

# Stand Structure Before and After Harvest Inspired by Natural Disturbance: Assessment by Photo-based Techniques

*Adam R. Dick, M.Sc.F. Candidate*

Advisory Committee:

Dr. David A. MacLean, Supervisor, University of New Brunswick  
Dr. John A Kershaw, Co-supervisor, University of New Brunswick  
Dr. Tom Beckley, University of New Brunswick

## Introduction

Traditionally, the role of a forester was to ensure a sustainable flow of wood was harvested from forests to produce commodities desired by society. Tools used by foresters were well suited to achieve these goals. Silvicultural techniques were designed to grow stands of trees to supply the required raw material in an efficient and economical manner, and mensuration tools were designed to measure forest conditions as a function of timber conditions. Today, however, the goods and services society wishes to derive from forests go far beyond the supply of timber products, but this has not necessarily meant that requirements for wood products has decreased. Foresters require new tools in order to create forest conditions that fulfil society's desires, and to be able to make the measurements required to verify that objectives are met. The ecosystem management concept (Agee and Johnson 1988) was proposed in the past decade as a way of maintaining ecological integrity of a forested landscape, while ensuring social and economic objectives were still achieved. A new tool set is required if forest managers are to adopt ecosystem management concepts. These tools include new silvicultural techniques that, when implemented, are able to maintain desired conditions, both at stand and landscape levels. As silviculture activities become more complex, more information is required to assist in the decision making process. Increasing amounts of stand level information are required, much of which is not available in traditional inventories designed for timber objectives. New tools are also required to enable foresters to collect an increasingly diverse set of information in an efficient manner.

One anticipated outcome of this Masters project is the implementation of natural disturbance-inspired harvest on 2600 hectares of forest in northwestern New Brunswick. Harvest guidelines will be developed based upon harvesting trees that would be killed in a spruce budworm (*Choristoneura fumiferana* Clem. (SBW)) outbreak. Analysis will compare the pre and post-harvest stand conditions for maintenance of stand structural elements believed to be important for maintaining ecological integrity. The second anticipated outcome is development and testing of new photograph-based techniques for comparing change over time from repeated measures, which will be used to assist in making the pre- and post-harvest comparisons, as well as providing a new tool for efficient plot measurements for a variety of values.

## Literature review

Ecosystem management has been widely discussed in the last decade (Gillis 1990; Grumbine 1994; Christensen et al. 1996; Grumbine 1997; Lackey 1998; Yaffee 1999) as a strategy to maintain structure and function of an ecosystem, while still deriving social, and economic benefits. A comprehensive definition of ecosystem management has been elusive, partially because it may differ among people or organizations with different perspectives. Several have proposed components or concepts that are essential to ecosystem management (Gillis 1990; Grumbine 1994; Christensen et al. 1996; Grumbine

1997; Lackey 1998; Yaffee 1999). The measure of sustainability is based not only on harvest levels, but also by maintaining of ecological processes across landscapes. There is an emphasis on taking current scientific understanding of ecological processes and incorporating it into the design of the silvicultural techniques that are implemented on the landscape.

One proposed way to develop ecologically based harvest prescriptions is to pattern them after natural-disturbance regimes endemic to a region (Seymour and Hunter 1992). Natural disturbances are important in maintaining diversity of stand conditions that form a landscape mosaic. For most of the 20<sup>th</sup> century, however, there was a belief that disturbances such as fire or insects were anything but natural, and managers took great lengths to exclude them from forests whenever possible. The story of Smokey Bear became the face of this public policy. Towards the end of the last century, events such as the Yellowstone National Park fires of 1988 (Franke 2000), resulted in renewed interest in the importance of natural disturbances in maintaining ecological function. While results of a spruce budworm outbreak appear devastating in terms of tree mortality and the bleak imagery that remains, (Baskerville 1975) described spruce budworm as a “super-silviculturist” for its influence in development of spruce-fir forests. While it may not be desirable to re-introduce natural disturbances, we can learn from the stand structures and conditions that result from them and use these concepts to tailor our management techniques. Ecosystems are constantly in flux, and seldom reach an equilibrium state that is perpetuated indefinitely (Lackey 1998). Periodic disturbances ensure that the only “natural” state is change. Forest disturbances can be described by three characteristics: disturbance cycle, extent and severity. Disturbance cycle or return interval is a measure of how often disturbances will re-occur in the same area. Time return intervals range from occurring on an ongoing or continual basis to re-occurring on a time scale of hundreds, or thousands of years. Extent of disturbance ranges from a single tree, to entire regions covering thousands of hectares. Severity, measured at the stand level, is a measure of amount of the pre-harvest condition that remains after the disturbance has subsided. Again, severity ranges from replacing single trees to replacing the entire stand. The combination of these factors means that eventually a tree or a forest will be re-initiated to make way for a successor.

Spruce budworm is a major insect defoliator of softwood species in northeastern North America (Swaine 1933). Spruce budworm populations undergo periodic increases to epidemic levels causing large-scale mortality in spruce and balsam fir dominated stands over hundreds of thousands of hectares of forestland. Historical records (Tothill 1922; Swaine and Craighead 1924; Blais 1958, 1962; Greenbank 1963; Blais 1965) indicate epidemic periods lasting between 5 and 15 years have occurred on at least three occasions in the last century, between 1912-1920, 1939-1949 and 1970-1980 (Royama 1984; Royama et al. 2005). Historically, outbreaks reoccurred approximately every 35 years. Spruce budworms consume current-year foliage from susceptible trees during outbreak periods, which results in a decrease in annual increment of trees. If the outbreak persists long enough, the result will be the tree mortality.

Forests are perpetually in a state of change, as trees grow and mature, insect outbreaks cause wide-scale mortality, or by human factors such as harvesting or silviculture. Whether these changes take place over a short or long time span, well planned monitoring programs need to be in place if we are to improve our understanding of the mechanisms and the outcomes of these processes and activities. Long-term research studies are important, since the outcomes may only become apparent decades after the original implementation (Walters and Holling 1990; Christensen et al. 1996). Maintaining the integrity of collected data is important to ensure comparisons can be made and change can be measured over time. Photography is an effective way to capture records of forest conditions, and photography has been used by foresters for many years, although mostly from an aerial perspective. There are some examples of stand level photography being used, but this has never been widely adopted. (Reineke 1940) described using photographs to catalogue permanent sample plots. (Hall 2002a, b) developed a system to monitor change over time using photographs, as well as techniques to make quantitative measurements from the

images. As more information is required to help in decision making, new techniques are needed to make collection more efficient. Electronic data collectors are now commonly used but they still require human input to enter the data. We can use photography to complete the process of digitizing the data collection process, resulting in gained efficiencies. Making data collection a more efficient process will give the forester more information and an enhanced ability to make decisions based on it.

(Bitterlich 1948) proposed the concept of angle count sampling (ACS) to perform efficient forest inventories. Using the ACS technique, basal area density of a unit area is estimated by counting those trees whose diameter at breast height (dbh) subtended angles appearing larger than the horizontal angle-gauge (Grosenbaugh 1958). This is represented by the formula:  $G = zk$ , where  $z$  is the count of “in” trees that are counted as in, and  $k$  is a ratio between the dbh of the tree being considered, and the distance ( $D$ ) between the tree, and the observer (Figure 1). Using a tool such as an angle gauge, calculation of  $k$  becomes a ratio between width of the gauge being used ( $a$ ) and distance between the gauge and the observer ( $b$ ).

(Decourt 1956) was the first to propose a modification of the ACS concept to allow the use of a camera. Decourt used width of the tree on the image ( $a'$ ) and camera focal length ( $f$ ) to calculate  $k$ . Since Decourt was using only a portion of a plot (the portion represented within the camera's field of view),  $k$  was divided by the portion of the plot captured in the photograph.

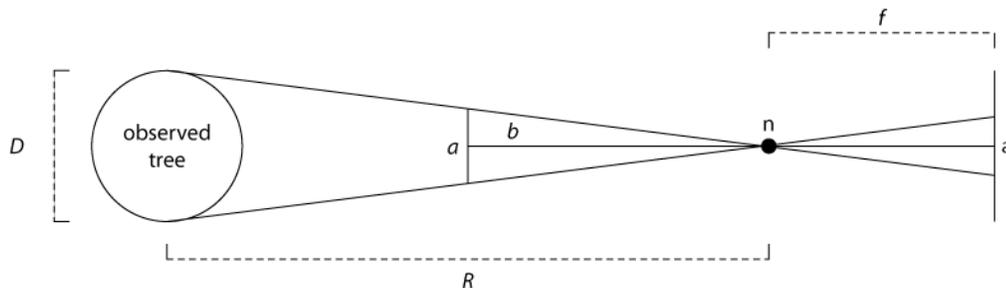


Figure 1: Illustration the angle count concept and its adaptation by Decourt (1956).

## Objectives

1. To develop a method for making stand level measurements, including stand density, stand basal area, stand diameter distribution, and tree spatial locations, using standard photography techniques
2. To compare pre- and post-harvest stand structures, species composition, large trees and coarse woody debris (CWD) in 242 permanent sample plots (PSP) representing several natural disturbance based harvest treatments and current silvicultural treatments.

## Study Area

### Black Brook District

Black Brook District is a privately held landbase in northwestern New Brunswick, owned and managed by J.D. Irving, Limited. It is 190,000 hectares in size and represents some of the most intensively managed forest in Canada. The district represents a continuum of intensive to extensive forest management, including 57,000 hectares of plantations primarily black spruce (*Picea mariana* (Mill.) B. S. P.), white spruce (*Picea glauca* (Moench) Voss) and Norway spruce (*Picea abies* (L.) Karst). These plantations are intensively managed by herbicide treatment, pre-commercial thinning and commercial thinning. These activities also take place on some naturally regenerated areas. Another 49,000 hectares of Black Brook District consist of tolerant hardwood stands on fertile and highly productive sites. This

portion of the forest is currently being managed to produce high-quality veneer and sawlogs by use of selection and patch cut systems where only individual or small groups of trees are harvested.

The Black Brook District also includes a 7,000 hectare network of scientific benchmark reserves. These reserves were established in conjunction with the World Wildlife Fund as a requirement of Forest Stewardship Council (FSC) certification (FSC certification has since been voluntarily cancelled). Reserves are of two types: Adaptive Management Areas (AMAs), where alternative silvicultural systems can be designed and tested; and Core Reserves, where no forest interventions will take place and which provide benchmark forest conditions to which the managed forest can be compared.

## Methods

### **Plot Establishment**

Research plots were established in three areas of the Black Brook District that represent a gradient of treatment intensity. Plots were established in the AMAs, where alternative harvest treatments are being conducted, Core Reserve where no treatment occurs, and in the working forest where the typical industrial forest treatments have been applied and plantations were established. In total, 242 plots were established and had a complete suite of measurements performed. Plots were established across a gradient of stand types in all landscape classes, with the exception of plantations that were all classed as softwood stands (Table 1).

*Table 1: Plot establishment summary by landscape class and stand type*

Stand Type <sup>1</sup>	Landscape Class				Total
	AMA	Core Reserve	Working Forest		
			Industrial	Plantation	
HW	4	8	3	0	15
MW	23	28	17	0	68
SW	63	14	22	20	119
TH	7	13	20	0	40
<b>Grand Total</b>	97	63	62	20	242

<sup>1</sup> HW - HW $\geq$ 50%, MW - HW $<$ 50% AND SW $<$ 50%, SW - SW $\geq$ 50%

TH - HW $\geq$ 75%

Plots were generally laid out in a grid that ran north to south and east to west. Data collection began in the summer of 2002, followed by a second and third season in the summers of 2003 and 2004. During the first season of data collection, plots were spaced at 350-m intervals. This spacing was selected to accommodate cooperation with Université de Moncton research involving bird species use relative to harvest treatment, with the inter-plot distances necessary to avoid overlaps. In 2003 and 2004, following review of the 2002 data, a spacing of 250-m between plots was determined sufficient and adopted.

Lines of plots were normally laid out starting from the edge of a road. Bearings were taken with a compass and distances were measured with a string box beginning from the edge of the forest adjacent to the road. Transects leading into the plots were marked with flagging tape. Since riparian areas occurring within the AMAs would not be harvested, plots were not established or were slightly shifted from the grid layout to avoid these areas.

Four different plot types and sampling protocols were followed for the collection of various data surrounding the established plot centre (Table 2). These consisted of 1) a permanent sample plot (PSP); 2) four strip plots emanating from plot centre; 3) a series of prism plots clustered around the plot centre; and 4) small fixed area plots used to collect data on small vascular plants on the forest floor. Establishment and data collection methods for these protocols are described in Table 2.

Table 2: Summary of sampling protocols used

Protocol	Permanent Sample Plot	Strip Plot Transects	Prism Plots
<b>Plot Layout</b>			
Type	Circular	Rectangular strip	Variable radius prism
Size	0.04 hectares	0.1 hectares	Variable using BAF2 prism
# of Plots	1	4	5
<b>Tree Measurements</b>			
Tree Status	Living, dead within last 5 years	Living	Living
Minimum Diameter	10.1cm <sup>1</sup>	30cm	10.1cm
Precision	0.1cm	0.1cm	2cm classes
Tree Height	Yes	No	No
Ht. to Base of Live Crown	Yes	No	No
Crown Radius	Yes	No	No
Tree Form	Yes	Cavities, Beech Bark Disease	No
Spatial Location Recorded	Yes	Yes	No
<b>Coarse Woody Debris</b>			
Minimum Diameter	n/a	30cm	n/a
Precision	n/a	0.1cm	n/a
Tree Form	n/a	Decomposition class <sup>2</sup>	n/a
Spatial Location Recorded	n/a	Yes	n/a

<sup>1</sup> Minimum diameter was 5.1 centimetres DBH during the first season

<sup>2</sup> 1=Freshly fallen, 2=Fallen sound; 3=Partly decayed; 4=Well rotted/Hollow

Plot centre was marked by driving a steel post into the ground. The coordinates of the plot centre were collected using a Trimble® GPS data collector, accurate to within ±1 m. Plots were assigned unique numbers to allow the data collected to be referenced back to the plot.

## Photography

On a subset of plots, at locations of each of the 5 prism points, additional data were collected to test effectiveness of the proposed techniques under a range of stand conditions. A total of 50 plots were measured using this protocol. Photographs also served as a means of cataloguing the condition of plots before and after harvest implementation, and may permit future plot comparisons. A traditional prism sweep using a BAF 1 m<sup>2</sup>/ha angle gauge was conducted measuring all “in” trees that had a DBH greater than or equal to 10.0 cm. The distance (to the nearest 0.1 metre) and azimuth of each tree was measured using a device mounted to a tripod at plot centre that measured distance and azimuth from origin to each tree.

A tripod mount manufactured by Kaidan was used to assist in taking photographs. The purpose of the tripod mount is to ensure that the focal point of the camera is fixed above the axis around which the camera rotates. This is a crucial step in taking the photographs in order to reduce distortions or errors in images. Once the tripod mount and camera are calibrated to ensure the focal point of the camera is positioned over the centre of the tripod, it is not a time consuming process to set it up repeatedly in the field. The tripod needs to be level to ensure that images are taken across a horizontal plane; the tripod mount has an integrated bubble level to accomplish this. Normally, 24 images are taken. This represents one image for every 15 degrees of camera rotation ensuring adequate overlap between adjacent images. The tripod was set up such that the camera was at eye level, to approximate the same view in the images that an observer in the field would have.

## Harvest Treatment

In the AMAs, the goal of the treatment, as prescribed to the harvest operators, was to harvest nine of every 10 mature balsam fir trees, and 6 of every 10 mature spruce trees. These instructions were

determined in conjunction with the forest managers at J.D. Irving Ltd., and are a balance between empirical knowledge on average mortality levels in spruce budworm outbreaks (MacLean 1980) and practicality of implementing it from the cab of a harvester in an efficient and economical manner. The harvest was carried out with a single-grip harvester and forwarder system. The harvester created trails at approximately 15-metre intervals. The harvester was able to reach in and harvest on either side of the trail, while the forwarder extracted the wood down the trails. All trees were harvested to construct the trails so the prescribed selection was made on either side of the trail. Trees were delimbed in the stand and limbs were used as a brush mat on trails to increase bearing capacity of the ground over which the machinery was travelling. Trees that were found to be rotten at the base were short-bucked in the stand until desirable specifications were found. Rotten tree butts were left in the stand. The harvest operators were instructed not to discriminate between trees with flagging tape or other markers that indicated where sample plots were established prior to harvest.

Harvest blocks in the working industrial forest were harvested according to prescriptions developed and currently employed by J.D. Irving, Limited on the Black Brook District. Clearcut and variable retention prescriptions are employed in intolerant mixedwood and softwood stands with the objective of creating or maintaining a single age class stand. The regenerated stand is initiated by either planting softwood species or through natural regeneration. The clearcut prescription is most often used in mixed-wood stands, while the variable retention prescription is used in pure softwood stands. In stands that are composed of tolerant hardwoods, or are tolerant mixed-woods, single-tree and group selection prescriptions are employed. These are improvement cuts with the objective of harvesting merchantable wood while promoting the natural regeneration of high-quality hardwood species on the site. The techniques are meant to emulate the natural gap dynamics of tolerant hardwood stands. The single-tree selection prescription mimics stand gaps created by the natural senescence of individual trees. Group selection prescriptions emulate the death of small clumps or patches of stands from natural pathogens such as root rot fungus. The decision criterion between the two hardwood prescriptions is based on the beech (*Fagus grandifolia* Ehrh.) content of the stand. If beech basal area makes up more than 30% of the stand, the group selection harvest will be employed. In this way, the prescription is used to promote a more desirable species such as yellow birch over beech. If beech makes up less than 30% of the stand basal area, the single-tree selection prescription will be employed.

## **Data Analysis**

### ***Photography***

#### **Angle count sampling**

The plot photographs and accompanying field data are used to validate the developed techniques to use photographs to perform angle count sampling. Stand conditions that are thought to affect the ability to perform ACS sampling using photography include: tree density (number of trees in a plot), spatial distribution of trees (dispersed vs. aggregated), density of understory vegetation, distance from plot centre to tree, and the basal area factor used to make measurements. The key to effectiveness of the photography technique is ability to see the trees in the photograph. Density of trees and spatial distribution determine the likelihood of obscured trees, dense understory vegetation may obstruct trees and basal area factor affects how many trees are visible. As basal area factor increases, the maximum limiting distance for a tree decreases, meaning that trees farther away from plot centre are not counted as in. I will analyze tradeoffs between increasing basal area factor, and number of trees successfully measured. Recommendations will be made about conditions under which the developed techniques can be used, and how the techniques could be modified to work under less than ideal conditions. I will investigate sampling techniques that may overcome the issue of obscured trees.

## **Spatial Tree Mapping**

Using relationships developed by Decourt (1956) and using a 360-degree view of the plot, it is possible to measure the distance from plot centre and the observed tree as well as the azimuth to the tree. These values can be used to calculate the spatial locations of the trees. The tree locations that were accurately mapped in the field will be compared to measurements derived from photographs to assess accuracy of photograph-derived locations. Regression analysis will be used to determine how well photography techniques compare to field measurements made using traditional measurement techniques. Scale of the photograph can be established by computing the ratio between width of the image in pixels divided by 360-degrees represented in the image. This relationship will be used to compute azimuth values for each tree in the image. Tree coordinates calculated from the photographs will be compared to coordinates measured in the field to assess accuracy and precision of the photograph compared to field measurements.

## **Accuracy of Harvest Implementation**

The harvest prescription will be simulated and applied to PSP data collected prior to actual harvest. The residual plot condition after the simulation represents the residual conditions expected after the harvest is implemented in the reserves. Removal levels will be compared to actual removal levels to assess how well the harvest, as implemented, was able to replicate expected removal levels. Post-harvest implemented, plot re-measurement information will be used to assess how well the harvest operators were able to implement the harvest prescription. Resulting plot conditions will be compared to predicted removal levels that resulted from the modelled harvest.

Complex stand structures are important for maintaining integrity of the forest as habitat for many animals. The elements of stand structure measured prior to the harvest including coarse woody debris, large trees and species composition will be assessed to measure structural integrity of the forest prior to and following the harvest treatment and compared to management guidelines (New Brunswick Department of Natural Resources and Energy 1999; Whitman and Hagan December 2004), used to assess biological integrity of forests. Stand conditions created through the harvest trials will also be compared to resulting conditions following traditional harvesting prescriptions that are used on the industrial forest portion of the landbase.

## **Anticipated Deliverables**

The results of this project will provide two important contributions. There has been much interest in the past decade in natural disturbance-based forest management to maintain ecological function while deriving economic and other benefits. Despite interest, few examples exist where experimental harvests have been carried out on a large scale. While this project will only deal with the resulting condition immediately following the harvest treatment, the permanent plots will offer the opportunity to understand the response and development of the forest over time, from both an ecological perspective and a silvicultural standpoint helping to understand how to conduct partial harvests.

Over the long term, repeated photography of the plots will serve as a monitoring tool to study the change in stand conditions. The photography techniques developed are an innovation that has the potential to be developed into new tools that will allow forest fieldwork to become more efficient and to aid the forest manager in understanding the data that are collected.

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