TITLE: Restoring White Pine in the Minnesota Landscape O-7

PROJECT MANAGER: Klaus Puettmann

ORGANIZATION: Forest Resources Department, University of Minnesota

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LEGAL CITATION: ML 1997, Chap. 216, Sec. 15, Subd. 19(b)
Appropriation Language: This appropriation is from the trust fund to the University of Minnesota to investigate factors currently limiting establishment of white pine seedlings in various forest cover types. Management recommendations for natural regeneration, seeding, and planting must be developed.

Statement of Objectives

The overall objective was to investigate factors limiting establishment of white pine in Minnesota and develop new management recommendations for white pine regeneration. Specific objectives included: First, to investigate the effects of overstory, mid-story, and understory vegetation as they alter the environment and compete with seedlings for light and water. Second, we investigated criteria that natural resource managers can use to prepare advanced regeneration for the removal or death of overstory trees and to decide whether a stand is suitable for release (i.e., partial overstory removal).

Overall Project Results

Objective 1: We installed two studies that investigated the effects of overstory, mid-story, and understory vegetation as they alter the environment and compete with seedlings for light and water. We have taken the first measurements to quantify these relationships to guide natural resource managers in providing suitable growing conditions for white pine seedlings.

Objective 2: A survey of three recently released stands provided preliminary information about the effects of initial seedling size, growing conditions, and overstory effects on a seedling's ability to respond to release. Three sites were set up to further investigate these relationships. We have taken pre- and post-treatment measurements on these sites.

Because of the long term nature of tree growth, all installations have been providing only preliminary results. However, funding is in place to follow all studies, maintain the treatments, and

measure the response as appropriate. As results become more definite, we are organizing and presenting these criteria as management recommendations to facilitate the efforts to restore white pine in Minnesota landscapes.

Project Result Use and Dissemination

We have made great efforts to disseminate new information. The results of these and related projects have been featured in a TV and Radio series, two workshops, 7 abstracts or proceedings, 11 talks, 7 poster presentations, and 3 referred journal articles. We plan to continue these outreach efforts as more results become available. Feedback from participants in workshops or other outreach activities indicated that our outreach efforts are perceived as very valuable and have increased foresters' and landowners' enthusiasm for white pine management.

Date of Report: June 30, 1999

Date of Next Status Report: NA

Date of Workprogram Approval: June 23, 1997

Project Completion Date: June 30, 1999

LCMR Final Work Program Update Report

I. PROJECT TITLE: Restoring White Pine in the Minnesota Landscape O-7

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Total Biennial Project Budget:

$ LCMR:	120,000
$ LCMR Amount Spent:	120,000
$ LCMR Balance	0

A. Legal Citation: ML 1997, Chap. 216, Sec. 15, Subd. 19(b)
Appropriation Language: This appropriation is from the trust fund to the University of Minnesota to investigate factors currently limiting establishment of white pine seedlings in various forest cover types. Management recommendations for natural regeneration, seeding, and planting must be developed.

II. PROJECT SUMMARY AND RESULTS:

This study investigated two components critical for the survival and growth of advance regeneration of white pine. First, we installed two studies that investigated the effects of overstory, mid-story, and understory vegetation as they alter the environment and compete with seedlings for light and water. We have taken early measurements and quantified these relationships to guide natural resource managers in providing suitable growing conditions for white pine seedlings. Second, we investigated criteria that natural resource managers can use to prepare advanced regeneration for the removal or death of overstory trees and to decide whether a stand is suitable for release (i.e., partial overstory removal). A survey of three recently released stands provided preliminary information about the effects of initial seedling size, growing conditions, and overstory effects on a seedling's ability to respond to release. Three sites were set up to further investigate these relationships. Pre- and post-treatment measurements have been taken.

Because of the long term nature of tree growth, all studies installed during the project period can provide only preliminary results. We will follow all studies, maintain the treatments, and measure the responses. As results become more definite, we are organizing, analyzing, and presenting these data as management recommendations to facilitate the efforts to restore white pine in Minnesota landscapes.

We have made great efforts to disseminate new information. The results of these and related studies have been featured in a TV and Radio series, 2 workshops, 7 abstracts or proceedings, 13 talks, 7 poster presentations, and 3 referred journal articles. We plan to continue these outreach efforts as more results become available.

III. PROGRESS SUMMARY:

Beginning in July 1997 Matt Duvall and Mike Counte started work on the LCMR project. After Matt Duvall left in February 1999, Mike Saunders took over his duties. Together they were responsible for management of the various project components. Following is a detailed summary of our activities:

Results 1:

During 1997 we searched for a study site that met our criteria of an overstory density gradient with a shade tolerant midstory component and selected a site on land owned by Itasca County. It is a 70-year-old hardwood stands (mainly paper birch) which was thinned during the winter of 1996/97. We obtained 800 bare-root seedlings (3-0) from the DNR nursery in Willow River and planted them in 21 plots. These plots were located under a wide range of overstory densities, i.e., some of them were in open areas, while others were under a dense overstory canopy. All shade tolerant midstory trees were cut on three plots. Thirty-six seedlings were planted in each plot and enclosed in mesh cages to prevent rabbit and deer damage. Half the seedlings were kept weed

free, i.e., once a month all weeds growing around these seedlings were removed by hand. Vegetation growing around the other seedlings was left unchecked. Survival of the planted white pine seedling was greater than 90%.

Nine of the 21 plots were trenched. A ditch digger was used to cut a 50-cm narrow trench around the plot. Root exclusion cloth was put in the trenches to prevent roots from growing into the plot and the soil was refilled. Twenty-eight gypsum blocks were buried in the plots to measure soil moisture conditions as affected by the various treatments. Gypsum block readings were taken every two weeks and rainfall was measured on the site on a two-week interval in 1997. During the 1998 growing season we repeated the treatments and began measurements. During both growing seasons we removed the weeds from around ½ of the seedlings on a monthly basis. Stand conditions were measured last fall, i.e., two growing seasons after initiation of this experiment. These measurements covered overstory conditions, understory vegetation, seedling size, and resource levels available to the seedlings. Overstory measures included basal area by species, and height and diameter of overstory trees around each plot. Understory vegetation was characterized by biomass measurements of herbaceous and woody shrubs around seedlings that did not experience weed control treatments. To characterize the understory competition for each seedling we measured understory cover in a circle with a 1 m radius around each seedling. Total height and basal diameter of each seedling were also measured after the completion of the second growing season. Light available to each seedling was measured using the Licor LAI2000 Plant Canopy Analyzer. Soil samples were collected and analyzed for nutrient availability. Gypsum block readings quantified the soil moisture on a bi-weekly basis during 1998.

A second study area has been selected in Carlton County. It consists of three stands, two red pine and one jack pine. All these stands contain a dense midstory of balsam fir with an average height of 5, 7, or 2 meters, respectively. We laid out two plots in each stand with a plot size of 10m by 10m, plus a buffer equivalent to one tree height (balsam fir). In each stand one plot is left as a control and we cut and removed all balsam fir from the second plot. In the fall of 1997, we measured the initial conditions of the overstory, midstory, and understory. In spring of 1998 we laid out the plots, removed the midstory in the treatment plots, and planted a total of 900 seedlings on these sites. Besides the planned design, we planted 100 seedlings in each stand in rows that extend from the edge of one treatment boundary to the edge of the adjacent treatment boundary. This addition will allow us to explore the growth of seedlings planted in the range of conditions from dense midstory stocking to complete midstory removal. We applied monthly weed control treatments to half the seedlings throughout the growing season. All seedlings have been protected from browsing by plastic mesh protection cages. Gypsum blocks were installed in spring and soil moisture measurements were taken at a bi-weekly interval throughout the summer of 1998. All of the measurements described above for the Itasca County site will be taken this fall following two growing seasons after installation. During the winter of 1998/99 white pine seedlings in one of the three selected stands showed high hare damage. We will monitor their recovery and replant lost seedlings as necessary.

Result 2:

We started to search for white pine stands that fit our research objectives. It was difficult to find stands in which white pine seedlings were released and had enough time (approximately five years) to respond. After contacting a number of people we selected three stands for the survey of white pine release. They are located in Camp Ripley, Morrison County. The overstory was killed by applying herbicides (hack and squirt) in 1991 (two stands) and 1992 (one stand). A sampling design was developed to measure conditions around released white pine and the growth of white pine in the last years. Twenty-three, 30 and 19 trees were sampled in the stands. Data (current height, last five years height growth, diameter, basal area of overtopping trees) for each of these white pines were entered on the computer. We have measured the last 12 years of diameter growth from the increment cores. Preliminary analysis has been done and the results have been presented to various Federal, State, and County foresters for discussion and feedback. After including the feedback from land managers final analysis and write-up should be completed later this fall.

In 1997 we selected two sites for the manipulative release study. One is a 50-year-old red pine stand with approximately 13-year-old white pine growing in an understory. In 1983 the stand was extremely dense (210 ft^2/acre basal area) and thinned to 90 ft^2/acre. After thinning white pine seeded in from a neighboring stand. The overstory had closed in (pre-thinning basal area was 165 ft^2/acre) and white pine seedlings (average height is approximately 2 m) were slowing down in growth. Red pine trees were marked for thinning and release of understory white pine during February and thinning took place in March of 1998. Detailed measurements of overstory trees and white pine seedlings were taken to document the conditions before the release. Prior to harvest, initial size and density of overstory trees and understory seedlings were recorded. A post harvest inventory determined the extent and severity of seedling damage as a result of the harvesting process (about 1/4 of the seedlings were damaged). We selected 90 seedlings as target research trees covering a range of sizes from 0.5 to more than 4 meters tall. One-half (45) of these seedlings were pruned, i.e., the lower 1/4 to 1/3 of the crowns were removed. Overstory conditions around these seedlings were characterized by measuring basal area and diameter and height of surrounding overstory trees. To quantify the degree of release, we also counted how many trees were removed and the number of residual trees within 5 m of the target seedling. For each target seedling we measured current height, the last two years height growth, crown dimensions, basal diameter and diameter at breast height. The shrub cover within 1m radius of the target seedlings was estimated. Gypsum blocks were installed and soil moisture measurements were taken at a bi-weekly interval.

A second site was located on land owned by St. Louis County. It is covered by 13-year-old quaking aspen. After a summer/fall harvest in 1984 and 1985 aspen suckered, but the sucker density was low enough to allow natural regeneration of white pine to establish on the site. Nine circular plots with a radius of 10m were located and marked for aspen thinning. Initial measurements were taken to allow blocking of the thinning treatment, i.e., before we installed 9 treatment plots, we measured the density and size of overstory aspen and white pine regeneration. Overstory density treatments included two control plots (no thinning) and thinning of the aspen

to densities from 7000 to 13000 trees per hectare. Thinning was done in spring of 1998 using a chemical (Garlon 4 ™) stem application. In order to determine the success of the chemical treatment, we measured the mortality of the thinned aspen stands in the summer. The chemical application was successful and we achieved the desired aspen densities. The same target seedling measurement were taken as described for the Carlton county site. In addition, we measured the initial heights and diameters of the residual aspen stand, so that growth of the aspen can be monitored as well.

In addition to the study sites described in the 1997 update, we installed the same study setup as described for the Carlton County site on US Forest Service land on the La Croix ranger district in the Little Alfie sale. A portion of this stand was harvested in winter 1998, and within the harvested area we picked 60 target seedlings that covered a range of seedling sizes from 0.5 to more than 3 meters tall. Half of the seedlings were pruned as described above. The same measurements were taken on the Little Alfie sites as were taken on the Carlton county site with two exceptions: 1) The degree of release was measured within 10 m of each target seedling, and 2) the remote location of this site prohibited periodic gypsum block readings.

IV. OUTLINE OF PROJECT RESULTS: (only budget was updated)

Result 1A: Establishment of overstory treatment, site preparation, and competition demonstration and study sites

Two study sites will be selected to test the effect of overstory trees, shade-tolerant midstory trees, and understory vegetation on growth and survival of underplanted white pine seedlings. Study sites will be set up by planting a total of 1,200 seedlings in two stands. The 3 by 2 by 2 factorial experiment will include removal of all overstory trees, removal of only the shade tolerant midstory, and no removal. In addition, we will remove all understory vegetation around half the seedlings. We will trench around 50% of the seedlings to separate competition for light from competition for soil resources. We will document the study setup, measure initial conditions, and delineate and post the plots.

LCMR Budget:	$ 22,503	Balance: $ 0
Match:	NA	Match Balance NA

Completion date: June 1999.

Result 1B: Development of overstory treatment, site preparation and competition guidelines

Soil moisture and light conditions during the growing season, and first year growth and survival of white pine seedlings will be measured. The data will be analyzed and interpreted. The results of this study will complement information for other ongoing studies and published sources to provide a solid understanding of interactions in various forest covertypes. This understanding will

be used to develop guidelines for treatment of overstory, midstory, and/or understory vegetation to ensure white pine seedling growth and survival. Light and moisture data will allow to cross references conditions with other study sites. This will provide information about how these vegetation management guidelines need to be modified to accommodate different soil and site conditions. The study setup will allow for future measurements and periodic analysis will be done to investigate long-term dynamics.

LCMR Budget: $ 20,493 Balance: $ 0
Match: NA Match Balance NA

Completion date: June 1999.

Result 2A: Survey of past overstory release effects

We will undertake a survey to catalog stands in which white pine seedlings have been released from overstory competition. Current and past overstory conditions will be assessed, by measuring residual trees, stumps, and harvesting records. Current diameter and current and past height and height growth of crop tree white pine will be measured. Current composition and size of competing vegetation will be documented. The statistical analysis and write-up will focus on determining which factors affected the survival and growth of white pine seedlings after the release and thus can be used to guide decisions about release treatments.

LCMR Budget: $ 19,995 Balance: $ 0
Match: NA Match Balance NA

Completion date: June 1998.

Result 2B: Establishment of overstory release demonstration and study sites

We will establish two study sites to investigate factors considered critical during the release operation. Sites with advance white pine regeneration will be selected and we will establish a 3 by 2 factorial experiment including overstory and pruning treatments. Overstory treatments include 1) complete overstory removal 2) 50% of overstory removed, 3) no overstory removal. Pruning treatments include 1) no pruning and 2) pruning of the lower portion of the tree (following the guidelines of Katovich and Mielke 1993). These treatments will be applied to seedlings of various sizes. Initial conditions will be documented, overstory release treatments will be implemented, and post treatment conditions will be measured. Plots will be delineated and posted to allow their use a demonstration sites.

LCMR Budget: $ 18,495 Balance: $ 0
Match: NA Match Balance NA

Completion date: June 1999.

Result 2C: Development of overstory release guidelines

First year response of white pine seedlings after overstory removal will be measured and analyzed. The development of the release guidelines will be based on the survey (Result 2A), published information, and the manipulated experiment. They will cover minimum size criteria for crop trees (e.g., minimum height, crown size), address condition of potentially competing vegetation (e.g., density of overtopping shrubs or hardwoods), and the effects of site quality. In addition, analysis of the effects of logging damage will provide information about the need for special protection during harvesting operations.

LCMR Budget: $ 38,515 Balance: $ 0
Match: NA Match Balance NA
Completion date: June 1999.

V. DISSEMINATION:

The studies and their results were featured in a TV and Radio series, two workshops, 7 abstracts or proceedings, 11 talks, and 7 poster presentations. Following is a detailed list:

1) TV Series: Environmental Journal. Interview and feature of LCMR study with Media Rare Inc. Aired in 1999.

2) Radio Interview: Environmental Journal. Interview and feature of LCMR study with Media Rare Inc. Aired in 1999.

3) Organization of two workshops: *White Pine Regeneration: Research Findings and practical applications.* MN DNR and University of Minnesota,

a) Cloquet, MN. June 3, 1998. 61 participants
b) Grand Rapids, MN. October 6, 1998. 54 participants.

4) Published proceedings and abstracts:

Duvall, M. D. and K. J. Puettmann. 1998. Using triclopyr to release white pine from overtopping aspen." North Central Weed Science Society, Annual Convention, Radisson Hotel, St. Paul, MN. Dec. 9, 1998. Abstract in Conference Proceedings. In press.

Puettmann, K. J. 1998. Don't just do it - regenerate white pine. IN: Proceedings of the Woodland owners and users conference, University of Minnesota Extension Service. February 28, 1998, Cloquet, MN.

Puettmann, K. J., M. Duvall, and M. Smidt. 1998. Soil and stand characteristics influence the relationship between above- and below ground competition in *Pinus strobus* underplantings. Ecological Society of America. 83rd Annual Meeting, Baltimore MD, pg. 206. Symposium Abstracts.

Saunders, M. and K. J. Puettmann. 1998. Effects of competition and simulated herbivory on eastern white pine seedlings. Ecological Society of America. 83rd Annual Meeting, Baltimore MD, pg. 212. Symposium Abstracts.

Smidt, M. F., K. J. Puettmann, and M. D. Duvall. 1998. The response of white pine (*Pinus strobus* L.) seedlings to weeding in shelterwood treatments. pp. 317-319 IN: R. G. Wagner and D. G. Thompson (comp.). Third International Conference on Forest Vegetation Management: Popular Summaries. Ont. Min. Nat. Resour., Ont. For. Res. Inst., For. Res. Info. Pap. No. 141.

Counte, M. A. and K. J. Puettmann. 1999. Effects of overstory canopy type and resource levels on seasonal growth and photosynthesis of white pine (Pinus strobus L.) seedlings. Minnesota Forester 18(2): 16-17.

Puettmann, K. J. and M. Duvall. 1999. Stand structure and disturbance intensity affect biomass of understory vegetation. Abstracts and Proceedings of the 2nd North American Forest Ecology Workshop. Orono, ME. June 27-30, 1999. Page 177.

5) Talks and Presentations

Puettmann, K. J. 1997. The story of white pine management. Retired Masons, July 1997. Minneapolis, MN.

Puettmann, K. J. and M. Smidt. 1997. Canopy, subcanopy, understory: who is competing with regeneration? Interdisciplinary uneven-aged silviculture symposium. International Union of Forest Research Organizations. September 19, 1997. Corvallis, OR.

Duvall, M. D. and K. J. Puettmann. 1998. Using triclopyr to release white pine from overtopping aspen." North Central Weed Science Society, Annual Convention, Radisson Hotel, St. Paul, MN. Dec. 9, 1998.

Puettmann, K. J. 1998. Don't just do it - regenerate white pine. Woodland owners and users conference, University of Minnesota Extension Service. February 28, 1998, Cloquet, MN.

Puettmann, K. J. 1998. Stand density and structure: their interactions and impact on understory vegetation. University of British Columbia, Vancouver, BC Canada. June 15, 1998.

Puettmann, K. J. 1998. White pine underplantings and weed control. Continuing education workshop: White Pine regeneration: research findings and practical applications. University of Minnesota, Cloquet MN. June 3, 1998 and Grand Rapids, October 6, 1998.

Puettmann, K. J. 1998. More than just a pretty view: Forest structure influences understory diversity and tree regeneration. Plant Biological Science Colloquium, University of Minnesota. St. Paul, MN. October 20, 1998.

Puettmann, K. J. 1998. Can overlapping rotations really improve productivity? Conference on Improving Forest Productivity for timber... A key to sustainability. Duluth, MN. Dec. 2, 1998.

Saunders M, and K. J. Puettmann. 1998. Effects of deer browsing on white pine Continuing education workshop: White Pine regeneration: research findings and practical applications. University of Minnesota, Cloquet MN. June 3, 1998 and Grand Rapids, October 6, 1998.

Smidt, M. F., K. J. Puettmann, and M. D. Duvall. 1998. The response of white pine (Pinus strobus L.) seedlings to weeding in shelterwood treatments. Third International Conference on Forest Vegetation Management. Aug. 24 to 28, 1998. Sault St. Marie, Ontario, Canada.

6) Poster presentations:

Puettmann, K. J., M. Duvall, and M. Smidt. 1998. Soil and stand characteristics influence the relationship between above- and below ground competition in *Pinus strobus* underplantings. Ecological Society of America. 83rd Annual Meeting. August 2-6, 1998. Baltimore MD.

Puettmann, K. J. and M. Duvall. 1998. Overstory density and harvesting systems affect competition from understory vegetation. Conference on Improving Forest Productivity for timber... A key to sustainability. Duluth, MN. Dec. 1 - 3, 1998.

Saunders, M. and K. J. Puettmann. 1998. Effects of competition and simulated herbivory on eastern white pine seedlings. Ecological Society of America. 83rd Annual Meeting. August 2-6, 1998. Baltimore MD.

Saunders, M. R. and K. J. Puettmann. 1998. Effects of competition and simulated herbivory on *Pinus Strobus L.* seedlings. Conference on Improving Forest Productivity for timber... A key to sustainability. Duluth, MN. Dec. 1 - 3, 1998.

Puettmann, K. J. and M. Duvall. 1999. Overstory density and harvesting systems affect competition from understory vegetation. Society of American Foresters. Minnesota State Meeting. Owatana, MN. Feb. 2-4, 1999.

Saunders, M. R. and K. J. Puettmann. 1999. Effects of competition and simulated herbivory on *Pinus Strobus L.* seedlings. Society of American Foresters. Minnesota State Meeting. Owatana, MN. Feb. 2-4, 1999.

* Puettmann, K. J. and M. Duvall. 1999. Stand structure and disturbance intensity affect biomass of understory vegetation. Abstracts and Proceedings of the 2nd North American Forest Ecology Workshop. Orono, ME. June 27-30, 1999. Page 177.

* Third price, Professional Poster Competition.

7. Referred Journal Articles:

Smidt, M., and K. J. Puettmann. 1998. Understory and canopy competition effect growth of underplanted white pine in Minnesota. *Forest Ecology and Management.* 105(1-3):137-150

Saunders, M. and K. J. Puettmann. 1999. Use of vegetational characteristics and browsing pattens to predict deer damage in eastern white pine (*Pinus strobus*) plantations. *Northern Journal of Applied Forestry.* 16(2):96-102.

Saunders, M. and K. J. Puettmann. 1999. Effects of overstory and understory competition and simulated herbivory on growth and survival of white pine (Pinus strobus) seedlings. *Canadian Journal of Forest Research.* 29:536-546.

8. Journal Articles in preparation:

Puettmann, K. J., M. Duvall, and M. Smidt. Above and below ground competition interact in their effects on white pine seedlings. In preparation for submission to *Forest Science.*

Puettmann, K. J. and M. Saunders. Growth response of white pine to overstory release. In preparation for the *Northern Journal of Applied Forestry.*

Puettmann, K. J. and M. Saunders. Overcompensation - does it occur in white pine plantations? In preparation for submission to *Oecologia.*

Smidt, M., K. Puettmann and M. Duvall. Overstory density and site quality affect the need for weed control in white pine underplantings. In preparation for submission to *Forest Ecology and Management.*

VI. CONTEXT:

A. Significance: Until early this century white pine was a major component of forest ecosystems in the Lake States. Red pine and white pine forests, which cannot be separated in the records, covered approximately 1.4 million ha in Minnesota (Frelich 1995). However, extensive harvesting followed by fires and lack of regeneration has significantly reduced the white pine acreage in Minnesota landscapes. Estimates show that the current white/red pine distribution covers only around 15% of the area it occupied in pre-European settlement times (Miles et al. 1995). In pre-harvest times white pine was found in pure stands, but also in mixtures with jack pine and red pine, aspen, birch, oak or maples (Frelich and Reich 1995). The early regeneration efforts focused on reforestation of clearcut areas, but white pine blister rust, white pine weevil, and white-tailed deer have been major impediments to successful regeneration (Sauerman 1992). Recently the interest in reestablishing white pine in Minnesota landscapes has increased, as evident by more than 600 participants of the White Pine Symposium in 1992 (Stine and Baughman 1992). Also, public discussions about management of white pine forests have been ongoing (see various articles in newspapers around the state). In 1995, a bill was introduced into the legislature (H.F.No. 1897) that suggested making white pine a major focus of all research and land management agencies. More controversial, it also included a moratorium on white pine harvest on public land until a comprehensive white pine management plan was developed.

The establishment of the White Pine Regeneration Strategies Work Group by the DNR was a response to this interest. The working group has developed recommendations for white pine regeneration. The recommendations lead to passage of the appropriation bill ML 1997, Chap. 216, Sec. 5, Subd. 4 which contributed $ 300,000 for white pine blister rust research and $ 1.2 million for regeneration of white pine. Consequently, the Minnesota DNR is planning a major initiative to establish white pine (ZumBahlen, personal communication) and the program manager is in consultation with the DNR. Since these efforts are not limited to establishment of even-aged white pine plantations but also focus on efforts for white pine to become a component in a variety of covertypes, we need to develop alternative ways to ensure regeneration of white pine under a range of forest conditions. Establishing white pine under a forest canopy (advance regeneration) results in reduced incidences of white pine blister rust and white pine weevil attacks (Houseweart and Knight 1986). Advance regeneration also allows establishing white pine without using the controversial practice of clearcutting and thus is suitable for State Parks and other visually or environmentally sensitive areas. However, we know little about the tradeoffs, as advance regeneration competes with both the overstory trees and understory vegetation. Also, little is known about what conditions ensure a successful conversion from advanced regeneration to canopy trees (Wendel and Smith 1991). We plan to address these shortcomings by establishing research studies and survey stands that received these treatments in the past. Information from these studies can be directly integrated with results from other ongoing studies by the program manager. Ongoing studies include 1) investigations into natural regeneration and seeding, including seed predation, seedbed conditions, germination, and first and second year competition and survival (Cornett et al. 1997). 2) competition studies that investigate the effect of canopy and understory competition on white pine seedlings growth and survival under a variety of forest

cover types and soils (Smidt and Puettmann 1997a, b) 3) the effect of shrubby vegetation on the frequency of deer browsing (Saunders and Puettmann, unpubl. data) and 4) the growth response and survival of white pine seedlings to various levels of herbivory (Saunders and Puettmann 1997). By ensuring a compatible data format and measuring soil, water, and light conditions, information from any specific study site can be put in perspective and integrated with information gained from other study sites. Thus while the specific situations (study sites) in the proposed project are necessarily limited, management guidelines will cover the variety of ecological conditions found in Minnesota.

B. Time:

Result 1: Competition study:

1997-1998	Summer and Fall	Site selection, initial measurements
	Winter and Spring	Overstory manipulation
1998-1999	Summer	Site maintenance
	Fall	Measurements,
	Winter and Spring	Data analysis, write-up

Result 2: Overstory release study:

A. Survey

1997-1998	Summer	Initiate survey
	Summer and Fall	Site visits, survey measurements,
	Winter and Spring	Data analysis, write up

B. Manipulative Study

1997-1998	Summer and Fall	Site selection, initial measurements
	Winter and Spring	Overstory manipulation
1998-1999	Summer	Site maintenance
	Fall	Measurements,
	Winter and Spring	Data analysis, write-up

Because of the long-term nature of forest dynamics, an early start of the experiments is important. Since these studies are nested within the bigger research efforts of the program manager, we were able to start the planning work in spring of 1997, e.g., consulting with foresters and screening potential study sites. Also, if additional funds are made available from other sources (see Budget Context), workshops will be held in 1999 to explain the guidelines and provide hand-on learning for interested landowner and natural resource managers.

C. Budget Context:

	July 1995-June 1997	July 1997-June 1999	July 1999-June 2001
	Prior expenditure on this project	Proposed expenditures on this project	Anticipated future expenditures on this project
1. LCMR		120,000	
2. Other State	10,000	5,000	
3. Non-State Cash	140,000	35,000	20,000
4. In-Kind	20,000	20,000	20,000
Total	170,000	180,000	40,000

As evident by the budget context, the LCMR project "Restoring white pine in Minnesota landscapes" will be part of a bigger white pine research effort by the program manager. This research effort is addressing all ecological and silvicultural aspects important to white pine regeneration (see discussion in VIII. A. Significance).

Based on the earlier studies, discussion with natural resource professionals, and review of the literature the proposed studies we determined critical gaps in knowledge, which the proposed studies address. Thus, the LCMR project will complement other ongoing studies. Compatible experimental setup and data format will allow comparison and cross-references between different studies and sites. Together, these studies will provide a package that will allow development of a management handbook that covers all important aspects of white pine regeneration.

We will also seek funding to hold workshops from USDA Forest Service, State and Private Forestry, the Blandin Foundation, Grand Rapids, and the White Pine Foundation, Grand Rapids. Further, we will seek future funding to summarize the guidelines in a comprehensive management handbook from the Agricultural Experiment Station and from the White Pine

Foundation, Grand Rapids.

The diversity of agencies currently funding white pine research (see list of cooperators) indicates the broad interest in white pine regeneration in Minnesota. The program manager will pursue these sources for potential future funding to allow 5 and 10-year remeasurments of the study sites.

Budget:

Personnel	
Research Fellow	$ 52,500
Undergraduate Assistant	$ 2,500
Graduate Student	$ 25,300
Benefit and Fringe	$ 29,409
Total Salary and Fringe.	$ 109,709
Equipment (Partial cost for computer, data logger, pressure bomb)	$ 1,500
Material (Seedling, flagging)	$ 3,000
Travel (to study sites)	$ 4,500
Publication	$ 500
Phone	$ 250
Mail	$ 200
Photocopies	$ 341
Total direct	$ 120,000

Personnel Justification: A research fellow will lead the competition project and with the program manager provide overall project oversight and assure coordination between different project parts. A graduate student will work on the release survey, manipulative study setup and analysis. Undergraduate students will provide labor for planting, weed control, and measurements.

VII. COOPERATION:

Iron Range Resources and Rehabilitation Board, Chisholm:

D. Jordan ($ 30,000 contribution)

Itasca County Land Department, Grand Rapids:

B. Jones (5% in-kind, provide land for study sites)

DNR Division of Forestry, St. Paul:

R. Pajala ($ 5,000 and 10% in-kind contribution, provide land for study sites)

Rajala Companies, Deer River:

J. Rajala (10% in-kind, provide land for study sites)

St. Louis County Land Department, Duluth:

G. Kirk ($ 5,000 and 5 % in-kind, provide land for study sites)

All cooperators have provided a letter indicating their intent to cooperate in this project, either through financial or in-kind (mostly labor) contributions or by providing land for establishment of research studies. Copies of these letters were included with the original proposal from Feb. 23, 1996. Because these agencies work with annual appropriations, the exact amount of the contribution is not available at this time. Also, all cooperators have agreed to review drafts of publications or guidelines and provide feedback.

VIII. LOCATION:

The exact location of study sites will be located after discussion with cooperators and other landowners or landowning agencies. So far, target stands have been identified in Itasca and Carlton County. Study sites will be selected to cover the geographical and ecological range of white pine.

IX. REPORTING REQUIREMENTS:

Periodic work program reports will be submitted not later than December 30, 1997 and December 30, 1998. A final work program report and associated products will be submitted by June 30, 1999, or by the completion date as set in the appropriation.

X. For Research projects: (not updated)

A. Abstract

The proposed study complements a set of other ongoing studies that investigate factors currently limiting white pine regeneration in various forest covertypes in Minnesota. This study focuses on two aspects, the competitive relationships of seedling growing underneath a forest canopy and the release of these seedlings when the overstory trees die or are removed.

In the competition study we will plant a total of 1,200 seedlings in two stands. The 3 by 2 by 2 factorial experiment will include removal of all overstory trees, removal of only the shade tolerant midstory, and no removal. In addition, we will remove all understory vegetation around half the seedlings. We will trench around 50% of the seedlings to separate competition for light from competition for soil resources.

Sites on which advanced regeneration of white pine was released will be inventoried by measuring current and past conditions. In addition, sites with advance white pine regeneration will be selected for the release study and we will establish a 3 by 2 factorial experiment including overstory and pruning treatments. Overstory treatments include 1) complete overstory removal 2) 50% of overstory removed, 3) no overstory removal. Pruning treatments include 1) pruning of the lower portions of the tree and 2) unpruned. These treatments will be applied to a range of seedling sizes. The analysis will compare the response of the released trees as they are effected by pruning. We will also screen additional measures, e. g., initial size, for their effectiveness in predicting the release response. With supplemental information from other ongoing projects this studies will provide the basis for development of a management handbook that will help ensure the restoration of white pine in Minnesota landscapes.

B. Background and Literature Review

Restoring white pine (Pinus strobus L.) to some of its former significance in Minnesota forests is of interest to the forest products industry, land managers, and ecologists and citizens (Stine and Baughman 1992). The history of white pine logging, forest fires, lack of white pine regeneration, and losses from white pine blister rust (Cronartium ribicola Fisher), white pine weevil (Pissoides strobi Peck), and deer browsing has reduced the acreage of the white pine cover type and the presence of white pine in other covertypes (Frelich 1995, Frelich and Reich 1995). The importance of white pine economically, ecologically, and aesthetically, and its infrequent occurrence over some of its natural range has lead to considerable interest in silvicultural methods and systems that can accommodate the difficulties provided by the lack of natural seed sources, deer browsing, white pine blister rust, and white pine weevil.

The moderate shade tolerance of white pine (Baker 1949) allows white pine to regenerate in the understory. The different patterns of natural regeneration, as determined by site conditions and overstory cover types are summarized in Smidt and Puettmann (1997b). The understory environment provides some protection from white pine blister rust (Van Arsdel 1961) and white pine weevil (Berry and Stiell 1976). White pine underplanting beneath a variety of cover types is a common practice in other parts of the white pine range. In the northeastern U.S. Lancaster and Leak (1978) indicated that removing all of the understory hardwoods and removing from 40 to 60% of the canopy would facilitate white pine regeneration. Also, shelterwood techniques applied in Minnesota (Rajala 1992), Wisconsin (Heckman 1992), and Ontario (Pinto 1992) have been successful in establishing white pine regeneration.

Shelterwoods can improve seedling water status on dry sites but reduce light and maintain a higher level of competition in the root zone (Childs 1985). Childs (1985) indicated that environmental and site factors interactively determine the net effect of shelterwoods on seedling survival and growth. Some authors have noted that the dominant white pine seedling competition was from the understory vegetation beneath aspen canopies (Clements 1966; Logan 1962; Logan and Farrar 1953; Shirley 1945). On the other hand, Gatherum *et al.* (1963) showed that the percent of full sunlight yielded similar white pine seedling growth whether the shade was due to understory or canopy vegetation. Freeman and Van Lear (1977) found a significant effect of understory control in a clearcut but not under a shelterwood treatment. A recent survey of white pine underplantings showed that the overstory and understory interactively affect white pine growth (Smidt and Puettmann 1997a). In some covertypes, e.g., sugar maple/balsam fir, the competitive effects from both vegetation layers were additive. In other covertypes (e.g., well drained northern hardwoods, the understory competition was minor when a dense canopy was present, but under open canopies competition from the understory vegetation had a great impact on white pine seedlings. The analysis also pointed out the importance of competition from a shade tolerant midstory layer (Smidt and Puettmann 1997a).

The shade tolerance of canopy trees also influences the types of trees and shrubs that regenerate beneath them (Roberts 1992, Turner and Franz 1986). In a mesic aspen-northern hardwood forests the presence of a shade tolerant midstory prevented white pine seedling recruitment while mid-tolerant species were recruited where no midstory was present (Roberts 1992). In a less mesic aspen-white pine stand, white pine seedlings appeared to be found where competition with aspen roots would be minimized (Squires and Klosterman 1981). Roberts (1992) concluded that the increased site productivity on the mesic aspen-northern hardwood site contributed to the difference between his results and Squires and Klosterman (1981). The number of factors that interact to influence seedling recruitment and growth in the understory result in complex relationships among white pine seedlings (recruitment and growth), the canopy (density, composition, and spatial arrangement), wildlife (amount of seed predation, browsing), and site characteristics (soil texture, fertility, and stand history).

Advance regeneration practices are of special interest for white pine for the reason mentioned above (to reduce the risk of white pine weevil and white pine blister rust) and to take advantages of other benefits of permanent forest cover, e.g., improved wildlife habitat, soil protection. One of the most critical times is the release of the seedlings from overstory trees. Very

few studies have focused on release of white pine (see Kelty and Encheva 1993), but valuable information can be gleaned from studies of other species. High growth rates after release are critical to ensure vigorous trees that express and maintain dominance in future stands. The exact nature and amount of the response are influenced by a variety of factors, the most important of which are discussed below.

Tree size and age at the time of release are critical factors that indicate release potential. Larger white pines have shown a better growth response, especially when competing with other released understory vegetation (Kelty and Entcheva 1993. While in some species older trees might be slower to react or may not respond at all (Hoyer 1980, Oliver 1976, Steneker 1974) white pine trees that were 10-38 years old showed a quick response after release and 20-years later made up most of potential white pine crop trees (Kelty and Encheva 1993). Other studies showed the ability of young (Buckman and Lundgren 1962) and 60 year-old white pine (Brace 1968) to respond.

Fast growth before release is another measure that has been consistently linked to the ability of trees to respond to release (Tesch and Korpela 1993, Helms and Sandiford 1985). Pre-release growth is reflecting overstory and understory competition and site quality. Available leaf area, measured as crown size or live crown ratio is a good indicator of a seedling's ability to respond to release (Helms and Sandiford 1985). For example, a minimum of 50% live crown ratio is recommended for balsam fir (Seidel 1983, 1985). Less shade tolerant species, like white pine, require more light to maintain crowns and thus the critical live crown ratio should be higher. However, young white pine with a live crown ratio of 25 to 50% have been shown to respond to release quite well (Stiell et al. 1983). To reduce the risk of white pine blister rust infections, Katovich and Mielke (1993) recommend pruning white pine to leave 50% to 66% live crown ratio. Density and color of foliage can also be used to judge tree vigor and release potential (McCaughey and Ferguson 1986).

On low quality sites the response is smaller than on better quality sites (Helms and Sandiford 1985, Seidel 1985). Logging damage can lead to reduced growth or even mortality of released trees (Gordon 1973, Tesch et al. 1993). Damage can be direct, by breaking leaders and/or limbs or scarring the bark on stems or roots (Shepperd 1993, Tesch et al. 1993) or indirect damage, by compacting soil or altering drainage patterns (Ruark et al. 1982).

The degree of release is related to the size of the response, as more open conditions after the release increase the response of the seedlings (Seidel 1985, McCaughey and Schmidt 1982). Also, treatment of competing vegetation that is released at the same time with white pine or established after the release cut improved the magnitude of the response to release (Berry 1982). On the other hand, sudden exposure to an "open microclimate" can lead to substantial mortality as needles are adapted to the shade and exposure to high intensity light can damage the chlorophyl (Tucker et al. 1987, Tucker and Emmingham 1977). Keeping a partial cover can reduce mortality (Tucker and Emmingham 1977).

The response to release typically included morphological changes (Tucker et al. 1987), increased crown sizes (Weber and Tesch 1985) followed by increased diameter and later increased

height growth rates (McCaughey and Ferguson 1986, Crossley 1976, eon 1978). Because of the high cost of backdating diameter growth and its importance in maintaining dominant positions, height growth is used most commonly to evaluate success of the release (McCaughey and Ferguson 1986, Deitschman and Pfister 1973). Height growth responses have been shown in the first year after release, but a delay or adjustment period that lasts from 2 to 7 years (McCaughey and Schmidt 1982, Herring 1977) is more frequent. Taller trees responded slower to the release (Tucker and Emmingham 1977).

The proposed studies will complement ongoing bigger research efforts by the program manager. Ongoing studies include a) investigations into natural regeneration and seeding, including seed predation, seedbed conditions, germination, and first and second year competition and survival (Cornett et al. 1997). b) competition studies that investigate the effect of canopy and understory competition on white pine seedlings growth and survival (Smidt and Puettmann 1997a, b) under a variety of forest cover types and soils, c) the effect of shrubby vegetation on the frequency of deer browsing and d) the growth response and survival of white pine seedlings to various levels of herbivory (Saunders and Puettmann 1997). By ensuring a compatible data format and measuring soil, water, and light conditions, information from any specific study site can be put in perspective and integrated with information gained from other study sites. Thus while the specific situations (study sites) investigated in the proposed project are necessarily limited, management guidelines will cover the full complexity of ecological conditions found in Minnesota.

C. Objectives

The overall objective of this study is to investigate conditions limiting regeneration of white pine seedlings. Specific objectives include to 1) separate the effects of competition from overstory trees, shade tolerant midstory trees and understory vegetation 2) within objective one, separate and evaluate the effects of above and below ground competition of the overstory, midstory, and understory vegetation and 3) investigate factors linked to the growth response of white pine seedlings after the overstory trees are removed or die.

D. Methods

Competition study: We will select two northern hardwood stands with a dense shade tolerant midstory (sugar maple and/or balsam fir). These stands should have been recently row thinned for the first time. Bareroot white pine seedlings will be planted in blocks (5*10 seedlings) under following conditions:

1) within a thinned row or area with all trees removed

2) in unthinned portions of the stands with all shade tolerant midstory trees removed

3) in unthinned portions of the stands without any tree removal .

For each of the above conditions we will split the plot into two subplots, and remove the vegetation with 1m radius around the seedlings in one subplot. The other subplot will receive no understory treatment. Four replications of each treatment will be established in each stand, resulting in a total of 24 plots and 1,200 seedlings. The result is an experimental setup that covers a wide gradient of competing overstory vegetation (all removed, only shade tolerant midstory removed, control) overlaid with a gradient of competition from understory vegetation.

To separate the above ground competition for light from the below ground competition for water and nutrients, we will dig trenches around 25 seedlings in each plot. Trenches will be dug 0.7 m deep, root exclusion cloth will be installed and the trenches will be filled back.

We will measure overstory conditions (basal area, percent crown cover) and understory conditions throughout the study. Understory density will be assessed as percent cover by species within 1m radius of the seedlings (Smidt and Puettmann 1997a). Survival and growth of white pine will be measured annually. Predawn plant moisture stress will be measured using a Scholander pressure bomb on a subset of white pine seedlings. Light availability on the ground will be measured in spring before leafout, in the middle of the growing season and after leaf fall using the Licor LAI 2000 (see Puettmann and Reich 1995). As necessary, repeated hand weeding throughout the study period will maintain vegetation levels.

Several approaches will be used in the analysis. We will use analysis of variance and analysis of covariance to test for main effects and interactions. Also, where appropriate, regression analysis will be used to quantify the impact by various competitive components (see Smidt and Puettmann 1997a).

Overstory release study: This study will consist of two components, a retrospective study in which we will measure stands where white pine seedlings have been released in the past and a manipulative study in which understory white pines will be released.

Retrospective study:

The retrospective study has limitations that need to be acknowledged up front. Especially critical is the limited information about tree size and conditions and competition levels at the time of release. However, earlier work by Smidt and Puettmann (1997a) and the results of ongoing competition studies will allow inference about competitive conditions based on backdated height and diameter growth. Also, retrospective studies are biased toward the survivors as trees that have died since release cannot be measured. This will limit the general ecological understanding but will most likely not limit the silvicultural information obtained, as we are interested in factors related to survival.

We will mail out questionnaires and rely on this survey to catalogue all stands in which white pine advance regeneration has been released. Candidate stands will be evaluated and visited to ensure that the overstory removal was not followed by fire or other site treatments. Up to 300

white pine will be selected that are >5 and < 50 years old or <5 m high at the time of release (Tesch and Korpela 1993). Randomly orientated transects will be established and undamaged trees or trees where the damage can still be quantified (e.g., amount of scarring) will be selected at fixed distances along the transects.

For each stand we will record location, aspect, elevation, slope, soil texture, and site index. Around each selected tree we establish circular plots with a radius of 15m. We will measure diameter of all stumps and basal area of all living and dead trees within this plot. Current and past height of target trees will be measured using a Criterion Laser instrument and backdating whirl counts. Past diameter increments will be measured by taking two increment cores per tree.

The analysis uses both a regression approach as used by Ferguson and Adams (1980) and Helms and Sandiford (1985) and discriminant analysis techniques as used by Helms and Sandiford 1985). Regression analysis will relate initial conditions to the response and discriminant analysis will identify criteria that can be used to predict whether advanced regeneration achieves a specified growth response (Johnson and Wichern 1988). We will transform data as appropriate to meet statistical assumptions.

Manipulative study:

We will consult with landowners and agencies to select two stands with advanced regeneration of white pine. Within each selected stand up to 300 potential future crop trees will be selected to cover a range of size and overstory conditions. Where appropriate, half of the crop trees will be pruned to live crown ratios of approximately 40% to 50% as recommended by Katovich and Mielke (1993).

We will measure the initial conditions of the target trees and associated vegetation. Measurements will include height, diameter, past year's height growth (by measuring whirl length), crown height and diameter. Overstory measurements include basal area and percent cover by species. Understory vegetation within a 1 meter radius of the target tree will be measured as percent cover. Also, if target trees are overtopped, the height of tallest competitors within a 2-meter radius will be measured. As an integrated measure of overtopping, the available light for the target trees is measured using the LAI 2000. Type and precision of measurements will be compatible with Smidt and Puettmann (1997a) and the retrospective study.

Removal of overstory will include two treatments.

1) Total removal of all overstory trees

2) Removal of 50% of overstory trees, leaving the most vigorous trees, to simulate a shelterwood system.

After harvest, the direct harvesting impact on the target trees will be measured. Measurements include scar size, number of branches broken, and percent of area within crown drip line that had apparent traffic. Where appropriate, the overstory condition will be measured as described above.

We will take measurements the first two years and every two years after that. They include size measurements of target trees (height, diameter, crown dimension). Overtopping is quantified both by measuring vegetation as described above and by measuring light availability. Also, summer moisture stress will be quantified by measuring the pre-dawn leaf water potential of target trees.

Analysis of target trees will use the same approaches as described for the retrospective study (regression analysis and discriminant analysis). Additional information, e.g., response of overstory canopy will also be included in the analysis.

For all studies described above, light levels and moisture information will be linked to growth responses in conceptual model that links growth patterns, resource use, and physiological characteristics similar to the one developed by Shainsky and Radosevich (1992).

E. Expected Results

The results of these study should be a thorough understanding of the regeneration requirements of white pine. It also will provide a thorough understanding of the light and moisture dynamics after thinning or overstory removal that is especially critical for seedling growth and survival. This information will be integrated with information from other ongoing studies, white pine management guides, and management experience from other regions to develop white pine management guidelines and recommendations.

F. Time Table:

Competition study:

1997-1998	Summer and Fall	Site selection, initial measurements
	Winter and Spring	Overstory manipulation
1998-1999	Summer	Site maintenance
	Fall	Measurements,
	Winter and Spring	Data analysis, write-up

Overstory release study:

A. Survey

1997-1998	Summer	Initiate survey
	Fall	Site visits, survey measurements,
	Winter and Spring	Data analysis, write up

B. Manipulative Study

1997-1998	Summer and Fall	Site selection, initial measurements
	Winter and Spring	Overstory manipulation
1998-1999	Summer	Site maintenance
	Fall	Measurements,
	Winter and Spring	Data analysis, write-up

G. Budget:

Research Fellow	$52,500
Fringe	$14,543
Undergraduate Assistant	$2,500
Fringe	$193
Graduate Student	$25,300
Fringe	$14,674
Equipment (computer, data logger, etc.)	$1,500
Material (Seedling, flagging)	$3,000
Travel (to study sites)	$4,500
Publication	$500
Phone	$250
Mail	$200
Photocopies	$341
Total	$120,000

In kind contributions include salary of program manager ($ 6,000 per year). Additional in kind help will be provided by the landowner in form of help with identifying potential study sites, review of manuscript, guidelines, etc.

F. Resume: see attached sheet. Full Curriculum Vitae is available upon request.

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