INTRODUCTION

Ontario's wood fibre shortage has focused the attention of forest scientists and practitioners on Intensive Silviculture (IS). In practical terms, they seek techniques that provide more wood sooner on a smaller land base. In theoretical terms, they wish to achieve the complete allocation of site resources to crop trees – in other words, competitive exclusion by desirable species. Our private sector partner – the Forestry Research Partnership (FRP) - has set the following target: "to identify technology and techniques to increase the annual allowable cut (AAC) on Tembec's licence areas by 10% within 10 years. The 10/10 targets are to be achieved in the context of ecological sustainability, reduced operational costs, improved fibre utilization and enhanced future fibre quality." This SPG proposal will enhance our sponsoring organizations' capacity to meet these targets by providing science based information about the role of competition in intensive silviculture. In addition, we will deliver a process-based single-tree model that 1) complements existing and developing inventory and growth projection tools and 2) allows for predictions based on changing climate and management practices.

Recent refinement of the IS approach includes species mixtures designed to better manage site resources based on the principles of competitive and facilitative production (Connell and Slatyer 1977, Vandermeer 1989). Unfortunately, the lack of specific investigations of competition theory in boreal forest stands means that operational techniques intended to enhance productivity are often based on untested assumptions. For example, mixtures of shallow and deep rooted species, such as black spruce and jack pine, are recommended through "expert advice" in order to stratify the soil profile, "share" the nutritional and water resources found there and increase yields. However, expert advice supported by observation is no substitute for rigourous evidence that such partitioning actually occurs and results in more resources being available to the mixture (one of the basic tenets of competitive production theory). Misguided management strategies are unlikely to succeed, represent a waste of human and financial resources and may lead to even more serious problems. For example, allegations that IS practices (such as vegetation or density control) result in a loss of biodiversity and lead to ecosystem instability and degradation are not uncommon (e.g. May 2005). We will address this gap in Canadian boreal silviculture by using an established series of experimental sites to examine two paradigms based on competition theory: 1) that competitive production mechanisms are operating when suitable species are grown together and 2) that symmetric competition prevails where competitive production is identified. We will measure physical, chemical, biological and physiological attributes that provide direct evidence to assess these paradigms and we will use "DNA bar coding", an innovative technique (Newmaster *et al.* 2006), to link above- and below-ground biomass, including mycorrhizal fungi.

Our project falls under research topic "**Ecosystem adaptation, interventions and modeling**" in Target Area 4. **Healthy Environment and Ecosystems**. We address priorities under both "Adaptation Strategies" and "Modeling" with a focus on the managed boreal forest. NSERC's interest in ecosystem response to human intervention and climate change and, subsequently, our ability to guide environmental policy and practices relative to impacts of resource use activities, was key to the design of this project. Specifically, we will provide the scientific basis for more successful IS interventions. Several jurisdictions (e.g. OMNR 2004, Binkley 1997) have indicated that IS will be necessary in order to respond to existing fibre shortages and future demands for forest products (e.g. biofuels, non-timber forest products, recreation). Our partners – specifically Tembec Inc., the FRP, and the Ontario Forest Research Institute (OFRI) - leaders in the application of forest science to practice, have invested nearly $4 million annually since April 2000 in research and extension to reduce uncertainties related to forest management (CEC-FRP 2005). A number of FRP projects (e.g. Enhanced Forest Inventory in boreal and Great Lakes St. Lawrence cover types, FRP 120-204 and 120-502 respectively) funded through programs such as the Forestry Futures - Enhanced Forest Productivity Science and the Ontario Centres of Excellence are advancing the science of inventory technologies (including multi-band digital imagery and LiDAR) and are developing individual tree classification systems and other automation approaches (including predictive ecosite modeling). The direct link between our work and theirs will be a tree level model that uses remotely measured tree parameters (e.g. tree height, crown dimensions and leaf area index) to predict growth and yield. Our work will improve the accuracy of these estimates by mathematically describing ecological processes associated with resource allocation and influencing species presence and interactions. A better understanding of ecological processes in forest systems gives us better tools to predict, and perhaps manipulate, species response to factors such as density control, site quality, increasing drought and longer, warmer growing seasons.

This is a re-submission from the 2006 competition (Appl. #336614). Reviewers identified the research team, training plan for HQP, links to partners and collaborators, necessity of the work and benefits to Canada as strengths and these were retained. However, the reviewers suggested tightening up the experimental design, which we undertook by unifying the research under competition theory and focusing on a smaller suite of edaphically similar sites. Our approach is suited to the 2007 competition because it will clarify the application of classical resource allocation theory to the managed boreal forest. Since many forest values are linked to the allocation of site resources, our proposal will contribute to the understanding of the impacts of IS on the forest resource as a whole. This, in turn, will better inform forest management practices as industry and government attempt to respond to increasing population pressures and climate change.

SECTION 1 - PROJECT DESCRIPTION and WORK PLAN

Our **Long-term Objective** is to enhance our understanding of competition theory in boreal forests. This knowledge will be used to improve the productivity of high value crop trees through IS which includes site preparation, planting, competition removal, and density management (Adamowicz *et al*. 2003). Benefits attributed to such increases include **a**. extending culmination of mean annual volume increment by several years (Bell *et al.* 1990), **b**. expediting harvesting schedules (Wells and Jorgensen 1979, Weih 2004), **c**. offsetting harvest of first growth forests (Binkley 1997, Bowyer 2001, Sedjo and Botkin 1997), **d**. mitigating CO_2 emissions (Van Kooten *et al.* 1999, Timmer and Teng 2003; Yemshanov *et al.* 2005), and **e**. providing suitable biomass for biofuels (Deyoe 2006). In contrast, potential liabilities include **a**. reduction in site productivity due to reduction in site organic matter (Morris *et al.* 1997, Xiao *et al.* 2005), **b**. loss of biodiversity (Roberts 2002; Brockerhoff *et al.* 2003; Betts *et al.* 2005), **c**. dependence on socially unacceptable vegetation management techniques, such as herbicides (ERGL 1989, Buse *et al.* 1995), and **d**. providing outbreak centres for insects and disease (Nyland 2002, May 2005). Although work has been done on conifers at the single tree level, it is largely mensurational and supports empirical rather than process-based models. Scaling up from single trees to stands and landscapes has led to unrealistic – and untested - expectations of production. At the stand level, results are variable - silvicultural investments have resulted in gains, losses and null effects. We contend that the current advocacy of IS is a classic case of policy/practice preceding science and that many of the reported "failures" (e.g. lack of a response to treatment) are linked to an incomplete understanding, and therefore an incorrect application, of competition theory. In order to make valid predictions about species response to silvicultural interventions, the underlying processes must be clarified.

Silviculture has traditionally been associated with single species plantations. For many reasons including natural disturbance pattern emulation, biodiversity maintenance, social acceptability and ecosystem-based management paradigms, scientists and practitioners are now considering the potential of mixed species stands. Productivity of mixed species stands may be enhanced due to either more effective use of existing site resources (competitive production) or one species improving the environment for the other (facilitation) (Vandermeer 1989). In the context of climate change, an important benefit of mixed species stands is to enhance the potential of carbon sequestration by reducing SOM decomposition rate (Jandl *et al.* 2007). Man and Lieffers (1999) theorized that combinations of white spruce (*Picea glauca* [Moench] Voss) and poplar (*Populus tremuloides* Michx.) have the potential for greater productivity. However, the theories have yet to be tested because the resources, especially the necessary range of field trials and laboratory analyses, are too expensive and difficult to establish from scratch (Rothe and Binkley 2001). Substitutive and/or additive series experiments are preferred, but the wide range of possible combinations (species, sites, mixtures) is operationally prohibitive (Kelty 2006). Another perpetual challenge to forestry research is the length of time required to track changes especially in subtle processes (Sharma *et al.* 2007, Sharma *et al.* 2003, Dyck and Cole 1994). We will address these issues by using four existing experimental trials at the establishment, crown closure and mature stages (i.e. 5, 20-25 years since harvest and 90-100 year old stands); and by elaborating a process-based model that combines the characteristics of both a carbon cycle model (Larocque 2002a, Larocque *et al.* 2006a) and a gap model (Larocque *et al.* 2006b) We have chosen five commercially important boreal tree species that represent a range of shade and drought tolerance and productivity as our focal species: white spruce, black spruce (*Picea mariana* [Mill.] B.S.P.), balsam fir (*Abies balsamea*), jack pine (*Pinus banksiana* L.) and poplar. These species exhibit the physical and physiological characteristics that may lead to good "combining ability"; in other words they have the capacity, at least theoretically, to partition and/or affect the above- and belowground environments such that productivity can be enhanced under certain conditions (e.g. density, site quality).

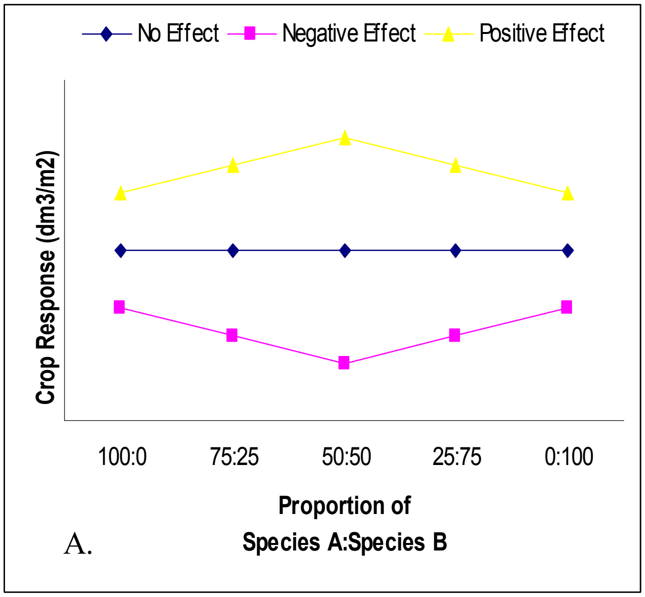
By the end of the project, we will deliver a single-tree model to our industrial partner that will predict forest productivity in pure and mixed stands by modeling the abiotic (elements of the C and nitrogen cycles) and biotic (competition) processes that govern stand productivity. This model will make it possible to use individual-tree inventory data (automated systems currently under development through FRP) to more accurately predict growth attributes in managed boreal forests. The **short-term** goals that will allow us to address our hypotheses (detailed below) and deliver this modeling tool are 1) confirmation as to whether or not these species mixtures do stratify limiting resources, 2) evidence as to their relative ability to sequester carbon and/or nutrients under mixtures and pure stands, 3) identification of the site factors (e.g. soil depth/texture, proportional mixtures and stem densities) that promote expression of good combining ability and 4) derivation of mathematical relationships describing key processes. In accomplishing these goals, we will also train HQP, provide opportunities for increased collaboration among partners, improve the research capacity of our respective institutions, publish results and transfer products to government and industrial receptor organizations.

Hypotheses 1 – Competitive production mechanisms operate where species mixtures fully occupy the site but diminish in their effects at low and high densities. [Definition: Competitive production – if two species are sufficiently distinct in resource use, they may utilize limited resources more efficiently; Facilitative production – one species may improve the environment experienced by another species.] At full site occupation, species specific strategies will be expressed. If these strategies lead to positive partitioning of limited resources, then productivity should be enhanced. For example, Poplar, shade-intolerant and fast-growing, develops a vertical advantage both above- and below-ground. White spruce, shade-tolerant, slower growing and more shallowly rooted, becomes established in the understory. Features attributed to poplar, such as faster nutrient turnover, closer spacing and the presence of a protective canopy are assumed to enhance through facilitation, the growth, wood quality and survival, respectively, of spruce. It is well accepted that tree growth is affected by above ground competition (stand density) (Larocque 2002b, Sharma and Zhang 2004a, 2004b, and 2007), but Rothe and Binkley (2001) noted that there are few studies that directly track the effect of such mixtures through the processes of litterfall, decomposition, root uptake, and change in foliar nutrient concentrations (Kelty 2006). The mechanisms of competitive production are even less well documented and understood – especially those that operate underground. For example, if the soil horizon is deep enough to permit stratification by the root systems and if more of the limiting resource (e.g. water or nitrogen) is therefore made available, then competitive production is assumed to be operating. Evidence confirming the stratification of soil resources in boreal settings is limited (Barnes *et al.* 1998) and the potential to stratify may only be expressed under certain environmental conditions (e.g. moisture or nutrient stress, stand density). At higher stem densities, resource demands of poplar often overwhelm the competitive abilities of white spruce, thus effectively confirming the "competitive exclusion" principle in favour of a less commercially desirable species. At lower densities, competition is too weak to result in the expression of differences, but both species suffer poor form from lack of self-pruning. We propose to use plot level and single-tree analysis to study if and when different mechanisms are operating. Kelty (2006) argues that studying the effect(s) of neighbourhood tree variables (species, size, distance) on the growth of subject trees is an efficient approach and that this kind of analysis can be done with any additive series experiment (e.g. D'Amato and Puetmann 2004). Using high resolution multi-band digital imagery, medium scale aerial photography, LiDAR and other available inventory information, we will identify several examples of a range of densities (e.g. from 2500 to 4500 stems/ha) and species proportions (e.g. species A:species B ~ 100:0, 75:25, 50:50, 25:75, 0:100) at each of the experimental trials. These density/proportion combinations will be our experimental units located within randomly and independently established replications within blocks at each trial. In addition to standard mensurational and physiological metrics, we will use DNA bar coding (Newmaster *et al*. 2006) to distinguish between fine roots of tree, shrub and understory species. This technology represents a breakthrough in our ability to detect vertical and horizontal stratification in the soil and allows us to link belowground structures and processes to aboveground ones.

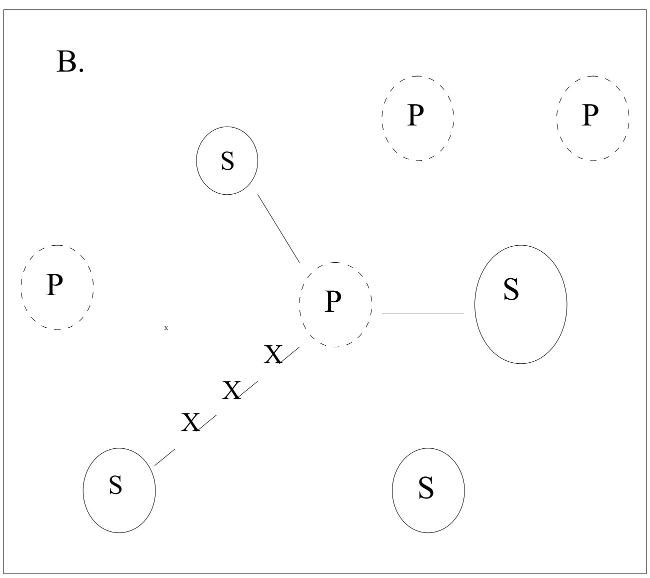
Hypothesis 2 – Symmetric competition prevails over asymmetric competition in productive species mixtures [Definition – symmetric competition is a sharing of resources amongst individuals while asymmetric competition is an unequal sharing as a consequence of larger individuals having an advantage over smaller ones (Weiner 1988)]. For example, it has been suggested that competition for light is asymmetric while competition for soil resources is symmetric (Kikuzawa and Umeki 1996, Weiner *et al.* 1997). That is, not only do the crowns of larger trees intercept a large proportion of photosynthetically active radiation (PAR) they also reduce the quantity and modify the quality of PAR reaching smaller trees at lower canopy positions. This simplistic explanation ignores the fact that some trees are shade tolerant and thus adapted to function under lower light levels. From the point of view of such a tree, the presence of the larger tree may not be particularly negative and may perhaps enhance the performance of the smaller tree with respect to crown development and stem biomass allocation (e.g. stem form). Belowground, the theory is that water and nutrients are shared relative to root mass. This too is simplistic in that it ignores the possible contributions of mycorrhizal associations and vertical stratification of the soil horizon. Furthermore, the interaction between above- and belowground components is not considered. For example, an aboveground resource that may be asymmetrically partitioned is precipitation. This could happen in at least two ways. First, foliage can directly capture water. Secondly, the aboveground architecture can redirect the water flow either down the stem of the tree or along the dripline to favour the intercepting tree. Subsequent enrichment of stem- and canopy flow has been shown to account for significant proportions of nutrient budgets (Prescott 2002, Helmisaari 1995). In this example, larger trees may very well pre-empt the availability of water and nutrients to smaller trees; hence an aboveground attribute is affecting availability of belowground resources. Little information exists on these synergistic mechanisms. Basic ecophysiological processes, such as photosynthesis, transpiration, water and nutrient uptake, are affected whenever plants interact and these interactions are species specific (Rothe and Binkley 2001). Therefore, it is important to study both the processes and the stand conditions under which they operate in order to refine the representation of competitive interactions and improve the accuracy of model predictions. Using the same research trials as for Hypothesis 1, we will compare the structural components (mass of foliage/roots/stems, branchiness, LAI) and physiological responses of trees in pure and mixed stand conditions. For example, if the photosynthetic response curve of a representative tree in the lower canopy is equivalent to or exceeds that of a similar tree in full sunlight we will have evidence that the competition for PAR in this case is symmetric. Another measure, pre-dawn water potential, integrates a matrix of effects regulating the availability of soil water to vegetation. If lower canopy trees are accessing disproportionately less available water then that will be evidence of asymmetric competition. Similarly, if lower canopy trees exhibit disproportionately lower nutrient concentrations and contents, asymmetric competition may be operating. Water and nutrient use efficiencies will also be informative. If lower canopy trees exhibit similar or higher efficiencies than their upper canopy neighbours, it will be evidence of symmetric competition and we could reasonably expect to find enhanced productivity occurring.

WORKPLAN - Our workplan consists of six main components. First, the hypotheses have been designed to integrate classical competition theory and operational silviculture. Second, the selection of sites has focused on established studies with extensive records. Furthermore, Luckai and Bell are already familiar with these areas and their history. Third, field methodology has been crafted to bring consistency to the database and provide information to test the hypotheses and further the development of models. Fourth, modeling will focus on the evolution and integration of a stand level process-based model (FORECAM), a tree-level deterministic model (IVY) and a gap model (ZELIG). Larocque and Groot are the developers of FORECAM and IVY and are fully capable of moving both these models forward. Five, milestones are outlined in the Activity Schedule and primarily relate to the progress of graduate students; these individuals are the key to maintaining momentum and achieving our goals. And sixth, the co-applicants, collaborators and sponsoring organizations will meet at least twice a year, co-supervise students, co-author papers and coordinate workshops in order to maintain communication and effectively transfer knowledge. The new knowledge gained will be beneficial to 1) understanding the complexity of species interactions (tree to tree, tree and fungi, tree and understory) in boreal forests, 2) further developing models that can assist with predictions based on changing climates and management scenarios, 3) designing silvicultural interventions that will better achieve management goals and 4) strengthening the interactions between our organizations (e.g. co-authorship). The research team will be primarily responsible for ensuring that the work done by and for the grad students is of the necessary quality to address the research questions (Supervision is indicated under Section 2). Bell and Luckai will ensure that field work is done in an effective and efficient manner. We will meet at least twice each year to review progress, develop work plans and share information. In addition, workshops, primarily for forest practitioners, will be held in the second and third years at the Canadian Ecology Centre (Mattawa, ON).

Hypotheses testing:



Hypothesis 1: Competitive production mechanisms operate where species mixtures fully occupy the site, but diminish at lower and higher densities. Evidence will be based on plot level data. Crop response (e.g. biomass of the component of interest such as stems or all aboveground) is estimated using dbh, ht and existing species specific allometric equations. Tree centred plots (Poplar at the centre and various mixtures/densities around) provide the inventory data. We might expect to find the negative effect where density is high, the null effect where density is low and the positive effect where density is optimum. Figure A (to the left) illustrates possible effects of species proportions on crop response at different densities.



Hypothesis 2: Symmetric competition prevails in productive species mixtures. Evidence of symmetric competition will be provided by
a. identifying linear (rather than exponential) relationships between tree size and the resource of interest (e.g. water, N, Photosynthetic response, intercepted PAR) and/or
b. finding examples of partitioning of belowground space (based on DNA bar coding and/or root excavation).
Field methods: Using the same locations as identified for Hypothesis 1 (densities and species mixtures), with poplar at the centre (Figure B)
a. we will randomly select 3 individuals from the "species B" trees immediately surrounding the centre poplar. (Note - Circles in diagram represent stems not crowns, S = spruce, P = poplar, X's represent soil cores.) This nearest neighbour approach provides a range of sizes and distances and allows us to use response surface analysis for the variables of interest. Additional mensurational (e.g. upper dia's for taper functions, crown width and depth) and physiological measures (water potential, photosynthesis) will be taken prior to destructive sampling (foliar chemistry, age determination, last five years growth, soil cores).
b. Mineral soil from three cores spaced equidistant between the centre tree and each of the perimeter trees (Figure B) will be sampled. Although there will be a range of tree sizes and distances, we will always have one sample equidistant from each tree and one from each side. This should allow us to capture the point of root interaction (if any) between the two trees.

Site Selection – The project has two age classes of experimental trials (5 and 20-25 years since harvest) plus mature stands representing the pre-harvest condition. The youngest studies (Timmins and Dryden), part of the NEBIE network (Pitt and Bell 2005), were implemented as Completely Randomized Block Designs with a range of silvicultural treatments from natural (no treatment after harvesting) to intensive/elite (fully assisted regeneration with vegetation management). At each site, the density of the primary tree species in the intensive/elite plots was controlled while that of the secondary species varied. This blend of consistency and variety allows us to identify examples of a range of competition intensities, thus simulating an additive design. For the 20-25 year age class, we have access to the Fallingsnow (Lautenschlager and Bell 1994) and Foleyet (McPherson *et al*. 2007) studies, which were established by the Ontario Ministry of Natural Resources. Fallingsnow was recently photographed at 1:250 and 1:3000 scales and an automated individual tree crown inventory completed (Pouliot *et al*. 2002, Pouliot and King 2005) which provides an unparalleled record of the arrangement and densities of approximately 160,000 trees. These two sites provide the opportunity for intensive measurements at crown closure, the second crucial time following stand establishment, thus extending the inference space in time and providing guidance for future work in the young stands. Finally, mature stands representing the previous forest condition exist at each site and will be used as "endpoints" in the chronosequence. The study sites are linked because they include the five tree species and are situated on moist, fine textured soils. These soils are generally considered suitable for IS because they have the potential to support higher levels of productivity if site resources can be fully accessed by the crop trees. The Timmins and Foleyet sites (located in northeastern Ontario) are homogenous, deep (>1m), and free of course fragments; Dryden and Fallingsnow (in northwestern Ontario) are more variable which will allow for the inference space to include soil depth and slope. In order to reduce the complexity of the sampling design and further link the studies, we will use poplar as species A in all our proportions. Poplar is present on all sites and represents both a valuable crop tree and a persistent competitor.

Field Methods:

a. Experimental units (EUs) will consist of groups of trees representing a range of densities (2500 to 4500 stems/ha) and species (A:B) proportions (100:0, 75:25, 50:50, 25:75, 0:100).

b. Photography and other inventory data will be used to identify suitable EUs at each site. The Dryden and Timmins sites will be re-measured by OMNR personnel in 2007 (eighty 400 m^2 plots, 800 4 m^2 vegetation plots). Fallingsnow has an extensive historical database (trees and understory) and Foleyet was re-measured in 2006. This data will provide us with estimates of variability with which to establish sampling intensity. EUs will be ground truthed, labeled, photographed and GPS'd prior to sampling.

c. Weather stations will be installed at selected locations in each site to gather information about soil moisture/temperature, PAR, air temperature.

d. Wherever soils and/or site information is lacking, an inventory of key features (texture, total C and N, total cations, CEC, pH, bulk density, moisture regime (field) and moisture retention (lab)) will be completed.

e. Field work will be divided between the eastern sites (primarily year 1) and the western sites (primarily year 2). We will liaise with OMNR staff working on the Dryden/Timmins sites to avoid duplication of effort and create cost-efficiencies.

f. Samples of selected tree, shrub and ground vegetation will be provided to the DNA lab at University of Guelph to establish the key that will be used to identify the roots of these species.

g. Aboveground – selected EUs will be carefully measured for dimensions and ground vegetation will be surveyed (species ID and % cover). Prior to any destructive sampling, LAI (hemispherical photography and sensor), and physiological measurements (pre-dawn water potential, photosynthesis) will be conducted. Standing crop biomass will be estimated using standard allometric equations (e.g. Alemdag 1983) based on basal or breast height diameter and height; some destructive sampling will be done to confirm accuracy of estimates. Site productivity will be estimated (growth intercept, soil site index, height age index).
h. Belowground – a motorized soil corer (developed by CNFER, OMNR to quickly and cleanly cut through roots) will be used to remove samples (stratified by depth) along transects from one tree to another (within an EU). Cores will be re-packed, labeled and re-sampled one year later for root ingrowth. The DNA bar coding will provide information about the identity and relative abundance of the species of interest. Additional soil will be used for incubations (index of soil fertility) in growth chambers. Excavations will be performed on selected EUs in order to map root structures.

Use of Models - Several process-based models, such as FOREST-BGC (Running and Coughlan 1988, Running and Gower 1991) or CENTURY (Parton et al. 1987), have proven useful in identifying the potential impacts of climate change (e.g., Peng and Apps 1998, Medlyn et al. 2000, Luckai and Larocque 2002, Rathgeber et al. 2003, Larocque et al. 2006) and management scenarios (Morris *et al.* 1997). These models are built on equations that describe the mechanisms governing tree and stand growth (e.g. photosynthesis, mineralization, carbon allocation). The parameterization and validation of process-based models requires detailed ecophysiological data not normally collected for forest management purposes. Despite their complexity, or perhaps because of it, process-based models have not achieved the accuracy needed for forest management planning, particularly at the individual-tree level. On the other hand, gap models belong to a class of mechanistic models that simulate the growth of individual trees by using relatively simplified representations of the biotic and abiotic processes that govern individual-tree growth. Therefore, future research efforts must focus on the development of a new class of individual-tree models that combine the characteristics of process-based models (focusing on nutrient and carbon cycling) and of gap models (focusing on biotic inter-tree interactions). In particular, the representation of competitive interactions among different species needs to be improved as discussed above. The IVY model, which uses light capture by individual tree crowns (Groot 2004) to estimate volume growth, is good example of this type of model development, and is applicable to mixed species stands growing at a wide range of densities (Groot *et al.* 2005).

The different types of data that will be gathered will allow us to derive a single-tree model combining the characteristics of both carbon cycle and gap models. In particular, allometric data, such as crown dimensions and root characteristics, will be important to describe the extent of competitive interactions among individual trees. In combination with PAR and physiological measurements (photosynthesis, respiration, transpiration at key phenological periods during the growing seasons under different PAR and temperature conditions), these data will improve the mathematical representation of interactions among different classes of competitors when they uptake site resources. To describe the carbon cycle in different ecosystems, carbon in the litter and the organic and mineral layers of the soils will be measured, litter traps will be installed and litterbags will be used to estimate decomposition rate. Incubation studies in growth chambers under different temperatures (3, 12 and 22°C) will be used to derive mineralization rate curves. For the study of the nitrogen cycle, samples of foliage, stems, roots and soils will be collected. Foliage sampling will be conducted when photosynthesis measurements are undertaken to link the effects of foliage nitrogen concentration on photosynthetic rate (e.g. maximum carboxylation rate and maximum electron transportation rate).

SECTION 2 – TRAINING POTENTIAL

The role of the PhD student will be to integrate the results of testing Hypotheses 1 and 2, to develop the model and to liaise with our sponsoring organizations, primarily Tembec Inc. and the FRP. The specifics of the research program will depend upon his/her demonstrated strengths and input into the project. Luckai is eligible to supervise as a member of the Lakehead Biotechnology Research Group; Larocque, Groot and Sharma (Adjuncts), Bell (OMNR and FRP Science Advisory committee) and Durst (FRP Project & Extension Manager, and Tembec) will be available to participate in the committee. When a suitable candidate is identified, we will work with our industrial partner to submit an NSERC IPS. The PhD student will benefit from collaboration with four **Masters** students who will tackle specific elements of the project. At this time, topics include 1) effects of inter-specific competition on quality of white spruce (Sharma and Bell to supervise), 2) effects of density and competition on biomass partitioning in the five tree species (Larocque, Luckai, and Sharma to supervise), 3) survival of mycorrhizal fungi following harvest and stand re-establishment (Luckai and Newmaster to supervise), and 4) effects of site, density and competition on abundance, vertical and horizontal distribution of roots in the five primary species (Luckai and Groot to supervise). Additional studies will be assigned to **undergraduate** students as thesis topics. These include developing taper equations for fir, poplar and black spruce (Sharma); using GIS and medium scale photography to map stand conditions at Timmins, Foleyet and Dryden (Bell); extending allometric equations for biomass distribution in white spruce (Larocque and Bell); and assessing foliar nutrition under differing competition regimes at Fallingsnow (Luckai and Bell). Our intent is that the Masters students will fill Summer positions in the first two field seasons (Summer 2008 and 2009) in order to become completely acquainted with the study methodology and objectives. Detailed study designs will be reviewed and further developed by the graduate students during their first two terms of study (e.g. Fall/Winter 2008/09 and 2009/10). This training and planning phase will provide excellent experience in project management in a complex setting and the students' interdisciplinary exposure will be invaluable for finding employment in a forest science related field. Graduate students will be expected to submit abstracts to conferences, to make at least one presentation (either paper or poster), to take advantage of the opportunities for networking that these conferences provide and to publish their work in peer-reviewed journals and as technical summary notes. Students will also participate in the FRP Extension Workshops to be held in Years 2 and 3 and attend and present at PI meetings (project review, interim results). The project team will provide guidance particularly in the area of hypothesis testing, modeling and statistical analyses. A **Post Doctoral Fellow (**PDF), under the supervision of Luckai and Meyer primarily, will be responsible for coordination of the field and lab work, safe and secure data management and organizing transfer of the research results through workshops and appropriate journal papers. The PDF will be responsible for the routine administration of the project including budget, reports, hiring and supervision of summer personnel. He/She will work with the Lab Manager of the Forest Soils Laboratory to ensure that analyses requiring those facilities are organized in a timely and efficient manner. The interaction of students with each other, the PDF, co-applicants and collaborators will provide an excellent working model for interdisciplinary research and cooperation. In addition, students will train in the research facilities at the OFRI (Sault Ste. Marie, ON), the Laurentian Forestry Centre (Quebec City, QC) and the University of Guelph which will introduce them to different institutional structures and scientists working in similar fields. This project will provide students with transferable skills required by Canadian organizations (written/oral communication, decision making/problem solving, experimental design/analysis, model use/development, and interpretation of complicated data).

SECTION 3 – INTERACTIONS WITH SUPORTING ORGANIZATIONS

The intentions of the research team are to 1) clarify and document the competitive mechanisms operating in managed boreal forests and 2) transfer that knowledge to receptors in industry and government to develop prescriptions and interventions appropriate to Intensive Silviculture. When we decided to apply for an NSERC SPG, we began with input from potential users and policy developers. We sought out partners and supporting organizations and included them in the development of the ideas and the deliverables. Through contacts with government and private sector (e.g. OMNR, CFS, FRP and Tembec), we are assured that industry has immediate and legitimate concerns about fibre supply and that they intend to use intensive silviculture to address mill shortages and the demand for new and traditional products. We also learned that industry has an immediate need for growth and yield prediction tools that address the first twenty years of growth of managed forests and can be linked to sophisticated GIS databases using survey techniques such as LiDAR. We will deliver this work to our industry partners and partner with Dr. M. Penner to integrate our data with her provincially recognized curves for full rotations. The FRP will bring their connection to a significant number of ongoing forest inventory projects and their unique focus in applying sound science directly, through their practitioners, to the ground. The results of this project will be of value to three of OMNR's new guidelines, specifically the Silviculture, Bio-energy, and Biodiversity strategies and the results will be incorporated into policy as soon as they become available. (Note: Bell and Sharma participate actively in committees supporting these strategies.) Luckai and Meyer, as teaching faculty at Lakehead, have the opportunity to pass their interest in these issues to students as part of curriculum. The Ontario Forest Research Institute (OFRI), a major supporter of this project, is the OMNR's main forest research unit and its staff collaborates with a range of partners to provide other branches of OMNR, Ontario's forest industry and other natural resources clients with top-quality science to support sustainable forest management. Furthermore, transfer of results is mandated through publication in peer-reviewed journals, and a variety of professional venues, including workshops, field tours and reports. Larocque will maintain contact with the research team and the students through his adjunct appointments at Lakehead University, Université de Sherbrooke and Université du Québec en Abitibi-Témiscamingue, with industry and governments through his professional work (e.g. Program Chair and member of the organizing committee of the Eastern CANUSA conference in October 2006, organizer of a Workshop on Uncertainty Analysis at the International Enviromental Modelling Software Society (IEMSs) in July 2006, his collaboration in the calibration of FVS with the OMNR) and with the research community through scientific societies, including the International Society for Ecological Modeling (ISEM). Sharma and Groot are also adjuncts at Lakehead and this project will provide a foundation for closer ties through graduate students and publication. Because of these ongoing relationships between the co-applicants, collaborators, industry and government, our plan for publication and the organization of two silviculture workshops and our track record of liaison with the user sectors, we are confident that results will be transferred in a timely manner.

This project directly involves the supporting organizations through the use of equipment, services, experimental sites, and historical data and will have its results utilized as follows:

a. OFRI's contributions include staff time to assist with planning, data collections at the NEBIE Installations, analysis, publishing and transfer. OMNR will also loan 20 weather stations for use on the Timmins/Dryden sites. OFRI has committed to transferring all data collected on the Fallingsnow, Dryden and Timmins sites, to Lakehead University to support the project.

b. Tembec Inc, a leading integrated forest products company based in Canada, has documented its interest in the outcomes of this project and will be providing access to its enhanced inventory datasets on the Romeo Malette Forest in support of the project.
c. The Forest Research Partnership, a joint undertaking with the OMNR, the Canadian Forest Service and Tembec, will provide support through its world class science and technology transfer and extension program and through liaison with its collaborators and their ongoing research projects as they may relate to this project.

All intellectual material gained by this project will remain with the partners. The sole exception to this arrangement is that material in the student theses and the intellectual rights of the students shall be protected for all University students engaged in this project. The student and/or his/her supervisor(s) shall retain the tight to publish information contained within the thesis in all cases, following the review of intended publications by the partners in this project. The first publication right on material in any student thesis belongs with the student author, who has the opportunity to waive this right to his/her supervisor(s).

SECTION 4 – BENEFITS TO CANADA AND THE SUPPORTING ORGANIZATIONS

The fibre shortage in Ontario, the pressures to remove more land from the industrial landbase, the necessity to grow more wood on a smaller landbase and the demands for bioenergy alternatives are real. Binkley (1997) and Lautenschlager (2000), among others, have outlined the benefits of intensive silviculture and plantations in northern ecosystems. We believe that we need to refine our understanding of competitive mechanisms in boreal systems in order to practice intensive silviculture effectively. This project will provide documentation and modeling results that will help to address this need. Our partners include government and industry who have committed to the project by providing in-kind and cash contributions, through equipment purchase, consulting, discussion and application of the results. The forest industry is a major contributor to the Canadian economy, particularly for regions across Ontario and into Manitoba, all of which have recently been devastated by news of mill and woodland closures and reductions. At the same time, demand for forest products continues to increase world-wide. According to the Food and Agriculture Organization of the United Nations, this demand will double by 2020. Canada will not be equipped to participate in this demand, nor to reap its economic benefits, if we cannot resolve important questions about sustainability and ecosystem stability as related to intensive silviculture. Research in intensive silviculture, as represented by species mixtures, shortened rotations and biomass for biofuels, is essential for the conservation of remaining natural forests of Canada while addressing fibre shortages and increasing local benefits of new and existing forest products. Finally, training of HQP at the undergraduate, graduate and post-doctoral level will provide future personnel for continuing this work. Projections in the forest science and operations sectors show many retirements over the next 5 to 10 years; individuals who can use models appropriately, interpret field and model output and make the connection between practical application and underlying theories will be essential to maintaining Canada's role as a leader in forestry.