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CANADIAN FOREST SERVICE
Spotlight on SCIENCE

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Enhanced Forest Inventory
A Tool for a Competitive Canadian Forest Sector

Canada's forest resource, the third largest in the world, is vast and complex, and plays a major role in Canada's economy. From rocky Atlantic shores to the coast of British Columbia, forest managers are tasked with sustainably managing millions of hectares of working forests balancing economic, environmental, and social values. To succeed, forest managers need to know several key pieces of information: what trees are where, what the wood in those trees can be used for, and how they can gain access to the trees and forests while respecting the other values the forest provides. To gather and use this information, forest managers inventory their forests and create inventory maps that characterize and describe stands. They use the forest inventory maps to plan their harvests, plan where they will renew the forest, and also plan to protect sensitive areas within their forests. Forest managers need a forest inventory that provides information and tools to ensure that the right amount and type of wood fiber are available at the right place at the right time.

The Canadian Wood Fibre Centre (CWFC) of the Canadian Forest Service (CFS) has been working with numerous partners in other government sectors, industry, and academia to develop a forest inventory tool called an Enhanced Forest Inventory (EFI). The EFI is an innovation that combines emerging technologies with current technologies to meet the planning needs of Canada's forest managers.

The CFS has been involved in developing many of the technologies the EFI uses. For example, the CWFC built the integrated platform the EFI used taking advantage of the strength of the CFS in long-term forest ecology research merged with the strength of FPInnovations in shorter-term operational research.

Forest inventory has a long history of research and development (R&D) in Canada. Originally, timber-cruise (timber-inventory) maps were hand drawn after surveying the land base on foot, on horseback, or in a canoe. Later, aircraft were used and stereographic air photos supported by ground plots became the standard inventory method. Over time, ecological and ecosystem-based variables were included to broaden the inventory to manage not only the timber but all forest values. In the 1980s, maps were converted to a computerized digital form with the development of Geographical Information Systems (GIS). The Government of Canada has continually supported the science behind these improvements.

The Government of Canada supported the work to improve the competitiveness of the Canadian forest sector to create jobs and generate wealth for Canadians while sustainably managing the forests. The federal role in forestry includes R&D of products like the EFI in a well-partnered collaboration with industry, the provinces, and academia. The EFI is also effective in supplying data to the National Forest Inventory for summary statistics used for national and international policy setting. Other CFS research initiatives can use the EFI in modeling and scenario testing at a landscape level.

The EFI uses airborne lasers in a method known as light detection and ranging (LiDAR). LiDAR provides the EFI with a computerized three-dimensional view of the ground (called a terrain map) and the morphological characteristics of trees including crown shape and tree height. Detailed measurements of trees from ground plots including internal wood characteristics complete the components used in the EFI.

Aerial LiDAR systems capture three-dimensional data of forests from above the canopy.

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LiDAR is a remote sensing technique that is based on measuring the time it takes a laser pulse to strike an object and return to the source. Typically, a laser scanner is flown in an airplane, the exact location of which is tracked by a GPS satellite. State-of-the-art scanners are capable of transmitting and receiving as many as 500 000 pulses of laser light per second, resulting in data that can be used to map the reflecting object in high three-dimensional detail http://www.nrcan.gc.ca/node/13425.

LiDAR data layers. DTM, Digital Terrain Model; DSM, Digital Surface Model; Profile, combined surface and terrain view. (Murray Woods, Advanced Forest Resources Inventory Technologies, Ontario)

The EFI places a spatially complete inventory along with detailed terrain mapping on a forest manager's desktop. It tells forest managers precisely what is where and how to get there so that they can plan how to manage it sustainably. The EFI is better, faster, and rapidly becoming more affordable than other methods (for example, in-person surveying) with the same goals.

The EFI concept was tested at sites across the country. These sites were industrial test cases of the concept confirming the benefits and suggesting how to improve the product. The sites have supplied some economic data on cost savings and benefits. At the Ontario site, $400 000 was saved annually with the estimated payback time for the EFI as short as two years. In the Newfoundland and Labrador example, lower cost balsam fir (*Abies balsamea* (L.) Mill.) was substituted into the pulp mix instead of higher cost black spruce (*Picea mariana* (Mill.) BSP) with about $175 000 saved annually for each 1% substitution at the mill. For this single mill, annual savings of $1.7 million are certainly feasible. In the Quebec example, annual savings in measuring ground plots are estimated at $3 million. These are significant economic benefits to the forest sector, which provides valuable employment in Canada's rural areas.

In the logging and sawmilling business, tree and log sizes are important parameters in choosing the type of equipment to be used. Logging and sawmilling tools are designed to work well based on the sizes of trees and the logs that are produced. Matching the harvesting equipment or sawmill set-up with the sizes of trees and logs decreases costs as the machinery will work more efficiently. The EFI provides a reliable estimate of tree sizes by location before harvesting starts. Forest managers can use this information to match equipment to tree size and to direct the various log sizes to the appropriate mill. Companies can also use the information to plan for long-term capital investments and to purchase equipment that is suited to the range of tree sizes they expect to be harvesting.

In mountainous or hilly terrain, road construction is extremely expensive. Ideally, forest managers need an accurate terrain map in their GIS to plan road locations. Terrain maps are a three-dimensional view that the GIS can use to compute the slope of a road, the radius of a bend, or even a trucker's sightline on the road. The EFI system supplies the base data for all of these aspects of effective road planning. Also, in hilly terrain, there are blocks of forest where it is impossible to build access roads. The EFI allows these blocks to be removed from the working forest
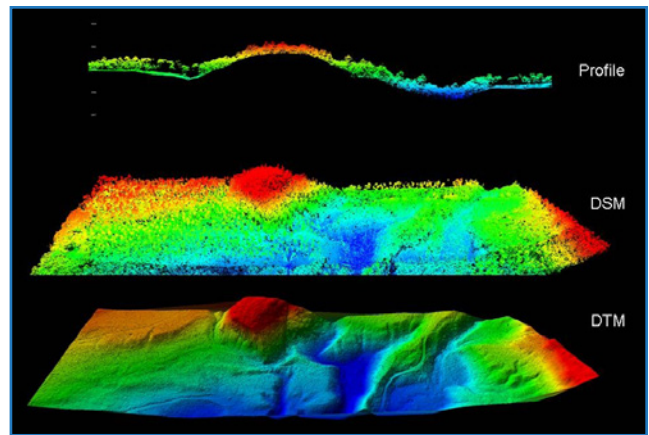
area and allowable cuts to be recalculated. The advanced terrain maps can be used to model wet areas or other sensitive sites. Forest managers use this information to avoid summer harvests in these low-lying areas, scheduling them for the winter to avoid compacting the soil or silting waterways.

At the pulp mill test site, the EFI was used to model wood fiber characteristics by species. In the pulping process, logs are broken down into their component wood cells, which can have different traits, some good for pulping and some not so good. Researchers discovered methods to relate the local conditions and environment that influenced a tree's growth to the tree's internal pulping characteristics. The EFI takes advantage of these methods and adds a map layer of wood pulping characteristics to the suite of maps forest managers use. This allows forest managers to include wood pulping characteristics in their plans so that the correct raw wood mix can flow to the mill to meet its pulp product requirements. This advance knowledge of pulping characteristics allows forests to be harvested more efficiently and customer demands to be satisfied.

In Quebec, detailed tree geometry measurements have been tested to perfect parts of the EFI system, improving reliability in how the system handles various tree shapes. Tree trunks are not uniform cylinders or cones. There is great natural variability in tree shapes and in what is called taper: the decrease in size from the larger end of a log to the smaller end. In nature, variability is a good thing as diversity provides more opportunities to survive the ever-changing environment. In processing trees into products such as lumber, unknown variability is a bad thing because the machinery and mill run best when they are optimized for specific log sizes and shapes. Knowing in advance the log size and shape allows the processing line to be optimized, which improves efficiency and reduces waste. In the Quebec example, researchers used ground-based LiDAR and log scanners to detail the shape of trees and the logs that could be cut from the trees. The research reduced the cost of sampling while providing more accurate estimates of the variability in the wood supply flowing to the mills.

One part of forest inventory that has proven to be a tough nut to crack is the automatic identification of tree species. Automation and increased accuracy are needed improvements over traditional methods. Manually interpreted air photo inventories can be less

than 70% accurate in identifying tree species. A new form of LiDAR called full wave-length LiDAR has been tested to tackle this long-standing problem. Results look promising.
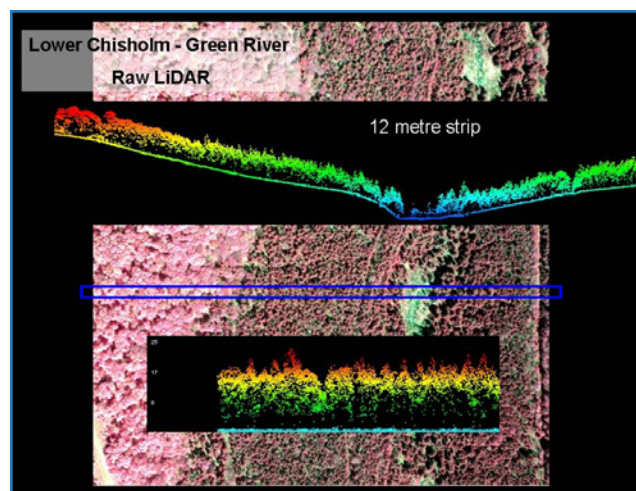
All of these EFI applications have been developed with numerous partners and contributors but fit together on the same platform. To move this technology from the research bench into the hands of users, the CWFC and its partners have spread out across Canada to present the EFI and explain its underlying technologies. The CWFC partnered with the Canadian Institute of Forestry to provide a series of regional workshops and Notes on how to operate the EFI. The CFS has produced a best practices guide providing users with step-by-step instructions. Continuing this knowledge exchange will ensure that users learn how the EFI works in their specific situation.

The EFI is an innovative tool that Canadian forest managers can use to make better business decisions in an integrated and environmentally sustainable manner. The EFI provides information that was previously unavailable, prohibitively expensive to collect, or not integrated into a useable tool. It empowers forest managers to make decisions that best use timber resources while protecting other forest values. The EFI provides an integrated platform for the strategic, tactical, and operational planning needs of today's Canadian forest managers.

Canada ranks among the largest forest products exporters in the world. Its products compete in a complex global marketplace.
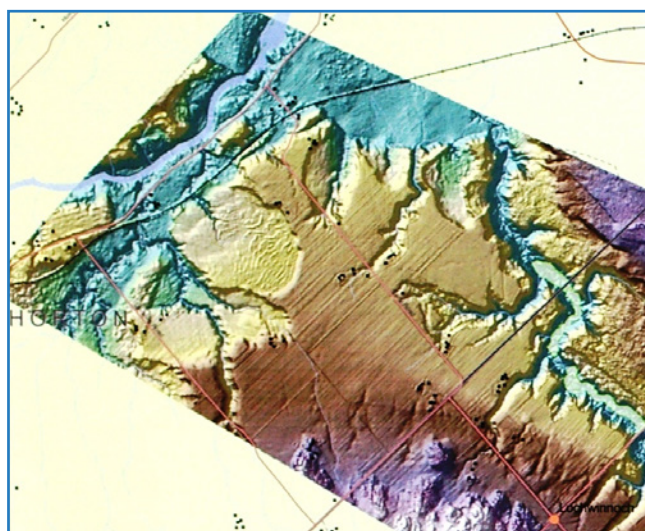
LiDAR data from the Green River area in New Brunswick. (Advanced Forest Resources Inventory Technologies, Ontario)

Canada will maintain its role as a leader only if its forest sector remains sustainable, environmentally sound, and economical. The EFI is one more tool that forest managers can use to achieve this goal. The CFS remains at the forefront of developing the science behind a better, faster, more affordable forest inventory.

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LiDAR data overlaid on an Ontario base map. LiDAR depicts the terrain; base map depicts roads, buildings (black dots), railroad tracks (dashed line at top), and the Bonnechere River (top left); near Renfrew, Ontario. (Christina Davis, Ontario Ministry of Natural Resources)