GEOIDE Network - Strategic Investment Initiative
Precision Planning Inventory Tools for Forest Value Enhancement

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Project Team

The research team remains as outlined in the original proposal. ***Dr. Treitz*** provides expertise in remote sensing for forestry; in particular, retrieval of structural and biophysical properties of vegetation canopies from LiDAR data as well as high resolution optical data. ***Dr. Dech*** is the Forest Bioproducts Research Chair at Nipissing University and his research addresses the ecological basis of productivity and sustainable management of bioproducts from the boreal forest. ***Dr. Mabee's*** research interests lie in sustainability of new forest products, including bioenergy; he brings specific expertise in environmental and energy modelling, and is experienced in deriving policy-relevant data from technical outputs. ***Dr. Scott*** holds a Canada Research Chair in Greenhouse Gas Dynamics and Ecosystem Management whose research includes the development and testing of carbon cycle models used to explore management impacts on forest carbon dynamics. ***Dr. Miranda's*** research interests focus on the implications of spatial structure and spatial processes in forest productivity. Research scientists at the Canadian Forest Service (CFS) (i.e., ***Drs. Gougeon, Pitt and Leckie***) are developing tools for Individual Tree Classification **(**ITC) and evaluation of Forest Resource Inventory (FRI) accuracy and effectiveness. Our provincial government partners in the **Ontario Ministry of Natural Resources** (OMNR) (***Addante, Etheridge, Johnson, Lennon, Nesbitt, Quist, Rouillard, Sampson, Stinson, Woods***) bring a wealth of expertise in diverse areas of geomatics related to forest inventory design, data collection, application development, and inventory production. Mr. Murray Woods has been intensively involved in the development of LiDAR models for forest inventory variables. The **Forestry Research Partnership (FRP)**, **Tembec Inc.** and **Hearst Forest Management Inc. (HFMI)** team members (***Pickering, Thorne, Cheff, Thompson***) provide forest management expertise for the development of commercially relevant applications from fundamental forestry research. **FPInnovations - FERIC** develops and helps implement innovative and safe forest operational solutions (i.e., engineering and environment) with ***Nader*** and ***Favreau*** bringing over four decades of combined experience in commercially driven forest research.

Description of the SII project – Phase IV (December 1, 2009 to November 30, 2010)

Project Originality and Excellence of Research

New remote-sensing and data-processing technologies provide a very detailed three-dimensional model of the forest, essential for FRI interpretation and ecosite classification. Over the past decade, research has clearly demonstrated the capacity for new technologies (i.e., airborne digital imagery, light detection and ranging - LiDAR) and methodological approaches (ITC; LiDAR metrics) to enhance our capacity for acquiring forest biophysical and ecological variables for forest planning and operations. These technologies and methods are now starting to be implemented operationally in forests around the world. In Ontario (and the rest of Canada), however, FRI data continue to be collected through the manual interpretation of aerial photographs, augmented with limited ground sampling. In many jurisdictions, the acquisition of digital photography and softcopy interpretation are the only substantive technological enhancements that have been made to operational FRI in the last half century.

Our research involves the development and validation of a tactical forest resource inventory derived from individual tree crown (ITC) recognition (i.e., species classification/segmentation) and LiDAR modeling of forest biophysical variables. This forest inventory system is meant to support value chain optimization by providing more accurate, precise, and relevant inventory information that may be used to characterize fibre attributes, quality and economic value. Over the past decade, we have successfully calibrated and validated LiDAR models for several inventory variables across a range of forest conditions in the Great Lakes – St. Lawrence and Boreal Forests of Ontario. This development has been funded by GEOIDE, the Ontario Centre of Excellence for Earth and Environmental Technologies (OCE-EET), Fluxnet Canada and the Canadian Wood Fibre Centre (CWFC). These models have performed well at the sites for which they were calibrated/validated (Lim et al., 2003; Lim and Treitz 2004; Thomas et al., 2006; 2008; Woods et al., 2008, Woods et al. 2010; Treitz et al., 2010). However, in the Canadian context, there remain three important aspects that we are now addressing in this GEOIDE project in order to move from localized research to the adoption of these new technologies in operational FRI:

1) Determination of the transferability (robustness) of existing models and algorithms developed in one region to other, similar regions.
2) Demonstration of the technologies and methodologies that deliver required inventory variables at reasonable cost for large complex areas (e.g., in the order of 500,000 ha).
3) Systematic comparison of conventional FRI data and *enhanced* FRI data in terms of accuracy, precision, cost, and function.

Our study takes place in Hearst, Ontario. The Hearst Forest (HF) is a typical northeastern boreal forest management unit consisting of approximately 1,230,000 ha. A conventional FRI is currently being conducted on the forest using high-resolution digital aerial photography (ADS40) and manual softcopy photo interpretation. Complete LiDAR coverage of the HF was obtained in 2007, at a resolution of approximately 1 return per m^2. We are working closely with the Advanced Forest Resources Inventory Technologies (AFRIT) project team to examine the potential of these high quality data to support a full-scale operational enhanced forest resources inventory. During the summer of 2010, GEOIDE and AFRIT supported two field crews (students from Queen's and Nipissing along with personnel from Hearst Forest Management Inc. and Thunderhouse Forest Services Inc.) to locate suitable forest plots (0.4 ha) and collect forest plot data to support LiDAR model development. Forest measurements were collected for 446 field plots that were established in the Hearst Forest covering a range of species types, age and site classes. In addition, an archive of over 1000 increment core samples collected from these plots has been established at Nipissing University. These cores will allow us to stratify our analyses by stand age and determine if this important forest modeling variable has any influence over the accuracy of the LiDAR models. These cores will allow us to stratify our analyses by stand age and determine if this important forest modeling variable has any influence over the accuracy of the LiDAR models.

This project addresses issues 1-2 above by (a) applying our existing models and algorithms (by species and/or species groupings derived from the Romeo-Mallette Forest) to LiDAR data collected for the Hearst Forest plots in 2010; and (ii) calibrate (and validate) LiDAR models specific to the Hearst Forest based on field plots collected in 2010. We are currently engaged in these activities. It is anticipated that this research will: (i) improve spatial resolution, accuracy and precision by which we are able to estimate traditional operational forest inventory parameters (e.g., tree species, height, volume, quadratic mean diameter, basal area) across the landscape; (ii) add valuable new attributes (e.g. biomass, fibre attributes, ecosite, carbon) to the inventory; and (iii) improve inventory cost efficiency.

In summary, the focus of this project is to determine the suitability of new sensor technologies (high resolution digital aerial photography, LiDAR) and methodologies (ITC and LiDAR height and density metrics) for the delivery of value-added variables to the contemporary FRI. Specifically, forest inventory variables extracted from high resolution digital imagery (i.e., ADS40 digital photography) and modelled from LiDAR height and density metrics will be generated for the Hearst Forest. The following table summarizes the major milestones as presented in our initial proposal. Milestones in **bold** have been completed, those in ***bold italics*** are in progress, and those in plain text have yet to be addressed.

Summary of Major Milestones

Milestone	Deliverables	Target Date
Initial Project Meeting January 19, 2010 (Timmins, Ontario)	• **Report outlining the research plan. (See Appendix 1)**	**30/01/10**
Generation of LiDAR DEM, DSM and CHM for Hearst Forest (1 km tiles)	• **Quality assurance/assessment of LiDAR DEM, DSM and CHM for Hearst Forest;** • ***Comparison of LiDAR DEM and CHM to DSM derived from ADS40 imagery. [Masters candidate – Graham Pope, supervised by Treitz]***	**01/06/10** ***01/12/10***
Application of ITC software to the ADS40 imagery.	• ***Rasterized surface of species/species groupings for sectors of the Hearst Forest.*** • ***Validation of ITC performance in classification.***	***01/02/11*** ***01/04/11***
Development of calibration/validation datasets for modelled forest inventory variables.	• **Synthesis of existing field data that can be used for validation of modeled outputs.** • **Collection of 450 fixed area plots (0.4 ha) during the summer of 2010 by plot locator and two field crews.**	**01/04/11** **01/04/11**
Application of LiDAR models to rasterized LiDAR height and density metrics.	• Rasterized surfaces for forest inventory variables (e.g., stand top height, average height, quadratic mean diameter, basal area, and gross total volume). • Accuracy estimates of each modeled output based on field validation data.	01/06/11 01/08/11
Integration of rasterized LiDAR modelled output variables with FRI polygon structure.	• Population of FRI polygons with the following forest inventory variables (stand top height, average height, stem density, basal area, and gross total volume, etc.). • FRI database exhibiting rasterized surfaces of modelled outputs as well as populated polygons with similar outputs.	01/10/11 01/11/11
Testing LiDAR variables with FPInterface Map	• Rasterized surfaces of various forest product values.	15/12/11
Final project workshop.	• Final project workshop to discuss results and provide recommendations. • Final project report and manuscripts for publication.	01/02/12 01/06/12

<u>Network, Communications and Collaborations</u>

This project is being managed by the Project Leader (Treitz) and the Deputy Leader (Dech). Co-investigators report directly to the Project and Deputy Leaders. Students work closely with their supervisors and participate in all meetings related to the project. ***Intra-Project Networking*** - The Project Leader maintains 'Project Team' and 'Collaborator' email distribution lists to communicate news and activities (as per GEOIDE Appendix A). In January 2010, we held a large project launch meeting with all participants in Timmins, Ontario to outline project goals, objectives and develop a plan for implementation (Figure 1, Appendix 1). One of the primary goals of this meeting was to scope out the plan for the summer field activities in the Hearst Forest for 2010. In November, a Project Team meeting was held at Queen's University (Appendix 2) to review the 2010 field campaign, assess progress of data input and quality assurance and plan for LiDAR model calibration and validation. ***National Networking*** – The project is networked across Canada, primarily through different groups in CFS, CIF and FPInnovations. Word of our activities in Ontario has resulted in invitations to other provinces to outline our research results (from related projects) and describe our current activities with respect to this project. Specifically, Mr. Murray

Woods, Dr. Doug Pitt and Dr. Kevin Lim have been invited to describe our methods in other provinces and countries (Appendix E). We are also assisting the CFS with a national inventory LiDAR sample based on sample plots we have collected. ***International Networking*** – As a member of the scientific review committee for Silvilaser, an annual international meeting of LiDAR researchers, Treitz is able to network with the leading LiDAR and forestry scientists from around the world. He described aspects of the Hearst Project at the most recent Silvilaser 2010 meeting in Freiburg Germany in September 2010. A number of researchers are involved in other research networks including the Canadian Wood Fibre Centre (CWFC) and the ForValueNet NSERC Strategic Network. This project builds upon networks each researcher has already developed and extends our research collaboration to Chile, with the participation of Dr. Marcelo Miranda.

Figure 1 – Project Team – January 19, 2010 in Timmins, Ontario

Participation of HQP and Training Strategy

It had been anticipated that a Post Doctoral Fellow (PDF) would be hired to be a technical leader for this project. However, due to the lack of success in securing funds from the Ontario Centre of Excellence for Earth and Environmental Technologies (OCE-EET) for this project, funds had to be reallocated from the GEOIDE budget to support the field activities of undergraduate students from Queen’s and Nipissing in Hearst during the summer field season of 2010. Further support for undergraduate and graduate students will be provided during the summer field activities in Hearst in 2011. It was anticipated that three graduate students (3 MSc) would be supported to work with Mabee, Scott, Dech and Miranda. The first of the MSc students registered in September 2010 (Pope) to work with Treitz on this project and will collect his field data in 2011. In addition, an MSc candidate supervised by Dr. Miranda will visit Queen’s in March 2011 to begin work on this project (application of k-NN for estimating forest biophysical variables). Mabee and Scott are actively seeking graduate students for the summer field campaign in 2011. Further, Treitz is currently reviewing applications from PhD candidates to participate in this project. In 2010, three BSc candidates from Queen’s (Gagliardi, McLeod, Tamminga) and a B.A. student from Nipissing (Blahey) spent the summer in Hearst collecting forest mensuration and ecological data to support project objectives, and in some cases to support their senior honours theses (Tamminga). All students took part in a one-week project training module for field crews led by Woods and Etheridge, detailing field safety protocols, forest mensuration and ecological land classification methods for plot data collection. Students worked closely with professional forestry staff from HFMI and Thunderhouse throughout the field campaign. Blahey is currently inputting the field data into digital form and performing Quality Assurance on field data. In 2011, this project will support a minimum of two senior undergraduate students in 2011 to assist in validation data collection during the summer months and carry out senior honours theses in their fourth year of study. These students will benefit enormously from interactions at workshops among geomatics and forestry practitioners, including experts in remote sensing, decision support systems, forest management, and policy-makers.

Leverage

The team is partnered with an integrative project (Advanced Forest Resource Inventory Technologies – AFRIT) with CWFC which includes industry (Tembec Inc., FPInnovations) and government (CFS, OMNR) partners. The focus of this integrated project is to move the current approach to FRI analysis, which operates at the strategic planning level; to a more refined and detailed approach that generates accurate stand level data as its basic elements. AFRIT project funds are allocated to on-going research, including light detection and ranging (LiDAR) and individual tree crown (ITC) identification at Romeo-Mallette Forest (RMF), Petawawa Research Forest (PRF) and Green River Forest (GRF) (in New Brunswick). The outcomes from this project in the first year of funding will support the work at the Hearst Forest. LiDAR data have been provided by Hearst Forest Management Inc. (an in-kind contribution of $700,000) and licensing agreements have been signed by the partners working with these data**.** The LiDAR data is now being linked with the field data to generate LiDAR height and density metrics specific to each forest sample plot. Hearst Forest Management Inc. and Tembec have provided significant in-kind contributions including staff time for sample plot location, imagery, and inventory data. Murray Woods (OMNR) is providing leadership over the LiDAR inventory production and validation aspects of the study. Models developed as part of GEOIDE/AFRIT projects will provide enhanced FRI information to the Hearst District. Don Leckie and François Gougeon (CFS-PFC) are providing leadership over the image interpretation aspects, including refinements and enhancements to ITC Suite software that will enable semi-automated interpretation of high-resolution digital imagery. Jean Favreau and Joseph Nader (FPInnovations - FERIC) will be involved in the testing of enhanced inventory products with FPInterface Map software for the mapping of product value in 2011.

Knowledge Translation

To date our knowledge translation has consisted primarily of meetings and presentations through the Canadian Institute of Forestry (CIF), federal government agencies (i.e., Canadian Wood Fibre Centre), and provincial ministries of natural resources (Ontario and Alberta). A number of these are outlined in Appendix D. The research proposed here will develop and validate an operational forest inventory system that supports value chain optimization by providing more accurate, precise, and relevant inventory information that may be used to characterize fibre attributes/quality/value and hence provide information on product potential across the landscape. These enhanced data will provide more reliable inputs to models such as InterfaceMap and thereby provide more realistic outputs related to product potential. This project will support strategies by HFMI to find accurate, cost-effective means of improving inventory attributes, to facilitate complete forest management planning and to lower operational costs of silviculture and road construction. Further, this research will also support related NSERC-funded programs such as ForValueNet, the NSERC Strategic Network dedicated to optimizing forest value chain flows through the modelling of existing and new product pathways by providing improved inventory methods for decision support tools. The results of this research will be presented at a project workshop in 2012, whereby sensor technologies and methodologies will be summarized and outputs demonstrated. The primary product, related to intellectual property and marketability, will be a prototype FRI (by polygon description and rasterized surfaces) validated for the Hearst Forest in Ontario. By applying models already developed for similar forests in Ontario to the HF, we will demonstrate the feasibility of modelling these forest variables (e.g., stand top height, average height, quadratic mean diameter, basal area, and gross total volume) over large areas as well as the transferability of LiDAR models between similar forest regions.

Project Management

This project is being managed by the Project Leader (Treitz) and Deputy Leader (Dech). The Project and Deputy Leader will share coordinated responsibilities for reporting to project partners. Project partners such as HFMI, OMNR and CWFC are actively involved in all aspects of this project, from field data collection to model development. Email contact and at least two project meetings per year ensure everyone's participation. Partnership with the AFRIT project, led by Dr. Doug Pitt and Mr. Murray Woods has been invaluable in pushing the agendas of both projects. We have taken full advantage of the networks and resources available to the team members and their partners to: (i) contribute to and enhance the body of research knowledge relating to geomatics in the forest sector; and (ii) promote the application, through practice and policy, of geomatics in support of forest management. The former is being accomplished by: (i) sharing information, ideas, and data with other researchers who are examining related topics; (ii) publishing refereed papers in respected journals; (iii) publishing plain-language project updates in partner newsletters and web sites; and (iv) presenting project results at national and international conferences. Although this project is specifically designed to provide solutions that will add value to Ontario's resource inventory, we have direct linkages with similar efforts being conducted in BC, AB, QC, and NL.

Quality of Research Results

Given this project began in 2010, it is still too early for results to be reported in the refereed literature. However, plans are underway with proposed papers for the Forestry Chronicle, Remote Sensing of environment, Silvilaser 2011, etc. Through the Canadian Wood Fibre Centre, the Forest Research Partnership and the Canadian Institute of Forestry we will be able to offer solutions that have strong potential for broader uptake across Canada.

Communication of Results

Canada's forest sector has long had the advantage of a large accessible forest resource base from which extraction of wood fibre was economical and abundant. However, this is not the reality within which the Canadian forest industry is currently operating. Evolving social values (protection, recreation requirements, etc.), increased recognition of forest ecological services and accessible global markets has resulted in a reduced and more expensive fibre supply. In addition, Canada's natural resources inventories are generally ill suited to provide spatially accurate detail to assist the forest industry (and government agencies) with making the best possible economic decisions (while meeting all sustainability requirements). These inventories were based on techniques and approaches that were designed and applicable to forest management in the 1950's. This GEOIDE project provides a platform to explore and report on the potential and application of remote sensing technology (specifically Light Detection and Ranging (LiDAR)) and semi-automated imagery analysis to an operational forest management area (Hearst, Ontario). These technologies can provide spatially explicit estimates of forest inventory attributes (with measures of precision) that enable better natural resource management decisions to ensure the maintenance of long-term healthy forests for public enjoyment while providing an economic advantage to the forest sector.

This project has acquired (through partners) and processed LiDAR modeling data for the entire 1.3 million hectares of the Hearst forest. Preliminary products include: a detailed topography layer, a canopy layer, and statistical measures of the LiDAR data distribution. All these products contribute to predicting better inventory information. Semi-automated analysis of digital imagery (accessed through the province of Ontario) is underway. This analysis will result in, for specific areas of the forest, individual tree crown species classification from which aggregations of groups of similar species can be made to meet specific management questions. These data are supported by a network of 450 field plots that will be used to build relationships and validate the results of this project.