eFRI AND GROWTH & YIELD IN ONTARIO:
A LITERATURE REVIEW

By

Brandie Loranger

An Undergraduate Thesis Submitted in
Partial Fulfillment of the Requirements for the
Degree of Honours Bachelor of Environmental Management

Faculty of Natural Resources Management
Lakehead University
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Second Reader – Dr. W. L. Meyer

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ABSTRACT

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Key Words: Aerial photography, eFRI, FEC system, Finland, Growth & Yield, LiDAR, modelling, Ontario, photo interpretation, policies & legislation.

The forests of Ontario are a vast resource owned by the Crown that has been subjected to many methods of forest management since the beginning of Ontario as a province. The forest resource was thought of as inexhaustible at first and was exploited greatly. It was soon realized that there was a need for sustainable forest management. The progression of aerial photography and the advancement of both airplane and camera technology have greatly advanced forestry in Ontario. Enhanced forest resource inventory (eFRI) and growth and yield (G&Y) programs were set up to collect data for various methods of forest modelling. With the advancement of technology also came light detection and ranging (LiDAR) technology that can take various measurements via laser pulses creating multispectral data layers with accurate measurements helpful to forest managers when in planning phases. Advancing with the times also includes the updating of policies and legislation for the forests in Ontario to better guide forest management when creating operational plans. There is a brief description and comparison on the current status of forest operations and the status of the eFRI programs in Finland that have taken place for nearly a century and where they are placing their focus today for the best outcomes in G&Y in the future.

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INTRODUCTION

This thesis will explore a literature review of the history of the collection of growth and yield (G&Y) data and enhanced forest resource inventory (eFRI) data collected throughout Ontario. It will begin with an introduction on the available resources within Ontario and a background of historical G&Y practices at the time of the Confederation of Canada and how the land was surveyed.

Early forestry practices were referred to as ground surveys and were limited due to a lack of infrastructure. The building of the Canadian Pacific Railway (CPR) opened up a new world and heavily exploited the forest. A lack of solid policy and legislation required solutions.

A reconnaissance survey done just after World War I marks the beginning of eFRI and G&Y processes that continues today. Although G&Y and eFRI data collected throughout Ontario is essential, there is some uncertainty as to how it can be more useful. The present need for the G&Y program was recognized by the Ministry of Natural Resources and Forestry (MNRF) in Ontario for timely, accurate and relevant G&Y data to support forest sustainability models (Sharma et al. 2008). The acquired aerial photography is interpreted by highly trained photo interpreters who use the collected field data for calibration. Once the data is collected and interpreted it is then sent to the MNRF and put into a database. To ensure quality standards are met, internal and government audits are performed on some of the newly established plots. The idea when establishing a permanent forest inventory growth/ground plot (PFIGP) is that a crew can return 10 years in the future and be able to remeasure the original crew's established plot.

Policies and legislation that have been put into place in Ontario and Canada over the last century have been created in the name of sustainable forestry and forest managers are now subject to multiple guides and policies when planning operations within Ontario. As times have changed and technology has taken over basically everything humans touch, current legislation is due for an update in Ontario.

Linear models using the data from eFRI and G&Y are tools that help forest managers to make the correct decisions during forest management planning phases. The use of Light Detection and Ranging (LiDAR) data is a technological advance that has aided forest managers throughout the world, including Ontario, to get a more accurate picture of what the vast forests within our borders actually look like.

There will also be a brief description of the forestry practices that have been in place in Finland since the 1920s to give some context to where Ontario is in comparison. Finland is able to grow their forests with models thanks to how long G&Y data has been available. The current focus for them is forest health and route optimization to make G&Y data collection more efficient. An ever increasing use of modern technology will help them to achieve this goal.

The future of G&Y and eFRI programs depend entirely on methods of data collection and analysis as well as the technology available to acquire the imagery used and the computers to compute the models being tested and to produce the maps needed as they are no longer drawn by hand.

LITERATURE REVIEW

AVAILABLE RESOURCES

There are approximately 70.2 million hectares of forest within the province of Ontario (Sharma et al. 2008). Ontario's forests comprise 17% of the forests in Canada, and 2% of the world's forests (Sharma et al. 2008). Canada's forests are responsible for the largest wood production industry worldwide (Jobidon et al. 2015). To be considered eligible for harvest however, land must have a tree cover of greater than 10% and it must meet conservational and operational accessibility requirements (Jobidon et al. 2015).

The Crown forests in Ontario are controlled by the MNRF and all activity within is therefore closely monitored and evaluated by a third party to ensure compliance to standards are met with the guidelines and laws set out by the Ontario government (St. Amour 2003). The Crown forest in Ontario is inevitably owned by the public whom have so much control over the environment today that the forests are largely considered a human dominated ecosystem (St. Amour 2003).

Due to evolution over time however, Ontario's forests are forever changing dynamic biological systems (Peng 2000) and in order to manage forests sustainably and effectively, foresters must know what is growing within them and where merchantable stands are located (Pickering & Pineau 2012).

Forest management and harvesting becomes more difficult as one travels northward in the Boreal forest due to extreme terrain variations and a lack of roads making access to desired stands a challenge (Jobidon et al. 2015). Northern forest stands also generally have low commercial value with trees having small diameters and being relatively short (Jobidon et al. 2015). But the consideration for remoteness is changing (Jobidon et al. 2015).

FORESTRY BEGINNINGS IN CANADA

Since the very beginnings of Canada as an independent nation it has been recognized that there is a vast forest resource available with enough stock to be beneficial to everyone. During the 1800s the only way of obtaining information about tree species, soil type and soil moisture regime in southern Ontario was after the land had been surveyed and prepared for development (Robere-McGugan 2012).

The Confederation of Canada took place July 1st, 1867 and at the time general notes from surveyors were considered satisfactory as a forest inventory due to the fact that much of the timber present was not used (Robere-McGugan 2012). The earliest ground surveys were conducted south of the Mattawa and French Rivers and were hindered by limited road networks, canoe routes and wooded trails (Robere-McGugan 2012). No infrastructure large enough existed at the time to move cut timber in the late 1800s except for the use of river systems (Robere-McGugan 2012). However by the turn of the century as Ontario continued to be settled it welcomed the development of the pulp and paper industry. Also, the Canadian Pacific Railway (CPR) open major interconnected transportation corridors within the province (Robere-McGugan 2012).

A growing concern of how the timber was being used arose from the desire to not waste any of the wood volume cut by leaving it behind adding to the forest fire fuel load (Robere-McGugan 2012). It was also believed that because the forests were vast and inexhaustible within Ontario the exploitation of the forest was justified by blind policies and legislation tailored mainly for immediate gains and short-term convenience (Robere-McGugan 2012).

HUMAN IMPACT ON THE FOREST

The abundance and availability of natural resources on earth has directly had an influence on the well-being of the human population (St. Amour 2003). The more resources there were to exploit, the more the human population has benefitted and lived for years with the assumption that these resources were infinite and inexhaustible (St. Amour 2003). The forests within Ontario were subject to similar pressures such as population growth and the increased consumption of resources spiraling out of control (St. Amour 2003). Forestry being the largest sponsor toward the Canadian international trade balance has historically funded the Canadian economy which was built on forest exploitation to begin with (Baskerville 1988).

Economic development usually translates to the expansion of an economy based on humans exploiting a resource to the point of degradation (Baskerville 1988). Canadians are able to enjoy such things as schools, nice roads, hospitals, health care, airlines, unemployment insurance and old-age security largely due to the revenue received for the industrial exploitation of Canada's publicly owned forests (Baskerville 1988). Baskerville (1988) believes that the fact that such a high percentage of Canada's forests are publicly owned has pushed the country's forests into the category of the tragedy of the commons due to the attitude that resources were inexhaustible. This push however, has not deterred Canadian forest managers from escalating the exploitation of forests for personal gain and have created slum forests by failing to return any profits to these properties even for basic maintenance (Baskerville 1988). The world has had no choice but to come to terms with the fact that we must learn to manage our resources sustainably or they will disappear and never return (St. Amour 2003).

St. Amour defined sustainable development (2003) as development that meets present demands without compromising future generations' abilities to meet their own needs. Throughout the post-World War II (WWII) economic boom a real sense of moral obligation toward the land ethic and doing right by nature when managing natural resources seemed to take hold and it was recognized that exploiting the forests was no longer an option (Robere-McGugan 2012).

THE PROGRESSION OF AERIAL PHOTOGRAPHY

As aircraft technology improved during WWI so did aerial sketching which showed field crews the way to their target forest types (Robere-McGugan 2012). This allowed for more time to be spent on harvesting rather than wasted on exploring non-productive forest stands (Robere-McGugan 2012). Due to the sheer size of the Province of Ontario it was decided around the same time that a forest so vast as that would need more than just aerial mapping and was therefore combined with field visits to refine the data (Robere-McGugan 2012).

The first aerial photographs were taken in 1926 for the purpose of forest inventory and mapping (Robere-McGugan 2012). By 1946 technologies had advanced significantly with air-craft, cameras and film due to them being widely used during WWII for reconnaissance (Robere-McGugan 2012). Film technology had advanced to panchromatic and infrared panchromatic film (Robere-McGugan 2012). By the end of

WWII the aerial photographic method had been perfected and was ready to be implemented in the forestry industry (Robere-McGugan 2012).

Aerial photography is generally acquired by private companies contracted to provide the imagery (Leckie & Gillis 1995). Historically, aerial photography specifications required the photos be taken at specific times throughout the solar cycle of the day depending on latitude and solar altitudes specifically during a 6 to 12 week time frame from June to September (Leckie & Gillis 1995).

Ontario specifically used Agfa 200 film from 1987 to 1989, but by the mid-1990s they had switched to Kodak 2405 B&W film with only some testing done with colour infrared film using a negative processing method (Leckie & Gillis 1995). A 23 x 23 cm format film was used at an original scale of 1:15,840 in Ontario, which was changed to a scale of 1:20,000 and even 1:10,000 in the southern Ontario regions in the early 1990s (Leckie & Gillis 1995). Black and white (B&W) panchromatic, black and white infrared, normal colour and colour infrared film are the standard film types used to acquire aerial photography (Leckie & Gillis 1995).

For stereo viewing of aerial photographs an overlap of 60% is required, including a sidelap of 30% which ensures complete coverage (Leckie & Gillis 1995). Each photograph therefore only contributes 28% of new area coverage to the area being mapped (Leckie & Gillis 1995). The digitizing of photographs was historically done manually through means of transferring and drafting stages, and later on automated scanning was introduced for base mapping (Leckie & Gillis 1995). As time passes, data and filing systems are also evolving into more compatible and transferable formats that can be displayed in other GIS systems for input and analysis by photo interpreters (Leckie & Gillis 1995).

PHOTO INTERPRETATION

The skills needed to successfully be a photo interpreter were laid out in a manual entitled *Photographic Interpretation of Tree Species in Ontario* in 1963 by Victor Zsilinszky (Robere-McGugan 2012). The manual received so much interest that a second edition was required within two years of publication putting Ontario in the spotlight world-wide for its proficiency in photo interpreting during the 1960s (Robere-McGugan 2012).

Photo interpreters are required to work with ground cruised information that includes moisture regime, stand structure and soil measures when defining individual stand boundaries (Kettridge 2003). Ecosites are defined as mapping units that combine a set of vegetation conditions with environmental factors that were created to help classify the diversity of forest communities in order to be sustainably managed (Kettridge 2003). By including ecosite data in the forest resource inventory (FRI), the companies using the data can also include ecosites in their strategic and operational plans (Kettridge 2003).

Photography for forest inventory is typically acquired the first summer of the inventory cycle and delivered in the fall so that photo interpretation can take place over the winter (Leckie & Gillis 1995). Forest inventory field work to calibrate the photo interpreters is generally conducted the following summer, but in some provinces it takes place before the photos are interpreted (Leckie & Gillis 1995). The accuracy of determining ecosites by means of photo interpretation however, is variable and should never be used as the sole source of information when making decisions in forest management (Kettridge 2003). The Forest Ecosystem Classification (FEC) system was developed in 1978 providing an opportunity to classify and organize the land with a solid framework of soil and vegetation units (Kettridge 2003). Ontario switched from a township base to the Universal Transverse Mercator (UTM) grids to carry out forest inventories in the mid-1990s (Leckie & Gillis 1995).

FEC SYSTEM IN ONTARIO

Soil types and vegetation are the basic units of the Forest Ecosystem Classification (FEC) system that are determined through the use of a field ecological land classification (ELC) key system (Sims & Uhlig 1992). Vegetation and soil types are considered basic units in the FEC system used in Ontario (Sims & Uhlig 1992). The OMNR developed plans for a province-wide program that integrates the FEC system with the ELC system (Sims & Uhlig 1992).

The standards for the FEC system data collection were created in 1978 to allow for accurate, practical and consistent descriptions of each forest ecosystem so that the existing as well as any new knowledge can be more effectively organized and communicated (Sims & Uhlig 1992). Designed to help foresters gather specific descriptive information regarding vegetation and soil conditions and local forest stands the FEC has helped develop management strategies and alternatives at the stand level (Sims & Uhlig 1992). The FEC systems in Ontario were the first of its kind built for a specific and predetermined range of uses (Sims & Uhlig 1992). Ontario FEC specs include the collection of data based on the relative abundance information and percentage cover of the larger species of vegetation present within the 10 x 10 meter sample plots (Sims & Uhlig 1992).

eFRI

To meet sustainable forest management requirements, forest inventories must be kept up to date to assess the composition, distribution, and structure of vegetation as this information can be used to make management decisions across a range of scales (Wulder et al. 2008). At operational scales forest inventories are used to plan silviculture activities, road placement, harvest planning, and assessing growing stock (Wulder et al. 2008). Forest inventories were designed to measure the quantity, composition, extent and condition of forest resources (Wulder et al. 2008).

In the 1920s just shortly after World War I (WWI), the Forestry Branch in Ontario arranged a province wide reconnaissance survey of the forests marking the beginning of the FRI process that we see in practice today (Robere-McGugan 2012). The goal of FRI is to provide basic statistical data and detailed information on every individual stand in Ontario's Crown forest (Robere-McGugan 2012). FRI includes data for stand age, average stand height, stocking based on basal area of the stand, species composition to the nearest 10% for each species, site class, as well as site region, site district and ownership (Penner et al. 2008).

Historically the budget for acquiring aerial photography includes everything from the flight, the film and processing, as well as all of the prints normally ordered (Leckie & Gillis 1995). Comprehensive forest inventory mapping began in the 1950s sharing the cost under federal-provincial agreements (Leckie & Gillis 1995).

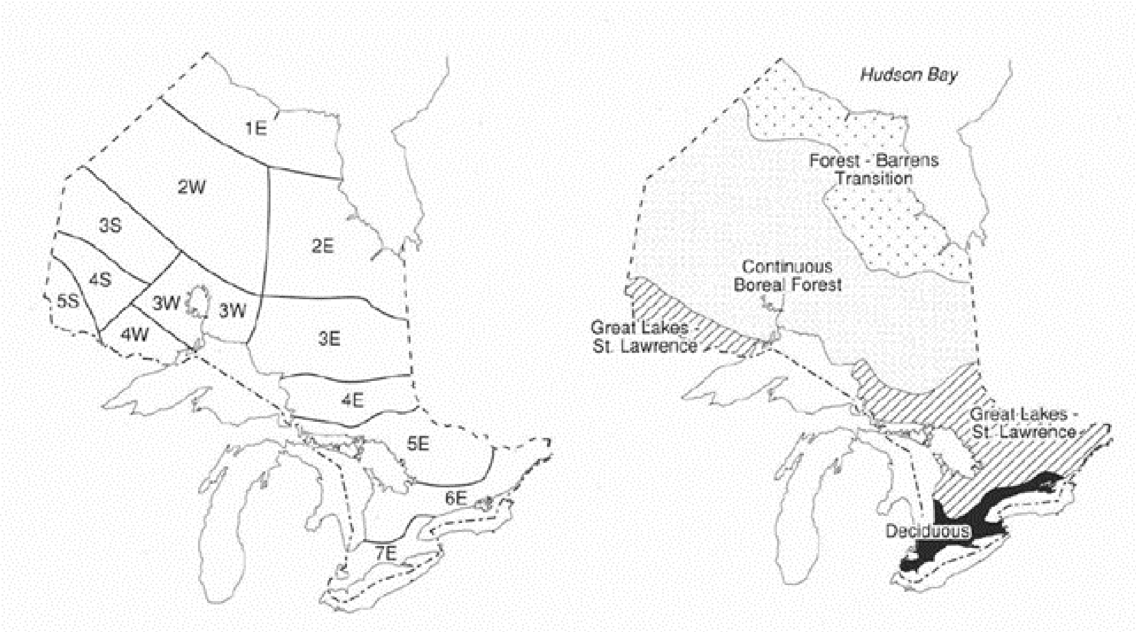
An FRI procedure manual published in 1978 holds two important concepts that are still relevant today (Robere-McGugan 2012). The first concept is that FRI only gives a rough calculation of conditions at any given time, and the second concept is that sampling is subject to errors due to the much smaller portion of the forest actually being sampled (Robere-McGugan 2012). Ontario's extensive network of FRI calibration plots are located on average every 500 ha within the area of productive forested land on the contract (Leckie & Gillis 1995). The FRI maps are not regularly updated with new aerial photographs, and it has become common practice for a forest inventory to contain valid data for 10 years or more (Thompson et al. 2007) although forests grow and change over the span of that decade making the photographs difficult to follow at times. FRI is not just a data source for forest management plans anymore, it has become an integral component for a multitude of program interests (Robere-McGugan 2012). Having a working inventory of Ontario's forests is beneficial for both strategic and operational levels of forestry (Pickering & Pineau 2012). Forest inventories consist of comprehensive stand mapping that is derived from an interpretation of aerial photographs and the volume estimates calculated from the field samples taken based on existing maps (Leckie & Gillis 1995).

During the 1980s people began to see evidence of natural resources being depleted and the concept of sustainable development started to become a necessary change that must be made (St. Amour 2003). The Rosehart Report was generated in 1987 to reflect the concerns of the public regarding forest management within Ontario (Robere-McGugan 2012). The Rosehart Report outlines the concern that what humans have come to need and expect from the forest has overtaken the progress of FRI and its development (Robere-McGugan 2012). Nineteen recommendations were made for the FRI program in the Rosehart Report from proper financing of the program to incorporating new technology to keeping things interesting for youth, most of which have since been addressed (Robere-McGugan 2012).

FRI in Ontario has evolved along with forest management and planning (Robere-McGugan 2012). Having a working inventory of Ontario's forests is beneficial for both strategic and operational levels of forestry (Pickering & Pineau 2012).

Computer technology has been the largest change made in FRI at every stage of its production (Robere-McGugan 2012) thus enhancing FRI to be called eFRI henceforth. The program designed for eFRI is to conduct a new, up to date FRI using current technologies (FFTC 2013). The Forestry Futures Committee partnered with the MNRF are the ones responsible for overseeing the eFRI program, with work contracted out to the qualified firms (FFTC 2013). Funding for the eFRI program is provided by harvest volume charges that are collected from the Sustainable Forest Licensees (SFL) for Crown timber (FFTC 2013).

Silvicultural history is not generally included in with interpreted eFRI (Penner et al. 2008). Forest management and inventory falls on each province individually and each have respectively developed its own requirements and procedures for the management of forest inventory (Leckie & Gillis 1995). When a forest inventory is conducted each province is then divided into forest management units where the inventories are done either in single blocks or many management units simultaneously (Leckie & Gillis 1995).



(Source: Sims & Uhlig 1992)

Figure 1. The historical maps of Ontario depicted here circa.1992 to show the province divided into physiographic site regions (left), and forest regions (right).

In Ontario, maps of forest stands including species composition are created from the interpretation of aerial photographs at a 1:20,000 scale and some ground truthing in the field to calibrate the interpretation (Thompson et al. 2007). When errors occur at the interpretation level of the aerial photographs errors could cause the miscalculation of the available wood supply and therefore the estimates for the long-term sustainability of the forest in question (Thompson et al. 2007). Accurate maps of forest stands form the basis for forest management activities on any forest unit and from there long-term large-scale predictions are made regarding harvestable wood volumes (Thompson et al. 2007).

Below is the map of the Area of the Undertaking where eFRI has been done in Ontario (GO 2011).

(Photo Source: GO 2011)

Figure 2. The red area highlighting the Area of the Undertaking in Ontario, Canada where eFRI has been done.

Forest managers must take into account not only wood supply but also recreational opportunities and wildlife habitats when using the eFRI data (Thompson et al. 2007). Within each 10 to 20 year cycle of provincial inventories, new maps are produced as the new inventory is collected (Leckie & Gillis 1995). During the time in between the inventory cycles are updated there are often major disturbances that must be accounted for (Leckie & Gillis 1995). It was predicted that inventories were likely to evolve quickly with the growth of new technology allowing digital remote sensing to become the primary data source when mapping inventory (Leckie & Gillis 1995).

GROWTH & YIELD

Growth and yield (G&Y) research in Ontario began in the late 1940s (Sharma et al. 2008). The G&Y program was created to accommodate regional public demands (Klassen 1997). Permanent sample plots (PSPs) are part of the G&Y program and are established to gather data on stand dynamics, the productivity of the forest, and basic biological processes (Sharma et al. 2008). The idea was that using remeasurement data from PSPs and all plot data there is available for Ontario would result in better yield estimates as well as provide trustworthy and realistic estimates of growth (Penner et al. 2008). Data collected however, did not have much value when it came to a province-wide scale of forest productivity as they were generally established on sites with a limited scope on species and ecosites, within a narrow geographical range (Sharma et al. 2008).

G&Y information is used for numerous things including harvest planning, making silvicultural decisions, hydrology planning, and wildlife management therefore a wide range of information is collected to satisfy as many categories as possible (LeMay et al. 1992). Field data collected on shrubs, regeneration, forest communities, ground vegetation, wildlife habitat, site information and G&Y of timber stocks will help the MNRF to better monitor Ontario’s forests (Klassen 1997).

The goal of the G&Y program is to have useful and up to date information for resource managers to use in the planning of growth and dynamics of forest stands

(Mathieson 1998). A comprehensive G&Y program was needed to provide the long-term data that was necessary for the program to monitor, model and predict the status of growth of the forest in Ontario (Sharma et al. 2008). The Ontario provincial G&Y program is in charge of setting up a vast grid of PSPs (Sharma and Parton 2007).

There is a network of plots on a 20 x 20 kilometer grid throughout Ontario's forests (Sharma et al. 2008). The PSPs in northern Ontario are located across most of the commercially operable forest (Sharma and Parton 2007). When the G&Y program was first introduced it required the establishment and maintenance of 4300 PSPs on an ecologically based network on a rotation of 5 years between remeasurements (Sharma et al. 2008). Many local trials in establishing PSPs took place in those early years, but the data has long since been lost if a final report was ever even drawn up (LeMay et al. 1992). The G&Y program was scaled back over the years to approximately 1100 PSPs and the remeasurement interval was changed to 10 years (Sharma et al. 2008).

The data collected in an inventory relates to the trees directly, and to the ecosystem the stand is located within as well (Pickering & Pineau 2012). Forest stands are basic units in forestry described as an area that is mostly homogenous depending on forest type and stocking, and ranging from half to five hectares of land (Etula & Antikainen 2014). Ultimately the physical form of a tree is swayed by stand density (Sharma et al. 2008). A forest stand is thus defined as a group of trees on an area of a minimum of 8-10 hectares of land that are somewhat uniform in composition, arrangement, age, or growing condition that will make the area stand out from neighbouring stands in aerial photographs (Thompson et al. 2007). The distribution of tree volume depends on the age of the trees, site class, soil and climate conditions (Zhou et al. 2005). Trees located within high density stands tend to have more competition for space between stems, the trees tend to be smaller in diameter than those of the same height in stands that are less dense (Sharma et al. 2008). The height to diameter relationship of a tree varies among stands depending on the environment and stand conditions (Sharma et al. 2008). Diameter taken at breast height (DBH) within even-aged stands varies somewhat, however there is an average diameter per age class that most trees in a stand will measure in relation to each other (Peng 2000). An inventory of the forest allows forest professionals to know where certain tree species can be found growing, and those species' distribution throughout many other stands as well (Pickering & Pineau 2012).

Tree DBH can be measured very efficiently and accurately, however measuring the total height of the tree takes time, money and energy to accomplish (Sharma and Parton 2007). Normally all of the trees in a sample plot are measured for diameter. Height is only measured on a select few trees, allowing models to estimate all remaining heights of the trees in the sample (Sharma et al. 2008).

G&Y programs are often seen as expensive plot networks without much use if the data are not used to aid in forest management (Sharma et al. 2008). However on the same note, it was also recommended that Ontario accelerate G&Y research to advance the progress of forest management in Ontario (MacDonald 1995).

The plot designs for PSPs and PGPs are similar; PGPs consist of one 400 m^2 circular plot within which every tree with a DBH of >2.5 cm are evaluated and tagged with a number whereas a PSP is a group of 3 PGPs within a 6400 m^2 circular plot that serves to produce data on snag dynamics and tree mortality (Penner et al. 2008). Site conditions are described for each stand using soil morphological features and soil moisture regimes on varying terrains that includes slopes and flat terrain (Vasiliauskas and Chen 2002). Manual soil augers are used to dig to a depth of 120 cm, three times per site condition present within the stand in order to determine the moisture regime and soil texture (Vasiliauskas and Chen 2002).

Ages are generally estimated by taking increment cores from the trunks of trees at breast height as nearer to the ground there is a commonly occurring butt flare with uneven growth rings and wood rot present (Vasiliauskas and Chen 2002). The difference between tree ages taken at breast height versus at ground level can result in age underestimations of, for example, up to 20 years in balsam fir (*Abies balsamea* (L.) Mill.) and up to 10 years in black spruce (*Picea mariana* (Mill.) BSP) (Vasiliauskas and Chen 2002). The suppressed individuals of shade tolerant species also may not produce annual growth rings in sections located nearer to the ground some years (Vasiliauskas and Chen 2002).

For accuracy age cores are taken to the pith across all species, and are brought back to a lab and counted under a dissecting microscope (Vasiliauskas and Chen 2002). Stand age accuracy is important when studying G&Y as underestimating a stand's age can result in overestimating the annual allowable cut (AAC), as well as the available habitat for wildlife (Vasiliauskas and Chen 2002). An overestimation of G&Y could end up in an AAC that is too high in forest management planning (Vasiliauskas and Chen 2002).

During the 1950s there were two province-wide studies done: Plonski's development of the Normal Yield Tables focusing on the primary tree species groupings within Ontario and Morawski's development of the provincial cull tables for the primary timber species (LeMay et al. 1992). The Plonski normal yield tables for merchantable tree species were produced in 1956, later modified to metric units in 1981 (Sharma et al. 2008). The demand for more up to date and detailed G&Y data escalated in the 1980s until the Plonski's Normal Yield Tables ceased to satisfy foresters' needs prompting a new G&Y Strategy to be drafted in 1989 for Ontario (LeMay et al. 1992).

Morawski's studies on cull opened up the methods of interpreting and defining decay or classifying wood defects at different levels of rot (Basham & Morawski 1964). However this was not the only definition that came about regarding the subject of cull where entire or partial trees or logs are of merchantable size but are considered to be unmerchantable due to defects (Haddon 1988). Cull trees often include trees with decay or deformities, too many limbs, or splits in the wood known as rough cull which is mostly suitable only for pulpwood and other fiber products (USDA 2016). Slash piles have also been referred to as cull piles. Stumps and logging residue left behind after harvesting operations and road construction (PBC 1995) also had to be accounted for when G&Y surveys were done.

MNRF realized the need for timely, accurate and relevant G&Y data to support forest sustainability in Ontario in the early 1990s (Sharma et al. 2008). It was predicted that throughout the 1990s the issue of forest sustainability would dominate forest management in Canada (Baskerville 1990). The main problem turned out to be that what public owners wanted sustained and what actually was sustained were so lop-sided that it quickly became clear that some major adjustments were needed (Baskerville 1990). The solution to bridging the gap between expectation and reality would only be possible when both were improved after much consideration (Baskerville 1990). The decision on how to bridge the gap came about during a Canadian Institute of Forestry (CIF) meeting in 1991 when a single representative from each of the provincial government, the federal government, a forestry university, and an industry head were invited to share their views on the present status of G&Y (LeMay et al. 1992). The result of this workshop was a program plan for the improvement of G&Y information and the call for the installation of a new provincial system of PSPs (LeMay et al. 1992).

The G&Y program was officially established in Ontario in 1991 with the purpose of collecting and analyzing data regarding the dynamics, growth, and productivity of the forests within Ontario (Furrer et al. 2014). The methods of data collection were standardized by the government to ensure consistency across the industry (Furrer et al. 2014). Throughout the network of PSPs that have been established throughout Ontario, tree site characteristics, forest floor, downed woody debris and understory data are collected (Furrer et al. 2014). The MNRF uses the data collected by field crews to create yield curves to calibrate G&Y models as well as to aid in the prediction of stand volume over time (Furrer et al. 2014).

ESSA Technologies Ltd. was contracted later in 1991 by the MNRF for the purpose of reviewing the G&Y program plan and to make any recommendations regarding the existing network of PSPs (Penner et al. 2008). ESSA Technologies Ltd. recommended that field methods be revised as well as the establishment and upkeep of thousands more PSPs to be done by the MNRF, the G&Y Science Unit, and the Forest Ecosystem Science Cooperative Inc. (Penner et al. 2008).

Since the early 1990s technology has also advanced significantly (Pickering & Pineau 2012). The data now collected in an inventory is useful in determining timber supply analysis, to run models, as well as taking wildlife habitat into account, maintaining biodiversity, road building plans for regeneration activities and are essential to developing forest management plans (Pickering & Pineau 2012). During a workshop in 1999 in Sault Ste. Marie, the G&Y related needs were identified as new and updated yield curves for mixed hardwood stands, for the range of silvicultural treatments, for managed stands including plantations, and for partial harvests and thinning regimes, as well as the need for peer review to confirm the reliability of the information (Penner et al. 2008).

GROWTH & YIELD MODELLING

G&Y models are mainly a tool for forest managers (Peng 2000). G&Y models describe forest dynamics as reproduction, growth, mortality, and any other observed changes with ability to predict the future of the yield (Peng 2000).

The Canadian Ecology Centre – Forestry Research Partnership has facilitated G&Y modelling in Ontario to analyze for the first time data that has been collected throughout the past 50 years as well as aiding in identifying gaps where there is experimental research needed (Sharma et al. 2008).

The definition of sustainable forest management is constantly evolving and over time the need for low cost but accurate spatially referenced forest data and information has increased substantially (Pickering & Pineau 2012). Validating ecological process-based models was a challenge in 2005 due to a lack of sufficient field data (Zhou et al. 2005). G&Y models were recommended to project the growth of the forest in both unmanaged and managed forests throughout Ontario (Penner et al. 2008).

G&Y models can consist of one single equation, or a series of interrelated equations that make up a simulation system (Peng 2000). Individual tree models simulate every tree as a basic unit depending on how the tree was established, growth and mortality, and the sum of the individual tree estimates resulting in stand level values (Peng 2000). Parameters of whole stand models include volume density, basal area, and diameter distributions to simulate the G&Y of a stand (Peng 2000). Yield in a volume growth rate equation is expressed as functions of initial volume, time, and basal area (Peng 2000). Diameter at breast height (DBH) and the total height of the tree are essential to many G&Y models (Sharma and Parton 2007).

Taper equations were used to calculate individual stem volumes in trees grown in plantations that would introduce a bias, thus translating to an overestimation in volume when used with Ontario's updated benchmark yield curves (Sharma et al. 2008). Taper, height to diameter relationship, and site index equations are the basis for G&Y models. The more accurate the models are the less uncertainty there is regarding future wood supply predictions from forest stands (Sharma et al. 2008). The yield curves may not be representative for various forest unit types due to site class within the FRI program not being based on the stand's leading species (Penner et al. 2008).

Variable growth intercept models are able to produce reliable site index estimates for plantations of white spruce, jack pine and black spruce in Ontario (Sharma et al. 2008). Site index is the most commonly used method of evaluating the productivity of a site (Socha et al. 2017). It was found that the best method of validation for these process-based models was to compare the model output with data from G&Y PSPs (Zhou et al. 2005). Empirical models are based on experimental data where the input and output data are considered the most appropriate (Peng 2000). Age and site index are variables that are not included in uneven-aged models as they are not applicable with stands composed of trees that are markedly different ages and therefore are not used to predict G&Y rates (Peng 2000).

G&Y models are used to predict the time it takes for a forest stand to develop (Sharma and Parton 2007). Due to the fact that most of the data used in forest inventories is interpreted from aerial photos, there is an implication that human error may influence the validation of the model (Zhou et al. 2005). The three data sources that can be used to test model accuracy and performance includes field data from G&Y plots, empirical normal G&Y tables/curves , and forest inventory data (Zhou et al. 2005).

A 5% audit of all field work is required of the MNRF to ensure the quality of the data collected by field crews contracted in Ontario (Leckie & Gillis 1995). The first forest audits took place in 1985 and were called Forest Management Agreement (FMA) Reviews (St. Amour 2003). FMA reviews were updated and replaced in 1996 by independent forest audits (IFAs) required in both Environmental Assessment (EA) Decision Terms and Conditions and the Crown Forest Sustainability Act (CFSA) (St. Amour 2003).

IFAs are done by a third party that is not affiliated with the MNRF or the sustainable forest licence (SFL) holder and are carried out in every Management Unit across Ontario (St. Amour 2003). IFAs are in place to keep forest managers accountable within the planning process and are important for maintaining transparency for public satisfaction reporting on the state of the forests every five years (St. Amour 2003). Since IFAs are done by an external third party who are required to make recommendations on current forest management techniques, forest managers are able to get a different and unbiased perspective on how their forests are managed (St. Amour 2003).

LiDAR

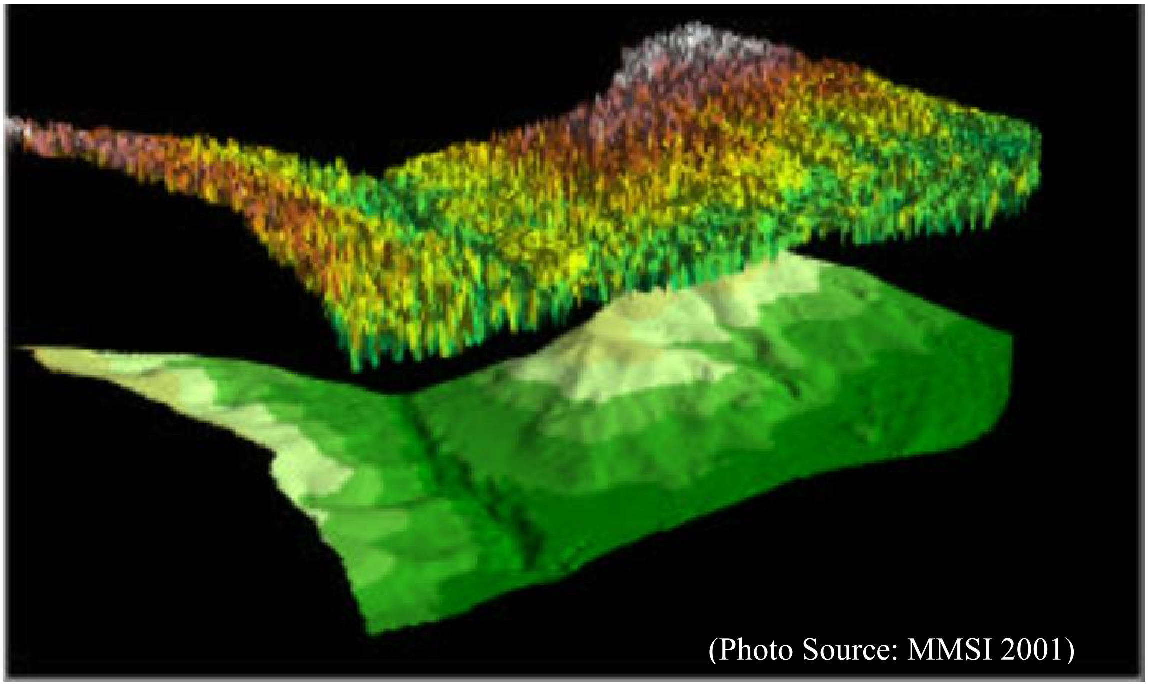
One technological advancement is called Light Detection and Ranging (LiDAR), remote sensing technology that produces the high resolution multispectral digital imagery used in creating eFRI of any forest (Pickering & Pineau 2012). One of the first commercial areas of application LiDAR technology was tested on was the forestry industry (MMSI 2001). LiDAR and its applications in the forestry industry have been linked since 1982 (Woods et al. 2011). Some of the themes and topics that LiDAR covers in forestry include wetland mapping, operational forest inventory with imagery, predicting forest and tree metrics, as well as LiDAR's ability to predict biomass and leaf area index (Courville & Hancock 2007). LiDAR provides data regarding tree density and tree heights, information that has been difficult to obtain using past techniques (MMSI 2001).

Airborne laser technology is able to map the ground and tree heights simultaneously, whereas radar or satellite imaging cannot (MMSI 2001). The LiDAR system sends out laser pulses that reflect off of objects returning the signal to a receiver which uses the speed at which the laser is returned to convert it into usable range measurements (Lusignan 2011). The lasers that are emitted hit vegetation and then hit the ground causing multiple returns and collecting data for both attributes simultaneously (Lusignan 2011). High resolution data is obtained when the lasers are able to emit more pulses per second (Lusignan 2011).

A main question frequently asked is what the optimal point density is for good quality data (Treitz et al. 2012)? Point density in LiDAR is a function of ever changing flight and sensor parameters as new sensor technologies are developed (Treitz et al. 2012). Low-density predictions based on LiDAR have significant potential to be integrated into tactical FRI in Ontario across a range of forest ecosystems and will only improve with time (Treitz et al. 2012).

LiDAR is able to measure distances by lighting up its target with laser pulses which can then be used to study canopy heights, leaf area indices, as well as take a measurement of biomass (Pickering & Pineau 2012). LiDAR data can be used for measuring understory topography and vegetation properties along several kilometres (km) of river (Lallias-Tacon et al. 2016). Reflective properties range from feature to feature however, and the accuracy of LiDAR varies depending on the vegetation and terrain in question (Lusignan 2011). For a more visual example please see Figure 3 on the following page.

LiDAR provides data regarding tree density and tree heights, information that has been difficult to obtain using past techniques (MMSI 2001). Processing the data makes it possible for each of the laser returns to be analyzed and classified as either ground or vegetation making it possible to retrieve such information as tree heights, biomass and crown cover (MMSI 2001, Figure 3).



(Photo Source: MMSI 2001)

Figure 3. LiDAR Accuracies, Measured at a 95% confidence level. Ground Layer (bottom) vs. Forest Layer (top).

Field plot inventory measurements are often highly detailed ecological data, however the data is only 100% true for the locations sampled and therefore lack complete spatial coverage (Zald et al. 2014). Data that are remotely sensed are ideally suited to accommodate spatially complete data of larger forests as regional maps of this nature are generally based on multispectral satellite imagery (Zald et al. 2014). There is, however, substantial interest to integrate the ecological data collected from the field plots with remotely sensed data and imagery to create maps with complete spatial coverage (Zald et al. 2014). LiDAR has proven most useful in predictive hydrology modeling, road location applications, harvest block engineering, defining wildlife habitat and the quantification of timber within forestry (Woods et al. 2011).

The use of LiDAR data has the potential to enhance sustainable forest management practices by growing its existing knowledge base and expertise within the forestry industry (Wulder et al. 2008). Limited knowledge regarding acquisition specifications existed at the time of the inaugural data collection flight done with LiDAR for the purpose of forestry within Ontario (Woods et al. 2011). The first decade of the new millennium saw major improvements in global positioning systems (GPS), computer technology from hardware to processing software, and inertial navigation systems. A reduction in acquisition costs have made putting these applications into operation even more possible than ever before (Woods et al. 2011). Tembec Inc., a forest products company, acquired digital imagery of the Romeo Malette Forest located near Timmins, Ontario in 2004-05 acquiring digital imagery as complete LiDAR coverage (Woods et al. 2011), the goal being that these data would support harvest block engineering and forest road construction (Woods et al. 2011).

Over the past decade LiDAR has become increasingly more affordable to acquire and has expanded for larger landscapes (Zald et al. 2014). The cost of acquiring LiDAR is comparable to the cost of airborne remote sensing applications (Wulder et al. 2008). While challenging to break down, LiDAR data costs only a few dollars per hectare configured to approximately 1 hit per metre thus driving up the costs for large-area forest inventories (Wulder et al. 2008). This cost includes the acquisition of the LiDAR data and basic processing (Wulder et al. 2008). The costs that are associated with the acquisition of LiDAR data are predicted to remain relatively high when compared with other data acquisition sources (Wulder et al. 2008).

The Forestry Research Partnership (FRP) was working on a project which included acquiring and testing digitally corrected aerial photography and integrated LiDAR for the production of enhanced forest inventories (Courville & Hancock 2007). It was decided in 2007 that research on LiDAR's applicability to forest management planning and operations was important for the industry's toolkit in day-to-day resource management and growing forest resource inventory production (Courville & Hancock 2007). Maps derived only from satellite imagery lacked the level of detail needed to depict forest structure and composition that was necessary for research applications and forest management (Zald et al. 2014).

When surveys are designed properly, LiDAR can be used to assess measurements of tree height growth over time (Wulder et al. 2008). LiDAR measurements can be biased due to a variety of reasons however, such as the flying height of the plane, the specifications set for the instruments, species structure and which method of measurements are used (Wulder et al. 2008). These biases created are the margins of reported accuracy, or better known as the allowable error that ranges from centimetres up to metres (Wulder et al. 2008, Table 1).

Table 1. LiDAR expected accuracies at a 95% confidence level.

Terrain and Vegetation	Horizontal Accuracy	Vertical Accuracy
Extremely dense vegetation	± 0.15 m	± 3.0 to 15 m
Hard Surfaces and open regular terrain	± 0.15 m	± 0.50 to 0.75 m
Soft/vegetated surfaces (flat to rolling terrain)	± 0.25 m	± 0.50 to 0.75 m
Soft/vegetated surfaces (hilly terrain)	± 0.30 to 0.50 m	± 0.50 to 0.75 m

(Source: MMSI 2001, Lusignan 2011)

LiDAR's ability to provide fine-scale information on surface features below the forest canopy like streams and channel morphology, canopy height, density of the vegetation cover which aids in riparian and water quality management activities (Wulder et al. 2008). LiDAR data are suitable for the task of monitoring the forest (Treitz et al. 2012).

POLICIES & LEGISLATION

The only legislative regulatory framework in place for forest management in the early 1900s was that of the Royal Navy ensuring all oak and pine timber harvested be reserved specifically for their purposes (Robere-McGugan 2012). Furthermore only licenced contractors from the Royal Navy were allowed to harvest timber on Crown lands up until 1926 when the regulation was altered so that anyone could cut oak and pine but with the addition of a stumpage fee to the Crown for all timber harvested (Robere-McGugan 2012).

In the largest part of Ontario where the Crown owns the majority of the land, little attention was paid to methods of regulating forest use until the 1960s (Harvey & Hillier 1994). Forest management plans appeared to be exempt from following the Environmental Assessment Act (EAA). Therefore the MNRF, who are responsible for forestry in Ontario, produced a Class Environmental Assessment (Class EA) document specifically for forest management on Crown lands in Ontario (Priddle 1995). MNRF recognized that transparency and accountability in any decisions made were vital to gaining the public's trust as well as their confidence in Ontario's forest management system (Sharma et al. 2008). The effort to increase environmental security must be established on solid foundation of knowledge (Sharma et al. 2008).

The EAA passed in Ontario in 1974, but the piece of legislation was seen as nothing more than a guideline due to an apparent lack of interest and commitment from the government to implement it effectively (Priddle 1995). The Environmental Assessment Process Improvement Program (EAPIP) was created to review and improve the EA process in Ontario as the organisations carrying them out complained the process was extremely time consuming, vague and expensive (Priddle 1995). It was during this time that land use plans and district guidelines on land use were developed for the majority of Ontario (Harvey & Hillier 1994).

This new document, the EAPIP, produced in 1983, was deemed inappropriate for forest management in Ontario as it neglected many large areas in many significant ways that a Class EA simply did not cover (Priddle 1995). The Class EA for forest management was also more geared toward timber management rather than forest management (Priddle 1995). Instead of dealing with the issue that the Class EA document was more focused on timber management, the MNRF produced another document entitled Class EA for Timber Management on Crown Lands in Ontario (Priddle 1995). This new document came with a whole new idea trying to exclude the previous criticisms altogether from the terms of reference of the scope of assessment (Priddle 1995). Once a first draft was circulated however, it was obvious that no best way existed to proceed as there were too many different organisations involved who all wanted a say and no one could agree on what the strategy needed, let alone the methods that should be employed to address those needs (LeMay et al. 1992).

Since the late 1980s policies and legislation such as the EAA and the CFSA have outlined Ontario's need for sustainable forest practices to be implemented (St. Amour 2003). In 1991, the Minister of Natural Resources in Ontario introduced the Sustainable Forestry Program which was intended to establish policy to improve forest management throughout the province (Harvey & Hillier 1994). The Timber Act was replaced with the CFSA by 1995 and it was suggested that it could allow for Integrated Resource Management and much more significant MNR commitment (Priddle 1995). The CFSA was created to support mixed wood management by putting emphasis on integrating silvicultural systems that encourage the future of biodiversity and resource management (MacDonald 1995). The Sustainable Forestry Program also allowed local citizens a hand in the development of policies and decision making, which was previously unprecedented in Ontario (Harvey & Hillier 1994).

PRESENT DAY

The introduction of computer technology has made the transition from traditional film based cameras to digital photography thus facilitating the new imagery we use today in eFRI (Robere-McGugan 2012). The imagery and planimetric data were integrated with Geographic Information Systems (GIS) making it more readily available, easier to update and edit, can be used in all levels of forest management planning (Robere-McGugan 2012). The use of LiDAR, remote sensing technology, the high resolution digital imagery and the corresponding interpretation software combined with field data collection can contribute to accurate digital elevation models and eFRI production in a cost-effective manner (Pickering & Pineau 2012).

The ecosystem comprising the boreal forest is one of the largest in the world that provides on a global scale services such as carbon sequestration, water regulation and water purification (Jobidon et al. 2015). Forest sites are defined as forest-landscape ecosystem units the resource managers must take into account during the planning and implementation phases of management (Sims & Uhlig 1992). Forest sites are also described as the basic building blocks for conducting integrated resource management which takes into consideration recreation, wildlife, environmental impact, timber harvesting and various other concerns (Sims & Uhlig 1992). G&Y models are mostly based on tree and stand characteristics therefore the total height of the tree and measurement on the diameter at breast height (DBH) are essential to the development and application (Sharma et al. 2008). Currently the trees within these fixed area plots are individually tagged whereas in the historic data sets trees were tallied by diameter class (Penner et al. 2008).

Thus far the old and new PSPs as well as the new Permanent Growth Plots (PGPs) have only been used as calibration data for photo interpreters (Penner et al. 2008). Historic PSPs have been recovered, remeasured, updated, and information added to the provincial database throughout the G&Y program in Ontario (Sharma et al. 2008).

FINLAND

Finland has the most forest area in Europe with a total land area of 304,000 km² of which 86% is covered in forest (Yli-Kojola 1995). Finland has also drained 4.6 million hectares of peatland to facilitate better forest growth which has contributed an estimated 15% the nation's annual increment figure (Heiramo & Ruutu 1994). The 20.1 million hectares of forest in Finland comprise of about two-thirds of the nation and serves as its major natural resource (Heiramo & Ruutu 1994). Climate is the main limiting factor of forest growth in Finland where the growing season is only 120 to 170 days long per year (Heiramo & Ruutu 1994). Approximately two-thirds of the forested area in Finland are privately owned, which plays a principal role in Finnish forestry as the majority of this land is heavily fragmented (Heiramo & Ruutu 1994). Agriculture has been linked traditionally with privately owning forested land and farmers have found a second livelihood managing their forests (Heiramo & Ruutu 1994).

In Finland in the 1800s the sawmill industry began to grow closely followed by the cellulose and paper industries (Yli-Kojola 1995). As the 1800s drew to a close the only untouched forests to be found were only in the northernmost and easternmost parts of Finland as the rest of the country had been ravaged by irresponsible forestry practices including slash and burn cultivation, the cutting of forests for firewood and construction timber, as well as tar distillation (Yli-Kojola 1995). The irresponsible forestry practices led to a period of decline for Finland’s forests which sparked the initiation of forest inventories (Yli-Kojola 1995).

Established in 1917 within the Ministry of Agriculture and Forestry, the Finnish Forest Research Institute is the central power in the field (Heiramo & Ruutu 1994). When the Finnish National Forest Inventory began it was to collect data on the quality and quantity of the forest resources within Finland as well as provide a solid foundation for property taxation and forest income (Yli-Kojola 1995). Finland relies heavily on its forests and the industries surrounding the forest (Heiramo & Ruutu 1994) and the Finnish people have built lives in this northern country based on the success of the forestry industry (Heiramo & Ruutu 1994). Ensuring that the forests in Finland are healthy is a primary concern (Heiramo & Ruutu 1994).

Finland’s inventory practices have been created and perfected since the early 1920s, and current procedures are considered to be as efficient as they can be which leaves minimal room for any more improvement (Etula & Antikainen 2014). Instead of focusing on making data collection methods any more efficient, the focus has switched now to route optimization which in turn will make collecting field data more efficient by avoiding any unnecessary movement within an inventoried area (Etula & Antikainen 2014). It is very important that field work be done efficiently as the Finnish Forest Centre covers around 1.5 million hectares of forest every year, constituting a significant effort in data collection and plot maintenance (Etula & Antikainen 2014). Ways of improving field inventory data collection, and therefore keeping costs to a minimum, include careful in-depth planning, ensuring that all required data is collected in one single visit to the field, as well as to concentrate first on areas where data can be collected easily (Etula & Antikainen 2014).

Between 1921 and 1963, the first four inventories done in Finland, plots were measured lying on transects from south-west to north-east throughout the entire country before switching inventory techniques to a more systematic cluster sampling (Yli-Kojola 1995). In 1989, during the 8th Finnish National Forest Inventory, a new era began when the use of satellite imagery and digital map data was introduced in addition to the field measurement requirements (Yli-Kojola 1995). In early 1990s the inventory was used as an information source for the development and utilization of forest resources (Yli-Kojola 1995). Finland has practiced sustained-yield, efficient forestry for many years and the forests are in excellent condition with annual growth (Heiramo & Ruutu 1994). Thinning of stands happens one to four times throughout each rotation (Heiramo & Ruutu 1994). There are four main tree species in Finland, two species of birch (*Betula pendula* and *B. pubescens)*, Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) that are commercially valuable (Heiramo & Ruutu 1994).

Increasing wood production, developing new regeneration techniques, and mechanizing harvesting were the main focus of forest research (Heiramo & Ruutu 1994). By the mid-1990s the fear that Finland would one day run out of forest to harvest had been replaced with the under-utilization of wood-resources (Heiramo & Ruutu 1994). Finland's forests are growing so well that demands for raw industrial material and other forest uses can be met with ease (Heiramo & Ruutu 1994). Finland was the first nation to ever conduct a countrywide forest resource inventory and is the only country with recorded data dating back to the 1920s (Yli-Kojola 1995). The future of the

Finnish National Forest Inventory will include an ever-increasing use of modern technology (Yli-Kojola 1995).

THE FUTURE

The key to the future of G&Y modeling for forest managers and planners is to decide to what extent the forest stand is treated as a whole (Peng 2000). Forest managers must take into account not only wood supply but also recreational opportunities and wildlife habitats when using the FRI data (Thompson et al. 2007). Protecting the remaining intact primary forest and sustainable forest management are first taken into consideration before land is allocated to timber harvesting (Jobidon et al. 2015).

Progress for G&Y models depends entirely on data collection, the way the data is analyzed, and the technology available to compute the model (Peng 2000). Some future challenges for the G&Y program are the amount of data that are available, the number of silvicultural alternatives available, in-depth information on the quality of the trees and their product yields, as well as being able to predict a forest’s response to environmental disturbance (Peng 2000). Accurate maps of forest stands form the basis for forest management activities on any forest unit and from there, long-term large-scale predictions are made regarding harvestable wood volumes (Thompson et al. 2007).

The majority of the questions that forest managers have to deal with are concerns regarding the future outcomes of actions taken today, which tend to be innovative and technologically oriented (Apps & MacIsaac 1989). An intensification in forest management activities will require managers to make smarter decisions regarding resource management and therefore also requires them to be better informed of the possible consequences of every decision (Apps & MacIsaac 1989). To be able to forecast for the development of a specific species of tree at the forest stand level, not only the tree but also its surrounding environment must be considered to accurately model for predictive purposes (Apps & MacIsaac 1989). Data collected in the field will allow the MNRF to create growth models that will predict the forests future growth and its dynamics (Klassen 1997).

CONCLUSIONS

Forestry in Ontario has been around since the beginning of Ontario as a province. The available resources within Ontario were difficult to harvest during the early days due to no infrastructure large enough that even existed yet. When the Canadian Pacific Railway opened up a transportation corridor within Ontario, the province’s economy began to flourish. Unfortunately Ontario’s good fortune came at the cost of much of the forest being cut down at an alarming rate due to the mentality that the resource was inexhaustible. Due to the amount of control the general population of humans have over forests, the forests have been considered a human dominated resource for quite some time.

As time passed and technology came about, the invention of the camera, different types of film and methods of photo acquisition conveniently happened around the same time of aircraft development during the first and second World Wars. Reconnaissance missions were flown throughout WWII to gather photographic imagery and by the end of the war the aerial photographic method had been perfected. Aerial photography was then applied to the forestry industry and has continued to advance technologically since WWII. Interpreting these aerial photographs for many of the different forest attributes and ecosite data is typically done during the winter season. The accuracy of the interpreted photos however, is variable and should never be used as the sole source of information when making forest management decisions.

The basic goal of FRI is to provide the basic data and detailed information on the forest stand being sampled. FRI is supposed to provide rough calculations of conditions at any time just keep in mind that the data is subject to errors because of the small size of the area sampled versus the size of the forest the data is supposed to represent. The G&Y program was created soon after with the idea that using remeasurement data from PSPs and all plot data there is available for Ontario would result in better yield estimates as well as provide trustworthy and realistic estimates of growth. Forest ecosystem classification (FEC) system was an advancement that allowed for more accuracy, practicality and consistency in communicating and organizing data collected in the field at the stand level. The FEC specifications within Ontario for data collection is based on relative abundance and percent cover of vegetation that is located within a 100 m^2 sample plot within the PSPs and PGPs.

Technological advancements such as LiDAR has advanced forest management planning significantly. LiDAR remotely senses and collects data in high resolution multispectral imagery that is helpful in determining timber supply, running models, maintaining biodiversity, building road plans and forest management plans. LiDAR has been most useful in conjunction with the FRI program enhancing it, hence its new name eFRI. LiDAR is effective in collecting data that helps with riparian and water quality management as well.

To better protect the natural environment within Ontario the government has compiled policies and legislation that have been passed and are enforced throughout the province. The Environmental Assessment Act, the Timber Act, and the Crown Forest Sustainability Act provided strict guidelines on how the forests in Ontario were to be managed. It gave the public a chance to be involved in forest management and to maybe have a voice in how forests are managed.

Finland has been doing forest inventories since the early 1920s and have found methods of data collection that is working for them. Increasing wood production, developing new techniques for regeneration and mechanizing harvesting were the focus until their method was perfected. Rather than trying to improve methods of inventory in the present, their focus is now on the optimization of roads throughout the forest to make data collection more efficient. Since Finland is mostly privately owned the land is very fragmented making some aspects of forestry are difficult to achieve. Finland was however, the first nation ever to achieve a countrywide forest resource inventory.

The future of the G&Y and eFRI programs depends on forest managers taking into account recreational opportunities and wildlife habitats when using the data. The quality of the data collected from the field and the technology available to compute the forest management models as well as being able to predict what a forests response is going to be to a disturbance are all important to the future of G&Y. Accurate maps are needed to inform managers of where the merchantable stands are located and how much timber is available for the harvest. The data collected in the field allows the MNRF to run growth models that will predict future forest growth and its dynamics.

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