore

Andy Whittier, Camcore Research Forester and lead field technician for Camcore's domestic conservation program relocated to Asheville, NC in August. Andy's new duty station in western North Carolina has greatly improved our focus and progress on our domestic conservation projects.

Juan Lopez with Camcore received his PhD from NC State in July 2015. His dissertation was titled "Economic Potential of Pine Hybrids: A Case Study for South Africa".

Benson Kanyi with Tree Biotechnology Programme Technology received his PhD in Entrepreneurship from Kenyatta University in 2015. His dissertation was titled "Exploration of Opportunities by Small Forest Growers".

Omar Carrero, Research Manager with Proteak in Mexico, left the company to take new opportunities in Brazil. We wish Omar great success in his new endeavors.

Juan Ramón Aguilar, who has worked for many years with Fomex and then with Proteak, has been promoted to Research Manager. Juan Ramón is the new contact at Proteak, coordinating all Camcore activities.

Rebeca Sanhueza has taken a position with CMPC Forestal Mininco as Director of Biotechnology. Rebeca's work will cover a number of areas including wood quality, genetic markers, and clonal propagation of pines.

Gisela Andrejow was given the position of Pine and *Eucalyptus* Tree Improvement Manager at WestRock Brazil in February 2015. This is a great opportunity for Gisela, who has been working for the company for many years. We welcome Gisela in her new role in WestRock.

John Crawford-Brunt was named the Technical Manager of Forestry at York Timbers, and will be overseeing York's research efforts and their involvement in Camcore.

Kitt Payn of Mondi was promoted to Director of Biotechnology, and will work in this area in support of the tropical eucalypt, cool temperate eucalypt and pine breeding programs in Mondi.

Noku Maplanka will be taking over as Pine Breeder for Mondi. Noku has many years of experience in breeding and research with both Sappi and Mondi, and recently coordinated all of Mondi's efforts as the Regional Coordinator for the third phase of the Camcore pine hybrid project.

Phillip Hongwane (Komatiland Forests) completed a MS at the University of Pretoria. His thesis was titled "Analysis of a Range of Pine Hybrid Trials over Diverse Sites in South Africa to Determine Suitable Alternatives to *Pinus patula* and Attempt to Define the Environmental Niche for Each Potential Hybrid". Steve Verryn (Merensky), Arnulf Kanzler (Sappi), and Glen Mitchell (formerly with York) were on Phillip's MS commitee. Phillip has left research and taken a new postion in the area of forest operations within KLF.

Lebo Mphalele, a longtime member of the research staff at KLF, will be taking over Phillip Hongwane's duties related to Camcore.

Irvine Kanyemba is now the General Manager of of MTO | Cape and is in charge of Forests and Sawmills. **Phillip Cox** is now General Manager for Forest Operations South.

Hampus Hamilton, Planning Manager at Green Resources Mozambique was given the responsibility of research activities with Camcore. Hampus has the support of **Platiel Chilaule,** who is in charge of the research field work. Hampus replaced **William Prado**, who left the company to work as a planting contractor with another company in Mozambique.

Martha Salas with Smurfit Kappa Colombia moved to the US to start her master's degree at NC State University working on a research project with Camcore.

Data Management Shortcourse in Venezuela

Members of Camcore establish many field trials to evaluate the growth and quality of the genetic material produced by the program. They plant thousands of tree seedlings and cuttings derived from natural population seed collections, 2nd generation selections and controlled pollination and hybrid crosses. Much data is generated to maintain the identity and pedigree of these trees and from the periodic assessments of growth and quality traits. It is a challenge to the members and the Raleigh office to capture, verify, organize, analyze and store this large quantity of data, especially since the individual members utilize different techniques to manage their data. In order to help standardize data formats and to train members' tree breeding staff, Camcore offers an annual short course in data management. Topics covered include coding and digitizing strategies, data verification, and trial design. Most of our data is recorded and manipulated in spreadsheets, so participants learn and practice a number of advanced Excel tools that are useful in managing trial data.

This year's course was hosted by Smurfit Kappa Venezuela and took place at the Tronadora nursey facility near Acarigua. Seven participants from SCV and three from Terranova (Masisa de Venezuela) spent a week with Camcore instructor Willi Woodbridge working on various aspects of data handling with an emphasis on tree growth measurements. They used mathematical formulas, pivot tables and excel macro programs to format datasets and check for errors and suspect measurements. One of the more challenging tasks is to combine measurements from different ages into one file where both tree identity and year-to-year consistency need to be validated. The most important lesson from the workshop is probably the importance of maintaining the integrity of data during each step from field collection to analysis and the ease with which simple or careless errors can negate the work that goes into establishing, maintaining, and measuring a genetic trial.

The participants in the course came with different backgrounds, job responsibilities, and levels of experience. Employees from SKV included: Alvaro González, Carlos Romano, Gerardo Balza, Giovany Zacarias, Javier Cordero, José Luis Peralta, and Royman Angulo; and from Terranova: Gabriel Sánchez, Ismael Montoya, and Romel Torcat.

Genomic Breeding Grant

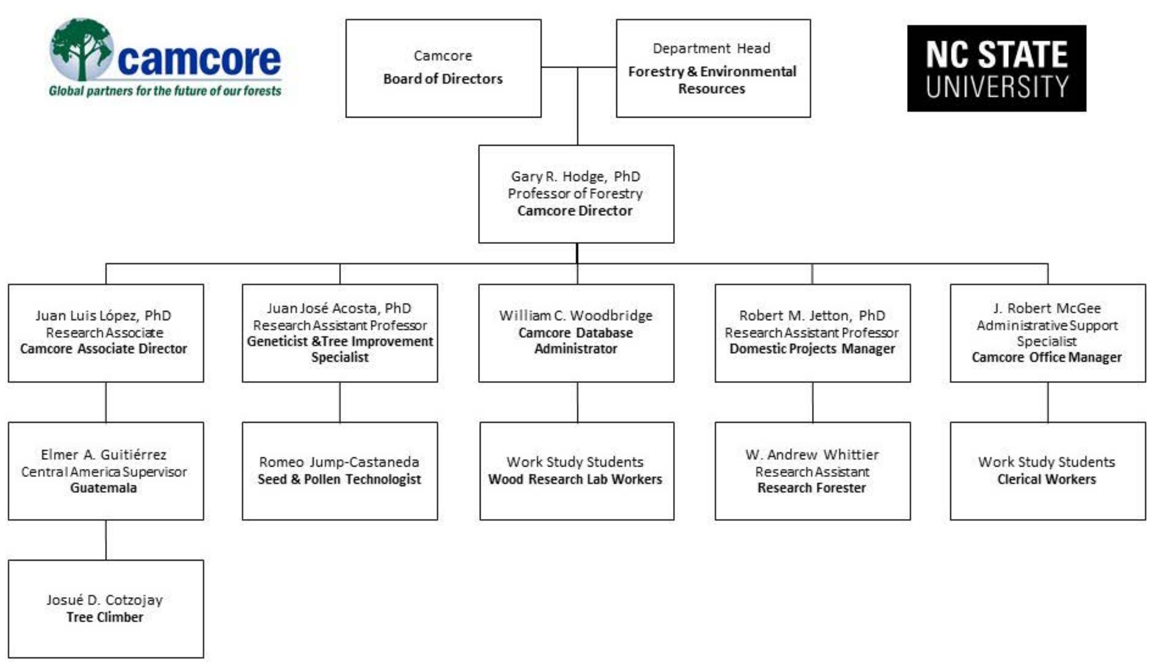
Fikret Isik (Tree Improvment, NC State University) is the Principal Investigator of a four-year $370,000 grant to work on the development of SNP markers (single-nucleotide polymorphisms) for use in genomic breeding of *Pinus taeda* and other pines. **Juan José Acosta** (Camcore) is a co-Principal Investigator, along with **Jill Wegrzyn** (University of Connecticut), **Andrew Eckert** (Virginia Commonwealth University), and **Richard Sniezko** (USDA Forest Service).

The grant was awarded from the US Department of Agriculture (NIFA Plant Health and Production and Plant Products). The primary goal of the grant is to search through more than 20 million candidate markers documented in public databases to identify a suite of 90,000 SNPs that could be useful for the development of a SNP chip. This will involve the use of bioinformatics and high-performance computing software. The primary focus species in the project will be *P. taeda* and *P. lambertiana*, but we hope the project will also have application for other pines, such as *P. radiata* and the Mesoamerican pines that are important to the southern hemisphere.

Tree Improvement Shortcourse in Chile

Gary Hodge and Juan Luis Lopez participated in the 2015 Tree Improvement Shortcourse in Chile in April. This course was sponsored by the University of Concepcion, Forestal Arauco, CMPC Forestal Mininco, Camcore, NC State University, and Cooperativa Mejoramiento Genetico (Chile). A total of 39 students attended the course, representing 12 countries (Argentina, Brazil, Chile, Costa Rica, Ecuador, Ghana, Guatemala, Mexico, Peru, Portugal, Uruguay, and Venezuela). There were two weeks of lectures and field visits. Gary taught three lectures on Genotype x Environment Interaction, Breeding for Wood Properties and Disease Resistance, and Breeding Strategies. Juan Luis taught two lectures on the Characteristics and Potential of Mesoamerican Pines, and Characteristics and Potential of Tropical and Subtropical Eucalypts. Other NC State faculty who taught in the course include Bob Kellison, Barry Goldfarb, and Steve McKeand.

Camcore Personnel



Vegetative Propagation Shortcourse in Mexico

Juan Lopez from Camcore was invited by the Mexican National Forest, Crops, and Livestock Research Institute (INIFAP), honorary member of Camcore, to teach a short course on vegetative propagation of forestry species. The course was coordinated by Dr. Esmeralda Judith Cruz Gutiérrez and took place at the Genetic Resources National Center at Tepatitlán De Morelos, Jalisco, Mexico in April 2015. Most of the students worked for INIFAP and the Mexican National Forestry Commission (CONAFOR). A tour was given to the group to visit state-of-the-art laboratories with modern equipment and professional workers. These meetings between Juan and Mexican scientists and governmental officials can create opportunities for collaboration between INIFAP and Camcore on research projects in tree conservation and genetic diversity.

Graduate Programs and Training

Juan Pedro Posse (Weyerhaeuser, Uruguay) continues his PhD program at NC State University. His research is on genetic variation for growth and wood property traits in *E. dunnii*. He will be examining density, MOE, wood chemistry traits, and splitting.

John Hastings continued work on his M.S. degree program under the direction of Robert Jetton and Kevin Potter. He will use a GIS system to analyze eastern hemlock (*Tsuga canadensis*) and assess climate change and hemlock woolly adelgid infestation risks to the species. John plans to defend his thesis and graduate at the end of the Spring 2016 semester.

Andy Whittier has completed research for his M.S. degree project entitled “Nutrient interactions and deficiency symptoms in teak raised in growth chambers” and is currently analyzing his data and writing his thesis. In March of 2015, Andy was invited to the Third World Teak Conference in Guayaquil, Ecuador to present preliminary results from his research.

Mmoledi Mphahlele (Mondi Forests) continues his PhD program at the University of Pretoria. Mmoledi's research is on genomic selection, and is a case study with a four-generation pedigree population of *E. grandis*. Mmoledi is working wth Zander Myburg, and also with Gary Hodge (Camcore) and Fikret Isik (NCSU-TIP).

Lizette DeWaal (York) is working on her M.S. degree at the University of Pretoria. Lizette's research is on genetic variation in frost-tolerance within *P. oocarpa,* and artificial screening for frost tolerance. Glen Mitchell (formerly York) and Gary Hodge (Camcore) are serving on her committee.

University Committees and Service

Gary Hodge served on the CNR Tenure and Promotion Committee. He also served as Special Associate Editor for the *Canadian Journal of Forest Research*, and reviewed manuscripts for *Tree Genetics* and *Genomes, Heredity,* and *Southern Forests*.

Robert Jetton, continues to serve as a manuscript Editor for the journal *Southeastern Naturalist* and was a peer reviewer for *Biological Conservation, Forest Science, Insect Science,* and *Southern Forests.* He currently serves on the executive committee as Chair-elect of the Southern Forest Insect Work Conference, the science advisory committee of the Alliance for Saving Threatened Forests, and as Chair of the USDA Forest Service Working Group on Genetics and Host Resistance in Hemlock.

Andy Whittier, Research Forester, was recently invited to serve on the SASRI (Southern Appalachian Spruce Restoration Initiative) steering committee. Camcore is excited to be part of this group and looks forward to working with new partners in guiding the future of red spruce conservation and restoration.

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

Publications and Papers

Publications

Hodge, G.R. and W.S. Dvorak. 2015. Provenance variation and within-provenance genetic parameters in *Eucalyptus urophylla* across 125 sites in Brazil, Colombia, Mexico, South Africa, and Venezuela. Tree Genetics and Genomes 11:57.

Jetton, R.M., Crane, B.S., Whittier, W.A. and Dvorak, W.S. 2015. Genetic Resource Conservation of Table Mountain Pine (*Pinus pungens*) in the Central and Southern Appalachian Mountains. Tree Planters' Notes 58: 42-52.

Lopez, J.L . 2015. Economic potential of pine hybrids: a case study for South Africa. PhD Dissertation, NC State University, Raleigh, NC.

Lstiburek, M, G.R. Hodge, and P. Lachout. 2015. Uncovering genetic information from commercial forest plantations: making up for lost time using "Breeding without Breeding". Tree Genetics and Genomes 11: 55.

Powers, Z., A. Mayfield, J. Frampton, and R. Jetton. 2015. Comparison of suspended branch and direct infestation techniques for artificially infesting hemlock seedlings with the hemlock woolly adelgid for resistance screening. Forests. 6: 2066-2081.

Presentations

Jetton, R.M., A.R. Campbell, W.S. Dvorak, G.R. Hodge, A.E. Mayfield III, K.M. Potter, J.R. Rhea, A.R. Tait, and W.A. Whittier. 2015. Conservation assessment, gene conservation, and silvicultural strategies for mitigating the impact of hemlock woolly adelgid. Southern Forest Insect Work Conference, July 20-24, Fayetteville, AR. (Invited)

Jetton, R.M., B.S. Crane, W.A. Whittier, and W.S. Dvorak. 2015. Genetic resource conservation of Table Mountain pine in the central and southern Appalachian Mountains. Southern Forest Tree Improvement Conference, June 8-11, Hot Springs, AR. (Contributed)

Jetton, R.M., A.R. Tait, and A.E. Mayfield III. 2015. Silvicultural strategies for hemlock restoration. Southern Appalachian Forest Entomology and Pathology Seminar, March 5-6, Crossnore, NC. (Contributed)

Lopez, J.L. 2015. Financial Model for a Tree Genetic Improvement Program with Teak. . 3rd World Teak Conference 2015, May 11-15, 2015, Guayaquil, Ecuador.

Whittier, W.A. 2015. Teak Nutrient Disorder Symptoms In a Hydroponic System Correlated With Near-Infrared Spectroscopy (NIR) models. 3rd World Teak Conference 2015, May 11-15, 2015, Guayaquil, Ecuador.

Posters

Fahrenkrog AM, Resztak JA, Santos RF, Neves LG, Acosta JJ, Barbazuk B, Kirst M. 2015. Genotypic and phenotypic characterization of a Populus deltoids. Poster at Plant and Animal Genome Conference, January 10 -14, San Diego, CA.

Hastings, J., R. Jetton, K. Potter, M. Megalos, and F. Koch. 2015. Using Climate and Genetic Diversity Data to Prioritize Conservation Seed Banking. Pine Integration Network: Education, Mitigation, and Adaptation Project (PINEMAP) Annual Meeting. June 3–4, 2015, Athens, GA

Hastings, J., R. Jetton, K. Potter, M. Megalos, and F. Koch. 2015. Using Climate and Genetic Diversity Data to Prioritize Conservation Seed Banking. Forestry and Environmental Resources Research Symposium - North Carolina State University. August 18, 2015. Raleigh, NC

Jetton, R.M., A.R. Tait, and A.E. Mayfield. 2015. Silvicultural and integrated management strategies for restoring hemlock to degraded southern Appalachian forests – phase 1. Poster at Twenty-sixth USDA Interagency Research Forum on Invasive Species, January 13-16, 2015, Annapolis, MD.

Jaakko Tyrmi, Juan José Acosta, Zhen Li, Tanja Pyhäjärvi, Outi Savolainen. 2015. Genetic diversity of European *Pinus sylvestris* populations studied with exome sequencing. Poster at ESEB Conference: Congress of the European Society for Evolutionary Biology, August 10-14. University of Lausanne, Switzerland.

Miniat, C., D. Zeitlow, S.T. Brantley, A. Mayfield, R. Rhea, R. Jetton, and P. Arnold. 2015. Physiological responses of eastern hemlock to biological control and silvicultural release: implications for hemlock restoration. Poster at Fifth Interagency Conference on Research in Watersheds, March 2-6, 2015, Charleston, SC.

Whittier, W.A. Teak *(Tectona grandis)* Seedling Nutrient Deficiency Symptoms in a Hydroponic System Correlated with Near-infrared Spectroscopy (NIR) Models. Poster presented at: The 10th Annual NC State University Graduate Student Research Symposium. March 25, 2016. Raleigh NC.

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Jose Fernando De La Torre Sánchez, INIFAP, México

Miguel Armando Lopez, Instituto de Genética Forestal, Universidad Veracruzana, México

Liselle Alamilla, Ministry of Forestry, Fisheries and Indigenous People, Belize

Andrea Burgos and Paola Molina (Weyerhaeuser Uruguay) with an outstanding family of *E. dorrigoensis* in a 3½ year-old Camcore progeny test. This species is showing excellent frost tolerance and very good growth across a wide range of sites in southern Latin America and South Africa.

Front Cover: Francois van Deventer in the new Mondi nursery at Kwambonambi, KZN, South Africa. This state-of-the-art nursery will increase the efficiency of rooted cutting production for the company's subtropical eucalypt program.