"20 Year Results, You're Just Getting Started" Long-term Experimentation at the Petawawa Research Forest

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Introduction

The Petawawa Research Forest (PRF) was established in 1918 as a result of the efforts of R.H. Campbell, Director of Forestry Branch from 1907 to 1923. Campbell lobbied and received $6,000 to begin forestry research with the goal that systematic investigation periodically observed was the only way to develop sound estimates for growth and yield and to calculate the results of silvicultural treatments (Johnstone 1991). It was decided to begin with a forest experiment station modeled after the successful agricultural experimental stations. The Petawawa site had been cut over for pine and was an ideal site to study this species (Place 2002).

Eighty-seven years later Petawawa contains a legacy of research spread over 10,000 ha and conservatively valued at $125 million (Cdn). The themes include: growth and yield permanent sample plots (PSPs), silviculture, plantation management, intensive forest management, genetics, forest fire, ecological reserves, and numerous others. The number of experiments established at Petawawa has never been precisely recorded but the following estimates are provided:

- —500 PSPs (~250 are open and 200 are up to date)
- —100 Silviculture studies (~50 are open and 30 are up to date)
- —125 Research plantations (~100 are up to date)
- —1100 Intensive Forest Management plots (~200 are up to date)
- —300 Genetics trials (~200 are open and ~100 are up to date)
- —100 Forest fire experimental sites (10 are open but none are up to date)
- —13 ecological reserves all of which are current
- —30 Remote sensing sites all of which are current
- —Additional data sets include 25,000+ photos, air photos back to the 1930s, 700+ unpublished internal reports, 300 project files, etc.

Experimentation Designs Over Time

Most of the early experiments can be considered 'demonstration' or 'test cases' since the theory of repetition and statistical design did not exist at the time these sites were installed and thus was not included. This era of work was very exploratory where "try something and see what occurs" was the norm. Experimenters had excellent knowledge based mostly upon European research work. They wondered how native forests in

Canada would respond. Normally the intensity of treatment was applied in order (not random) across the landscape so you move from control to light treatment to heavy treatment from, say, east to west. Effort was made during this era to utilize uniform and comparable sites. Most designs included a control. Design efficiency was not considered and the plots are usually larger than those installed later. There is a lot to be learned from these sites as they have been in place for up to 87 years; it is just not up to statistical standards for today's scientific journals.

The second generation of experimentation usually involved randomized designs, a control plot, and sometimes a second repetition of a treatment or a measurement plot. Consideration was given to randomizing treatments across the landscape. This era was "try something and see if the treatment caused the response." Again homogenous sites and comparable measurement plots were well thought out. Treatments often consciously included something extreme that was expected to fail to provide a complete suite of treatments.

The third era of experimentation (the statistical era) involved randomized designs, multiple repetitions, and statistically significant results. This era can be summarized as "prove the treatment causes the response." Larger homogenous sites were required to meet the scientific design. Design trends changed as new advances were circulated amongst the research community. New experiments are still being established under these criteria.

The current era (or fourth era) of experimentation involves process level experiments where the researcher is attempting to not only prove the treatment causes the response but also to understand what biological process is driving/causing the response. Instrumentation of environmental variables and careful control over treatment installation to ensure a 'clean' experiment is the norm. Treatments are applied in all possible combinations to isolate the effect of a treatment or a combination of treatments. The number of plots expands exponentially for each treatment added to the experiment. Larger homogenous sites are needed to accommodate the increased number of plots in factorial designs and the cost of installation of these experiments is prohibitive to all but the well-funded and partnered researcher.

Lessons That Could Only Have Been Learned with Long-term Plots

In reviewing the suite of experiments at Petawawa a few examples highlight the value of long-term plots in forest research and its application in forest management. Three specific examples are presented: silvicultural treatments (1958-2002) in plantation white spruce (*Picea glauca* (Moench) Voss), tree breeding for genetic gain in white spruce (1960-2005), and stand development in an old growth white pine (*Pinus strobus* L.) stand from 1948-1998.

Silvicultural Treatments in Plantation White Spruce and the Impact of Tomentosus Root Rot

When the Petawawa Research Forest was established there existed about 400 ha (925 ac) of farm fields that had been expropriated in the early 1900s and abandoned thereafter. These fields were planted with various species including 37 ha (81 ac) of white spruce in 34 research plantations established mostly between 1920 and 1922 and between 1930 and 1932 (Stiell 1955). In 1958 the first of three experiments was established to investigate sound silvicultural practices in representative plantations. There was virtually no literature available on intermediate cuttings in white spruce plantations although the species was preferred for reforestation by the pulp and paper companies in eastern Canada.

The experiment was intended to address periodic growth under different levels of growing stock by thinning back to a prescribed basal area at regular intervals (Stiell 1960). A 10-year thinning interval was selected as likely the shortest to be adopted and thinning from below was the method selected; it being the most easily duplicated. In selecting the residual basal areas for the thinning, the control plot was designated as highest possible stocking and the low end was to be so open that inadequate site utilization would result in lost production. Literature on Norway spruce (*Picea abies* (L.) Karst) showed little drop in increment so long as half the greatest possible basal area for the stand age was retained. A check of the Petawawa spruce plantations revealed the most dense to be about 45 m^2/ha (200 ft^2/ac) so removing half plus another 10% as a safety factor calculated the too-open treatment as 18 m^2/ha (80 ft^2/ac). Intermediate treatments of 25 m^2/ha (110 ft^2/ac) and 32 m^2/ha (140 ft^2/ac) were chosen and the plots were to be thinned in 1958, 1968, 1978, and 1988.

Over the next 45 years the experiment evolved; partly as planned then later with new meaning (Table 1). Tomentosus root rot went from being found near the plots 10 years into the experiment to overriding any thinning effect 25 years into the experiment. New lines of investigation and conclusions totally unexpected from the original design resulted. The most recent re-measurement indicates the impact of this root rot in this situation all but eliminates the choice of white spruce as a long-living plantation species. The importance of these results on selecting white spruce as a plantation species remains with around 22% of Canadian conifers sown in 1999 being white spruce (Morgenstern and Wang 2001).

Tree Breeding for Genetic Gain in White Spruce: Tale of Height vs. Survival

When the tree breeding program was evolving at Petawawa in the 1950s the logical tree species first chosen for study were the two needle pines and spruces because of their high commercial value, wide distribution,

Year	Ave. stand age	Exp. age	Result reported	Tomentosus	Reference
1958	36	0	Establishment report	Not mentioned	Stiell 1960
1963	41	5	Highest growth 125 ft^2/ac	Not mentioned	Stiell 1965
1968	46	10	80 ft^2/ac too open, thin between 100 and 140 ft^2/ac	Nearby, could be serious	Stiell 1970
1978	56	20	Thin between 110 and 140 ft^2/ac	Present in one plot	Stiell 1980
1983	61	25	Reject plots for growth and yield calculations due to Tomentosus. Clear-cut heavily infected stands at age 40-50	Causing significant mortality	Stiell 1986
1988	66	30	Avoid pure stands of white spruce irregardless of thinning	Caused up to 12% mortality	Whitney 1993
1998	76	40	Plots not measured		
2002	80	44	Average volumes in 2002 5% less than in 1988; 25% of sawlogs lost as pulp	Mortality > growth	unpublished

Table 1. Thinning white spruce plantations from below.

and their potential for improvement (Place 2002). The Petawawa program was part of a national and international effort and quite often experiments were duplicated or part of a series established at other sites. Over 50 white spruce experiments were established at Petawawa from the mid 1950s until the mid 1980's. Early test designs were often large plots and few replicates. Statistical differences could only be detected at low levels of probability (Morgenstern and Copis 1999). Ideas from growth and yield influenced the installation of the earlier large plots/few replicates experiments (which allows volume per unit area calculations) whereas later plots were influenced by the ideas of Wright and Freeland (1960) which stressed the advantage of many replications and small plots (Morgenstern et. al. 2005). For example, experiment 194-D-1 was planted with 144 tree plots and 25 seed sources with a reported statistical significance of 25% whereas 194-M was planted with 10 tree plots and 54 sources and a reported significance of 1%.

The program identified and evaluated various genetic traits with tree height as the most common variable (Table 2). One of the achievements of the program was the identification of the Upper Ottawa Valley white spruce (also known as Beachburg white spruce) as a robust and superior source across a range of environments. Later, Libby (1987) questioned whether early gains in height were the desired outcome of a tree-breeding program and found few studies where unit area productivity, tree height, and neighbor interactions were all accounted for. Industrial round wood users are interested in volume gains per unit area and larger piece sizes.

To test the long-term implications of emphasizing early individual tree height gain we re-measured the 194-G-1 test in 2002 at age 44 (Morgenstern et. al. 2005). Because this test was planted with 12 x 12 tree plots and systematically thinned we were able to calculate volumes per ha and average stem size for a given source much like a growth and yield plot in an industrial plantation. This allowed us to compare early selection based upon individual mean tree heights against parameters of interest to the clients of a tree improvement program. We found the volume ranged from 189 to 287 m^3/ha. The top 10 sources (out of 25 in the experiment) in terms of volume had ranked between 1st and 18th place in height at age 19. The top ranked source by height at age 10 and 19 produced only 3% more volume than the experimental mean at age 44.

Variable(s) reported	Age when measured	Result	Conclusion	Reference
Form and height	8	Best 18% taller than worst	Only plus trees should be progeny tested	Holst 1967
Survival and height	10	Best 28% taller than mean	Substantial variation for height amongst families	Dhir 1975
Survival and height	13-15, and 20	Best 21% taller than local provenances, no significant differences in survival	Local provenances about average in height	Teich *et. al.* 1975
Height	6	Provenance crosses 5-30% taller than controls	Control of inbreeding is important	Ying 1978a
Survival and height	7, 14, and 18	Selfed trees 18-33% shorter than open pollinated	Importance of avoiding inbreeding	Ying 1978b
Survival, height, and form	8 and 22	Correlation between heights at ages 8 and 22 was high	Early selection of superior progenies appears to be feasible	Ying *et. al.* 1979
Height	8-10, and 19-20	Statistically significant differences in mean height of provenances	Ranking by height at age 8-10 correlated with rankings at age 19-20	Murray and Skates 1985

Table 2. Selected reports from the Petawawa genetics group.

Validation of the superior sources can be achieved through a series of realized gain tests designed to confirm the correspondence between juvenile individual tree height growth and mature stand volume productivity under various management regimes. These were never installed at Petawawa although a series established in 1993 in New Brunswick contains the Upper Ottawa Valley source (NBTIC 2002). It may prove unfortunate most of the experimental designs stressed many replications and small plots which do not allow the unit area calculations as the 194-G-1.

What Does a Natural Area of Older White Pine Have to Do with Rotation Age?

Natural Areas were representative areas set aside starting in 1949 to monitor undisturbed ecosystem development. The rationale was to preserve suitable sites while undisturbed as it was impossible to predict the information required by future foresters or biologists. Baseline ecological data was recorded although preservation was the primary goal. Scientific interest in these areas over the years has been minimal as no manipulative results could be reported.

One of the areas in 1948 was a 5 ha stand with 115 year old white pine and tolerant hardwoods. It was expected to demonstrate succession leading to the establishment of a tolerant hardwood stand. The establishment documentation notes that the present pine overstory will not be perpetuated to any extent in the next stand on this rich site (Anon. 1961). It was expected the white pine was past its peak and would shortly fall out of the canopy due to natural mortality. A 2.2 ha plot was established in 1948 within the Natural Area and measured for dbh and heights and in 1949 ground cover, regeneration, saplings, and standing dead trees (chicots) were tallied. The plot was remeasured for dbh and heights in 1959, 1971, 1981, and 1998 (Table 3). The expected conversion to tolerant hardwoods is not occurring as rapidly (if at all) as originally expected because the dominant white pines continue to grow with the last periodic increment being 3.2 m^3/ha/year for a 150+ year old stand.

The majority of pine stands at Petawawa in 1948 were about 70 years old. Less than 1% of the forest was inventoried as older than 100 years. Rotation age used in the management plan at Petawawa in the 1940's for white pine was 100 years (Bickerstaff 1948). Horton and Bedell (1960) suggested rotation age by site class as 80 years for site class I and 110 years for site class II. Monty (1990) utilized 100 years as rotation age and final removal cut for white pine in the 1990-2010 management plan.

In light of the growth rate in Natural Area 1 and the value of clear white pine lumber we have revisited rotation age for the white pine cover type at Petawawa. We now utilize a 'mature+' class for ages 120 to 140 for this cover type/age group that makes up over 20% of the forest. Our intention is to extend rotation age using the shelterwood system to at least 160 years on selected sites. What started out as a scientifically unpopular ecological monitoring site has demonstrated information that could only be realized over a 50 year period on this unique site.

Publications Summarizing Results

A complete layman's history of Petawawa and the work that has taken place on the site has been recently published and readers interested in a complete background are directed to Place's "75 Years of Research in the Woods: A History of Petawawa Forest Experiment Station and Petawawa National Forestry Institute, 1918 to 1993" (Place 2002). A complete documentation of all experimental and operational activities has never been compiled to this author's knowledge. Some references come to mind that may assist the reader with the scientific history.

Forest Fire Research was compiled in a series of annotated bibliographies: "Forest-Fire Hazard Research as Developed and Conducted at the Petawawa Forest Experiment Station" (Wright 1932), "Bibliography of Departmental Forest Fire Research Literature, Information Report FF-X-2" (Ramsey 1966), "Annotated Bibliography of Forest Fire Research at the Petawawa Forest Experiment Station 1961-1979" (Van Wagner 1979), and "Annotated bibliography of fire behaviour and ecology research at the Petawawa National Forestry Institute 1979-1994" (McAlpine 1995).

Species	**1948**	**1959**	**1971**	**1981**	**1998**
White pine	170	254	293	351	405
Sugar maple	18	40	54	68	76
Largetooth Aspen	33	32	52	67	84
Basswood	10	9	13	14	16
All Species	*283*	*370*	*449*	*523*	*601*

Table 3. Total volume (m^3/ha) for Natural Area 1.

A summary of the efforts of the Tree Breeding group(s) in an unpublished report by Yeatman, 1993 titled Tree Breeding and Genetics; Petawawa 1935-1993 is available in the PRF records.

Stiell's "Chronicle of white pine and red pine research at the Petawawa National Forestry Institute" (Stiell 1994) chronicles 103 publications and the projects dealing with red and white pine. Also "A Compendium of Experimental Sites and Scientific Investigations in the Petawawa Research Forest" available at the PRF contains a summary of publications as well as research sites (Anon. 1997).

Summary

The passing of time cannot be modeled or accelerated in forestry research. Unexpected or new uses of the information may be just around the corner. The very nature of the monster under study is long term and change can be slow but cumulative. Will Stiell, whose career in silvicultural research extended 60 years, once commented on some results 20 years into a study: "20 year results, you're just getting started."

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