1993 Project Abstract
FOR THE PERIOD ENDING JUNE 30, 1995
This project was supported by MN Future Resources Fund.

JUL 05 1995

TITLE: Developing Quality Hardwood Forests
PROGRAM MANAGER: Dr. Melvin J. Baughman
ORGANIZATION: University of Minnesota
LEGAL CITATION: M.L. 93, Ch. 172,Sec. 14, Subd. 5(d)
APPROPRIATION AMOUNT: $210,000

Statement of Objectives
Our objectives were to: (A) assess the relationship between canopy gap characteristics and stand development, (B) measure the effects of site preparation and crown closure on red oak regeneration, and (C) conduct an educational program on hardwood forest management.

Overall Project Results
A. The amount of red oak regeneration in canopy gaps was affected by gap age, area, aspect, upper-slope steepness, presence/absence of a root restricting zone within 32 inches below the ground surface, the soil's A:E horizon sand ratio, and amount of advance regeneration prior to harvest. This information will help forest managers assess the red oak regeneration potential of a site and adapt the harvest, site preparation, or planting practices to more successfully regenerate oaks. From a study of leaf shapes and isozyme analyses, we found that leaf shape generally could be used to differentiate northern pin oak trees from northern red oak trees and hybrids, but it was not always possible to distinguish northern red oaks from hybrids.
B. Three research sites were installed to measure the effects of site preparation and crown closure on red oak regeneration. This was the start of a long-term study. Preliminary results will not be know for at least another two years. In a small-scale related project, we assessed acorn abundance and germination under different overstory and burn treatments. We learned that acorn numbers are higher in understory and shelterwood sites than in clearcut sites but the combined influence of dispersal, predation, and microsite result in a greater likelihood of germination and early survival for any given seedling in shelterwood and clearcut sites than in understory sites. In all overstory treatments, burning had a positive impact on acorn numbers, germination, and early establishment. In still another project we planted red oak seedlings and acorns in clearcuts where there had been different understory control treatments. After three years, planted red oak seedlings were larger in plots treated with herbicides than in plots receiving mechanical (bulldozing) or no understory treatments; oak seedlings with large root systems grew larger than nursery run seedling; and tree shelters increased tree seedling height, but not diameter.
C. We conducted 110 educational events (e.g., seminars, workshops, field tours, residential camps) on forestry subjects and reached over 900 woodland owners and loggers, 2,500 youth and educators, and 1,650 other adults.

Project Results Use and Dissemination
We expect to publish several articles in scientific forestry journals based on this research. Some of the oak regeneration research was presented to over 100 foresters at a Society of American Foresters state meeting on December 8, 1994. Information about the isozyme analysis of oaks will be presented at the annual meeting of the Botanical Society of America in August 1995.

JUL 05 1995

Date of Report: July 1, 1995

LCMR Final Report - Summary - Research

I. Project Title: Developing Quality Hardwood Forests
Program Manager: Dr. Melvin J. Baughman
Agency Affiliation: University of Minnesota
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A. Legal Citation: M.L. 93 Chpt. 172, Sec. 14, Subd. 5(d)

Total Biennial LCMR Budget: $210,000 Balance: $0

Appropriation Language: Subd. 5(d). This appropriation is from the future resources fund to the commissioner of natural resources for a contract with the University of Minnesota to conduct research on the effects of different canopy gap sizes and site preparation methods on natural hardwood regeneration.

B. LMIC Compatible Data Language: Not applicable.

C. Status of Match Requirement: Not applicable.

II. Project Summary:
Oaks dominate the canopies of most mature hardwood stands in southeastern Minnesota. When these oaks are harvested or die of natural causes, however, the stands frequently convert to more shade tolerant tree species that were present in the understory at the time of harvest. These shade tolerant tree species generally are less valuable for wood products and for wildlife than the oaks. This project involves research to learn more about how to stimulate natural oak regeneration from acorns and stump sprouts.

We will inventory multi-age class hardwood stands to determine the relationship, if any, between the characteristics of canopy gaps created by harvest or other causes and the species and growth rates of trees that regenerated in those gaps.

Isozyme analysis of oaks will be performed to identify the genetic makeup of overstory trees and regeneration. This analysis will help us identify which oak species or hybrids really exist in our woodlands. Some oak species and hybrids are less desirable than oth r wood products and wildlife, but in many cases, fore cannot easily distinguish which species are present. Knowing more about how to distinguish the oak species and hybrids will enable foresters to plan harvest and regeneration strategies that will regenerate the most desirable species.

Field trials will be conducted to test the affects of different amounts of canopy cover and different site preparation methods (chemical, mechanical, and burning) on natural oak regeneration. This is a long-term project that will be initiated in 1993, but only preliminary results will be available by the end of the project in 1995. It takes several years following the treatments to obtain reliable results concerning the affects of harvesting and site preparation methods on regeneration. Costs for measuring field plots after 1995 will be relatively low and will be covered by other funding sources.

An educational program will be developed to inform private woodland owners, loggers, the forest products industry, and foresters about the latest research concerning hardwood regeneration techniques. We will report on the research results from a 1991-93 LCMR project as well as results from projects in other states. We will promote enrollment in the 4-H Forest Resources Project and conduct an ecology camp for 4-H youth so that they can become more knowledgeable about forest management and natural resource career opportunities.

III. Statement of Objectives:

A. Assess the relationship between canopy gap characteristics and stand development.
B. Measure the effects of site preparation and crown closure on red oak regeneration.
C. Conduct an educational program on hardwood forest management.

IV. Research Objectives:

A. **Title of Objective:** Assess the relationship between canopy gap characteristics and stand development.

A.1. Activity: Characterize composition of 15 to 35 year old gaps created in existing red oak stands.

A.1.a. Context within the project: Advanced regeneration is important for the establishment of red oak. Study of regeneration performance in gaps formed by natural and man-caused disturbance is one means of quantifying factors important in this process. Fifteen to 35 year old red oak trees are particularly important to study as high mortality can occur in th ge range due to excess inter-species competition. Such pproach becomes even more relevant as gypsy moth begins moving into southeastern Minnesota and the public places greater demands on resource management agencies for "more natural", e.g. "uneven-aged," management methods. We will characterize gaps created in existing red oak forests in southeastern Minnesota as to their size, method of creation, physical site condition, age, surrounding vegetation, composition and growth of occupying plants, etc. in an attempt to relate regeneration performance of red oak to these gap characteristics.

A.1.b. Methods:
Field: The field work was focused on "forest gaps". A forest gap was defined as the vertical projection onto the ground of an opening in the forest canopy that had been caused by the mortality or harvest of one or more trees (gap makers). Working with MN DNR, Phase II Inventory records were used to identify 100+ stands for potential gap study; the primary criteria for stand selection were northern red oak overstory and 40-90 square feet of basal area. These stands were field visited to determine the presence of suitable gaps. In the end, we investigated every forest gap that we could find on DNR lands in Goodhue, Wabasha, Winona and Houston Counties and that met our preset criteria. For each of these 36 gaps, the following were quantified:

(1) gap age, aspect, slope (steepness, curvature, length);

(2) gap makers: species, DBH; degree of decay of the remains, and their azimuth, slope distance and slope change from the gap center;

(3) rock exposure (percent area), depth to bedrock (or hardpan), forest floor thickness and percent cover, A horizon thickness, soil texture of A and E horizons (samples collected in the field were analyzed for sand, silt, and clay contents in the laboratory);

(4) extended gap trees (trees that bordered the gap): species, height, DBH, and crown extensions in 6 directions (due south and every 60 degrees thereinafter in azimuth); azimuth, slope distance and slope change of each tree bole from the gap center;

(5) vegetation in the gap by plot: species, DBH and height of saplings and shrubs >4.5 ft in height and <6 inches in DBH by 1/100-acre plot; height, species, and number of seedlings, key indicator species, and degree of brush closure at 2-, 4.5-, and >4.5-ft height, by 1/300-acre plot. The plots of the two sizes were concentric. The actual number of plots increased with gap size, with one plot centered at the gap center, and additional plots, when the gap was sufficiently large, located 33 ft apart from the center plot and from each other along three transacts (0, 120, and 240 degrees azimuth);

(6) vegetation in the undisturbed area of the stand: the same as for vegetation in the gap, plus basal area measured with a 10 BAF prism. The plots were located at 0, 120, and 240 degrees azimuth, half a chain away from the gap border.

Office: All data collected in the field were transferred from field sheets into a Microsoft Excel™ data base. Data were thoroughly checked and initial analyses performed to identify suspect data items.

Further gap information was derived from the field data of extended gap trees upon verification. The derived gap factors included: aperture area (the area of canopy opening); extended gap area (the area bounded by the boles of extended gap trees); detailed slope curvature and slope steepness within each gap, based on azimuth, slope distance and slope change (from the gap center) of each extended gap tree.

Further, monthly air temperature and precipitation summaries were obtained from the Minnesota State Meteorologist for weather stations in southeastern Minnesota. The weather station data were interpolated to each gap location for the five years centering on the year of gap formation.

Two basic types of data analysis were performed: (i) summarizing the data set, with a focus on variables potentially useful in the second analysis; and (ii) developing an explanatory model for gap-to-gap variation in northern red oak regeneration. The first analysis provided an overall picture of characteristics of the studied gaps (hence the boundary conditions of the second analysis), and possibly of forest gaps in northern red oak dominated forests in southeastern Minnesota in general (within the gap-age range of the data). The second analysis addressed relations between canopy gap characteristics and northern red oak regeneration.

We defined northern red oak regeneration in terms of cumulative total height per 4.3-ft radius plot. Cumulative total height is essentially stems per area weighted by size. Besides describing the current amount of regeneration, it may also serve as an indicator of relative competitiveness (hence future success) when divided by regeneration of other species. The reference plot size of 4.3-ft radius was chosen as it is often used in the literature to represent the area needed by a 4-inch-DBH northern red oak in a fully-stocked sapling stand. Further, when expressed in a small area such as this, the amount of regeneration can be conveniently visualized (compare 1 ft/4.3-ft radius with 750 ft/acre).

A.1.c. Materials: Tapes, height poles, calipers, prisms, and clinometers will be used to characterize the gaps studied and their composition. A camera will be used to photo document all gaps; this will include a fish-eye lens. An auger will be used to extract soil samples. A soil nitrogen analyzer is already available to the investigators. A chain saw will be used to fell individuals for more detailed growth analysis.

A.1.d. Budget: $40,000
Balance: $0

A.1.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Analyze DNR phase II data	***				
Visit initial stands identified		****			
Select final subset of stands			****		
Collect intensive field data			********		
Data analysis				*******	
Reporting					****

A.1.f. Status:
Our mathematical modeling led to these conclusions about the relationship between red oak regeneration and characteristics of gaps and sites:

(1) Annual growth rate is a function of slope steepness above the regeneration (degree rising of upper slope), an indicator of water and nutrient inflow from upper slope.

(2) Regeneration of northern red oak under forest canopies tends to increase exponentially with the ratio of sand contents in surface A horizon and depository E horizon.

(3) Establishment of northern red oak recruited after gap formation is primarily a function of gap area adjusted for slope and aspect. The minimum gap size for given regeneration is not fixed, but varies with slope and aspect. In general, the minimum gap size is about 39 ft in radius (i.e., 0.108 acre) on flat terrain. The smallest minimum size tends to occur at WSW (245 degrees) where it gets even smaller as slope becomes steeper (28-ft radius at 30-degree slope, the upper limit of our slope data; see Figure 2.c). The largest minimum size tends to be required at ENE (65 degrees) where it becomes even larger with steep slope (106-ft radius at 30-degree slope, or 76-ft radius at 20-degree slope, the upper limit of our slope data at that aspect). Most of our gaps, however, were located at aspects where slope steepness did not seem to make much difference (i.e., the sine function in Equation 4 is equal to zero at an aspect of 155 or 335 degrees; Figure 2.c). Given slope and aspect, each 1-acre increase in gap size above the minimum size yields about 1.1 inch/4.3-ft radius increase in annual establishment of northern red oak from recruitment after gap formation. Note that this rate is of "established" recruitment. It is not uncommon to find abundant northern red oak seedlings following a bumper-acorn year, but few survive.

Gap size, slope steepness and aspect may be viewed as surrogates primarily for light availability, but also for temperature and moisture conditions of both air and soil. Because of the solar trajectory in the Northern Hemisphere, a north-facing slope shades a forest gap from solar radiation and reduces radiation intensity per unit gap area, whereas the opposite is true for a south-facing slope. This polarizing effect of aspect on solar radiation tends to be aggravated by slope steepness. Soil clay content and slope steepness also vary with aspect in our data set. The projection that WSW (245 degrees) rather than south tends to yield maximum regeneration suggests that more light does not necessarily yield more regeneration of northern red oak. Either other factors override the effect of light, or there is a threshold light level beyond which regeneration of northern red oak is impaired. Mortality of advance regeneration may also occur when the gap falls below a certain size, because of frost-pocket formation, light level tipped in disfavor of northern red oak, etc.

Hypotheses testing on northern red oak regeneration: In a one-on-one simple regression without adjustments for other factors, the cumulative height of northern red oak regeneration, both under forest canopies and in forest gaps, showed no significant correlation with any studied site/gap factor except for soil texture. Among soil texture variables, the composite sand content ratio between A and E horizon was by far the best indicator, explaining 40 and 30 percent of gap-to-gap variation for under-canopy and in-gap regeneration, respectively. Hence, there appears no fast one-factor rule to reliably predict regeneration of northern red oak.

Gap age, area, aspect, upper-slope steepness, and presence/absence of restricting zone within 32 inches below ground surface, in addition to A:E horizon sand ratio, became useful predictors when taken together. Advance regeneration under the forest canopy was also a good indicator of regeneration success after gap formation, although the predictive power was substantially improved after the other model factors were taken into account.

Other studied gap/site factors, while potentially influential in theory, had little quantitative effect on northern red oak regeneration. They included: slope curvature, position, and length; rock outcrop; gap-creating method, northern red oak being gap makers or being extended gap trees; site index; precipitation at and around gap formation.

With or without adjustments for site/gap factors, the cumulative height of northern red oak regeneration, both under forest canopies and in forest gaps, was not correlated with total regeneration of all species combined. This lack of relationship appears to support the idea that competition between regeneration plants was limited for our data sites.

Further, northern red oak regeneration was not correlated with the presence/absence of particular plant species in the gap. Ferns are sometimes suspected to impair oak regeneration by forming suffocating dense canopies and root mats and by a possible allelopathic effect. Among the 19 gaps with ferns, only one gap did not have northern red oak (seedlings or saplings), and 11 gaps did not have northern red oak saplings. Only seedlings were found in one gap with a particularly dense fern cover, but above average regeneration was found in another.

Both under forest canopies and in forest gaps, the cumulative height of northern red oak regeneration was closely correlated with its proportion in total regeneration of all species combined. This strong correlation suggests that, assuming that relative proportion to be an index of competitiveness, the amount of northern red oak regeneration at present is a good indicator to its future success at the location. This suggestion is further supported by the close correlation between under-canopy and in-gap northern red oak regeneration discussed earlier.

A.2. Activity: Study the genetic makeup of red oak regeneration found in gaps in relation to existing red oak overstory.

A.2.a. Context within the project: Red oak species vary in commercial importance and wildlife and aesthetic appeal. Harvesting and natural means of removal of individuals from a site obviously impact future species composition on the site. We will study the genetic makeup of red oak individuals occupying gaps and attempt to associate that with the composition of a previously existing overstory.

A.2.b. Methods: Twenty gaps in the data base of Activity A.1., but not selected for detailed study will be visited for collection of material. Four overstory and four understory (but greater than 2.5 m tall) individuals will be located and tagged for further study in or associated with each gap. The individuals will be chosen to cover the range of red oak species (and seeming hybrids) present on the site. During the growing season, leaf samples from the upper crown and standard morphological measurements will be taken. These latter measurements will include DBH, height, crown size, crown fullness, number of retained dead branches, etc. Photos of the bark and a vertical (upward looking) photo of the crown will be taken. During the winter months, bud samples from the upper crown will be removed from the trees.

Leaf tissue and winter bud samples will be sent to Michigan State University for isozyme analysis. Whole leaf samples will be scanned for morphological analysis.

Data analysis will begin by relating genetic information to observed tree and leaf morphological observations. Graphical and multivariate exploratory techniques will be used. Overstory versus understory genetic makeup relationships will be examined by categorical data analysis procedures.

A.2.c. Materials: Standard mensurational devices, such as tapes and clinometers, will be used to collect morphological characteristics in the field. Photos will be taken of tree bark and crowns, the latter with 200 mm and fish-eye lens. Bud and leaf samples will be collected with the aid of a shotgun and #2 shot. A computer based scanning system will be used for leaf shape analysis. Storage and laboratory apparatuses required for isozyme analysis are already available.

A.2.d. Budget: $10000
Balance: $0

A.2.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Identify study individuals	*****				
Make initial collections		***			
Lab analysis		****			
Data analysis			********		
New collections (if required)				****	
Reporting					****

A.2.f. Status:
Mature leaves were collected from 117 oak trees from southeastern Minnesota for the purpose of determining their morphological taxonomy. Most trees were assigned to either northern red oak *(Q. rubra)*, northern pin oak *(Q. ellipsoidalis)*, and black oak *(Q. velutina)* species, although there were a number of trees with questionable taxonomic affinity, suggesting hybridization. A morphological data set was collected for each leaf including leaf length, width, petiole length, and number of bristle tips. The data set was analyzed with principal components analysis (PCA). The result from the PCA was that there was no clear separation among species groups by traditional morphological methods. However, the high degree of overlap in PCA space is indicative of hybridization. This work will be presented in August 1995 at the Annul Meeting of the Botanical Society of America, in San Diego, CA.

DNA markers were analyzed for oak genotypes from the above populations near Kellogg, Wabasha, and Minnieska in southeastern Minnesota. Morphologically pure species of northern red oak, northern pin oak, and black oak, and their hybrids were studied as in the morphological study. Genotypes were screened using 46 PCA primers. Most polymorphisms were shared across species, although a few were specific to red, pin, and black oak. The above methods show promise for identifying species and species hybrids, but more individuals need to be analyzed to verify this conclusion.

To examine the relationship between mother tree and seedlings, seedlings were raised from acorns collected from 30 individual mother trees representative of northern red oak, northern pin oak, and their hybrids. Ten trees were chosen on the basis of leaf, canopy, and bole characteristics to represent each of these three groups. The trees chosen as representing hybrids were still considered "good" trees by Lake States Forest Service geneticists; those representing red oak would be considered "excellent" trees by this same group. One-year old seedlings were reared and characterized prior to outplanting to evaluate subsequent growth. The genetic position along the spectrum between these two interbreeding species of both mother trees and seedlings is being estimated by leaf morphometry and isozyme analysis.

Seedlings reared from seeds of both red oak and hybrid mother trees were similar, but distinct from those reared from pin oak mother tree acorns. Data for height, number of first-order lateral roots, and taproot area gave results similar to those shown for root collar diameter. When data were plotted as a function of acorn volume, again seedlings from the red oak and hybrid mother tree groups were similar to one another, but distinct from those from the pin oak mother tree group. Thus, seedlings from other trees intermediate between northern red oak and northern pin oak were not distinguishable from those from mother trees highly northern red oak in appearance. However, seedlings from northern pin oak trees were distinct.

Genetic positioning of the mother tree groups is ongoing. However, data to date are consistent with the characterization of the mother trees based on seedling characteristics. Leaf morphometry data fell into three groups:

(a) Number of bristle tips, leaf blade width, and petiole length did not distinguish any differences in mother trees;

(b) Leaf blade length and distance from the leaf base to the widest point of the blade discerned no difference between hybrids and red oak although pin oak was fairly distinct from either of the other two groups; and

(c) Leaf blade dissection, perimeter per unit leaf area, was the only term which showed differences among all three mother tree groups.

These "raw" data and the "ratio" data calculated from them (leaf blade width per unit length, petiole length per unit blade length, distance to widest point as a fraction of leaf blade length) were then used in cluster and principal components analyses.

These results indicate that there is, in general, a good separation of the pin oak from the other two groups, but no clear separation between red oak and hybrid mother trees. Further there is some indication that at least two trees in the pin oak group may also be hybrids with a greater contribution by pin oak than red oak.

Isozymes of 6 enzyme systems were analyzed electrophoretically. Although no mother trees from the pin oak group have been analyzed yet, the data for the trees analyzed in the red oak and hybrid groups are consistent with the leaf morphometry data.

In summary, all data to date suggests that mother trees and seedlings represent only two, not three, distinct groups representing northern pin oak and northern red oak plus hybrids. The possible segregation of two groups of northern pin oak on the basis of leaf morphometry is interesting. Although much analysis is still required, it does appear that any tree which appears to be considered either as a "good" or "excellent" tree by current visual classification standards can yield an equally large seedling. None of the criteria, to the extent they have been tested to date, is able to discriminate among these "good" to "excellent" mother trees to predict larger seedling size. Conversely, both visual characterization and leaf morphometry are capable of discerning highly northern pin oak mother trees which produce small seedlings. Much data collection and analysis remains; in particular, isozyme analysis of mother trees in the pin oak group, seedling isozyme and morphometry data, and characteristics of subsequent growth could provide different perspectives not evident with the data to date.

B. Title of Objective. Measure the effects of site preparation and crown closure on red oak regeneration.

B.1. Activity: Establish field trials with alternative crown closure and site preparation treatments.

B.1.a. Context within the project: We expect to learn how well oaks naturally regenerate, survive, and grow under different amounts of crown closure created by harvesting timber in clearcut and shelterwood systems. We also will measure oak regeneration, survival, and growth under different site preparation treatments aimed at controlling undesirable trees, shrubs, and herbaceous plants that compete with oak seedlings.

B.1.b. Methods: We will select at least three woodlands that have canopies dominated by mature oaks and replicate our trials in each of these woodlands. In each woodland we will harvest timber in two blocks (each 6 to 8 acres in size) to create residual canopy covers of approximately 0 percent and 33 percent. Harvesting will be scheduled during late fall after the acorns drop or during winter.

Within each 6- to 8-acre harvest block, we will conduct five different site preparation treatments. Each site preparation treatment plot will be approximately 1 acre in size. Site preparation treatments are intended to control nonmerchantable, undesirable trees, shrubs, and herbaceous plants. These site preparation treatments will include:

(1) Control plot where no site preparation occurs.

(2) A bulldozer will be used to knock down and uproot undesirable woody trees and shrubs. We propose this treatment as a practical method of controlling competition on gentle slopes. Bulldozing will occur in late summer or early fall prior to harvest.

(3) Herbicides will be applied to nonmerchantable, undesirable trees, shrubs, and herbaceous vegetation. A variety of application

methods will be considered and used as appropriate depending on the species and size of plants to be controlled.

(4) Prescribed burning will be used to control small woody trees and shrubs. Appropriate times for prescribed burning include mid-spring (late April or early May) and occasionally early fall.

(5) Tree tops will be dragged over the site with a skidder following timber harvesting. The purpose is to knock over and damage or kill woody understory vegetation.

Within each 1-acre site preparation treatment area, we will designate one 40 meter by 45 meter plot. In this plot we will measure percent crown closure and basal area per acre, and the number of trees per acre by species for all trees larger than 10 centimeters in stem diameter (DBH).

Within each 40 meter by 45 meter site preparation treatment plot, we will randomly choose locations for two understory plots, each 15 meters by 15 meters in size. In these understory plots we will count saplings (2.5 centimeters to 10 centimeters in diameter) by species.

Within each 40 meter by 45 meter site preparation treatment plot we will randomly choose locations for 4 seedling plots, each 3 meters in radius. In these seedling plots we will count tree seedlings (< 2.5 centimeters in diameter) by species and estimate the percentage of ground surface covered by dominant herbaceous plant species.

Within each seedling plot (3 meters in radius), we will randomly choose locations for 4 seedling plots, each 1.5 meters in radius, in which we will count seedlings by species and measure the height and stem diameter of each seedling. We also will record the type and extent of any damage that exists on seedlings (e.g., deer browse, insect, disease).

Plot measurements will be taken before any site preparation or harvesting occurs and at the end of each growing season during the course of this project. Seedling damage measurements will be taken at the beginning and end of each growing season so that we can be better informed about the time when damage occurs and evaluate whether the time of year when damage occurs has a significant effect on tree growth and survival.

In addition to the plots and measurements described above, we will measure specific environmental conditions (e.g., light level and seedling moisture stress) and indices of competition for a number of oak seedlings under every combination of harvest and site preparation treatment so that these can be related to oak seedling survival and growth.

Vegetation responses to the treatments will be analyzed by standard analysis of variance techniques. Regression analysis may be used to further investigate what appear to be key relationships among variables.

B.1.c. Materials: A bulldozer will be used for one site preparation treatment. Herbicides applied as foliar sprays may be applied by backpack mist blower or hydraulic sprayer as appropriate. An axe and/or chainsaw may be needed to girdle or fell undesirable trees. Prescribed fires will be controlled by hand tools and water trucks. A tape measure, diameter tape, height pole, 10 BAF prism, and caliper will be needed to measure overstory and understory vegetation.

B.1.d. Budget: $74,000
Balance: $0

B.1.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Identify research sites	****				
Apply herbicide & bulldozer treatments to understory	****				
Apply prescribed burn treatment to understory			** or	**	
Harvest stands		****			
Measure vegetation response to treatments			**		
Analyze data and report results					**********

B.1.f. Status:
We established three research sites according to standards described in the Methods section. Because of the short time between the start of the project (July 1, 1993) and the time when we needed to take our first plot measurements (August, 1993) we were able to hire qualified staff to install only one site in 1993. The other two sites were installed in 1994. The sites are located on state forest land near the Fillmore County Airport and Money Creek watershed in Houston County and on the Whitewater Wildlife Management Area. Below is a schedule of the work we accomplished at each site:

	Airport	Whitewater	Money Creek
Original inventory	16-23 Aug 93	23-31 Aug 94	23-31 Aug 94
Harvest	Winter 93-94	5-9 Dec 94	Not done
Control	---	(+inadvertently burned 31 Nov 94)	---
Burning	Not done	31 Nov 94	Not done
Bulldozer	24 Aug 93	6 Oct 94 (+inadvertently burned 31 Nov 94)	4 Oct 94
Dragging tops	Winter 93-94	Dec 94	Not done
Herbicide	15 Aug 93	13 Sep 94 (+inadvertently burned 31 Nov 94)	19 Sep 94
Followup inventory	15-20 Sep 94	Not done	Not done
Planting oak seedlings	Spring 94		
Seedling measurements	11 Nov 94		

There were some difficulties in establishing these sites. (1) At the Airport site, the DNR crew that applied herbicide sprayed the wrong research plot and allowed herbicide to drift onto adjacent plots. This caused us to reconfigure the plots, but did not cause lost data. (2) The prescribed burn at the Whitewater site was well-executed, but the fire unexpectedly flared up at night after the DNR and University fire crew had left and swept through the entire experimental area beyond the designated burn plots. This will affect our interpretation of data in the future because the control, chemical, dragging tree tops, and bulldozer sites were all burned inadvertently. (3) No prescribed burns have been done at the airport and Money Creek sites because of poor weather conditions for the burns. From the inception of this project we expected difficulty in finding good burning conditions. (4) Logging at the Money Creek site was delayed because the DNR forester in charge of the timber harvest did not have time to inspect the site and prepare the sale documents. The current plan is for the DNR to offer this timber for sale at auction on May 24, 1995. We do not know the outcome of this auction. We recommended that harvesting occur in the winter to be consistent with the other harvest sites that are part of this same experiment. Dragging tree tops has not yet been done at Money Creek because no timber harvest occurred there yet.

B.2. Activity: Measure acorn production, dispersal, "storage", and survival.

B.2.a. Context within the project: Timber harvesting and site preparation treatments are expected to enhance oak regeneration most when they are conducted in years of, or years just following, acorn abundance. Other than casual observations by experienced foresters, there is no reliable method or data base that enables foresters to reliably measure or predict acorn abundance or understand its year-to-year or site-to-site variation. We will initiate acorn surveys that will continue beyond 1995 to establish a data base and procedures that can be used by foresters to better measure and predict acorn abundance.

B.2.b. Methods: Surveys of acorn production, dispersal, "storage", and survival will be conducted on a range of sites chosen to reflect relevant climatic, vegetative, soil, and topographic gradients in southeastern Minnesota. This will require collecting falling acorns, assessing acorn numbers in soil "seed banks", assessing predation on acorns in several micro-environmental locations, and estimating germination of acorns that have undergone several types of dispersal and micro-environmental conditions. Because acorn dynamics vary widely over a longer time frame, these studies will be continued under other funding sources following the two-year period. The gradient of sites on which this study is performed will yield valuable information about spatial variation in acorn dynamics. Information on acorn dynamics will be linked with information about different types of site preparation techniques in order to develop strategies for successful natural regeneration.

B.2.c. Materials: Seed traps, soil cores, and mesh bags.

B.2.d. Budget: $5,000
Balance: $0

B.2.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Select sites for acorn collection	***				
Collect acorns	**		**		
Analyze data		***		****	

B.2.f. Status:

We tested three acorn collection methods in a woodland near the Twin Cities in fall 1993. (1) Several 10 ft. by 10 ft. polyethylene sheets were placed under several oak trees and the acorns were removed and counted about every two days. (2) Under each of six oak trees we counted and removed the acorns in a single 1/1,000 acre plot. (3) Under each of six oak trees we counted (but did not remove) the acorns in a single 1/1,000 acre plot. Either this was a very poor acorn crop this year in that area or we started our acorn collection too late, because we collected very few acorns using these methods. We conducted a literature search and talked to other researchers to obtain additional ideas for collecting acorns and assessing the size of the acorn crop. Since our collection devices yielded only a handful of acorns in fall 1993, there were no data to analyze. In these surveys, it appeared that this technique was not efficient. It was difficult to get sufficient geographic coverage; acorns could be removed by animals; it was very time intensive because traps should be checked frequently; and an inordinate amount of time, money, and effort would have been needed to use this technique effectively.

As an alternative, we assessed distribution of acorns with respect to overstory and burn treatments at the St. John's site (described above in section B.1.f Status), and attempted to link those measurements to seed predation and seed germination and establishment. This turned out to be a more appropriate way to address this issue. We measured numbers of acorns at eight subplots (1 m diameter circular plots) within each of the six treatment combinations, and then used a combination of natural, seeded, and seeded + caged subplots (1 m diameter circular plots) (eight of each within each replicate treatment) to assess the contributions of acorn production, dispersal, predation, and microsite conditions on potential seedling establishment.

Analysis of variance was used to test for statistical effects of treatment combinations. Of the six treatment combinations (3 overstory manipulations by 2 burn treatments), the data on acorn abundance, predation, germination, and survival suggest that shelterwood sites that receive prescribed burning are most likely to have the best seedling regeneration potential. Numbers of acorns were much higher ($p<0.05$) in understory and shelterwood sites than in clearcuts, which is not surprising, but numbers were slightly higher in shelterwood than in understory plots, suggesting either greater dispersal into shelterwoods or less predation there. In both the shelterwood and understory plots, numbers of germinants were higher in burned than in unburned treatments in all (natural, seeded, and caged + seeded) plots ($p<0.05$). When seedlings were protected from predation, they did best in the burned clearcut and shelterwood sites. Thus, it appears that numbers of acorns are higher in understory and shelterwood sites, but that the combined influence of dispersal, predation, and microsite result in a greater likelihood of germination and early survival for any given seedling in shelterwood and clearcut sites. Taken together, this indicates a positive result for shelterwoods. Finally, in all overstory treatments, prescribed burning also appeared to be positive with respect to combined impact on acorn numbers, germination, and early establishment. These plots will be resurveyed during the summer of 1995.

B.3. Activity: Remeasure artificial oak regeneration plots established in 1991-93.

B.3.a. Context within the project: The project as a whole is aimed at finding methods for regenerating more oaks. These plots were originally established under an LCMR grant for 1991-93. They involved site preparation by herbicide and mechanical methods followed by planting oak seedlings and acorns. We currently have measurements of the oak seedling survival and growth and effects of the site preparation treatments for only one growing season. It is important to measure oak seedling and acorn survival as well as effects of the site preparation treatments for at least three growing seasons to learn how effective they really were. This information is an important part of the educational effort planned under Objective C.

B.3.b. Methods: The following understory data will be recorded at each plot: (1) The species and height to the nearest one foot of all tree seedlings less than one inch in diameter, (2) The species and height to the nearest one foot of all shrubs, (3) An estimate of the percentage of the ground covered by all herbs and forbs and the percent ground cover provided by each of the four most prevalent species. For each oak seedling and acorn planted, we will measure stem height, stem caliper, and survival as well as the type and amount of any damage (e.g., deer browsing, insects, diseases) that may have occurred. These data will be analyzed by appropriate statistical methods to determine the affects, if any, of site preparation treatments on the survival, stem diameter, and height growth of oak seedlings and acorns, the number and height of competing trees and shrubs, and the percentage of ground covered by competing herbaceous vegetation.

B.3.c. Materials: Tape measure, height pole, 10 BAF prism, and caliper.

B.3.d. Budget: $6,000
Balance: $0

B.3.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Measure plots	***		***		
Analyze data		******		******	

B.3.f. Status:
These plots were originally established under a 1991-93 LCMR Project: Regeneration and Management of Minnesota's Oak Forests, Objective A: Artificial regeneration of red oak in southeastern Minnesota.

These plots were remeasured in the fall of 1993. Data covering two years (1992-93) were analyzed to determine the treatment affects. Results were reported in a master's degree thesis prepared by John DuPlissis. One copy of this 246-page thesis was delivered to the DNR--Division of Forestry. Additional copies are available in the University of Minnesota Forestry Library.

The following are the results of the statistical analysis of the competing vegetation inventories for 1991, 1992, and 1993.

Currently competition levels for all stand resources (light, nutrients, and water) are highest in the control site preparation treatment whole plots where mean stem height (115 cm) and mean stems per hectare (21,585) are greater than either the chemical (89 and 9,836 respectively) or mechanical (100 and 19,529 respectively) site preparation treatment whole plots.

There has been a general decline in the number of stems per hectare for all species except for boxelder, which has nearly doubled, and northern red oak which is slightly higher. This general decline in the mean number of stems of woody vegetation coincided with a significant increase in the mean percent ground cover of the herbaceous vegetation.

The following are the results of the statistical analysis of the seedling and acorn inventories from April 1992 through September 1994.

At the end of the third growing season (September 1994) there was no significant difference in mean seedling height of planted red oak seedlings between the control, chemical, and mechanical site preparation treatments. However, after three growing seasons (September 1994) the mean stem diameter of red oak seedlings in the chemical site preparation treatment whole plots was significantly greater than those in the mechanical site preparation treatment whole plots which in turn was significantly greater than those in the control site preparation treatment whole plots.

The following are the results of statistical analysis of seedling growth, survival, and damage for the seedling and acorn subplots.

At the end of the third growing season (1994) the premium seedlings with treeshelters were significantly taller than the premium seedlings without treeshelters. The premium seedlings were significantly taller than the nursery run seedlings, however, the unprotected acorns were not significantly different from either the premium or nursery run seedlings. The nursery run seedlings were significantly taller than the protected acorns.

The tubex quills were removed from the acorns at the end of the second growing season to prevent constriction of the acorn sprouts. After three full growing seasons there was no significant difference in the mean stem diameter of premium seedlings with and without treeshelters; however the mean stem diameter of the premium seedlings was significantly larger then the nursery run seedlings which had a larger mean stem diameter than the acorn sprouts without treeshelters which were significantly larger than acorn sprouts with treeshelters.

After the first growing season (1992) 99.7 percent of the planted northern red oak seedlings were still alive. After the second growing season 95 percent of the bareroot planting stock was still alive. This increase in mortality was due in large part to animal browsing and storm damage. Additionally, a number of seedlings were simply missing. These seedlings may have been pulled out of the ground by some animal, most likely deer or squirrel, but there is no evidence as to why they are missing. There was no significant difference in seedling mortality between the planting stock types at the end of the first growing season. However, at the end of the second growing season the premium seedlings with treeshelters had a significantly higher mortality rate than the nursery run seedlings; the premium seedlings without treeshelters were not significantly different from either of these.

The germination rates of the planted acorns was unexpectedly low; approximately 34 percent of the acorns germinated and survived to the end of the first growing season. This result was quite different from the greenhouse trials in which 87 percent of the acorns germinated and survived for at least one month. At the end of the second growing season (1993), only 19 percent of the planted acorns were still alive, a mortality rate of approximately 44 percent. There was no association between any damage categories and the death of acorn sprouts.

CONCLUSIONS

This research project has established several important facts that will be useful in the management of the oak forest type in both the Big Woods area and the central hardwoods forest type in southeastern Minnesota. First, the question of overstory removal and its affect on regeneration has been answered in part. Oak seedling growth was best where overstory cover was light as exhibited by seedling growth at the Trout Valley West site. This is surprising since this site was considered to be the poorest for seedling growth based on soil type and indicator plant species.

Second, oak seedling growth appeared to be greatest in the chemical research plots especially as a measure of above ground biomass. While there was no significant difference in oak seedling height between the control, chemical, and mechanical treatments, oak seedling diameter growth was greatest on the chemical treatment site. The important thing to note here is the overall growth trend. Actual oak seedling height growth on the chemical treatment areas was significantly less after the first growing season, however, height growth during the second and third growing season on the chemical treatment areas equaled or exceeded growth on the other treatment areas.

Third, the premium oak seedling type has continued to outperform the nursery run seedling type. This study should help to make a legitimate case that our hardwood nurseries should attempt to grow seedlings with larger, more fibrous root systems. Also note the acorn sprouts have continued to grow to where their actual height at the end of three growing seasons is not significantly different from either the premium or nursery run seedlings. However this should be tempered by the fact that our sample size is only 29 after three years because of low survival.

Fourth, premium seedlings protected by tree shelters were significantly taller than unprotected premium seedlings, but protected seedlings were not significantly larger in diameter than unprotected seedlings.

Finally, all of this needs to be examined in the light of seedling mortality rates, however, data on seedling mortality at the end of the third growing season is incomplete and it would be inappropriate to extrapolate from second year data. However, mortality data would seem to suggest that at least 85 percent of each of the seedling types are still alive while approximately half of the acorn sprouts died at the end of the second growing and another third of those were dead at the end of the third growing season. Planting acorns has possibilities, however, the mortality issue will have to be addressed.

C. Title of Objective. Conduct an educational program on hardwood forest management.

C.1. Activity: Conferences and field tours.

C.1.a. Context within the project: Since most of the hardwood resource is owned by nonindustrial private forest landowners who generally know little about forestry, it is important to stimulate their interest in regeneration and management of this resource. Loggers harvest timber and have a tremendous impact on regeneration, yet they generally are not knowledgeable about the biological affects of their activities on the forest. Educational programs aimed at landowners, loggers, and the foresters who advise them are important to bring the latest research knowledge into practice, including knowledge gained from our 1991-93 LCMR research project on Regeneration and Management of Minnesota's Oak Forests.

While conducting educational programs for landowners and loggers, we learn more about their land management concerns and the practicality of forest management practices being investigated in our research. This two-way communication process makes the University's research and education programs more relevant to local issues and needs.

C.1.b. Methods: Field tours will be held for foresters to show them the research plots and describe the results of research conducted in 1991-93 regarding artificial regeneration of oaks.

A series of conferences and field tours will be held throughout a 7-county area in southeast Minnesota to inform woodland owners and loggers about hardwood forest management for multiple-uses. We will emphasize management techniques that help to perpetuate a desirable mix of tree species for wood products and wildlife while protecting the aesthetic, recreational, and watershed protection values of woodlands.

We will recruit and train additional 4-H Forest Resource Project leaders and promote increased enrollment in this 4-H project through workshops, field tours, and a 4-H ecology camp.

Mass media will be used to inform area residents about the value of our hardwood forest resource, management problems, current research, and upcoming educational events.

C.1.c. Materials: We will use existing educational materials including brochures, publications, slide sets, and video tapes on forestry subjects.

C.1.d. Budget: $75,000
Balance: $0

C.1.e. Timeline:	7/93	1/94	6/94	1/95	6/95
4-H Ecology & County 4-H camps	*****		*****		****
Field tours for foresters					****
Conferences and field tours for landowners and loggers		********		******	

C.1.f. Status:
We conducted 37 different educational events for woodland owners and loggers. Our attendance exceeded 900 adults and over 3,570 educational contact hours. As part of this effort we provided 40 hours of training to 32 private woodland owners who now are expected to provide 50 hours of volunteer service over the next two years helping their neighbors and communities better manage their woodlands.

We conducted 35 different educational events for youth and educators, reaching over 2,500 people. Our most intensive youth education program was a week-long Forest Ecology Summer Camp that we ran three times, reaching 96 youth with career interests in natural resources.

We participated in 38 educational events for other adult audiences, reaching over 1,650 people.

Our educational programs offered current information on hardwood forest management for wood products, water quality protection, wildlife habitat, recreation development, and ecological benefits.

Beginning in March 1994, a pilot program was conducted to learn more about how we could interest nonindustrial private forest landowners in learning about forestry. In this pilot program we directly mailed forestry-related educational materials to a sample of woodland owners.

We sent personally addressed and individually signed letters to 400 woodland owners. We randomly chose 200 names from our list of 1,500 woodland owners in southeastern Minnesota (Olmsted, Fillmore, Houston, Wabasha, and Winona counties) and 200 names from a list of about 1,000 woodland owners in northern Minnesota (Beltrami, Lake of the Woods, Clearwater, Hubbard, and Mahnomen counties). Both lists were obtained by looking at aerial photographs to determine where woodlands were located and then looking up land ownership records in county courthouses to identify the landowners and their addresses. Besides receiving our cover letter, each landowner also received the publications: <u>Minnesota Woodland Owners' Resource Directory</u> and <u>Woodland Stewardship: Plan on it!</u> and they received a questionnaire entitled, Request for Woodland Information. We gave landowners the opportunity to order one free publication and to ask a forestry-related question. The questionnaire also requested some additional information about their educational needs.

One-half of the original mailings had addresses hand-written on the envelopes; the other half had addresses printed on gummed mailing labels. There were no substantial differences in response rates. In fact a few more responses were received from landowners whose addresses were printed on gummed labels. Based on this small sample, it appears that hand writing addresses on envelopes is not warranted as a means to stimulate responses to similar mailings.

After undeliverable letters were deleted from the data base, we learned that 17% of the remaining landowners requested another publication, but there were more requests in northern Minnesota (25% response rate) than in southern Minnesota (11% response rate).

Respondents could order one additional publication from a list of 14 publications. In order of preference, respondents most commonly requested publications dealing with wildlife management (wildlife, nongame, deer, grouse, turkey) first (41%); they requested publications dealing with income-related subjects (timber marketing, timber measuring, taxes, conservation programs) second (35%); and they ordered publications dealing with more general woodland resources (aspen, oak, wetlands, protection) third (26%). However, responses varied by region. Woodland owners in southeast Minnesota most commonly requested a general woodland resource publication, especially one on on oak management. Respondents in northern Minnesota most commonly requested a wildlife publication.

Respondents also were asked to rank the three woodland management information sources they preferred most from a list of 11 options. Responses were weighted by multiplying first choices by 3, second choices by 2, and third choices by 1 and then dividing the sum of those scores for each category by the total number of responses. There were several ties in the preference list. Preferences were (1a) publication or book and (1b) video tape for home viewing, (2a) field tour and (2b) newsletter, (3a) evening workshop and (3b) correspondence course, (4) day-long conference, and (5a) cable TV program, (5b) newspaper article and (5c) magazine article. There appear to be regional differences. Evening workshop ranked first in southeast Minnesota, while video tape for home viewing ranked first in northern Minnesota.

A higher than expected number of respondents had previously received information from or participated in educational events sponsored by the Minnesota Extension Service (56 percent). Forty-six percent also reported that a forester had visited their property to advise them on its management. Both proportions are considerably higher than those reported by other woodland owner studies conducted in Minnesota. These responses seem to indicate that our procedure of mailing publications to a random selection of landowners had the greatest appeal to landowners that had previously received forestry information and technical assistance. We do not appear to have stimulated as many uninformed landowners as we would like to have done.

V. **Evaluation:**

Objective A will result in a written report summarizing the survey work performed to identify the relationship, if any, between canopy gap characteristics and species composition of the trees that regenerated in those gaps. A written report will be prepared that describes results of the isozyme analysis. This report will describe how physical attributes of oaks can be used to help distinguish oak species and hybrids.

Objective B will result in a written report summarizing one year of data regarding the affects of crown closure and site preparation methods on natural oak regeneration and two years of survey data regarding the acorn crop. In the long term its success can be measured by the continued monitoring of these sites and reporting on the treatment affects and acorn crops.

Objective C can be evaluated by the number of conferences and field tours conducted, by the attendance at those events, by written evaluations completed by program participants, and by the number of mass media contacts and materials produced.

VI. **Context within field:**

The key to regenerating oaks in other states has been the presence of large (greater than 4 feet tall) advance reproduction or trees capable of producing stump sprouts (Sander, 1977 and Loftis, 1989). However, in a recent survey of 100 mature oak stands in southeastern Minnesota, no such stands were found (Ken Anderson, personal communication). Efforts to increase the amount of advance oak reproduction have focused on regulating crown cover, controlling the understory, and timing the harvest to take advantage of an abundant acorn crop.

Clearcutting trials in Iowa and Wisconsin produced mixed hardwood stands in which red oak was or could be a major component if competing trees were controlled. Successful oak regeneration occurred where mature stands had 80-90 percent of the basal area in red oak, all overstory trees 1.6 inches DBH and larger were harvested or killed, harvesting coincided with a good acorn crop, understory competition was controlled before or during overstory removal, and the soil was disturbed by logging or site preparation, often when acorns were on the ground. In Wisconsin the understory control was achieved with herbicides applied prior to the harvest. In Iowa the understory control was achieved by mechanical scarification at the time of logging (Jacobs and Wray, 1992). These trials were not conducted as experiments, therefore, the relative importance of each factor is unknown, but it appears that a good acorn crop is essential when advance reproduction is lacking.

There is no long-term research that provides information about how to evaluate acorn abundance or predict the size of the acorn crop in Minnesota. Our proposed research will initiate a long-term study of acorn crops and a long-term study of the relative effects of overstory and understory control.

An LCMR project funded during 1991-93 involves control of the understory in oaks stands prior to harvest by the use of herbicides and bulldozing. Those treatments were conducted in conjunction with planting oak seedlings.

We are measuring the effects of understory treatments on all natural regeneration and on planted oak seedlings, however, the advance oak regeneration was not protected from herbicide and bulldozer treatments.

Prescribed burning has been used in Wisconsin on small clearcut plots on both xeric and mesic sites to control understory competition. While burning did not increase the number of oak seedlings it dramatically reduced the cover and number of competitors while leaving the oak virtually unaffected (Reich, et.al, 1990 and Kruger, 1992). Our proposed research will conduct prescribed burning in shelterwood and clearcut situations on larger areas to test whether the initial results from Wisconsin are applicable under our somewhat different climate, soils, and species mix.

The value of soil disturbance other than to control understory competition is uncertain. However, Crow (1988) suggests that soil scarification is vital for protecting acorns from predators. In southeastern Minnesota Bundy et.al. (1991) found that bulldozer scarification did not increase the total number of oak seedlings, but it did increase the height growth of oak seedlings. Our proposed research will include bulldozer scarification to knock down competition and we will try to schedule it after the acorns drop. Because of the short, two-year duration of this project, it may not be possible to schedule the scarification and other understory control treatments in years when there is an abundant acorn crop.

Two shelterwood trials in Wisconsin produced stands that were adequately stocked with oaks, but neither stand was stocked as well as a nearby clearcut where herbicides were used prior to the harvest to control the understory. Shelterwood harvests should be more successful if the understory is also controlled (Johnson and Jacobs, 1981). These were unreplicated studies without inventories of reproduction prior to the final harvest. Both shelterwood cuts reduced basal area to approximately 60 square feet of basal area.

There are shelterwood harvests and understory control practices in oak stands near Rhinelander, Wisconsin that were installed by the North Central Forest Experiment Station. Shelterwood cuts include 25 percent, 50 percent, 75 percent, and 100% canopy cover. Understory competition was controlled by herbicides and/or bulldozing. These experiments are not yet old enough to provide reliable results and they were designed to test the affects of crown closure and understory control on planted oak seedlings, not natural oak regeneration. Their planting sites also differ from sites in southeast Minnesota regarding soil, slope, and climate.

Our research will include a shelterwood cut that leaves approximately 33 percent crown cover. We will control the understory by use of herbicides and by scarification (bulldozing and dragging tree tops over the site). Our treatments and vegetation measurements will be planned to assess the affects of crown closure and understory control on natural oak regeneration. A few relevant studies have been conducted examining gap dynamics in oak forests. Gaps caused by gypsy moth induced mortality were contrasted with nearby gap-free areas by Ehrenfeld (1980). She found little evidence of red oak re-invading gaps or capitalizing on gap formation. For a seven-year period after gap formation, reorganization of existing tolerant understory species was the rule (primarily dogwood on the site studied). In contrast, Lorimer (1983) found evidence that an existing understory of red oak quickly occupied and flourished in gaps created by harvest of a sugar maple overstory. McGee (1984) found growth of advance oak regeneration to occur earlier under partial canopies (gap-type conditions) than in clearcuts. These works and those of a similar nature all point out the high dependency of results on stand, site, and gap conditions. Broader scale studies, such as that of Nowacki et al. (1990), are needed if more broadly applicable conclusions are to be drawn. This just mentioned study only indirectly studied red oak regeneration relationships but did conclude that edaphic conditions had a dramatic impact on success with the oak only succeeding on the more xeric sites. Hix and Lorimer (1990) have studied growth and competition relationships in young hardwood stands in Wisconsin. Their sites, while containing northern red oak, have a quite different set of associate species, primarily those of northern hardwood forests, than is typically found in southeastern Minnesota.

Hybridization between northern pin and northern red oak appears to be quite common (Hokanson et al. in press). Isozyme and polymerase chain reaction analysis methods (Jensen et al. in press) have been employed to positively identify hybrids and pure species. Previous LCMR funded research by the investigators has applied this work to southeastern Minnesota, including a third species--black oak. Isolated, large individuals were sampled based on differences in morphological characteristics. That work to date has shown results similar to that published by other researchers. However, a more systematic approach to collection of sample material is now needed if the conditions under which hybridizations occur are to be identified.

The educational program outlined under Objective C is a continuation of work begun during a 1991-93 LCMR project. Our proposed new project will enable us to greatly expand the audience reached by our educational program and it will enable us to extend the research findings from our 1991-93 oak research project.

VII. **Benefits:**

We will learn about the relationship between canopy gap sizes and the species composition of regeneration. Because of public pressure to reduce the size of clearcuts, this information will enable foresters to plan timber harvests that regenerate the most desirable species while minimizing the size of harvest areas.

Isozyme analysis of oaks will better enable us to identify oak species and determine whether or not to artificially or naturally regenerate timber stands depending on the genetic makeup of the species present.

This project will generate benchmark data about forest stand conditions before and immediately after clearcut and shelterwood harvests, about understory control treatments (herbicides, bulldozer scarification, and burning) and about acorn crops. Stands will be monitored in the future to learn the longer term implications of these treatments. Over time we will be able to assess the value of different amounts of crown closure and different understory control measures to enhance oak regeneration. We will be better able to assess the relative abundance of acorns and possibly predict in what years good acorn crops are likely to occur. This latter information will be especially helpful to foresters when scheduling timber harvests.

This research and the educational efforts that go with it will foster improved regeneration of hardwood species that produce commercially valuable wood products and that are important for wildlife habitat.

VIII. **Dissemination:**

Research results from this project will be presented at state and national scientific meetings for natural resource professionals and we will submit them for publication in peer-reviewed periodicals aimed at natural resource specialists. Research results will be incorporated into future educational materials, conferences, and field tours aimed at private woodland owners, loggers, and the forest products industry that will be conducted by extension foresters at the University of Minnesota.

IX. **Time:**

Objectives A and C will be completed in their entirety during the 1993-95 biennium. Research plots described in Objective B will be completely installed and monitored during 1993-95, but the most useful results will not be available for several years in the future. Forest vegetation is dynamic and the species composition of stands following cultural treatments may change fairly rapidly over time. We expect to monitor these plots for several years to better assess the treatment affects on oak regeneration. We do not anticipate requesting additional funds from LCMR for long-term monitoring of these plots. The most expensive and time-consuming part of this research will be accomplished during 1993-95. Expenses that we incur to monitor these plots after 1995 will be paid from other funding sources, most likely sources available through the Minnesota Agricultural Experiment Station.

X. **Cooperation:**

Melvin J Baughman will serve as the Principal Investigator for the project as a whole and will be responsible for monitoring the overall budget and for reporting accomplishments to the LCMR.

Thomas Burk will coordinate all of the research under Objective A. He will be principally responsible for the inventory work aimed at assessing the affects of canopy gap size on species composition. Jud Isebrands from the North Central Forest Experiment Station, Forest Service will provide leadership for the isozyme analysis of oaks outlined under Objective A. He will be involved in collecting tree samples and will be responsible for conducting laboratory tests and analyzing the results.

Peter Reich, Melvin Baughman, and Klaus Puettmann will be responsible for planning and conducting all the research under Objective B.

Melvin Baughman, Steven Laursen, and Joe Deden will plan and conduct the educational programs outlined under Objective C. Other state specialists and county agents from the Minnesota Extension Service will be involved in organization and promotion of specific events.

The Minnesota Department of Natural Resources, Division of Forestry is expected to help us identify potential sites for the research that will be conducted under Objectives A and B. We expect to conduct our research on forest land administered by the DNR. We will rely upon the DNR to schedule timber harvests needed to accomplish Objective B and within the limits of their budget capability to help conduct site preparation treatments. We also will provide funds from this project appropriation to support the site preparation costs as needed. We expect the DNR to provide some of the personnel and equipment necessary to control the prescribed burns.

Cooperators	Percent Time Object A	Object B	Object C
Dr. Melvin J. Baughman	--	8	8
Dr. Thomas E. Burk	8	--	---
Mr. Joe Deden	--	--	80
Dr. Jud Isebrands	5	--	---
Dr. Steven B. Laursen	--	--	8
Dr. Peter B. Reich	--	8	---
Dr. Klaus Puettmann	--	5	---

XI. Reporting Requirements:

Semiannual status reports will be submitted not later than Jan. 1, 1994; July 1, 1994; Jan. 1, 1995; and a final status report by June 30, 1995.

XII. Literature Cited:

Bundy, P.P.; A.A. Alm and M.J. Baughman. 1991. Red oak regeneration following scarification and harvesting: a case study. Northern Jour. of Applied Forestry. 8(4):173-4.

Crow, T.R. 1988. Reproductive mode and mechanisms for self-replacement of northern red oak (Quercus rubra)--a review. Forest Science. 34(1):19-40.

Ehrenfeld, J.G. 1980. Understory response to canopy gaps of varying size in a mature oak forest. Bull Torrey Bot Club 107:29-41.

Hix, D.M. and C.G. Lorimer. 1990. Growth-competition relationships in young hardwood stands on two contrasting sites in southwestern Wisconsin. For Sci 36:1032-1049.

Jacobs, R.D. and R.D. Wray. 1992. Managing oak in the driftless area (NR-BU-5900). St. Paul, MN: Minnesota Extension Service, University of Minnesota. 32 p.

Johnson, P.S. and R.D. Jacobs. 1981. Northern red oak regeneration after preherbicided clearcutting and shelterwood removal cutting. Res. Pap. NC-202. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 5 p.

Kruger, E.L. 1992. Survival, growth, root:shoot relations, and ecophysiology of northern red oak (Quercus rubra L.) and competing tree regeneration in response to fire and related disturbance. Ph.D. Thesis. University of Wisconsin--Madison.

Loftis, D.L. 1989. Species composition of regeneration after clearcutting southern Appalachian hardwoods. In: Proceedings of the 5th Biennial Southern Silvicultural Research Conference, 1988; Memphis, TN. Gen. Tech. Rep. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. p. 253-257.

Lorimer, C.G. 1983. Eighty-year development of northern red oak after partial cutting in a mixed-species Wisconsin forest. For Sci 29:371-383.

McGee, C.E. 1984. Oak regeneration begins growth earlier under forest canopies than in clearcuts. Paper presented at Southern Silvicultural Research Conference, Atlanta, GA, Nov 7-8, 1984.

Nowacki, G.J., M.D. Abrams, and C.G. Lorimer. 1990. Composition, structure, and historical development of northern red oak stands along an edaphic gradient in north-central Wisconsin. For Sci 36:276-292.

Reich, P.B., M.D. Abrams, D.S. Ellsworth, E.L. Kruger and T.J. Tabone. 1990. Fire affects ecophysiology and community dynamics of central Wisconsin oak forest regeneration. Ecology 71:2179-2190.

Sander, I.L. 1977. Manager's handbook for oaks in the North Central States. Gen. Tech. Rep. NC-37. St Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 35 p.

JUL 05 1995

Date of Report: July 1, 1995

LCMR Final Report - Detailed for Peer Review - Research

I. Project Title: Developing Quality Hardwood Forests
Program Manager: Dr. Melvin J. Baughman
Agency Affiliation: University of Minnesota
Address: Department of Forest Resources
1530 North Cleveland Avenue
St. Paul, MN 55108
Phone: (612) 624-0734

A. **Legal Citation:** M.L. 93 Chpt. 172, Sec. 14, Subd. 5(d)

Total Biennial LCMR Budget: $210,000 Balance: $0

Appropriation Language: Subd. 5(d). This appropriation is from the future resources fund to the commissioner of natural resources for a contract with the University of Minnesota to conduct research on the effects of different canopy gap sizes and site preparation methods on natural hardwood regeneration.

B. **LMIC Compatible Data Language:** Not applicable.

C. **Status of Match Requirement:** Not applicable.

II. **Project Summary:**
Oaks dominate the canopies of most mature hardwood stands in southeastern Minnesota. When these oaks are harvested or die of natural causes, however, the stands frequently convert to more shade tolerant tree species that were present in the understory at the time of harvest. These shade tolerant tree species generally are less valuable for wood products and for wildlife than the oaks. This project involves research to learn more about how to stimulate natural oak regeneration from acorns and stump sprouts.

We will inventory multi-age class hardwood stands to determine the relationship, if any, between the characteristics of canopy gaps created by harvest or other causes and the species and growth rates of trees that regenerated in those gaps.

Isozyme analysis of oaks will be performed to identify the genetic makeup of overstory trees and regeneration. This analysis will help us identify which oak species or hybrids really exist in our woodlands. Some oak species and hybrids are less desirable than others for wood products and wildlife, but in many cases, foresters cannot easily distinguish which species are present. Knowing more about how to distinguish the oak species and hybrids will enable foresters to plan harvest and regeneration strategies that will regenerate the most desirable species.

Field trials will be conducted to test the affects of different amounts of canopy cover and different site preparation methods (chemical, mechanical, and burning) on natural oak regeneration. This is a long-term project that will be initiated in 1993, but only preliminary results will be available by the end of the project in 1995. It takes several years following the treatments to obtain reliable results concerning the affects of harvesting and site preparation methods on regeneration. Costs for measuring field plots after 1995 will be relatively low and will be covered by other funding sources.

An educational program will be developed to inform private woodland owners, loggers, the forest products industry, and foresters about the latest research concerning hardwood regeneration techniques. We will report on the research results from a 1991-93 LCMR project as well as results from projects in other states. We will promote enrollment in the 4-H Forest Resources Project and conduct an ecology camp for 4-H youth so that they can become more knowledgeable about forest management and natural resource career opportunities.

III. **Statement of Objectives:**

A. Assess the relationship between canopy gap characteristics and stand development.
B. Measure the effects of site preparation and crown closure on red oak regeneration.
C. Conduct an educational program on hardwood forest management.

IV. **Research Objectives:**

A. **Title of Objective**: Assess the relationship between canopy gap characteristics and stand development.

A.1. Activity: Characterize composition of 15 to 35 year old gaps created in existing red oak stands.

A.1.a. Context within the project: Advanced regeneration is important for the establishment of red oak. Study of regeneration performance in gaps formed by natural and man-caused disturbance is one means of quantifying factors important in this process. Fifteen to 35 year old red oak trees are particularly important to study as high mortality can occur in that age range due to excess inter-species competition. Such an approach becomes even more relevant as gypsy moth begins moving into southeastern Minnesota and the public places greater demands on resource management agencies for "more natural", e.g. "uneven-aged," management methods. We will characterize gaps created in existing red oak forests in southeastern Minnesota as to their size, method of creation, physical site condition, age, surrounding vegetation, composition and growth of occupying plants, etc. in an attempt to relate regeneration performance of red oak to these gap characteristics.

A.1.b. Methods: This will be a retrospective, observational study. Initially, DNR Phase II inventory records for the five counties in southeastern Minnesota will be examined to find red oak stands of various ages, existing on a variety of site conditions. One hundred to 200 stands will be selected for more detailed examination in the field; these stands will represent the cross-section of existing conditions as can best be determined from DNR records. Cursory examination of these stands will be used to validate DNR records and identify the presence of gaps. Gaps will be ocularly characterized as to size, shape, age, composition of surrounding vegetation, physical site condition, means of creation, grazing impact, and size and species of occupying individuals. A data base will be created from this information where each record in the data base will be a gap. Cross-tabulations of data base records will be made to determine the breadth of conditions available for study. If this is insufficient compared to what is known to be found in southeastern Minnesota, additional DNR records will be consulted. Upon compilation of a satisfactory base data set, a sample of 25 - 30 gaps will be selected by stratified sampling where the strata are defined by the variables ocularly observed in the field. These 25 - 30 gaps will be the focus of more intensive study. No more than two gaps will be selected from any one stand. Instances where grazing has had a recent, significant (and visible) impact will be avoided where feasible. Only gaps created between 15 and 35 years ago will be studied.

Intensive study of the 25 - 30 gaps will make more rigorous the previous observations taken. Gap perimeter will be measured and transects taken to determine gap area. Three sample locations will be established at random locations within a 20 meter distance of the border of the gap. A 10 BAF plot will be used to characterize trees 10 cm and above larger in diameter with respect to species, DBH, height, crown length, crown width, and crown fullness. A 1/300-acre plot will be used for smaller trees and shrubs exceeding 2 m in height. Depending on the size of the gap, either a complete census of tree and shrub vegetation will be taken or fixed-area plots will be established to sample for the same information. Measurements will be the same as those taken on the gap border plots. Physical site conditions in the gap will be characterized with respect to slope, aspect, percent exposed bedrock, and slope position. A soil core will be extracted to six feet or until rock is encountered. The core will be profiled for depth of horizons, percent stone, structure, and texture. A sample from the 'A' horizon will be removed for total nitrogen analysis. Fish-eye photos above brush level will be taken at a number of locations in the gap. Determinations on means of gap formation will be observation of harvested stumps and the presence of fallen trees or pit and mound topography. Where feasible and necessary, cores will be extracted from stumps or downed material and cross-dated with cores of bordering trees to determine gap age. These cores will also be used for general identification of the previously existing trees.

Two representative (in terms of size) live red oaks will be felled in the gap for detailed stem analysis. If present, recently dead red oaks will be similarly analyzed.

Initial data analysis will focus on summaries of composition of gaps sampled. Graphical based analysis will be used to determine if composition appears to be related to other characteristics of the gaps observed in the study. DBH and total height growth patterns of trees will be computed from the stem analysis data. Again, graphical based procedures will be used to detect any trends in growth rate as related to gap characteristics. If promising relationships are found, regression analysis will be used to better quantify them. Analysis of variance procedures will be specifically avoided due to the observational nature of the data collection efforts.

A.1.c. Materials: Tapes, height poles, calipers, prisms, and clinometers will be used to characterize the gaps studied and their composition. A camera will be used to photo document all gaps; this will include a fish-eye lens. An auger will be used to extract soil samples. A soil nitrogen analyzer is already available to the investigators. A chain saw will be used to fell individuals for more detailed growth analysis.

A.1.d. Budget: $40,000
Balance: $0

A.1.e. Timeline:

	7/93	1/94	6/94	1/95	6/95
Analyze DNR phase II data	***				
Visit initial stands identified		****			
Select final subset of stands			****		
Collect intensive field data			********		
Data analysis				*******	
Reporting					****

A.1.f. Status:

ADDITIONAL METHODS BACKGROUND

Field: The field work was focused on "forest gaps". A forest gap was defined as the vertical projection onto the ground of an opening in the forest canopy that had been caused by the mortality or harvest of one or more trees (gap makers). Working with MN DNR, Phase II Inventory records were used to identify 100+ stands for potential gap study; the primary criteria for stand selection were northern red oak overstory and 40-90 square feet of basal area. These stands were field visited to determine the presence of suitable gaps. In the end, we investigated every forest gap that we could find on DNR lands in Goodhue, Wabasha, Winona and Houston Counties and that met our preset criteria. For each gap, the following were quantified:

(1) gap age, aspect, slope (steepness, curvature, length);

(2) gap makers: species, DBH; degree of decay of the remains, and their azimuth, slope distance and slope change from the gap center;

(3) rock exposure (percent area), depth to bedrock (or hardpan), forest floor thickness and percent cover, A horizon thickness, soil texture of A and E horizons (samples collected in the field were analyzed for sand, silt, and clay contents in the laboratory);

(4) extended gap trees (trees that bordered the gap): species, height, DBH, and crown extensions in 6 directions (due south and every 60 degrees thereinafter in azimuth); azimuth, slope distance and slope change of each tree bole from the gap center;

(5) vegetation in the gap by plot: species, DBH and height of saplings and shrubs >4.5 ft in height and <6 inches in DBH by 1/100-acre plot; height, species, and number of seedlings, key indicator species, and degree of brush closure at 2-, 4.5-, and >4.5-ft height, by 1/300-acre plot. The plots of the two sizes were concentric. The actual number of plots increased with gap size, with one plot centered at the gap center, and additional plots, when the gap was sufficiently large, located 33 ft apart from the center plot and from each other along three transacts (0, 120, and 240 degrees azimuth);

(6) vegetation in the undisturbed area of the stand: the same as for vegetation in the gap, plus basal area measured with a 10 BAF prism. The plots were located at 0, 120, and 240 degrees azimuth, half a chain away from the gap border.

Office: All data collected in the field were transferred from field sheets into a Microsoft Excel™ data base. Data were thoroughly checked and initial analyses performed to identify suspect data items.

Further gap information was derived from the field data of extended gap trees upon verification. The derived gap factors included: aperture area (the area of canopy opening); extended gap area (the area bounded by the boles of extended gap trees); detailed slope curvature and slope steepness within each gap, based on azimuth, slope distance and slope change (from the gap center) of each extended gap tree.

Further, monthly air temperature and precipitation summaries were obtained from the Minnesota State Meteorologist for weather stations in southeastern Minnesota. The weather station data were interpolated to each gap location for the five years centering on the year of gap formation.

Two basic types of data analysis were performed: (i) summarizing the data set, with a focus on variables potentially useful in the second analysis; and (ii) developing an explanatory model for gap-to-gap variation in northern red oak regeneration. The first analysis provided an overall picture of characteristics of the studied gaps (hence the boundary conditions of the second analysis), and possibly of forest gaps in northern red oak dominated forests in southeastern Minnesota in general (within the gap-age range of the data). The second analysis addressed relations between canopy gap characteristics and northern red oak regeneration.

We defined northern red oak regeneration in terms of cumulative total height per 4.3-ft radius plot. Cumulative total height is essentially stems per area weighted by size. Besides describing the current amount of regeneration, it may also serve as an indicator of relative competitiveness (hence future success) when divided by regeneration of other species. The reference plot size of 4.3-ft radius was chosen as it is often used in the literature to represent the area needed by a 4-inch-DBH northern red oak in a fully-stocked sapling stand. Further, when expressed in a small area such as this, the amount of regeneration can be conveniently visualized (compare 1 ft/4.3-ft radius with 750 ft/acre).

In general, cumulative height of individual species in forest gaps should be a function of pre-canopy-opening regeneration, post-canopy-opening establishment, and regeneration growth, each of which in turn depends on site and gap characteristics. Specifically,

$$[1] \qquad H_{gap} = H_0 e^{Bage} + h_1 AGE e^{B(cAGE)},$$

where

- H_{gap} is total height (ft/4.3-ft radius) of northern red oak in a gap;
- e is the base of natural logarithm (≈2.7183);
- H_0 is pre-canopy-opening regeneration (ft/4.3-ft radius);
- b is annual exponential growth rate (/year);
- AGE is gap age (year);
- h_1 is mean annual recruited establishment (ft/4.3-ft radius/year) after gap formation;
- cAGE is the average number of years of growth, weighted for nonlinearity, of post-canopy-opening recruitment (year).

We substituted for H_0, h_i, and b, various site and gap factors as surrogates, and fit the equation to cumulative-height data by way of nonlinear regression in order to test the significance of the factors and to develop an explanatory model for northern red oak regeneration in forest gaps. Effort was concentrated on site and gap factors that were easy to quantify and interpret and that are stationary rather than transient. Specifically, screened site factors included: elevation, aspect, slope (overall, upper and down slopes from the gap center), slope curvature (upper/down slope ratio, ratio of left- to right-side slope perpendicular to the aspect), slope length (total, upper, dispersal); soil texture, soil depth, rock outcrop as percent of gap area; site index. Gap factors included: gap area (canopy aperture, extended gap), type of disturbance creating the gap, northern red oak as percent of gap makers or extended gap trees, mean May-October monthly precipitation for the five years centering on the year of gap formation; cumulative height of regeneration of all species, and of species other than northern red oak.

The criteria for declaring a factor to be significant and for inclusion in the final model were: (i) it was statistically significant based on a standard F-test (with a probability of mistaking a coincidental correlation as a true correlation to be less than 5 percent); (ii) it contributed at least 10 percent of the variance that was not already accounted for by other model factors; and (iii) the contribution of the factor was not due to improvement of the regression fit to only a few data points. Apparent outliers were excluded from final analysis to focus on the "main-stream data" trends.

RESULTS

The data base: In total, 36 forest gaps were examined (see Figure 1 for locations), among which 16 gaps had corresponding stand information. Together, the 36 gaps were distributed fairly evenly along the gradient of each measured gap/site factor within the data range (Figure 2).

Physical factors: The gaps ranged 13-36 years in age, with a median of 20 years (Figure 2.a). Gap areas ranged 19-60 ft in radius for extended gaps, or 10-42 ft in radius for aperture areas (Figure 2.b). As would be expected, the two areas were highly correlated. Canopy apertures were about 60 percent of extended gap areas after the latter reached a minimum of 14.7-ft radius; that minimum appeared reasonable compared with the overall average crown size (12.8-ft radius) of all the extended gap trees, or the overall average crown space (10.5-ft radius) available to each stand tree (plot size/number of trees) for all the stand plots sampled.

While data distribution was fairly even over two-thirds of the circular range, there was only one gap investigated within the remaining third range, i.e., from SSW to NW (205-322 degrees) (Figure 2.c). This missing range is especially significant as it contains the projected aspect with predicted maximum northern red oak regeneration (245 degrees; see below).

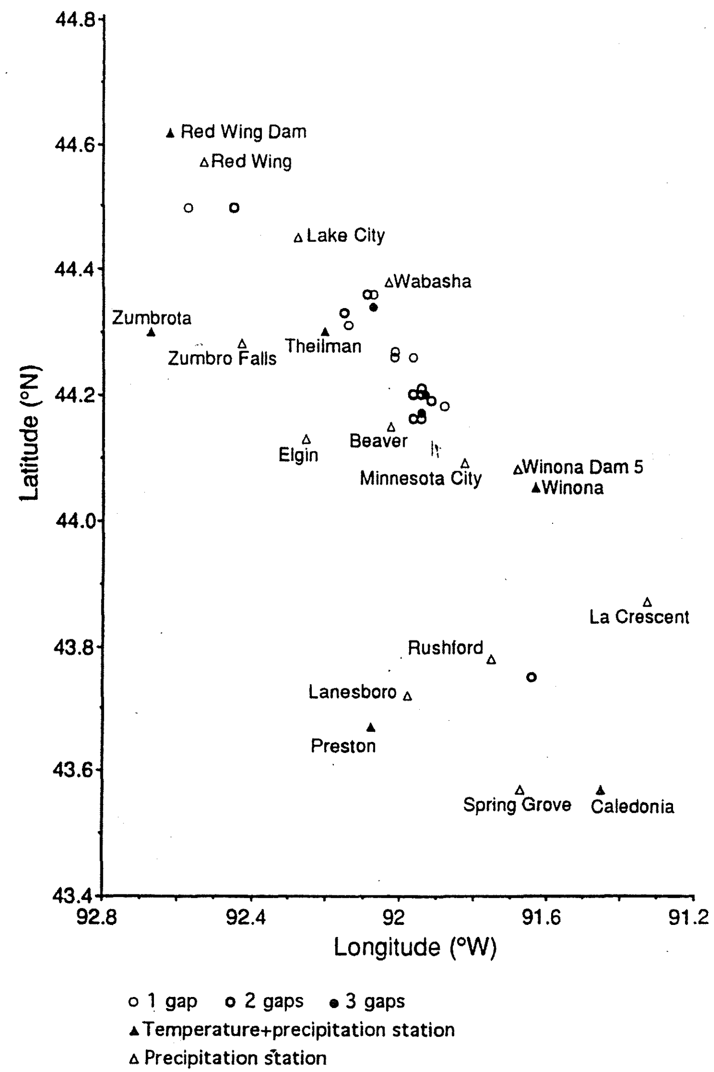

Figure 1. Gap locations and nearby weather stations.

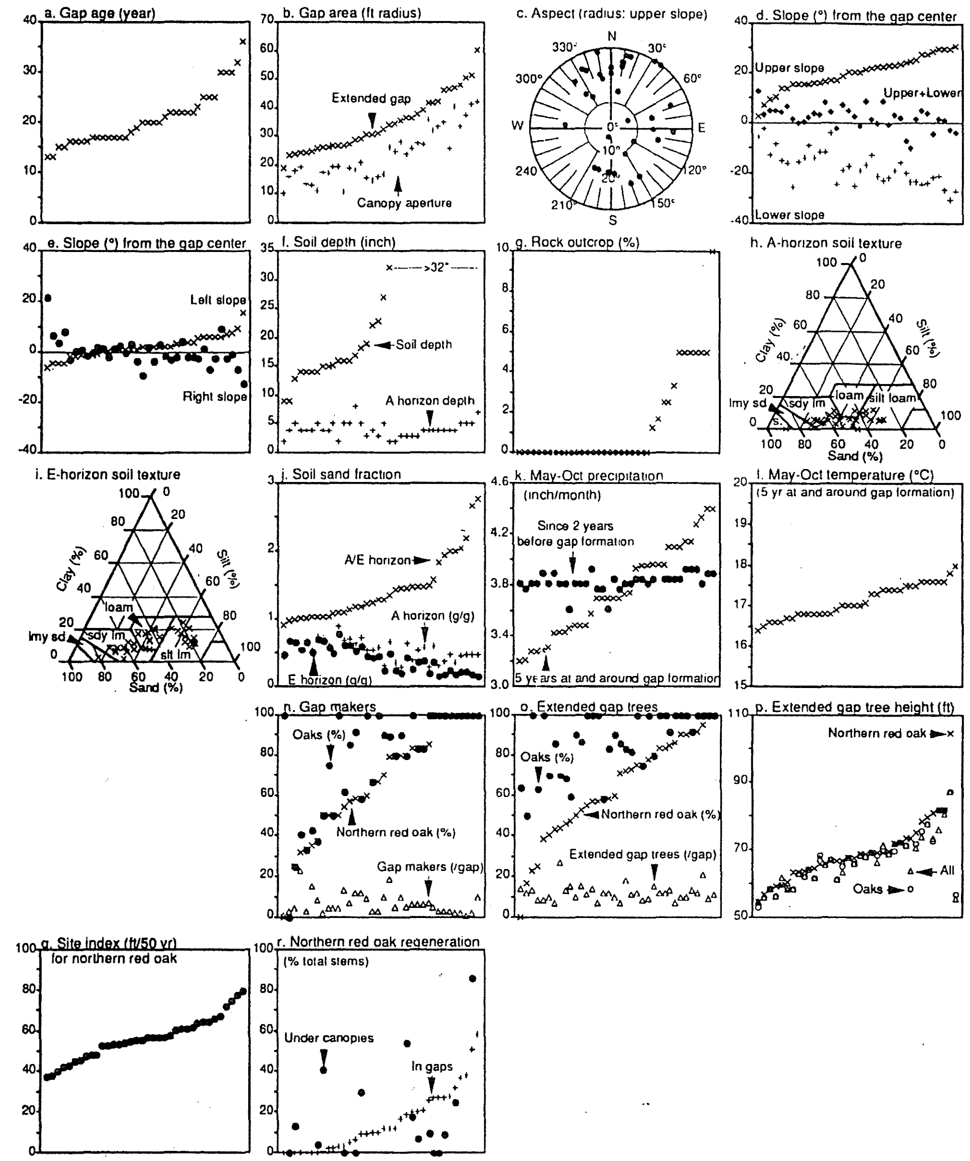

Figure 2. A data summary for the forest gap study (the horizontal axes are gaps, following the order of the title or select variable).

None of the 36 gaps was located in a depression, as upper slope degree rising from the gap center was positive, and lower slope was negative, in all the gaps (Figure 2.d). Fifteen of the gaps were on a more or less straight slope (i.e., upper and lower slopes differed by less than 3 degrees or 5 percent rising), 4 gaps were on a convex slope, and the remaining 17 on a concave slope. The upper slope ranged 3-31 degrees, or 5-60 percent rising. A steep upper slope was associated more with a convex slope than with a concave slope (Figure 2.d). The left and right slopes perpendicular to the aspect azimuth were fairly flat, or otherwise tended to be straight overall (Figure 2.e).

Soil depth was greater than the sampling maximum of 32 inches for nearly half of the gaps (16 gaps). Most of the remaining gaps (16 gaps) had a restricting zone located within 12-23 inches below the ground surface (Figure 2.f). This relatively clustered distribution may have contributed to an indicator step function being sufficient for soil depth in the regeneration model (see below). A horizon thickness showed no correlation with overall soil depth, and covered a similar range regardless of presence or absence of a restricting zone within 32 inches below the ground surface (Figure 2.f). There was rock outcrop in one-third of the gaps, ranging up to 10 percent of ground surface area (Figure 2.g).

Most of the gaps had a soil texture of sandy loam (21 gaps), or silt loam (8 gaps), for the A horizon (Figure 2.h). The soil texture for the E horizon was about equally divided among loam, sandy loam, and silt loam (11 or 12 gaps each; Figure 2.i). Sand fraction ranged 29-89 percent in A horizon, and 17-80 percent in E horizon; the sand fraction ratio between the two horizons ranged 0.9-2.8 (Figure 2.j).

Mean May-October monthly precipitation for the five years at and around gap formation varied widely among the gaps: ranging from 3.2 to 4.4 inches per month (Figure 2.k). Gap-to-gap differences diminished to less than a third of an inch, when precipitation was averaged over the entire gap history (up to the year of sampling). This shift primarily reflects great temporal variation at given locations, but relatively small variation location to location. Mean May-October air temperature varied little from gap to gap, ranging 16.4-18 degrees Celsius (Figure 2.l).

<u>Vegetation</u>: For the 16 sampled stand plots, northern red oak consisted of 58 percent of the basal area on average, ranging from 15 to 100 percent; the corresponding values for all oaks combined were: 89, 46 to 100 percent, respectively. Besides northern red oak, oak species were primarily white oak and black oak with occasional bur oak. Other tree species were shagbark hickory, bitternut hickory, American elms, black cherry, with a minor presence of butternut, black walnut, basswood, red maple, trembling aspen, and bigtooth aspen.

The 36 investigated forest gaps resulted from the mortality of 1-23 trees (Figure 2.n), about 10 percent of which, distributed among 10 gaps, were due to direct logging. Northern red oak consisted of the majority of gap makers in 26 gaps, and oaks in all 36 gaps. All logged gap makers were either northern red oak (81 percent) or white oak. The forest gaps were enclosed by 7-27 extended gap trees, of which 50 percent or more were northern red oak in 29 gaps (Figure 2.o). The proportions of northern red oak, and oaks in general, as gap makers or extended gap trees spanned a range similar to their proportions in the undisturbed stands. As would be expected, both gap makers and extended gap trees tended to increase in number with gap size (not shown).

Extended-gap tree height, averaged by gap, fell within the range of 53-82 ft, similar among northern red oak, all oaks or all species combined (Figure 2.p). There was an exception to that range where northern red oak was 105 ft on average, compared with 87 ft for others. The average height of selected site index trees (extended gap trees and/or in-stand trees, 1-3 per gap/site) spanned a similar range (51-93 ft, with both a mean and a median of 72 ft), their ages varied from 43 to 140 years. These values were equivalent to a site index of 38-80 ft (on a 50-yr base) for northern red oak in the Lakes States Region (Figure 2.q).

The number of tree species present as saplings and seedlings under forest canopies ranged from 2 to 8 species per plot (5 on average). Tree species diversity in forest gaps increased slightly, with a maximum of 10 species, and an average of 6.3 species per gap (not shown).

Under forest canopies, northern red oak accounted for up to 86 percent of stems present, with an average of 18 percent and a median of 10 percent. When all oaks were included, the maximum still held, with an average of 25 percent, and a median of 15 percent. The average percent count of northern red oak, or oaks in total, decreased somewhat in forest gaps, being 15 and 18 percent, respectively. Actual change, however, varied widely from gap to gap (Figure 2.r).

In-depth analysis of northern red oak regeneration: The cumulative height of northern red oak regeneration under forest canopies ranged from 0 to 2.7 ft/4.3-ft radius, with an average of 0.7-ft/4.3-ft radius. It about doubled in forest gaps, with an average of 1.5 ft/4.3-ft radius and a range from 0 to 5.3 ft/4.3-ft radius. Where both data were available, regeneration in forest gaps and under forest canopies were closely correlated (Figure 3.a).

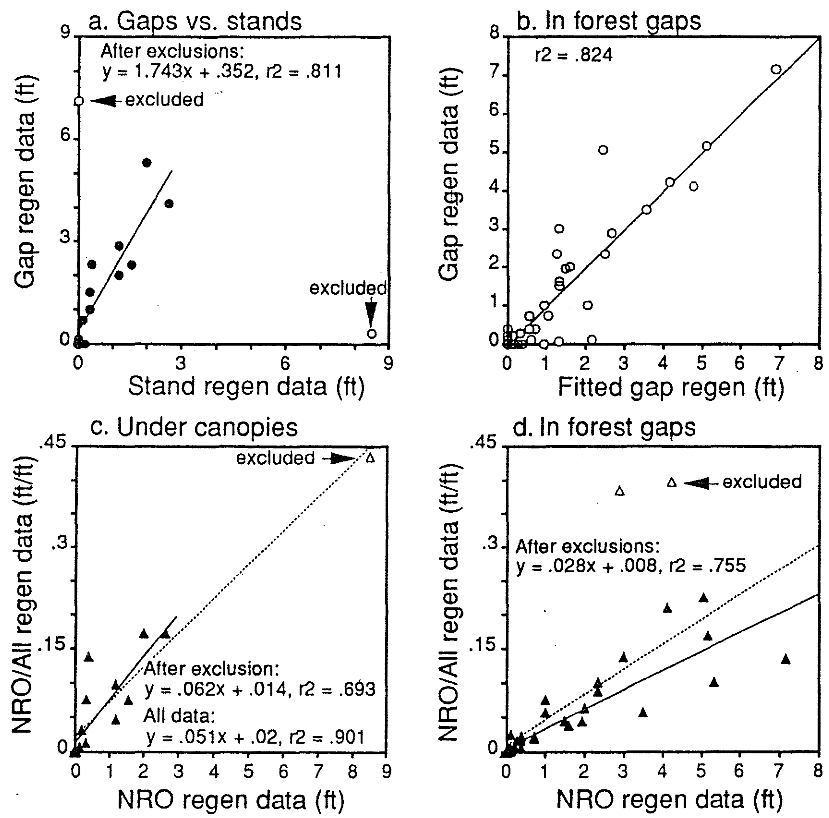

Figure 3. Regeneration of northern red oak NRO (cumulative height: ft/4.3 radius).

The cumulative height of northern red oak in forest gaps conformed to Equation 1 well, with pre- and post-canopy-opening regeneration and annual growth rate represented by a few rudimentary site and gap factors. In particular,

$$[2] \quad H_{gap} = H_0 e^{\frac{SLOPE_{up}+1}{208}AGE} + h_1 AGE e^{\frac{SLOPE_{up}+1}{208}(0.937AGE)},$$

where

$$[3] \quad H_0 = 0.179e^{1.24(SAND_A/SAND_B-1)-1.08D_s},$$

$$[4] \quad h_1 = 0.0919\left\{AREA\left[1+\left(1-e^{-0.0671SLOPE_{up}}\right)\sin\left(\frac{ASPECT+205}{c}\right)\right]-0.108\right\},$$

and

- $SLOPE_{up}$ is degree rising of upper slope (°) from the gap center,
- $SAND_A$ is fraction of sand in A horizon (g/g),
- $SAND_E$ is fraction of sand in E horizon (g/g),
- D_s is a soil-depth indicator (1 if soil depth is greater than 32 inches, and 0 otherwise),
- AREA is extended gap area (acre),
- ASPECT is aspect in azimuth (degree), sin is sine,
- c is the inverse of period ($360/2\pi$).

Equation 2 accounted for 82 percent of variance in the data for cumulative regeneration height (or over 90 percent when two data points were excluded; Figure 3.b). That proportion rose to 98 percent for gaps where both stand and gap regeneration data were available, when pre-canopy-opening regeneration H_0 was substituted with data of regeneration under forest canopies. Estimates from Equation 3 were highly correlated with data for under-canopy regeneration (75 percent of variation explained). Equation 2 implies the following:

(1) Annual growth rate is a function of degree rising of upper slope, an indicator of water and nutrient inflow from upper slope. It is about half of a percentage point (i.e., 1/208) where the gap is in a flat

area, and increases at the same rate as the degree rising of upper slope of the gap.

(2) Regeneration of northern red oak under forest canopies tends to increase exponentially with the ratio of sand contents in surface A horizon and depository E horizon. Compared with a unity ratio, regeneration would more than triple (i.e. increase by a factor of $e^{1.24}$) with a doubling of that ratio, or be reduced to 54 percent when the ratio is cut in half. The ratio possibly represents a negative index of water percolation through the soil, and hence water availability in the surface horizon. So does the effective soil depth: a restrictive layer fairly close to the ground surface would favor water retention. Regeneration tends to triple where this layer is present within 3.2 inches of the surface, compared with gaps where this layer is deeper.

(3) Establishment of northern red oak recruited after gap formation is primarily a function of gap area adjusted for slope and aspect. The minimum gap size for given regeneration is not fixed, but varies with slope and aspect. In general, the minimum gap size is about 39 ft in radius (i.e., 0.108 acre) on flat terrain. The smallest minimum size tends to occur at WSW (245 degrees) where it gets even smaller as slope becomes steeper (28-ft radius at 30-degree slope, the upper limit of our slope data; see Figure 2.c). The largest minimum size tends to be required at ENE (65 degrees) where it becomes even larger with steep slope (106-ft radius at 30-degree slope, or 76-ft radius at 20-degree slope, the upper limit of our slope data at that aspect). Most of our gaps, however, were located at aspects where slope steepness did not seem to make much difference (i.e., the sine function in Equation 4 is equal to zero at an aspect of 155 or 335 degrees; Figure 2.c). Given slope and aspect, each 1-acre increase in gap size above the minimum size yields about 1.1 inch/4.3-ft radius increase in annual establishment of northern red oak from recruitment after gap formation. Note that this rate is of "established" recruitment. It is not uncommon to find abundant northern red oak seedlings following a bumper-acorn year, but few survive.

When a gap area falls below the minimum size, h_1 in Equation 4 becomes negative, thereby implying a mortality of regeneration that originated before gap formation. That mortality is equivalent to 1.1 inch/4.3-ft radius/year for every 1-acre decrease in gap area.

Gap size, slope steepness and aspect may be viewed as surrogates primarily for light availability, but also for temperature and moisture conditions of both air and soil. Because of the solar trajectory in the Northern Hemisphere, a north-facing slope shades a forest gap from solar radiation and reduces radiation intensity per unit gap area, whereas the opposite is true for a south-facing slope. This polarizing effect of aspect on solar radiation tends to be aggravated by slope steepness. Soil clay content and slope steepness also vary with aspect in our data set. The projection that WSW (245 degrees) rather than south tends to yield maximum regeneration suggests that more light does not necessarily yield more regeneration of northern red oak. Either other factors override the effect of light, or there is a threshold light level beyond which regeneration of northern red oak is impaired. Mortality of advance regeneration may also occur when the gap falls below a certain size, because of frost-pocket formation, light level tipped in disfavor of northern red oak, etc.

It is important to emphasize that under-canopy regeneration, post-canopy-opening recruited establishment, and annual growth rate, as interpreted in Equations 2, 3 and 4, are difficult to distinguish statistically in fitting the equation. Arguably, the three may be affected by similar site and gap factors in reality. Multiple representation of individual factors in the model, however, would result in over-parametrization and numerical uncertainty, and would reduce the predictive power of the model.

Hypotheses testing on northern red oak regeneration: In a one-on-one simple regression without adjustments for other factors, the cumulative height of northern red oak regeneration, both under forest canopies and in forest gaps, showed no significant correlation with any studied site/gap factor except for soil texture. Among soil texture variables, the composite sand content ratio between A and E horizon was by far the best indicator, explaining 40 and 30 percent of gap-to-gap variation for under-canopy and in-gap regeneration, respectively. Hence, there appears no fast one-factor rule to reliably predict regeneration of northern red oak.

Gap age, area, aspect, upper-slope steepness, and presence/absence of restricting zone within 32 inches below ground surface, in addition to A:E horizon sand ratio, became useful predictors when taken together as summarized in Equation 2. Advance regeneration under the forest canopy was also a good indicator of regeneration success after gap formation, although the predictive power was substantially improved after the other model factors were taken into account. The fit of Equation 2 to our data was remarkably tight. Independent data are needed to validate the model, particularly in light of the lack of data in a third of the possible range for aspect, and somewhat clustered data for soil depth as described earlier (Figures 2.c, f).

Other studied gap/site factors, while potentially influential in theory, had little quantitative effect on northern red oak regeneration with or without adjustments according to Equation 2. They included: slope curvature, position, and length; rock outcrop; gap-creating method, northern red oak being gap makers or being extended gap trees; site index; precipitation at and around gap formation.

With or without adjustments for site/gap factors, the cumulative height of northern red oak regeneration, both under forest canopies and in forest gaps, was not correlated with total regeneration of all species combined. This lack of relationship appears to support the idea that competition between regeneration plants was limited for our data sites, as was also evidenced by the close fit of growth-based Equation 2 to our data for northern red oak regeneration.

Further, northern red oak regeneration was not correlated with the presence/absence of particular plant species in the gap. Ferns are sometimes suspected to impair oak regeneration by forming suffocating dense canopies and root mats and by a possible allelopathic effect. Among the 19 gaps with ferns, only one gap did not have northern red oak (seedlings or saplings), and 11 gaps did not have northern red oak saplings. Only seedlings were found in one gap with a particularly dense fern cover, but above average regeneration was found in another.

Both under forest canopies and in forest gaps, the cumulative height of northern red oak regeneration was closely correlated with its proportion in total regeneration of all species combined (Figures 3.c, d). This strong correlation suggests that, assuming that relative proportion to be an index of competitiveness, the amount of northern red oak regeneration at present is a good indicator to its future success at the location. This suggestion is further supported by the close correlation between under-canopy and in-gap northern red oak regeneration discussed earlier (Figure 3.a).

A.2. Activity: Study the genetic makeup of red oak regeneration found in gaps in relation to existing red oak overstory.

A.2.a. Context within the project: Red oak species vary in commercial importance and wildlife and aesthetic appeal. Harvesting and natural means of removal of individuals from a site obviously impact future species composition on the site. We will study the genetic makeup of red oak individuals occupying gaps and attempt to associate that with the composition of a previously existing overstory.

A.2.b. Methods: Twenty gaps in the data base of Activity A.1., but not selected for detailed study will be visited for collection of material. Four overstory and four understory (but greater than 2.5 m tall) individuals will be located and tagged for further study in or associated with each gap. The individuals will be chosen to cover the range of red oak species (and seeming hybrids) present on the site. During the growing season, leaf samples from the upper crown and standard morphological measurements will be taken. These latter measurements will include DBH, height, crown size, crown fullness, number of retained dead branches, etc. Photos of the bark and a vertical (upward looking) photo of the crown will be taken. During the winter months, bud samples from the upper crown will be removed from the trees.

Leaf tissue and winter bud samples will be sent to Michigan State University for isozyme analysis. Whole leaf samples will be scanned for morphological analysis.

Data analysis will begin by relating genetic information to observed tree and leaf morphological observations. Graphical and multivariate exploratory techniques will be used. Overstory versus understory genetic makeup relationships will be examined by categorical data analysis procedures.

A.2.c. Materials: Standard mensurational devices, such as tapes and clinometers, will be used to collect morphological characteristics in the field. Photos will be taken of tree bark and crowns, the latter with 200 mm and fish-eye lens. Bud and leaf samples will be collected with the aid of a shotgun and #2 shot. A computer based scanning system will be used for leaf shape analysis. Storage and laboratory apparatuses required for isozyme analysis are already available.

A.2.d. Budget: $10000
Balance: $0

A.2.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Identify study individuals	*****				
Make initial collections		***			
Lab analysis		****			
Data analysis			********		
New collections (if required)				****	
Reporting					****

A.2.f. Status:

ADDITIONAL METHODS BACKGROUND

Three collection visits were made to southeastern Minnesota for this part of the project. In the first two visits, additional pure black oak materials were collected; lab analyses from a previous LCMR-sponsored hardwood study had indicated that we may have lacked such material in our earlier collections. Gaps used in Objective A.1. were also surveyed to identify which would be sampled for collection of materials for isozyme analysis. During the third trip, materials were collected from potential mother trees and associated regeneration at five locations. A full mix of black, red, and hybrid individuals were included in the collection effort.

A second contract was let to the USDA Forest Service to collect seeds from individual mother trees of different red and pin oak hybrids and to study early growth habits. Collected seeds were evaluated and planted in nursery beds. Reared seedlings were measured after one year of growth for various morphological characteristics.

RESULTS

Mature leaves were collected from 117 oak trees from southeastern Minnesota for the purpose of determining their morphological taxonomy. Most trees were assigned to either northern red oak *(Q. rubra)*, northern pin oak *(Q. ellipsoidalis)*, and black oak *(Q. velutina)* species, although there were a number of trees with questionable taxonomic affinity, suggesting introgressive hybridization. A morphological data set was collected for each leaf including leaf length, width, petiole length, and number of bristle tips. The data set was analyzed with principal components analysis (PCA). The results from the PCA was that there was no clear separation among species groups by traditional morphological methods (Figure 1). However, the high degree of overlap in PCA space is indicative of hybridization. This work will be presented in August 1995 at the Annul Meeting of the Botanical Society of America, in San Diego, CA.

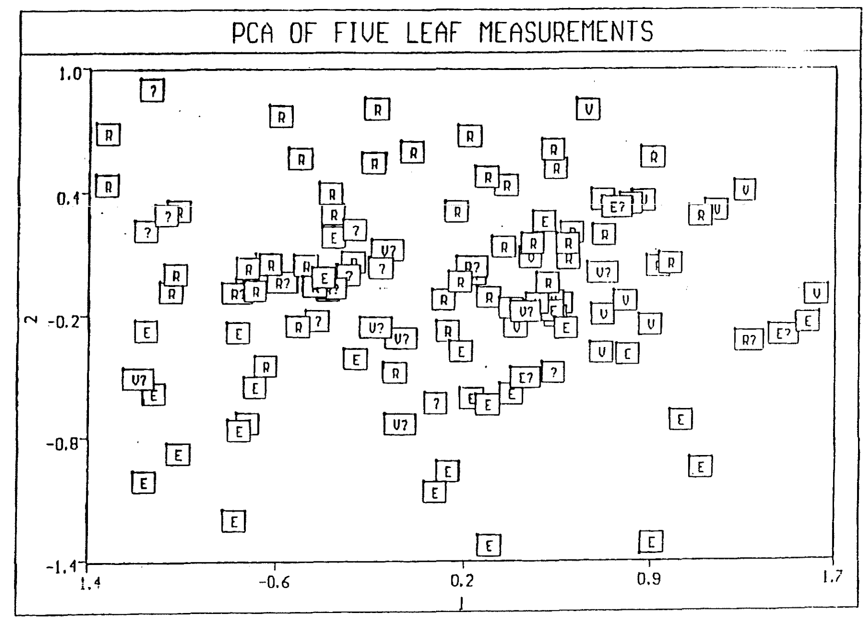

Figure 1. PCA of five leaf measurements from oak trees from SE Minnesota. R = northern red oak; E = northern pine oak; V = black oak.

Random Amplified Polymorphic DNA markers were analyzed for oak genotypes from the above populations near Kellogg, Wabasha, and Minnieska in southeastern Minnesota. Morphologically pure species of northern red oak, northern pin oak, and black oak, and their putative hybrids were studied as in the morphological study. Genotypes were screened using 46 PCA primers; 49 of them produced useful polymorphic fragments for species hybrid identification. Most polymorphisms were shared across species, although a few were specific to red, pin, and black oak. Putative hybrids contained combinations of these fragments in some cases. The above methods show promise for identifying species and species hybrids, but more individuals need to be analyzed to verify this conclusion.

To examine the relationship between mother tree and seedlings, seedlings were raised from acorns collected from 30 individual mother trees representative of northern red oak (NRO, *Quercus rubra L.*), northern pin oak (NPO, *Q. ellipsoidalis* E.J. Hill), and their hybrids (INT). Ten trees were chosen on the basis of leaf, canopy, and bole characteristics to represent each of these three groups. The trees chosen as representing hybrids (INT) were still considered "good" trees by Lake States Forest Service geneticists; those representing NRO would be considered "excellent" trees by this same group. One-year old seedlings were reared and characterized prior to outplanting to evaluate subsequent growth. The genetic position along the spectrum between these two interbreeding species of both mother trees and seedlings is being estimated by leaf morphometry and isozyme analysis.

Seedlings reared from seeds of either NRO and INT mother trees were similar, but distinct from those reared from NPO mother tree acorns (Figure 2). Data for height, number of first-order lateral roots, and taproot area gave results similar to those shown for root collar diameter.

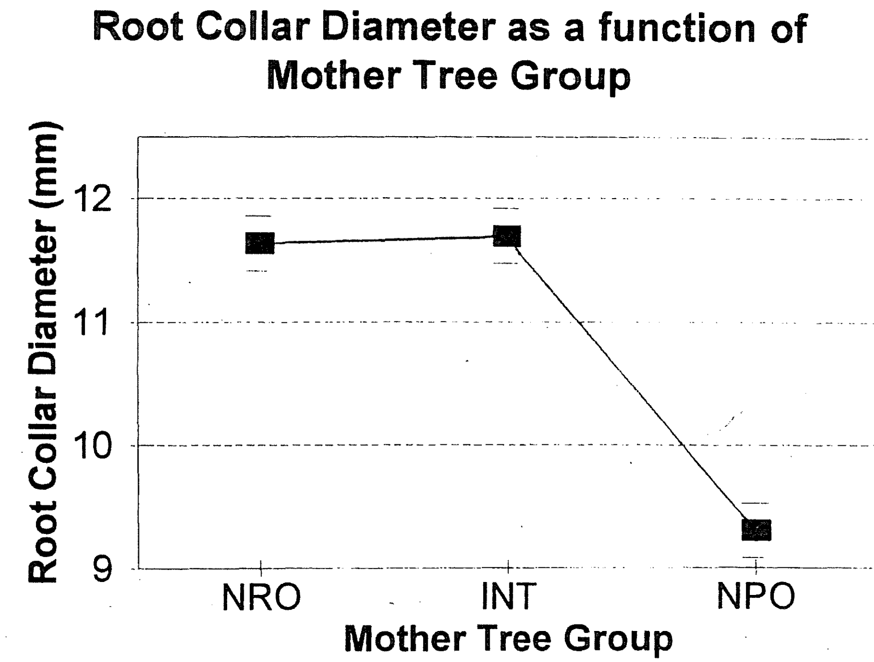

Figure 2. Root collar diamter as a function of mother tree group. First-year seedlings reared from acorns collected from 30 individual mother trees were characterized. Ten mother trees represented each of three groups: northern red oak (NRO, *Quercus rubra* L.), northern pin oak (NPO), *Q. ellipsoidalis* E. J. Hill), and their hybrids (INT). Data are the average across the 10 mother trees representing each group ± standard error of the mean. Ten seedlings from each of the 4 replicates were characterized for each mother tree.

When data were plotted as a function of acorn volume, again seedlings from the NRO and INT mother tree groups were similar to one another, but distinct from those from the NPO mother tree group (Figure 3). Thus, seedlings from other trees intermediate between northern red oak and northern pin oak were not distinguishable from those from mother trees highly northern red oak in appearance. However, seedlings from northern pin oak trees were distinct.

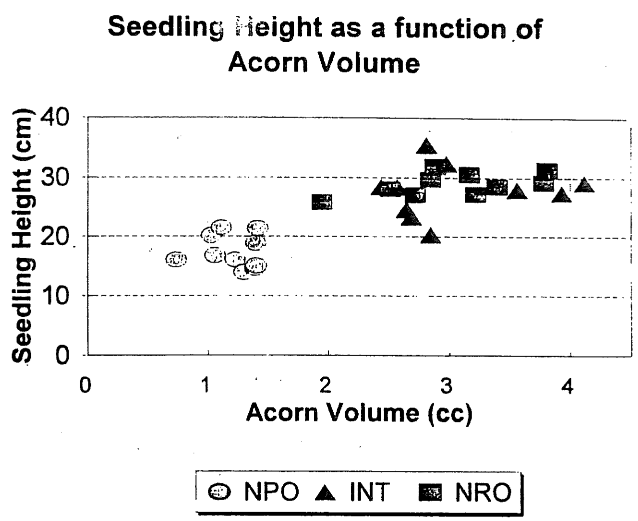

Figure 3. Seedling height as a function of red oak acorn volume. First-year seedlings reared from acorns collected from 30 individual mother trees were characterized. Ten mother trees represented each of three groups: northern red oak (NRO, *Quercus rubra* L.), northern pin oak (NPO, *Q. ellipsoidalis* E. J. Hill), and their hybrids (INT). Height data are the average of ten seedlings from each of 4 replicates; acorn volume data are the average of four replicate displacemnt measurements of 50 acorns.

Genetic positioning of the mother tree groups is ongoing. However, data to date are consistent with the characterization of the mother trees based on seedling characteristics. Leaf morphometry data fell into [illegible] groups:

(a) Number of bristle tips, leaf blade width, and petiole length did not distinguish any differences in mother trees;

(b) Leaf blade length and distance from the leaf base to the widest point of the blade discerned no difference between INT and NRO although NPO was fairly distinct from either of the other two groups; and

(c) Leaf blade dissection, perimeter per unit leaf area, was the only term which showed differences among all three mother tree groups.

These "raw" data and the "ratio" data calculated from them (leaf blade width per unit length, petiole length per unit blade length, distance to widest point as a fraction of leaf blade length) were then used in cluster and principal components analyses. Both these approaches with either "raw" data or "ratio" data were fairly successful in discerning NPO from INT and NRO, but not in discerning INT from NRO. Using the "ratio" data, one of the pin oaks (NP9) clustered with the NRO/INT group while the other 6 NPO mother trees formed a second cluster (Figure 4).

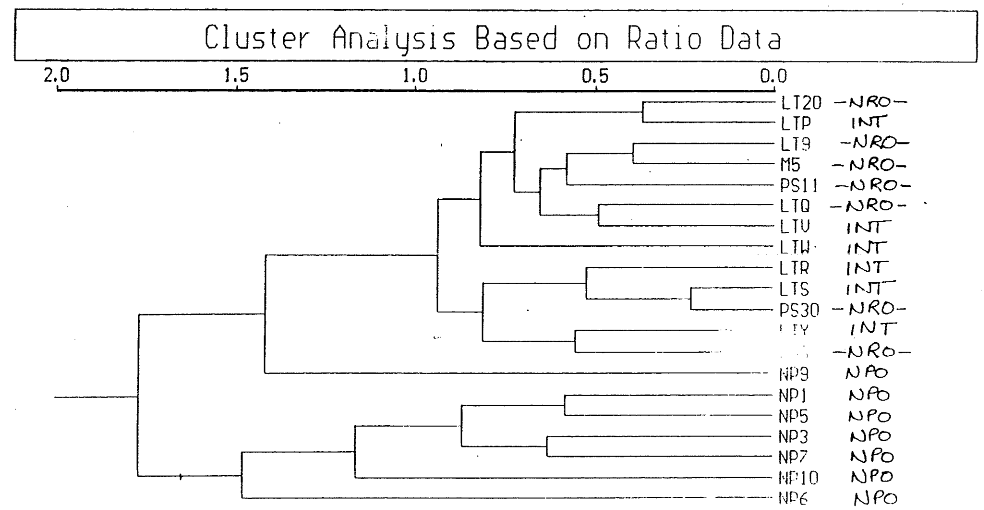

Figure 4. Cluster analysis results showing apparent relatedness among mother trees based on "ratio" data such as leaf blade width per unit length, petiole length per unit blade length, distance from base of leaf to widest point as a fraction of blade length. Mother tree name is given down the right side of the figure along with the mother tree group to which it belongs.

Principal components analysis also placed NP9 in the group of data for the NRO/INT group. Discriminate analyses using "raw" data misclassified 3 of 25 NPO leaves as INT leaves, 9 of INT leaves as NRO, and 8 of the NRO leaves as INT; none of the NRO or INT leaves were misclassified as NPO leaves using these data.

These results indicate that there is, in general, a good separation of the NPO from the other two groups, but no clear separation between NRO and INT mother trees. Further there is some indication that at least two trees in the NPO group (NP6 and NP9) may also be hybrids with a greater contribution by NPO than NRO.

Isozymes of 6 enzyme systems representing 9 putative loci (LAP-1, SKDH-1, MDH-1, MDH-2, MDH-3, IDH-3, 6PGDH-2, PGI-1, and PGI-2) are being analyzed electrophoretically. Mother trees in the NRO and INT groups appeared monomorphic for MDH-1, MDH-2, MDH-3, PGI-1, and IDH-3; one mother tree was heterozygous at both the SKDH-1 and 6PGDH-2 loci. Two alleles were found at LAP-1; mother trees analyzed to date from one location carried a slow migrating band while those from a second location carried either fast-migrating band or were heterozygous (2 mother trees). Although no mother trees from the NPO group have been analyzed yet, the data for the trees analyzed in the NRO and INT groups is consistent with the leaf morphometry data.

In summary, all data to date suggests that mother trees and seedlings represent only two, not three, distinct groups representing northern pin oak and northern red oak plus hybrids. The possible segregation of two groups of northern pin oak on the basis of leaf morphometry is interesting. Although much analysis is still required, it does appear that any tree which appears to be considered either as a "good" or "excellent" tree by current visual classification standards can yield an equally large seedling. None of the criteria, to the extent they have been tested to date, is able to discriminate among these "good" to "excellent" mother trees to predict larger seedling size. Conversely, both visual characterization and leaf morphometry are capable of discerning highly northern pin oak mother trees which produce small seedlings. Much data collection and analysis remains; in particular, isozyme analysis of mother trees in the NPO group, seedling isozyme and morphometry data, and characteristics of subsequent growth could provide different perspectives not evident with the data to date.

B. Title of Objective. Measure the effects of site preparation and crown closure on red oak regeneration.

B.1. Activity: Establish field trials with alternative crown closure and site preparation treatments.

B.1.a. Context within the project: We expect to learn how well oaks naturally regenerate, survive, and grow under different amounts of crown closure created by harvesting timber in clearcut and shelterwood systems. We also will measure oak regeneration, survival, and growth under different site preparation treatments aimed at controlling undesirable trees, shrubs, and herbaceous plants that compete with oak seedlings.

B.1.b. Methods: We will select at least three woodlands that have canopies dominated by mature oaks and replicate our trials in each of these woodlands. In each woodland we will harvest timber in two blocks (each 6 to 8 acres in size) to create residual canopy covers of approximately 0 percent and 33 percent. Harvesting will be scheduled during late fall after the acorns drop or during winter.

Within each 6- to 8-acre harvest block, we will conduct five different site preparation treatments. Each site preparation treatment plot will be approximately 1 acre in size. Site preparation treatments are intended to control nonmerchantable, undesirable trees, shrubs, and herbaceous plants. These site preparation treatments will include:

(1) Control plot where no site preparation occurs.

(2) A bulldozer will be used to knock down and uproot undesirable woody trees and shrubs. We propose this treatment as a practical method of controlling competition on gentle slopes. Bulldozing will occur in late summer or early fall prior to harvest. The ideal time would be after the acorns drop, but before leaves fall, but it may not be possible to schedule the work during this short interval.

(3) Herbicides will be applied to nonmerchantable, undesirable trees, shrubs, and herbaceous vegetation. A variety of application methods will be considered and used as appropriate depending on the species and size of plants to be controlled. Foliar application, basal spraying, girdling and spraying, and cut-stump applications

may be used. Herbicides will be applied in late summer or early fall. Existing oak regeneration in these blocks will be cut at ground level by hand prior to the herbicide application to protect it from the herbicide. Oaks cut in this manner are expected to resprout.

(4) Prescribed burning will be used to control small woody trees and shrubs. Appropriate times for prescribed burning include mid-spring (late April or early May) and occasionally early fall. It is more likely that burning can be accomplished in the spring. Burning will be conducted when forest floor litter is sufficiently dry, air temperatures and humidities are moderate, and wind speeds are low. Eight-person crews will carry out the burns.

(5) Tree tops will be dragged over the site with a skidder following timber harvesting. The purpose is to knock over and damage or kill woody understory vegetation.

Within each 1-acre site preparation treatment area, we will designate one 40 meter by 45 meter plot. In this plot we will measure percent crown closure and basal area per acre, and the number of trees per acre by species for all trees larger than 10 centimeters in stem diameter (DBH).

Within each 40 meter by 45 meter site preparation treatment plot, we will randomly choose locations for two understory plots, each 15 meters by 15 meters in size. In these understory plots we will count saplings (2.5 centimeters to 10 centimeters in diameter) by species.

Within each 40 meter by 45 meter site preparation treatment plot we will randomly choose locations for 4 seedling plots, each 3 meters in radius. In these seedling plots we will count tree seedlings (< 2.5 centimeters in diameter) by species and estimate the percentage of ground surface covered by dominant herbaceous plant species.

Within each seedling plot (3 meters in radius), we will randomly choose locations for 4 seedling plots, each 1.5 meters in radius, in which we will count seedlings by species and measure the height and stem diameter of each seedling. We also will record the type and extent of any damage that exists on seedlings (e.g., deer browse, insect, disease).

After further consideration of statistical analysis, woodland conditions, and results from on-going regeneration research, we may decide to change the shape of plots described above and we may make slight changes in plot size. Plot measurements will be taken before any site preparation or harvesting occurs and at the end of each growing season during the course of this project. Seedling damage measurements will be taken at the beginning and end of each growing season so that we can be better informed about the time when damage occurs and evaluate whether the time of year when damage occurs has a significant effect on tree growth and survival.

In addition to the plots and measurements described above, we will measure specific environmental conditions (e.g., light level and seedling moisture stress) and indices of competition for a number of oak seedlings under every combination of harvest and site preparation treatment so that these can be related to oak seedling survival and growth.

Vegetation responses to the treatments will be analyzed by standard analysis of variance techniques. Regression analysis may be used to further investigate what appear to be key relationships among variables.

B.1.c. Materials: A bulldozer will be used for one site preparation treatment. Herbicides applied as foliar sprays may be applied by backpack mist blower or hydraulic sprayer as appropriate. An axe and/or chainsaw may be needed to girdle or fell undesirable trees. Prescribed fires will be controlled by hand tools and water trucks. A tape measure, diameter tape, height pole, 10 BAF prism, and caliper will be needed to measure overstory and understory vegetation.

B.1.d. Budget: $74,000
Balance: $0

B.1.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Identify research sites	****				
Apply herbicide & bulldozer treatments to understory	****				
Apply prescribed burn treatment to understory		**	or	**	
Harvest stands		****			
Measure vegetation response to treatments			**		
Analyze data and report results				**********	

B.1.f. Status:

At a meeting with the Minnesota DNR's Region 5 forestry staff on July 29, 1993, the DNR representatives offered to help us identify research sites, to locate contractors and equipment needed to perform the site preparation treatments, to provide staff support for field work as schedules and funds permitted, and to set up and administer the timber sale contracts.

Based on discussions with DNR foresters and field checks of some of the sites where they had scheduled timber harvests, we selected two sites where we hoped to set up field research in 1993. However, because of the short time period between the start of the project (July 1, 1993) and the time when site preparation needed to be accomplished (mid-August, 1993) we were unable to hire qualified staff to perform the vegetation surveys on both of the sites.

We decided to install just one research site in 1993 and to delay installation of two additional sites until the summer of 1994. The one research site that was installed in 1993 is located west of the Fillmore County Airport on state forest land.

In August 1993, after the harvest blocks and the site preparation treatment areas were located and marked with stakes at the airport research site, 30 overstory plots and 90 understory vegetation plots were surveyed according to the work plan.

Next, site preparation treatments involving chemicals, bulldozing, and dragging tree tops were completed at the airport research site. The chemical treatment was performed by the DNR on August 15, 1993. In one plot the wrong treatment area was sprayed and there was some drift into adjacent treatment areas. This caused the plot layout to be reconfigured. The bulldozing treatment was completed on August 24, 1993 by a TD-8 bulldozer. The operator did a good job knocking down the understory vegetation, however, many of the standing trees had some stem damage from the bulldozer. The timber sale was marked by the DNR, a contract was let, and the airport research site was harvested during the winter of 1993-94. Both shelterwood harvesting and clearcutting were executed according to the work plan. At the time of harvest, tree tops were dragged over two site preparation treatment areas, but the operator worked in the designated control plots rather than the sites designated for this treatment. This caused another reconfiguration of the treatments, but no lost data.

An attempt was made to burn a site preparation treatment area at the airport site in spring 1994, but the fire did not carry because of insufficient dead plant material and high moisture content of the fuel.

As a part of this study we want to compare the growth of planted red oak seedlings to the growth of naturally occurring seedlings. In spring 1994 we planted 1,000 red oak seedlings (100 on each of 10 site preparation treatment areas) on the airport research site.

John DuPlissis, who had been providing day-to-day leadership for this research project since July 1, 1993, resigned from his appointment and left the University on January 31, 1994 to begin a new job in Nebraska. Tim Baker was hired on an interim basis to continue the work that DuPlissis had begun. After encountering several months of delay by U.S. government agencies that were involved in issuing a visa, we hired Xiwei Yin to provide day-to-day leadership for this research. He began work on April 25, 1994.

Beginning in May 1994, the DNR District Foresters helped us locate several more potential research sites. Ten sites were field checked and four appeared to meet our criteria. After further inspection, we selected two new sites (in addition to the site near the Fillmore County Airport) for the experiment. The Whitewater site is located in Winona County within the Whitewater Wildlife Management Area. The other site is in the Money Creek watershed in Houston County.

The first vegetation inventory (pre-treatment) at Money Creek and Whitewater, and the first follow-up vegetation inventory (post-treatment) at the Airport site were completed in August and September 1994. The layout of vegetation inventory plots at Money Creek and Whitewater is systematic for easy set-up (which is particularly important as harvesting/treatment operations tend to destroy plot marks). Inventory data included: species and DBH of trees; species, height and DBH (or diameter at 2.5 cm height) of saplings and shrubs; species and cover class of herbaceous plants; and percent cover of overstory, understory, and ground flora.

Chemical treatments were completed on the two new research sites in fall 1994. They were done as specified in the work program (a mixture of Accord and Garlon 4-1.5 quarts each per acre) at Money creek on September 13, 1994 and Whitewater on September 19, 1994. The killing effect of the treatment on the targeted vegetation was apparent as observed on October 6.

Mechanical treatments also were completed on the two new research sites in fall 1994. They were done by the same contractor with a D6 caterpillar tractor at Money Creek on October 4, 1994 and Whitewater on October 6, 1994.

Prescribed burning was done at Whitewater on November 31, 1994. The initial burning was well-executed, but fires unexpectedly flared up at night after the fire crew had left and swept through the entire experimental area beyond the designated burning plots. Weather conditions and work schedules precluded prescribed burning at the airport and Money Creek sites in fall 1994.

Logging operations at Whitewater were completed during the week of December 5-9, 1994. Dragging tree tops was well-executed in conjunction with logging at the site. Following logging, post-sale treatment was completed according to these specifications: chain saw fell all residual oaks larger than one inch dbh (except for large oak trees intentionally left in the shelterwood cut area), and chain saw fell and stump treat with "Pathway" all non-oak residuals except for walnut and basswood.

Logging at the Money Creek site was delayed because the DNR forester in charge of the timber harvest did not have time to inspect the site and prepare the sale documents. The current plan is for the DNR to offer this timber for sale at auction on May 24, 1995. Timber harvesting would occur after that date. We recommended to that forester that harvesting occur in the winter to be consistent with the other harvest sites that are part of this same experiment. Dragging tree tops is yet to be done at Money Creek because no timber harvest has occurred there yet.

Weather conditions did not permit us to conduct prescribed burns in spring 1995 on sites that have been harvested.

Besides establishing three research plots in southeastern Minnesota at the Fillmore County Airport, Money Creek, and Whitewater Wildlife Management Area, research plots were installed at St. John's University to help us learn more about the affects of fire on oak regeneration. Plots at St. John's are not exact replicates of the three other plots in southern Minnesota. St. John's University conducted clearcut and shelterwood harvests in 1993 before we initiated our research there. In April 1994 we measured woody reproduction in the clearcut and shelterwood areas where burns were planned. We have no data on reproduction prior to the harvests except by measuring reproduction on nearby control plots where no harvesting occurred. In mid-May 1994 we burned two plots. This site has two replicates (12 plots total). In July 1994 one-half of each plot was fenced with lightweight nylon deer fence to exclude deer. In August and September 1994 herbaceous and woody vegetation were surveyed and light levels were measured on all plots. Data from this site have been entered into a database and preliminary analysis indicates fairly strong effects of fire and canopy cover on oak seedling numbers. Recent observations on the deer fences show they have been badly damaged by falling limbs and trees, especially in the shelterwood areas. Deer have entered the exclosures and browsed seedlings. The deer fences will be taken down and that portion of the experiment discontinued.

B.2. Activity: Measure acorn production, dispersal, "storage", and survival.

B.2.a. Context within the project: Timber harvesting and site preparation treatments are expected to enhance oak regeneration most when they are conducted in years of, or years just following, acorn abundance. Other than casual observations by experienced foresters, there is no reliable method or data base that enables foresters to reliably measure or predict acorn abundance or understand its year-to-year or site-to-site variation. We will initiate acorn surveys that will continue beyond 1995 to establish a data base and procedures that can be used by foresters to better measure and predict acorn abundance.

B.2.b. Methods: Surveys of acorn production, dispersal, "storage", and survival will be conducted on a range of sites chosen to reflect relevant climatic, vegetative, soil, and topographic gradients in southeastern Minnesota. This will require collecting falling acorns, assessing acorn numbers in soil "seed banks", assessing predation on acorns in several micro-environmental locations, and estimating germination of acorns that have undergone several types of dispersal and micro-environmental conditions. Because acorn dynamics vary widely over a longer time frame, these studies will be continued under other funding sources following the two-year period. The gradient of sites on which this study is performed will yield valuable information about spatial variation in acorn dynamics. Information on acorn dynamics will be linked with information about different types of site preparation techniques in order to develop strategies for successful natural regeneration.

B.2.c. Materials: Seed traps, soil cores, and mesh bags.

B.2.d. Budget: $5,000
Balance: $0

B.2.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Select sites for acorn collection	***				
Collect acorns	**			**	
Analyze data		***			****

B.2.f. Status:

We tested three acorn collection methods in a woodland near the Twin Cities in fall 1993. (1) Several 10 ft. by 10 ft. polyethylene sheets were placed under several oak trees and the acorns were removed and counted about every two days. (2) Under each of six oak trees we counted and removed the acorns in a single 1/1,000 acre plot. (3) Under each of six oak trees we counted (but did not remove) the acorns in a single 1/1,000 acre plot. Either this was a very poor acorn crop this year in that area or we started our acorn collection too late, because we collected very few acorns using these methods. We conducted a literature search and talked to other researchers to obtain additional ideas for collecting acorns and assessing the size of the acorn crop. Since our collection devices yielded only a handful of acorns in fall 1993, there were no data to analyze. In these surveys, it appeared that this technique was not efficient. It was difficult to get sufficient geographic coverage; acorns could be removed by animals; it was very time intensive because traps should be checked frequently; and an inordinate amount of time, money, and effort would have been needed to use this technique effectively.

As an alternative, we assessed distribution of acorns with respect to overstory and burn treatments at the St. John's site (described above in section B.1.f Status), and attempted to link those measurements to seed predation and seed germination and establishment. This turned out to be a more appropriate way to address this issue. We measured numbers of acorns at eight subplots (1 m diameter circular plots) within each of the six treatment combinations, and then used a combination of natural, seeded, and seeded + caged subplots (1 m diameter circular plots) (eight of each within each replicate treatment) to assess the contributions of acorn production, dispersal, predation, and microsite conditions on potential seedling establishment.

Analysis of variance was used to test for statistical effects of treatment combinations. Of the six treatment combinations (3 overstory manipulations by 2 burn treatments), the data on acorn abundance, predation, germination, and survival suggest that shelterwood sites that receive prescribed burning are most likely to have the best seedling regeneration potential. Numbers of acorns were much higher ($p<0.05$) in understory and shelterwood sites than in clearcuts, which is not surprising, but numbers were slightly higher in shelterwood than in understory plots, suggesting either greater dispersal into shelterwoods or less predation there. In both the shelterwood and understory plots, numbers of germinants were higher in burned than in unburned treatments in all (natural, seeded, and caged + seeded) plots ($p<0.05$). When seedlings were protected from predation, they did best in the burned clearcut and shelterwood sites. Thus, it appears that numbers of acorns are higher in understory and shelterwood sites, but that the combined influence of dispersal, predation, and microsite result in a greater likelihood of germination and early survival for any given seedling in shelterwood and clearcut sites. Taken together, this indicates a positive result for shelterwoods. Finally, in all overstory treatments, prescribed burning also appeared to be positive with respect to combined impact on acorn numbers, germination, and early establishment. These plots will be resurveyed during the summer of 1995.

B.3. Activity: Remeasure artificial oak regeneration plots established in 1991-93.

B.3.a. Context within the project: The project as a whole is aimed at finding methods for regenerating more oaks. These plots were originally established under an LCMR grant for 1991-93. They involved site preparation by herbicide and mechanical methods followed by planting oak seedlings and acorns. We currently have measurements of the oak seedling survival and growth and effects of the site preparation treatments for only one growing season. It is important to measure oak seedling and acorn survival as well as effects of the site preparation treatments for at least three growing seasons to learn how effective they really were. This information is an important part of the educational effort planned under Objective C.

B.3.b. Methods: The following understory data will be recorded at each plot: (1) The species and height to the nearest one foot of all tree seedlings less than one inch in diameter, (2) The species and height to the nearest one foot of all shrubs, (3) An estimate of the percentage of the ground covered by all herbs and forbs and the percent ground cover provided by each of the four most prevalent species. For each oak seedling and acorn planted, we will measure stem height, stem caliper, and survival as well as the type and amount of any damage (e.g., deer browsing, insects, diseases) that may have occurred. These data will be analyzed by appropriate statistical methods to determine the affects, if any, of site preparation treatments on the survival, stem diameter, and height growth of oak seedlings and acorns, the number and height of competing trees and shrubs, and the percentage of ground covered by competing herbaceous vegetation.

B.3.c. Materials: Tape measure, height pole, 10 BAF prism, and caliper.

B.3.d. Budget: $6,000
Balance: $0

B.3.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Measure plots	***		***		
Analyze data		******		******	

B.3.f. Status:

These plots were originally established under a 1991-93 LCMR Project: Regeneration and Management of Minnesota's Oak Forests, Objective A: Artificial regeneration of red oak in southeastern Minnesota.

These plots were remeasured in the fall of 1993. Data covering two years (1992-93) were analyzed to determine the treatment affects. Results were reported in a master's degree thesis prepared by John DuPlissis. One copy of this 246-page thesis was delivered to the DNR--Division of Forestry. Additional copies are available in the University of Minnesota Forestry Library.

COMPETING VEGETATION INVENTORY

The following are the results of the statistical analysis of the competing vegetation inventories for 1991, 1992, and 1993.

Stand Basal Area

An analysis of variance showed that there was no statistically significant difference between the initial overstory mean basal area and overstory mean basal area in the subsequent years following the harvesting operation between the three research blocks. However, there were extreme differences between the amount of the overstory basal area that was removed at the Money Creek site and the Trout Valley sites (Table 1).

Table 1. Mean stand basal area of the three research areas prior to harvesting and in each of the following years.

	BASAL AREA (square meters/hectare) BY YEAR		
RESEARCH BLOCKS	**1991**	**1992**	**1993**
Money Creek	21.4	10.7	10.7
Trout Valley East	17.6	1.5	1.5
Trout Valley West	16.8	2.3	2.3

The outcome of the harvesting operation at the Money Creek site was a stand that most closely resembled a shelterwood. Approximately 50 percent of the overstory basal area was removed compared to the Trout Valley sites where at least 90 percent of the overstory basal area was removed. Since these research blocks were to be clearcut, basal area was measured on only one 10 BAF variable radius plot per site preparation treatment whole plot. This limited the data set and may be the reason why the analysis showed no statistical difference between the research blocks. After harvesting there were many more residual trees left standing than were expected, resulting in variable crown cover between the research blocks.

<u>Stems Per Hectare</u>
There was no significant difference in the mean number of woody stems (tree seedlings and woody shrubs) per hectare between the site preparation treatment whole plots within a given year (1991, 1992, 1993). However, there were statistically significant changes in the mean number of stems per hectare, from 1991 to 1992 within the control and chemical site preparation treatment whole plots. There was no statistically significant difference from year to year within the mechanical site preparation treatment whole plots (Table 2). There was a 55 percent decrease in the mean number of stems per hectare in the chemical site preparation treatment whole plots from 1991 to 1992; this trend continued into 1993. There was a 45 percent increase in the mean number of stems per hectare in the control whole plots from 1991 to 1992; however from 1992 to 1993 the mean number of stems per hectare decreased to a level below although not statistically different from 1991.

Table 2. Mean number of woody stems (tree seedlings and shrubs) per hectare for the combined control, chemical, and mechanical site preparation treatments whole plots.

SITE PREPARATION TREATMENTS	STEMS PER HECTARE[1]		
	1991	1992	1993
Control	25,992[a]	37,744[b]	21,585[a]
Chemical	32,440[a]	14,684[b]	9,836[b]
Mechanical	23,935[a]	32,162[a]	19,529[a]

1 Stems per hectare measurements per site preparation treatment that did not differ significantly between years ($p > 0.05$) share a common superscript letter.

In the mechanical site preparation treatment whole plots the mean number of stems per hectare increased from 1991 to 1992 and then decrease in 1993 to below the 1991 level, however, these year to year changes were not statistically significant.

The control and mechanical site preparation treatments appear to have stimulated regeneration from respouting of existing stems, or from seed stored in the duff or that dispersed into the plots. Only the chemical site preparation treatment reduced the number of woody stems in the year following the site preparation treatment and harvest. It is interesting to note that the mean number of stem per hectare in each of the site preparation treatment whole plots decreased from 1992 to 1993 although no further silvicultural treatments were performed.

<u>Mean Stem Height</u>
Prior to the site preparation treatments and harvest there was no significant difference in mean stem height of the woody understory vegetation (tree seedlings and woody shrubs) between the site preparation treatment whole plots. One growing season after these silvicultural treatments, mean stem height in the control whole plots was significantly greater than in either the chemical or mechanical site preparation treatment whole plots. However, after the second full growing season there was no longer any statistically significant difference in the mean stem height of the woody vegetation between the three site preparation treatment whole plots (Table 3).

There was no significant difference in mean stem height of the woody understory vegetation within each of the treatments from 1991 to 1992. Although mean stem height within the control whole plots increased from 1991 to 1992 and it decreased within the chemical and mechanical site preparation treatment whole plots. However from 1992 to 1993 there was a statistically significant increase in mean stem heights in both the control and mechanical site preparation treatment whole plots. While mean stem height in the chemical site preparation treatment whole plots increased from 1992 to 1993 to slightly above pre-treatment levels this change was not statistically significant.

Table 3. Mean stem height of woody understory vegetation (tree seedlings and shrubs) for the combined control, chemical, and mechanical site preparation treatment whole plots.

SITE PREPARATION TREATMENTS	MEAN STEM HEIGHT (cm)		
	1991	1992[2]	1993
Control	78^{a}	**86^{a}**	115^{b}
Chemical	87^{a}	**64^{a}**	89^{a}
Mechanical	70^{a}	**59^{a}**	100^{b}

1 Mean stem height measurements per site preparation treatment that did not differ significantly between years ($p > 0.05$) share a common superscript letter.
2 Mean stem height measurements that were significantly different ($p > 0.05$) between site preparation treatments within a given year are highlighted in bold.

Both of the site preparation treatments had the effect of reducing the mean stem height of the competing vegetation after one growing season. This was in stark contrast to the control where competing vegetation increased in height. However, after two growing seasons the effect of the site preparation treatments diminished, especially in the mechanical which is no longer significantly different from the control.

Percent Ground Cover

The mean percent ground cover of herbaceous vegetation was initially lower in the control site preparation treatment whole plots than in the chemical and mechanical site preparation treatment whole plots, however this difference was not statistically significant. After the silvicultural treatments the percent ground cover in the chemical site preparation treatment whole plots was significantly lower than in either the control site preparation treatment whole plots (which showed a slight though non-significant increase) or the mechanical site preparation treatment whole plots (which showed a statistically significant decrease). During the second growing season (1993) each of the site preparation treatment whole plots showed a statistically significant increase in the percent ground cover from the previous year (1992); however there no longer were any significant differences between treatments (Table 4).

Table 4. Mean percent ground cover of herbaceous vegetation for combined control, chemical, and mechanical site preparation treatment whole plots by year.

SITE PREPARATION TREATMENTS	PERCENT GROUND COVER[1]		
	1991	1992[2]	1993
Control	19 %^{a}	22 %^{a}	66 %^{b}
Chemical	37 %^{a}	8 %^{b}	58 %^{c}
Mechanical	33 %^{a}	22 %^{b}	70 %^{c}

1 Percent ground cover measurements per site preparation treatments that did not differ significantly between years ($p > 0.05$) share a common superscript letter.
2 Percent ground cover measurements that were significantly different ($p > 0.05$) between treatments within a given year are highlighted in bold.

Summary

Currently competition levels for all stand resources (light, nutrients, and water) are highest in the control site preparation treatment whole plots where mean stem height (115 cm) and mean stems per hectare (21,585) are greater than either the chemical (89 and 9,836 respectively) or mechanical (100 and 19,529 respectively) site preparation treatment whole plots.

There has been a general decline in the number of stems per hectare for all species except for boxelder, which has nearly doubled, and northern red oak which is slightly higher. This general decline in the mean number of stems of woody vegetation coincided with a significant increase in the mean percent ground cover of the herbaceous vegetation.

SEEDLING AND ACORN GROWTH AND SURVIVAL

The following are the results of the statistical analysis of the seedling and acorn inventories from April 1992 through September 1994.

Research Blocks

The following are the results of statistical analysis of seedling growth for the research blocks.

Seedling Height Growth

At the time of planting (April 1992), there was no difference in mean height of the planted northern red oak seedlings among the three research blocks. However, at the end of the third growing season (1994) mean seedling height on the Trout Valley West site was significantly greater than the mean seedling height on the Trout Valley East site, which was significantly greater than the mean seedling height on the Money Creek site (Table 5).

Table 5. Mean height and growth of planted northern red oak seedlings and acorns by research block over time.

	RESEARCH BLOCKS[1]		
	Money Creek	Trout Valley East	Trout Valley West
1992 HEIGHT (cm)	26.2[a]	25.6[a]	26.4[a]
1992 GROWTH (cm)	11.0	9.8	13.5
1993 GROWTH (cm)	19.1	27.9	30.0
1994 GROWTH (cm)	28.1	27.5	26.4
1994 HEIGHT[2] (cm)	76.9[a]	88.5[b]	96.0[c]

1 Research blocks that did not differ significantly within a height or growth category ($p > 0.05$) share a common superscript letter.
2 1994 height measurements may not be equal to 1992 height plus annual growth due to seedling mortality and rounding errors.

Seedling Diameter Growth

At the time of planting (April 1992) there was no significant difference in mean stem diameter of the planted northern red oak seedlings among the three research blocks. However, after three full growing seasons (September 1994) the mean stem diameter of seedlings at the Trout Valley West and Trout Valley East sites, which were not significantly different from one another, was significantly greater than at the Money Creek site (Table 6).

Table 6. Mean diameter and growth of planted northern red oak seedlings and acorns by research blocks over time.

	RESEARCH BLOCKS[1]		
	Money Creek	Trout Valley East	Trout Valley West
1992 DIAMETER (mm)	4.9[a]	4.8[a]	4.9[a]
1992 GROWTH (mm)	.6	.6	.8
1993 GROWTH (mm)	1.3	1.6	1.9
1994 GROWTH (mm)	.6	1.3	.9
1994 DIAMETER[2] (mm)	6.6[a]	7.8[b]	8.1[b]

1 Research blocks that did not differ significantly within a diameter or growth category ($p > 0.05$) share a common superscript letter.
2 1993 diameter measurements may not be equal to 1992 diameter plus annual growth, due to seedling mortality and rounding errors.

Site Preparation Treatments

The following are the results of statistical analysis of seedling growth for the site preparation treatment whole plots.

Seedling Height Growth

At the time of planting (April 1992) the mean height of the planted northern red oak seedlings in the control site preparation treatment whole plots was significantly greater than in the chemical site preparation treatment whole plots, but the mean height of seedlings in the mechanical site preparation treatment whole plots was not significantly different from either. At the end of the third growing season (September 1994) there was no significant difference in mean seedling height between the control, chemical, and mechanical site preparation treatments (Table 7).

Table 7. Mean height and growth of planted northern red oak seedlings by site preparation treatment over time.

	SITE PREPARATION TREATMENT[1]		
	Control	Chemical	Mechanical
1992 HEIGHT (cm)	27.0[a]	25.3[b]	26.0[ab]
1992 GROWTH (cm)	12.2	9.8	12.3
1993 GROWTH (cm)	24.9	24.4	28.1
1994 GROWTH (cm)	24.[illegible]	28.5	27.6
1994 HEIGHT[2] (cm)	90.7[a]	89.1[a]	84.7[a]

1 Site preparation treatment whole plots that did not differ significantly within a height or growth category ($p > 0.05$) share a common superscript letter.

2 1993 height measurements may not be equal to 1992 height plus annual height growth, due to seedling mortality and rounding errors.

Seedling Diameter Growth

At the time of planting (April 1992) the mean stem diameter of the planted northern red oak seedlings in the control site preparation treatment whole plots was significantly greater than in either the chemical or mechanical site preparation treatment whole plots, which were not significantly different from one another. However, after three growing seasons (September 1994) the mean stem diameter of seedlings in the chemical site preparation treatment whole plots was significantly greater than those in the mechanical site preparation treatment whole plots which in turn was significantly greater than those in the control site preparation treatment whole plots (Table 8).

Table 8. Mean diameter and growth of planted northern red oak seedlings by site preparation treatment over time.

	SITE PREPARATION TREATMENT[1]		
	Control	Chemical	Mechanical
1992 DIAMETER (mm)	5.1[a]	4.7[b]	4.8[b]
1992 GROWTH (mm)	.4	.8	.7
1993 GROWTH (mm)	1.1	1.8	1.8
1994 GROWTH (mm)	.3	1.2	1.0
1994 DIAMETER[2] (mm)	6.9[c]	8.0[a]	7.5[b]

1 Site preparation treatment whole plots that did not differ significantly within a diameter or growth category ($p > 0.05$) share a common superscript letter.

2 1993 diameter measurements may not be equal to 1992 diameter plus annual diameter growth, due to seedling mortality and rounding errors.

Planting Stock Types

The following are the results of statistical analysis of seedling growth, survival, and damage for the seedling and acorn subplots.

Seedling Height Growth

At the time of planting (April 1992), the premium seedlings (both with and without treeshelters) were significantly taller than the nursery run seedlings. There was no height difference between the premium seedlings with treeshelters and premium seedlings without treeshelters. The acorns were planted at the same time as the seedlings, however, no measures were taken at that time. At the end of the third growing season (1994) the premium seedlings with treeshelters were significantly taller than the premium seedlings without treeshelters. The premium seedlings were significantly taller than the nursery run seedlings, however, the unprotected acorns were not significantly different from either the premium or nursery run seedlings. The nursery run seedlings were significantly taller than the protected acorns.

The tubex quills were removed from the acorns at the end of the second growing season to prevent constriction of the acorn sprouts (Table 9).

Table 9. Mean height and growth of planted northern red oak seedlings by planting stock type over time.

	PLANTING STOCK TYPES[1]				
	(Premium)[2]	Premium	Nursery Run	Acorns	(Acorns)
1992 Height (cm)	26.8[a]	27.2[a]	22.2[b]	na	na
1992 Growth (cm)	21.2	4.1	2.1	13.1	21.6
1993 Growth (cm)	45.3	14.8	13.3	19.7	14.9
1994 Growth (cm)	31.4	25.6	21.7	39.6	21.9
1994 Height[3] (cm)	125.1[a]	69.4[b]	60.2[c]	60.5[bc]	48.9[d]

1 Planting stock types that did not differ significantly within a height or growth category ($p > 0.05$) share a common superscript letter.
2 Planting stock types in () were protected by tree shelters.
3 1993 height measurements may not be equal to 1992 height plus annual growth, due to seedling mortality and rounding errors.

__Seedling Diameter Growth__
At the time of planting (April 1992), the premium seedlings (both with and without treeshelters) were significantly larger in stem diameter than the nursery run seedlings. There was no significant difference in stem diameter between the premium seedlings with treeshelters and the premium seedlings without treeshelters. After three full growing seasons there was no significant difference in the mean stem diameter of premium seedlings with and without treeshelters; however the mean stem diameter of the premium seedlings was significantly larger then the nursery run seedlings which had a larger mean stem diameter than the acorn sprouts without treeshelters which were significantly larger than acorn sprouts with treeshelters (Table 10).

Table 10. Mean initial diameter, current diameter and diameter growth data for each planting stock type combined over all site preparation treatments.

	PLANTING STOCK TYPES[1]				
	(Premium)[2]	Premium	Nursery Run	Acorns	(Acorns)
1992 Diameter (mm)	5.0[a]	5.0[a]	4.2[b]	na	na
1992 Growth (mm)	.5	.5	.5	2.1	1.7
1993 Growth (mm)	1.5	1.7	1.5	2.2	1.5
1994 Growth (mm)	1.0	.8	.5	3.1	2.4
1994 Diameter[3] (mm)	7.9[a]	7.8[a]	7.0[b]	6.0[c]	4.7[d]

1 Planting stock types that did not differ significantly within a diameter or growth category ($p > 0.05$) share a common superscript letter.
2 Planting stock types in () were protected by treeshelters.
3 1993 diameter measurements may not be equal to 1992 diameter plus annual growth, due to seedling mortality and rounding errors.

Seedling Mortality

After the first growing season (1992) 99.7 percent of the planted northern red oak seedlings were still alive. After the second growing season 95 percent of the bareroot planting stock was still alive (Table 11). This increase in mortality was due in large part to animal browsing and storm damage. Additionally a number of seedlings were simply missing. These seedlings may have been pulled out of the ground by some animal, most likely deer or squirrel, but there is no evidence as to why they are missing. There was no significant difference in seedling mortality between the planting stock types at the end of the first growing season (Table 12 (a)). However, at the end of the second growing season the premium seedlings with treeshelters had a significantly higher mortality rate than the nursery run seedlings; the premium seedlings without treeshelters were not significantly different from either of these (Table 12 (b)).

Table 11. Mean percent survival of planting stock types over time[1].

	PLANTING STOCK TYPES				
	(Premium)[2]	Premium	Nursery Run	Acorns	(Acorns)
1992 Percent Survival	99.6	99.8	99.6	27.0	41.5
1993 Percent Survival	93.3	95.0	95.9	16.3	21.9

1 Data for 1994 was not collected
2 Planting stock types in () were protected by treeshelters.

The germination rates of the planted acorns was unexpectedly low; approximately 34 percent of the acorns germinated and survived to the end of the first growing season (Table 11 and Table 12 (a)). This result was quite different from the greenhouse trials in which 87 percent of the acorns germinated and survived for at least one month. At the end of the second growing season (1993), only 19 percent of the planted acorns were still alive, a mortality rate of approximately 44 percent. There was no association between any damage categories and the death of acorn sprouts (Table 11 and Table 12 (b)).

Table 12(a). Mean percent seedlings mortality by planting stock types at the end of the first growing season (1992).

1992 Dead or not Measured	PLANTING STOCK TYPES[1]				
	(Premium)[2]	Premium	Nursery Run	Acorns	(Acorns)
Dead	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]
Missing	0.4[a]	0.2[a]	0.4[a]	0.0[a]	0.0[a]
Non-germinate[3]	na	na	na	73.3[a]	58.5[a]
Not measured[4]	0.0[a]	0.0[a]	0.0[a]	0.0[a]	0.0[a]

1 Percentages within a damage types category that did not differ significantly between planting stock types ($p > 0.05$) share a common superscript letter.
2 Planting stock types in () were protected by treeshelters.
3 This damage code does not apply (na) to the nursery grown planting stock types.
4 Seedling were not measured when they were made inaccessible by fallen trees or ground nesting wasps.

Table 12(b). Mean percent seedling mortality by planting stock type at the end of the second growing season (1993).

1993	PLANTING STOCK TYPES[1]				
Dead or Not Measured	(Premium)[2]	Premium	Nursery Run	Acorns	(Acorns)
Dead	4.3[b]	1.9[ab]	1.1[a]	58.9[c]	45.4[c]
Missing	0.4[a]	2.2[a]	2.2[a]	0.0[a]	0.0[a]
Not measured[3]	1.6[a]	0.7[a]	0.3[a]	0.0[a]	0.0[a]

1 Percentages within a damage types category that did not differ significantly between planting stock types ($p > 0.05$) share a common superscript letter.
2 Planting stock types in () were protected by treeshelters.
3 Seedling were not measured when they were made inaccessible by fallen trees or ground nesting wasps.

CONCLUSIONS

This research project has established several important facts that will be useful in the management of the oak forest type in both the Big Woods area and the central hardwoods forest type in southeastern Minnesota. First, the question of overstory removal and its affect on regeneration has been answered in part. Oak seedling growth was best where overstory cover was light as exhibited by seedling growth at the Trout Valley West site. This is surprising since this site was considered to be the poorest for seedling growth based on soil type and indicator plant species.

Second, oak seedling growth appeared to be greatest in the chemical research plots especially as a measure of above ground biomass. While there was no significant difference in oak seedling height between the control, chemical, and mechanical treatments, oak seedling diameter growth was greatest on the chemical treatment site. The important thing to note here is the overall growth trend. Actual oak seedling height growth on the chemical treatment areas was significantly less after the first growing season, however, height growth during the second and third growing season on the chemical treatment areas equaled or exceeded growth on the other treatment areas.

Third, the premium oak seedling type has continued to outperform the nursery run seedling type. This study should help to make a legitimate case that our hardwood nurseries should attempt to grow seedlings with larger, more fibrous root systems. Also note the acorn sprouts have continued to grow to the point where their actual height at the end of three growing seasons is not significantly different from either the premium or nursery run seedlings. However this should be tempered by the fact that our sample size is only 29 after three years because of low survival.

Fourth, premium seedlings protected by tree shelters were significantly taller than unprotected premium seedlings, but protected seedlings were not significantly larger in diameter than unprotected seedlings.

Finally, all of this needs to be examined in the light of seedling mortality rates, however, data on seedling mortality at the end of the third growing season is incomplete and it would be inappropriate to extrapolate from second year data. However, mortality data would seem to suggest that at least 85 percent of each of the seedling types are still alive while approximately half of the acorn sprouts died at the end of the second growing and another third of those were dead at the end of the third growing season. Planting acorns has possibilities, however, the mortality issue will have to be addressed.

C. Title of Objective. Conduct an educational program on hardwood forest management.

C.1. Activity: Conferences and field tours.

C.1.a. Context within the project: Since most of the hardwood resource is owned by nonindustrial private forest landowners who generally know little about forestry, it is important to stimulate their interest in regeneration and management of this resource. Loggers harvest timber and have a tremendous impact on regeneration, yet they generally are not knowledgeable about the biological affects of their activities on the forest. Educational programs aimed at landowners, loggers, and the foresters who advise them are important to bring the latest research knowledge into practice, including knowledge gained from our 1991-93 LCMR research project on Regeneration and Management of Minnesota's Oak Forests.

While conducting educational programs for landowners and loggers, we learn more about their land management concerns and the practicality of forest management practices being investigated in our research. This two-way communication process makes the University's research and education programs more relevant to local issues and needs.

C.1.b. Methods: Field tours will be held for foresters to show them the research plots and describe the results of research conducted in 1991-93 regarding artificial regeneration of oaks.

A series of conferences and field tours will be held throughout a 7-county area in southeast Minnesota to inform woodland owners and loggers about hardwood forest management for multiple-uses. We will emphasize management techniques that help to perpetuate a desirable mix of tree species for wood products and wildlife while protecting the aesthetic, recreational, and watershed protection values of woodlands.

We will recruit and train additional 4-H Forest Resource Project leaders and promote increased enrollment in this 4-H project through workshops, field tours, and a 4-H ecology camp.

Mass media will be used to inform area residents about the value of our hardwood forest resource, management problems, current research, and upcoming educational events.

C.1.c. Materials: We will use existing educational materials including brochures, publications, slide sets, and video tapes on forestry subjects.

C.1.d. Budget: $75,000
Balance: $0

C.1.e. Timeline:	7/93	1/94	6/94	1/95	6/95
4-H Ecology & County 4-H camps	*****		*****		****
Field tours for foresters					****
Conferences and field tours for landowners and loggers		********		******	

C.1.f. Status:
We conducted 37 different educational events for woodland owners and loggers. Our attendance exceeded 900 adults and over 3,570 educational contact hours. As part of this effort we provided 40 hours of training to 32 private woodland owners who now are expected to provide 50 hours of volunteer service over the next two years helping their neighbors and communities better manage their woodlands.

We conducted 35 different educational events for youth and educators, reaching over 2,500 people. Our most intensive youth education program was a week-long Forest Ecology Summer Camp that we ran three times, reaching 96 youth with career interests in natural resources.

We participated in 38 educational events for other adult audiences, reaching over 1,650 people.

Our educational programs offered current information on hardwood forest management for wood products, water quality protection, wildlife habitat, recreation development, and ecological benefits.

Beginning in March 1994, a pilot program was conducted to learn more about how we could interest nonindustrial private forest landowners in learning about forestry. In this pilot program we directly mailed forestry-related educational materials to a sample of woodland owners.

We sent personally addressed and individually signed letters to 400 woodland owners. We randomly chose 200 names from our list of 1,500 woodland owners in southeastern Minnesota (Olmsted, Fillmore, Houston, Wabasha, and Winona counties) and 200 names from a list of about 1,000 woodland owners in northern Minnesota (Beltrami, Lake of the Woods, Clearwater, Hubbard, and Mahnomen counties). Both lists were obtained by looking at aerial photographs to determine where woodlands were located and then looking up land ownership records in county courthouses to identify the landowners and their addresses. Besides receiving our cover letter, each landowner also received the publications: <u>Minnesota Woodland Owners' Resource Directory</u> and <u>Woodland Stewardship: Plan on it!</u> and they received a questionnaire entitled, Request for Woodland Information. We gave landowners the opportunity to order one free publication and to ask a forestry-related question. The questionnaire also requested some additional information about their educational needs.

One-half of the original mailings had addresses hand-written on the envelopes; the other half had addresses printed on gummed mailing labels. There were no substantial differences in response rates. In fact a few more responses were received from landowners whose addresses were printed on gummed labels. Based on this small sample, it appears that hand writing addresses on envelopes is not warranted as a means to stimulate responses to similar mailings.

After undeliverable letters were deleted from the data base, we learned that 17% of the remaining landowners requested another publication, but there were more requests in northern Minnesota (25% response rate) than in southern Minnesota (11% response rate).

Respondents could order one additional publication from a list of 14 publications. In order of preference, respondents most commonly requested publications dealing with wildlife management (wildlife, nongame, deer, grouse, turkey) first (41%); they requested publications dealing with income-related subjects (timber marketing, timber measuring, taxes, conservation programs) second (35%); and they ordered publications dealing with more general woodland resources (aspen, oak, wetlands, protection) third (26%). However, responses varied by region. Woodland owners in southeast Minnesota most commonly requested a general woodland resource publication, especially one on on oak management. Respondents in northern Minnesota most commonly requested a wildlife publication.

Respondents also were asked to rank the three woodland management information sources they preferred most from a list of 11 options. Responses were weighted by multiplying first choices by 3, second choices by 2, and third choices by 1 and then dividing the sum of those scores for each category by the total number of responses. There were several ties in the preference list. Preferences were (1a) publication or book and (1b) video tape for home viewing, (2a) field tour and (2b) newsletter, (3a) evening workshop and (3b) correspondence course, (4) day-long conference, and (5a) cable TV program, (5b) newspaper article and (5c) magazine article. There appear to be regional differences. Evening workshop ranked first in southeast Minnesota, while video tape for home viewing ranked first in northern Minnesota.

A higher than expected number of respondents had previously received information from or participated in educational events sponsored by the Minnesota Extension Service (56 percent). Forty-six percent also reported that a forester had visited their property to advise them on its management. Both proportions are considerably higher than those reported by other woodland owner studies conducted in Minnesota. These responses seem to indicate that our procedure of mailing publications to a random selection of landowners had the greatest appeal to landowners that had previously received forestry information and technical assistance. We do not appear to have stimulated as many uninformed landowners as we would like to have done.

Below is a list of educational events we conducted by categories: Woodland Owners, Youth and Educators, and Others.

Educational Events for Woodland Owners

October 19, 1993. Talked about windbreaks and oak regeneration at Fillmore County Forestry Day at Underbakke Tree Farm near Preston. 40 attended.

[Seminars listed below from January 8 - 22, 1994, under the titles: Landscaping for Wildlife and Preserving Trees During Construction, were promoted by a brochure mailed directly to 1,500 residents owning land in Fillmore, Houston, and Winona Counties. A television commercial was produced and run on Rochester's KTTC TV. Press releases were submitted to the local media. Brochures and news releases also were sent to forestry-related agencies and organizations. Attendance was lower than expected. These classes were held in January during the coldest and snowiest weather of the season.]

January 8, 1994. Landscaping for Wildlife, at Forest Resource Center, Lanesboro. 5 hour seminar and field tour on forest management and wildlife management concepts. 12 attended.

January 10, 1994. Landscaping for Wildlife, at Rochester. 2.5 hour seminar on forest management and wildlife management concepts. 15 attended.

January 11, 1994. Landscaping for Wildlife, at Houston. 2.5 hour seminar on forest management and wildlife management concepts. 7 attended.

January 12, 1994. Landscaping for Wildlife, at Red Wing. 2.5 hour seminar on forest management and wildlife management concepts. 12 attended.

January 13, 1994. Landscaping for Wildlife, at Winona. 2.5 hour seminar on forest management and wildlife management concepts. 8 attended.

January 17, 1994. Preserving Trees During Construction, at Rochester. 2.5 hour seminar. 10 attended.

January 22, 1994. Preserving Trees During Construction, at Forest Resource Center, Lanesboro. 5 hour seminar and field tour. 10 attended.

February 1, 1994. Shiitake Mushrooms, at Cloquet. 2 hour seminar on shiitake mushroom cultivation and related forest management concepts. 10 attended.

February 2, 1994. Shiitake Mushrooms, at Grand Rapids. 2 hour seminar on shiitake mushroom cultivation and related forest management concepts. 30 attended.

February 5, 1994. Shiitake Mushrooms, at Forest Resource Center, Lanesboro. 6 hour seminar and tour on shiitake mushroom cultivation and related forest management concepts. 22 attended.

[Seminars listed below from February 28 through March 15, 1994 under the titles Growing High Quality Walnuts and Managing Oak Woodlands were promoted by a brochure mailed directly to 1,500 woodland owners in three counties. A television commercial was produced and run on Rochester's KTTC TV and LaCrosse TV. Paid advertising was used in the Rochester Post Bulletin, Agri-News, Red Wing Eagle, Winona Daily, Caledonia Argus, Fillmore County Journal and the Tri-County Record. Paid advertising in the local newspapers seemed to generate the greatest response for the dollar invested.]

February 28, 1994. Growing High Quality Walnuts, at Rochester. 2.5 hour seminar. 75 attended.

March 2, 1994. Growing High Quality Walnuts, at Red Wing. 2.5 hour seminar. 36 attended.

March 3, 1994. Growing High Quality Walnuts, at Winona. 2.5 hour seminar. 36 attended.

March 5, 1994. Growing High Quality Walnuts, at Forest Resource Center, Lanesboro. 5 hour seminar and field tour. 28 attended.

March 7, 1994. Managing Oak Woodlands, at Rochester. 2.5 hour seminar. 65 attended.

March 8, 1994. Managing Oak Woodlands, at Caledonia. 2.5 hour seminar. 18 attended.

March 9, 1994. Managing Oak Woodlands, at Red Wing. 2.5 hour seminar. 38 attended.

March 10, 1994. Managing Oak Woodlands, at Winona. 2.5 hour seminar. 33 attended.

March 12, 1994. Managing Oak Woodlands, at Forest Resource Center, Lanesboro. 5 hour seminar and field tour. 26 attended.

March 15, 1994. Growing High Quality Walnuts, at Caledonia. 2.5 hour seminar. 22 attended.

[A series of 10 workshops were conducted from January through April, 1995 for private woodland owners. In conjunction with these workshops, we recruited and trained 34 Woodland Advisors. These are woodland owners and others who plan to provide 50 hours of volunteer service working as ambassadors for forestry following their 40 hours of continuing education in forestry. To advertise these workshops and the corresponding Woodland Advisor Program, two news releases were sent to the media, conservation organizations, county Extension offices, and natural resource agencies in southeast Minnesota. A brochure and personal letter were sent to prospective Woodland Advisors whose names were provided to us by natural resource professionals. Newspaper advertisements were designed and run in the Red Wing Republican Eagle, Winona Post, Rochester Post-

Bulletin, Tri-County Record, Caledonia Argus, Spring Valley Tribune, Preston Republican-Lanesboro Leader, and Harmony News-Mabel Record. A one-page flyer was printed and inserted in Agri News and distributed to 6,000 subscribers in Goodhue, Wabasha, Dodge, Olmsted, Winona, Mower, Fillmore, Houston, Allmakee, and Winneshek counties. A radio interview was conducted with a radio station in southeast Minnesota.]

January 7, 1995. Woodland Advisor training began on this date. These volunteers are expected to participate in 40 hours of forestry-related training and then provide 50 hours of volunteer service over the next two years. Advisors are expected to attend 6 out of the 10 forestry classes offered during winter and spring 1995 at the Forest Resource Center. 36 potential Woodland Advisors attended the first workshop.

January 7, 1995. Acquiring and Developing Woodland, at Forest Resource Center, Lanesboro. 6 hour seminar and field tour. 45 attended.

January 8, 1995. Marketing Timber and Reducing Your Taxes, at Forest Resource Center, Lanesboro. 6 hour seminar and field tour. 30 attended.

February 4, 1995. Christmas Tree Production and Woody Agriculture, at Forest Resource Center, Lanesboro. 6 hour seminar and field tour. 36 attended.

February 5, 1995. Shiitake Mushroom and Maple Syrup Production, at Forest Resource Center, Lanesboro. 6 hour seminar and field tour. 58 attended.

March 3, 1995. Tree selection and planting talk to farmers with Conservation Reserve Program contracts that are about ready to expire. 1 hour seminar at Rochester. 9 attended.

March 4, 1995. Managing Oak Woodlands, at Forest Resource Center, Lanesboro. 6 hour seminar and field tour. 39 attended.

March 5, 1995. Growing Walnut Trees for Profit, at Forest Resource Center, Lanesboro. 6 hour seminar and field tour. 26 attended.

March 7, 1995. Tree selection and planting talk to farmers with Conservation Reserve Program contracts that are about ready to expire. 1 hour seminar at Rochester. 12 attended.

March 21, 1995. Tree selection and planting talk to farmers with Conservation Reserve Program contracts that are about ready to expire. 1 hour seminar at Rochester. 12 attended.

April 1, 1995. Landscaping for Wildlife and Recreational Trail Design, at Forest Resource Center, Lanesboro. 6 hour seminar and field tour. 32 attended.

April 2, 1995. Game Management, at Forest Resource Center, Lanesboro. 6 hour seminar and field tour. 28 attended.

April 29, 1995. Acquiring and Developing Woodland, at Forest Resource Center, Lanesboro. 6 hour seminar and field tour. 15 attended.

April 30, 1995. Managing Oak and Walnut Stands, at Forest Resoruce Center, Lanesboro. 6 hour seminar and field tour. 20 attended.

May 20, 1995. Managing Forest Ecosystems: Assessing New Opportunities, a national videoconference produced by Oklahoma State University Extension, was shown at several public viewing sites around Minnesota, including Preston, Faribault, Caledonia, Winona, and Lewiston in southeastern Minnesota. Ecosystem management programs in Minnesota, especially the Big Woods Project near Faribault, were shown as a case study. Attendance records are not available.

June 16, 1995. Graduation dinner and volunteer activity planning session for Woodland Advisors that recently completed 40 hours of forestry training, at Forest Resource Center, Lanesboro. 30 attended.

<u>Educational Events for Youth and Educators</u>

June 27-July 2, 1993. Conducted Forests for the Future Summer Camp to teach youth about multiple-use management of forests. Students learned about managing timber, wildlife, soil and water resources and developed an integrated forest management plan. 40 youth attended.

December 6, 1993. Gave a 1-hour talk on tree identification and a 1-hour talk on forest management concepts at FFA Regional Meeting. 10 youth attended.

January 29-30, 1994. University of Minnesota, College of Natural Resources students were led through educational activities focused on timber stand improvement, tree identification, and hardwood management principles at the Forest Resource Center, Lanesboro. 17 students attended

February 16-19, 1994. Attended National 4-H Camping Institute in Virginia and gave 1.5 hour talk on how we organized the Forests for the Future Summer Camp. 25 Extension staff attended the presentation.

March 15, 1994. Met for 3 hours with environmental educators around the state to discuss the potential role of the University of Minnesota's College of Natural Resources in environmental education.

March 21, 1994. Participated in 3 hour meeting of the Southeastern Minnesota Environmental Education Council to plan the 1995 Environmental Educators Conference.

April 11, 1994. Participated in 3 hour meeting of the Southeastern Minnesota Environmental Education Council to plan the 1995 Environmental Educators Conference.

April 25, 1994. Gave 20-minute talk on tree identification at Fillmore County Earth Day Celebration at Forest Resource Center, Lanesboro. 350 students attended.

April 27, 1994. Gave 20-minute talk on tree identification at Houston County Earth Day Celebration at Winnebago Girl Scout Camp. 180 students attended.

May 3, 1994. Gave 20-minute talk on tree identification at Winona County Earth Day Celebration at Farmers Park near Winona. 350 students attended.

May 3-8, 1994. Led 5 Swedish and 4 Minnesota environmental educators on a tour of environmental education facilities and programs throughout Minnesota. Met state agency staffs and other educators involved in environmental education.

May 10, 1994. Gave 20-minute talk on tree identification at Wabasha County Earth Day Celebration at a farm near Zumbro Falls. 240 students attended.

May 13, 1994. Conducted 3-hour workshop on the 4-H Forest Resources Project, at Brainerd. [illegible] adult 4-H leaders attended.

May 21, 1994. Gave 1-hour introduction to 4-H Forest Resources Project at Forest Resource Center, Lanesboro. 10 4-H members attended.

June 19-25, 1994. Conducted Forests for the Future Summer Camp at Forest Resource Center, Lanesboro. Students learned about managing timber, wildlife, recreation, soil, and water resources and developed an integrated forest management plan. 27 students, ages 14-18, attended. Although attendance was lower than expected, the quality of instruction was excellent as indicated by student evaluations. We appreciated receiving assistance from several Minnesota Department of Natural Resources staff during the camp. Another camp is scheduled for June 18-24, 1995 and publicity is beginning.

August 23, 1994. Tree identification, at Forest Resource Center, Lanesboro. 1-hour class for 4-H junior leaders. 11 youth attended.

September 8, 1994. Met with School Nature Area Program (SNAP) to discuss how the Forest Resource Center can work with SNAP to deliver youth education programs. Set up a teacher workshop for January, 1995. 4 attended.

September 20, 1994. Met with Frank Tiffany, Chairman of the Board, Dodge Nature Center, to review adult outreach and demonstration projects at the Forest Resource Center and to advise him about how to conduct adult environmental education programs. 1 attended

September 22, 1994. Introduction to forestry, at Fillmore County Conservation Day. 15-minute presentation to school students repeated many times. 360 students attended.

September 30, 1994. Advised staff at Bonner School Nature Area about how to set up a nature study area with demonstrations. 4 teachers attended.

October 4, 22, and November 3, 1994. Planning meetings for upcoming youth leader "Weekend In The Woods Program."

October 4, 1994. Met with Southeastern Minnesota Environmental Educators to plan the October, 1995 statewide environmental education conference. 12 people attended.

October 5, 1994. Helped design, set up, and conduct Regional FFA Forestry Contest--tree identification trail, wood identification, and soil identification pits. 250 youth attended.

October 8, 1994. Conducted 1-hour Project Learning Tree workshop. 16 teachers attended.

October 19, 1994. Conducted 3-hour presentation on ecotourism, forestry demonstrations, and the Forest Resource Center to University of Wisconsin--Stout tourism class. 18 students attended.

October 25, 1994. Participated on a panel discussing development options for new 160-acre acquisition at Dodge Nature Center. 8 people attended.

November 1, 1994. Examined Stewartville School Nature Project site and reviewed demonstration options. 6 people attended.

November 16, 1994. Gave 1-hour presentation on ecotourism and forestry demonstrations at tourism meeting for University of Wisconsin--LaCrosse students. 23 students attended.

November 29, 1994. Spent 3 hours in on-site examination and trail layout at Stewartville School Nature Project site. 6 people attended.

January 10, 1995. Gave 40 minute talk to Wood Promotion Council about Forest Ecology Camp, at St. Louis Park. 28 wood product manufacturers attended.

February 9, 1995. Gave 1 hour talk to Owatonna Ikes on Forest Ecology Camp and the Forest Resource Center, at Owatonna. 44 attended.

February 20, 1995. Staffed display about Forest Ecology Camp at Mississippi Valley Partners meeting in Wabasha. Talked to 35 tourism industry representatives.

April 27, 1995. Gave 20 minute presentation on forest management and tree identification at Houston County Earth Day Celebration. 225 fifth graders attended.

May 12 & 13, 1995. Conducted Weekend in the Woods, District 4-H Weekend featuring natural resource activities, at Forest Resource Center, Lanesboro. 18 leaders attended.

June 18-24, 1995. Forest Ecology Summer Camp, at Forest Resource Center, Lanesboro. Students learned about managing timber, wildlife, recreation, soil, and water resources and developed an integrated forest management plan. 30 youth attended.

<u>Educational Events for Others</u>

October 6, 1993. Gave 3-hour talk on forest management in southeastern Minnesota to Travel Writers Van Tour, at Forest Resource Center, Lanesboro. 18 attended.

October 7, 1993. Conducted 3-hour ecotour for Fillmore County Bankers Association at Forest Resource Center, Lanesboro. 22 attended.

October 14, 1993. Gave 40-minute forestry talk to Wabasha Rotary Club. 32 attended.

October 16, 1993. Gave 5-hour shiitake mushroom talk and an ecotour to Olmsted County Master Gardeners. 23 attended.

October 18, 1993. Gave 1-hour forest management talk to Town and Country Women's Group. 14 attended.

November 19, 1993. Gave 40-minute forest management talk to Mantorville Exchange Club. 25 attended.

January 11, 1994. Gave 35-minute forest management talk to Chatfield Rotary. 35 attended.

January 16, 1994. Staffed a booth at Audubon Annual Meeting in St. Paul and distributed brochures on Forests for the Future Summer Camp and other upcoming forestry education events.

February, 1994. Gave 30-minute talks on forest management to Stewartville Lions and LaCrosse JayCees. 80 attended.

February 17, 1994. Gave 20-minute talk on forest management concerns related to county zoning ordinances at Fillmore County Zoning Meeting. 30 attended.

February 21, 1994. Staffed a booth on Eco-tourism at the "River Runs Through It" tourism conference in Wabasha. Distributed brochures on upcoming forestry education events. 200 attended.

March 13, 1994. Staffed a booth at Isaac Walton League Metro Meeting and distributed brochures about Forests for the Future Summer Camp and other forestry education events.

March 29, 1994. Helped conduct a Logger Workshop focused on silviculture. Worked with DNR to make local arrangements [illegible] afternoon field tour. 11 attended.

April 8-10, 1994. Attended Minnesota Deer Hunters Association Convention. Gave 40-minute talk on forest management in southeast Minnesota that was attended by 33 people. Staffed a booth to distribute brochures about upcoming forestry education events including the Forests for the Future Summer Camp.

April 19, 1994. Provided 3-hour interview and tour for Ray Lorenz, writer for Metro Retail, a forest products-related magazine. May result in a forestry article for this magazine in the near future.

April 21, 1994. Gave 1-hour talk on how to buy and manage forest lands at IBM company in Rochester as part of Earth Day Celebration. 180 attended.

April 23, 1994. Staffed booth at Nature Conservancy Regional Meeting in Rochester and distributed brochures about upcoming forestry education events. 80 attended.

May 4-5, 1994. Attended Natural Resources Specialization Training for Minnesota Extension Service staff and gave 1-hour talk on forestry education programs for private woodland owners and youth. 10 attended the talk.

July 7, 1994. Forestry/wildlife management, at Forest Resource Center, Lanesboro. 1-hour talk to Minnesota Bow Hunters. 24 attended.

July 23, 1994. Evaluating forests and forest management options, at Forest Resource Center, Lanesboro. 1-hour talk as part of Farm Business Managers Tour. 58 attended.

July 27, 1994. Upcoming Forests for the Future Classes, at Bloomington. 20-minute presentation to Metro Area meeting of the Minnesota Deer Hunters Association. 35 attended.

July 28, 1994. Upcoming Forests for the Future Classes, at Mankato. 20-minute presentation to Southeast Minnesota meeting of the Minnesota Deer Hunters Association. 25 attended.

August 17, 1994. Upcoming Forests for the Future Classes, at Forest Resource Center, Lanesboro. 20-minute presentation to Southeastern Regional meeting of the Minnesota Deer Hunters Association. 18 attended.

September 7, 1994. Walnut management, at Adams (Carl Winkels property). 1-hour talk and tour to Adams Kiwanis. 18 attended.

October 7, 1994. Gave 6-hour tour of Forest Resource Center facilities and demonstrations to Iowa Society of American Foresters. 18 foresters attended.

October 12, 1994. Gave 1-hour presentation on Forest Resource Center demonstrations and attended day-long forestry tour and seminars at Tri-State Forestry Meeting at Forest Resource Center, Lanesboro, MN. 50 foresters attended.

October 13-14, 1994. Spent 1 1/2 days showing forestry demonstrations and unique natural resource features of southeast Minnesota to administrators from University of Minnesota, College of Natural Resources. 4 faculty attended.

November 20, 1994. Coordinated 4-hour wood carving seminar at Forest Resource Center, Lanesboro. Introduced presenters and gave overview of how to obtain wood for carving. 15 attended.

December 6-7, 1994. Gave 1/2 hour talk to Southeast District Extension staff on forestry demonstrations at the Forest Resource Center and role of Minnesota Extension Service in forestry education. 60 staff attended.

December 8, 1994. Gave introduction and listened to native American concepts on natural resource management at Ho-Chunk Council meeting at Forest Resource Center, Lanesboro. 45 attended.

January 19, 1995. Gave 1-hour talk on forest management and shiitake mushroom cultivation to Tri-State Economic Development Council. 65 attended.

February 25, 1995. Gave 30-minute talk on value of environmental education at MN Bowhunters Banquet at Forest Resource Center, Lanesboro. 207 attended.

February 28, 1995. Facilitated 3.5-hour Society of American Foresters videoconference on Ecosystem Management, at Rochester. 33 natural resource professionals attended.

March 14, 1995. Facilitated 3.5-hour Society of American Foresters videoconference on Ecosystem Management, at Rochester. 33 natural resource professionals attended.

March 14, 1995. Gave 1-hour talk on attracting wildlife to your property to Mower County Chapter, MN Horticulture Society, at Austin. 36 attended.

April 5, 1995. Moderated program at SE Minnesota Tourism Conference: Quality--Service, Development, Growth & Tourism, at Forest Resource Center, Lanesboro. 85 attended.

May 11, 1995. Gave 1 1/2 hour talk and tour on shiitake mushroom production at Tri-State Economic Development Conference, at Forest Resource Center, Lanesboro. 8 attended.

June 1, 1995. 30-minute presentation on forest management at MN Wood Promotion Council Regional Meeting, at Forest Resource Center, Lanesboro. 15 attended.

V. **Evaluation:**

Objective A will result in a written report summarizing the survey work performed to identify the relationship, if any, between canopy gap characteristics and species composition of the trees that regenerated in those gaps. A written report will be prepared that describes results of the isozyme analysis. This report will describe how physical attributes of oaks can be used to help distinguish oak species and hybrids.

Objective B will result in a written report summarizing one year of data regarding the affects of crown closure and site preparation methods on natural oak regeneration and two years of survey data regarding the acorn crop. In the long term its success can be measured by the continued monitoring of these sites and reporting on the treatment affects and acorn crops.

Objective C can be evaluated by the number of conferences and field tours conducted, by the attendance at those events, by written evaluations completed by program participants, and by the number of mass media contacts and materials produced.

VI. **Context within field:**

The key to regenerating oaks in other states has been the presence of large (greater than 4 feet tall) advance reproduction or trees capable of producing stump sprouts (Sander, 1977 and Loftis, 1989). However, in a recent survey of 100 mature oak stands in southeastern Minnesota, no such stands were found (Ken Anderson, personal communication). Efforts to increase the amount of advance oak reproduction have focused on regulating crown cover, controlling the understory, and timing the harvest to take advantage of an abundant acorn crop.

Clearcutting trials in Iowa and Wisconsin produced mixed hardwood stands in which red oak was or could be a major component if competing trees were controlled. Successful oak regeneration occurred where mature stands had 80-90 percent of the basal area in red oak, all overstory trees 1.6 inches DBH and larger were harvested or killed, harvesting coincided with a good acorn crop, understory competition was controlled before or during overstory removal, and the soil was disturbed by logging or site preparation, often when acorns were on the ground. In Wisconsin the understory control was achieved with herbicides applied prior to the harvest. In Iowa the understory control was achieved by mechanical scarification at the time of logging (Jacobs and Wray, 1992). These trials were not conducted as experiments, therefore, the relative importance of each factor is unknown, but it appears that a good acorn crop is essential when advance reproduction is lacking.

There is no long-term research that provides information about how to evaluate acorn abundance or predict the size of the acorn crop in Minnesota. Our proposed research will initiate a long-term study of acorn crops and a long-term study of the relative effects of overstory and understory control.

An LCMR project funded during 1991-93 involves control of the understory in oaks stands prior to harvest by the use of herbicides and bulldozing. Those treatments were conducted in conjunction with planting oak seedlings.

We are measuring the effects of understory treatments on all natural regeneration and on planted oak seedlings, however the advance oak regeneration was not protected from herbicide and bulldozer treatments.

Prescribed burning has been used in Wisconsin on small clearcut plots on both xeric and mesic sites to control understory competition. While burning did not increase the number of oak seedlings it dramatically reduced the cover and number of competitors while leaving the oak virtually unaffected (Reich, et.al, 1990 and Kruger, 1992). Our proposed research will conduct prescribed burning in shelterwood and clearcut situations on larger areas to test whether the initial results from Wisconsin are applicable under our somewhat different climate, soils, and species mix.

The value of soil disturbance other than to control understory competition is uncertain. However, Crow (1988) suggests that soil scarification is vital for protecting acorns from predators. In southeastern Minnesota Bundy et.al. (1991) found that bulldozer scarification did not increase the total number of oak seedlings, but it did increase the height growth of oak seedlings. Our proposed research will include bulldozer scarification to knock down competition and we will try to schedule it after the acorns drop. Because of the short, two-year duration of this project, it may not be possible to schedule the scarification and other understory control treatments in years when there is an abundant acorn crop.

Two shelterwood trials in Wisconsin produced stands that were adequately stocked with oaks, but neither stand was stocked as well as a nearby clearcut where herbicides were used prior to the harvest to control the understory. Shelterwood harvests should be more successful if the understory is also controlled (Johnson and Jacobs, 1981). These were unreplicated studies without inventories of reproduction prior to the final harvest. Both shelterwood cuts reduced basal area to approximately 60 square feet of basal area.

There are shelterwood harvests and understory control practices in oak stands near Rhinelander, Wisconsin that were installed by the North Central Forest Experiment Station. Shelterwood cuts include 25 percent, 50 percent, 75 percent, and 100% canopy cover. Understory competition was controlled by herbicides and/or bulldozing. These experiments are not yet old enough to provide reliable results and they were designed to test the affects of crown closure and understory control on planted oak seedlings, not natural oak regeneration. Their planting sites also differ from sites in southeast Minnesota regarding soil, slope, and climate.

Our research will include a shelterwood cut that leaves approximately 33 percent crown cover. We will control the understory by use of herbicides and by scarification (bulldozing and dragging tree tops over the site). Our treatments and vegetation measurements will be planned to assess the affects of crown closure and understory control on natural oak regeneration. A few relevant studies have been conducted examining gap dynamics in oak forests. Gaps caused by gypsy moth induced mortality were contrasted with nearby gap-free areas by Ehrenfeld (1980). She found little evidence of red oak re-invading gaps or capitalizing on gap formation. For a seven-year period after gap formation, reorganization of existing tolerant understory species was the rule (primarily dogwood in the site studied). In contrast, Lorimer (1983) found evidence that an existing understory of red oak quickly occupied and flourished in gaps created by harvest of a sugar maple overstory. McGee (1984) found growth of advance oak regeneration to occur earlier under partial canopies (gap-type conditions) than in clearcuts. These works and those of a similar nature all point out the high dependency of results on stand, site, and gap conditions. Broader scale studies, such as that of Nowacki et al. (1990), are needed if more broadly applicable conclusions are to be drawn. This just mentioned study only indirectly studied red oak regeneration relationships but did conclude that edaphic conditions had a dramatic impact on success with the oak only succeeding on the more xeric sites. Hix and Lorimer (1990) have studied growth and competition relationships in young hardwood stands in Wisconsin. Their sites, while containing northern red oak, have a quite different set of associate species, primarily those of northern hardwood forests, than is typically found in southeastern Minnesota.

Hybridization between northern pin and northern red oak appears to be quite common (Hokanson et al. in press). Isozyme and polymerase chain reaction analysis methods (Jensen et al. in press) have been employed to positively identify hybrids and pure species. Previous LCMR funded research by the investigators has applied this work to southeastern Minnesota, including a third species--black oak. Isolated, large individuals were sampled based on differences in morphological characteristics. That work to date has shown results similar to that published by other researchers. However, a more systematic approach to collection of sample material is now needed if the conditions under which hybridizations occur are to be identified.

The educational program outlined under Objective C is a continuation of work begun during a 1991-93 LCMR project. Our proposed new project will enable us to greatly expand the audience reached by our educational program and it will enable us to extend the research findings from our 1991-93 oak research project.

VII. Benefits:

We will learn about the relationship between canopy gap sizes and the species composition of regeneration. Because of public pressure to reduce the size of clearcuts, this information will enable foresters to plan timber harvests that regenerate the most desirable species while minimizing the size of harvest areas.

Isozyme analysis of oaks will better enable us to identify oak species and determine whether or not to artificially or naturally regenerate timber stands depending on the genetic makeup of the species present.

This project will generate benchmark data about forest stand conditions before and immediately after clearcut and shelterwood harvests, about understory control treatments (herbicides, bulldozer scarification, and burning) and about acorn crops. Stands will be monitored in the future to learn the longer term implications of these treatments. Over time we will be able to assess the value of different amounts of crown closure and different understory control measures to enhance oak regeneration. We will be better able to assess the relative abundance of acorns and possibly predict in what years good acorn crops are likely to occur. This latter information will be especially helpful to foresters when scheduling timber harvests.

This research and the educational efforts that go with it will foster improved regeneration of hardwood species that produce commercially valuable wood products and that are important for wildlife habitat.

VIII. Dissemination:

Research results from this project will be presented at state and national scientific meetings for natural resource professionals and we will submit them for publication in peer-reviewed periodicals aimed at natural resource specialists. Research results will be incorporated into future educational materials, conferences, and field tours aimed at private woodland owners, loggers, and the forest products industry that will be conducted by extension foresters at the University of Minnesota.

IX. Time:

Objectives A and C will be completed in their entirety during the 1993-95 biennium. Research plots described in Objective B will be completely installed and monitored during 1993-95, but the most useful results will not be available for several years in the future. Forest vegetation is dynamic and the species composition of stands following cultural treatments may change fairly rapidly over time. We expect to monitor these plots for several years to better assess the treatment affects on oak regeneration. We do not anticipate requesting additional funds from LCMR for long-term monitoring of these plots. The most expensive and time-consuming part of this research will be accomplished during 1993-95. Expenses that we incur to monitor these plots after 1995 will be paid from other funding sources, most likely sources available through the Minnesota Agricultural Experiment Station.

X. Cooperation:

Melvin J Baughman will serve as the Principal Investigator for the project as a whole and will be responsible for monitoring the overall budget and for reporting accomplishments to the LCMR.

Thomas Burk will coordinate all of the research under Objective A. He will be principally responsible for the inventory work aimed at assessing the affects of canopy gap size on species composition. Jud Isebrands from the North Central Forest Experiment Station, Forest Service will provide leadership for the isozyme analysis of oaks outlined under Objective A. He will be involved in collecting tree samples and will be responsible for conducting laboratory tests and analyzing the results.

Peter Reich, Melvin Baughman, and Klaus Puettmann will be responsible for planning and conducting all the research under Objective B.

Melvin Baughman, Steven Laursen, and Joe Deden will plan and conduct the educational programs outlined under Objective C. Other state specialists and county agents from the Minnesota Extension Service will be involved in organization and promotion of specific events.

The Minnesota Department of Natural Resources, Division of Forestry is expected to help us identify potential sites for the research that will be conducted under Objectives A and B. We expect to conduct our research on forest land administered by the DNR. We will rely upon the DNR to schedule timber harvests needed to accomplish Objective B and within the limits of their budget capability to help conduct site preparation treatments. We also will provide funds from this project appropriation to support the site preparation costs as needed. We expect the DNR to provide some of the personnel and equipment necessary to control the prescribed burns.

	Percent Time		
Cooperators	Object A	Object B	Object C
Dr. Melvin J. Baughman	--	8	8
Dr. Thomas E. Burk	8	--	---
Mr. Joe Deden	--	--	80
Dr. Jud Isebrands	5	--	---
Dr. Steven B. Laursen	--	--	8
Dr. Peter B. Reich	--	8	---
Dr. Klaus Puettmann	--	5	---

XI. **Reporting Requirements:**

Semiannual status reports will be submitted not later than Jan. 1, 1994; July 1, 1994; Jan. 1, 1995; and a final status report by June 30, 1995.

XII. **Literature Cited:**

Bundy, P.P.; A.A. Alm and M.J. Baughman. 1991. Red oak regeneration following scarification and harvesting: a case study. Northern Jour. of Applied Forestry. 8(4):173-4.

Crow, T.R. 1988. Reproductive mode and mechanisms for self-replacement of northern red oak (Quercus rubra)--a review. Forest Science. 34(1):19-40.

Ehrenfeld, J.G. 1980. Understory response to canopy gaps of varying size in a mature oak forest. Bull Torrey Bot Club 107:29-41.

Hix, D.M. and C.G. Lorimer. 1990. Growth-competition relationships in young hardwood stands on two contrasting sites in southwestern Wisconsin. For Sci 36:1032-1049.

Jacobs, R.D. and R.D. Wray. 1992. Managing oak in the driftless area (NR-BU-5900). St. Paul, MN: Minnesota Extension Service, University of Minnesota. 32 p.

Johnson, P.S. and R.D. Jacobs. 1981. Northern red oak regeneration after preherbicided clearcutting and shelterwood removal cutting. Res. Pap. NC-202. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 5 p.

Kruger, E.L. 1992. Survival, growth, root:shoot relations, and ecophysiology of northern red oak (Quercus rubra L.) and competing tree regeneration in response to fire and related disturbance. Ph.D. Thesis. University of Wisconsin--Madison.

Loftis, D.L. 1989. Species composition of regeneration after clearcutting southern Appalachian hardwoods. In: Proceedings of the 5th Biennial Southern Silvicultural Research Conference, 1988; Memphis, TN. Gen. Tech. Rep. SO-74. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. p. 253-257.

Lorimer, C.G. 1983. Eighty-year development of northern red oak after partial cutting in a mixed-species Wisconsin forest. For Sci 29:371-383.

McGee, C.E. 1984. Oak regeneration begins growth earlier under forest canopies than in clearcuts. Paper presented at Southern Silvicultural Research Conference, Atlanta, GA, Nov 7-8, 1984.

Nowacki, G.J., M.D. Abrams, and C.G. Lorimer. 1990. Composition, structure, and historical development of northern red oak stands along an edaphic gradient in north-central Wisconsin. For Sci 36:276-292.

Reich, P.B., M.D. Abrams, D.S. Ellsworth, E.L. Kruger and T.J. Tabone. 1990. Fire affects ecophysiology and community dynamics of central Wisconsin oak forest regeneration. Ecology 71:2179-2190.

Sander, I.L. 1977. Manager's handbook for oaks in the North Central States. Gen. Tech. Rep. NC-37. St Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 35 p.