

<b><i>Project Title</i></b>	Assessing forest biomass as a bioenergy feedstock: the availability and recovery of biomass in uneven-aged forests
<b><i>Project Identification Number</i></b>	BIO 063
<b><i>Proponent</i></b>	The governing council of the University of Toronto
<b><i>Number of Participating Partners</i></b>	8
<b><i>Total Project Cost (\$000s)</i></b>	813
<b><i>Total Contribution from Proponent and partners (\$000s)</i></b>	227
<b><i>Total ecoEI Contribution (\$000s)</i></b>	273
<b><i>Total Government Contribution (\$000s)</i></b>	273
<b><i>Project Highlights</i></b>	<ul style="list-style-type: none"> <li>○ Developed remote sensing methods for inventorying uneven-aged stands</li> <li>○ Developed a model for estimating the recovery of unmerchantable biomass</li> <li>○ Published 4 papers and submitted 5 manuscripts</li> </ul>
<b><i>Date submitted to NRCan</i></b>	5/31/16

**Executive Summary.** In recent years, the forest sector in Canada has suffered from increasing international competition and waning demand for traditional timber and paper products. At the same time, there is a growing market for renewable energy and unused biomass feedstocks. These trends will give a competitive edge to companies that can utilize unmerchantable wood to reduce energy costs and/or supply the energy market.

There is a considerable amount of unmerchantable wood in the uneven-aged forests of the Great Lakes – St. Lawrence (GLSL) region, as well as the demand and capacity to use it as feedstock for the production of bioenergy. However, in order to exploit these regional advantages, forestry and energy companies require better estimates of the availability of unmerchantable biomass. Furthermore, they need to know how much can actually be recovered, so that they can decide whether to integrate biomass recovery into their operations and determine how it will influence the rest of their supply chain.

Toward this end, we have developed new methods for inventorying uneven-aged stands using remote sensing, including LIDAR and multispectral imagery. We have also developed a model for estimating the recovery of unmerchantable biomass from uneven-aged stands. The results of our research have been written up in nine papers: four of the papers have already been published in peer reviewed journals, and the other five have been submitted for publication.

**Background.** The uneven-aged forests of the GLSL region are typically managed using partial cutting methods (selection or shelterwood) that fell 1/3<sup>rd</sup> to 2/3<sup>rd</sup> of the trees (respectively), including both merchantable trees and unmerchantable trees. Unmerchantable trees are not suitable for timber or pulp for various reasons: because they are undesirable species with poor

timber or fibre properties, because they are diseased or deformed, or because they are too small for sawmilling (i.e. polewood less than 24 cm in diameter). These unmerchantable trees are often felled to release the remaining merchantable trees from competition (and to thin the understory when overstocked with polewood), but they are not hauled out of the stand, except when used as firewood. The tops and branches of merchantable trees are also left behind with the rest of the unmerchantable trees.

Thus, there is a considerable amount of unmerchantable biomass in the GLSL region, as well as the demand and capacity to use it as feedstock for the production of bioenergy. However, in order to exploit these regional advantages, forestry and energy companies require better estimates of the availability of unmerchantable biomass. Furthermore, they need to know how much can actually be recovered, so that they can decide whether to integrate biomass recovery into their operations and determine how it will influence the rest of their supply chain.

Many forestry companies use a software platform called FPIInterface to make such decisions. FPIInterface was developed by FPIInnovations, and uses a model called BiOS to predict the recovery of unmerchantable biomass based on forest inventory data or remote sensing data. However, BiOS was initially developed for even-aged boreal forests, so it was not suitable for use in the GLSL region. Thus, the goal of this project was develop new methods for inventorying uneven-aged stands and predicting the recovery of unmerchantable biomass.

**Objective 1.** Our first main objective was to use LIDAR data to predict the size structure of uneven-aged stands. In order to make predictions with a direct connection to product recovery, diameter distributions were first divided into six structural classes: sapling, polewood, small sawlog, medium sawlog, large sawlog, and extra-large sawlog. Then, the density of trees in each size class was predicted using two non-parametric methods: k-nearest neighbor (k-NN) imputation and random forest.

The random forest method was more accurate than the k-NN method. After the predicted diameter distributions were grouped into nine stand structure classes, heterogeneous accuracy scores revealed that particular stand structures are challenging to predict. Nevertheless, the random forest method is sufficiently robust to predict stand structure for the most common stands. Thus, this method can be used by our partners to specify the structure of uneven-aged stands, since the modified BiOS model predicts recovery based on the density (and species identity) of trees in different size classes (see below).

**Objective 2.** Our second main objective was to use imagery to delineate individual tree crowns for subsequent identification (see Objective 3 below). In addition, we sought to develop a watershed transformation method that utilizes all the spectral bands that are available when using multispectral imagery, as well as a multi-scale fitting method that identifies the parameter value that provide the best fit for each reference crown, rather than selecting a single parameter value based on its overall fit to the image as a whole.

The multi-band watershed segmentation method was more accurate than existing valley-following methods. The multi-scale fitting method was also more accurate than selecting a single parameter value based on its overall fit to the image as a whole. Thus, this method can be used by our partners as a first step towards quantifying species composition (as described further below).

**Objective 3.** Our third main objective was to use imagery to identify each of the delineated crowns to species. In addition, we sought to use multi-season imagery to distinguish similar species that may have seasonal differences in reflectance.

When using images from a single season, the highest accuracy (0.7) was obtained with a mid-summer image. Using multi-season imagery substantially improved accuracy (0.77). Thus, either method can be used by our partners to specify the relative abundance of leading species, which is equally important as stand structure for predicting recovery.

**Objective 4:** Our fourth main objective was to modify the BiOS model for use in uneven-aged forests. In particular, we modified the model to predict recovery based on size distribution of trees (rather than the mean size of trees), and adjusted the recovery ratios for each size class to account for size-related variation in cull.

The model now captures the variation in recovery observed across silvicultural systems (e.g. shelterwood) and harvest methods (e.g. cut-to-length). Thus, our partners can use the model to assess biomass supply in uneven-aged forests of the GLSL region, as can other members of FPIInnovations who use FPIInterface for supply chain optimization. We are currently implementing the model for Acadian forests of the Atlantic provinces as well.

**Benefits.** We have developed new remote sensing methods for inventorying uneven-aged forests, as well as a model for estimating recovery of unmerchantable biomass. Both the methods and the model can be used by our partners (as well as members of FPInnovations who use FPInterface) to decide whether to integrate biomass recovery into their operations and determine how it will influence the rest of their supply chain. The model can also be used by provincial agencies to better allocate wood supply to companies that can best utilize low quality wood and residues, including harvest blocks that would otherwise be passed over by companies seeking only higher quality wood. In turn, the model will help those companies optimize their operations by fully utilizing the current value of low quality stands, while increasing future value through stand improvement.

In recent years, the forest sector in Canada has suffered from increasing international competition and waning demand for traditional timber and paper products. At the same time, there is a growing market for renewable energy and the unused biomass feedstocks. These trends will give a competitive edge to forestry companies that can utilize unmerchantable wood to reduce energy costs and/or supply the energy market. These trends will also allow governments and crown corporations to boost the competitiveness of other industries by increasing the supply of energy while limiting carbon emissions.

### **Next steps**

*Publications:* As noted above, we have published five papers already, but the four submitted manuscripts are still under review. Given that each paper typically requires extensive revision, we expect to spend the next year ushering the four submitted manuscripts through review. We also intend to finalize and submit a tenth manuscript that estimates the supply and cost of biomass at a regional scale.

*Acadian forests:* Our next step for the BiOS model is to extend it to the Acadian forests of the Atlantic provinces, as part of an innovation hub organized by FPInnovations.

*Further research:* Most of the researchers on this project have joined a new project titled AWARE: Assessment of Wood Attributes using Remote Sensing. AWARE is a Collaborative Research and Development (CRD) project funded by NSERC. The AWARE project builds on the results of our ecoENERGY project by assessing whether the remote sensing methods can be extended across a wide range of forest types, including boreal forests.

