1995 Project Abstract
For the period ending June 30, 1997
This project was supported by Environment and Natural Resources Trust Fund
TITLE: Forest management to maintain structural and species diversity
PROJECT MANAGER: Kurt A. Rusterholz
ORGANIZATION: Natural Heritage and Nongame Research Program
Department of Natural Resources
ADDRESS: 500 Lafayette Rd., Box 25
St. Paul, MN 55155

LEGAL CITATION: M.L.1995, Chp.220, Sec. 19, Subd. 5(n).
APPROPRIATION: $160,000

Statement of Objectives

The overall goal of this project was to develop initial, site-based silvicultural guidelines that will maintain structural and compositional aspect of diversity on commercial forests in east-central Minnesota. This goal was to be achieved by using the LINKAGES forest growth and harvesting model to simulate and evaluate a variety of silvicultural practices, on common soil types and under condition of the current climate as compared to conditions predicted for climate change over the next 400 years.

Overall Project Results

A total of 57 LINKAGES simulations were made. These included 16 different harvesting regimes on two common soil types and under three different climate regimes. Assuming no change in climate over the next 400 years, partial cutting management scenarios with a maximum removal of 30% basal area every 10-20 years would allow for the maintenance of high-quality northern hardwoods cover type and compatible commodity timber production, in the Nemadji State Forest, on the soil types examined. However, under climate change conditions the forest cover type does not persist and therefore, no commodity production is possible.

This study demonstrates that guidelines based on average stands on average soils are inadequate for making the best management decisions at the stand level. Distribution and training of field professionals in the use of the LINKAGES model would not only increase the effectiveness and responsiveness of the decision making process for forest managers, but it would also provide strong direction for future research and improvements for silvicultural practices in Minnesota.

The results of this study will be important to consider as Minnesotans and their legislative representatives are called upon to make important social and economic decisions with regard to the preservation of our natural resources. This is especially true in the face of increased demand on forested lands coupled with potential effects of climate change.

Project Results Use and Dissemination

The results of this project were presented through the Natural Resources Seminar series in Grand Rapids, MN on April 30, 1997. The audience was largely composed of natural resources professionals. There was a great deal of discussion of the results and interest in having the LINKAGES model made available.

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Date of Report: July 1, 1997
LCMR Final Work Program Report

I. Project Title and Project Number: Forest Management to Maintain Structural and Species Diversity - C-9

Program Manager: Kurt A. Rusterholz
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A. Legal Citation: M.L. 95, Chp.220, Sec.19, Subd. 5(n).
Total biennial LCMR appropriation: $160,000
Balance $806; Unencumbered Balance: $806

Appropriation Language: This appropriation is from the trust fund to the commissioner of natural resources to document forest management practices in a pilot area, assess the long-term effects of current and alternative timber harvest practices on structural aspects of biodiversity (especially old-growth forest characteristics), and prepare forest management guidelines to maintain these features in commercial forests.

B. Status of Match Requirement: N/A

II. Project Summary:

The overall goal of this forest management project is to develop initial, site-based silvicultural guidelines that will maintain structural and compositional aspects of biodiversity on commercial forests in east-central Minnesota. The recently completed Roundtable on the Implementation of the Generic Environmental Impact Statement on Timber Harvest and Forest Management in Minnesota (GEIS) called for the development of site-based forest management guidelines to mitigate the negative effects of timber harvest. A primary goal of such guidelines is to maintain biodiversity.

Rather than basing guidelines on untested ideas developed in other geographical regions, in this pilot project we will develop guidelines based on the results of simulations from the ecosystem model LINKAGES. These simulations will allow us to predict the potential long-term effects of different harvest practices that are designed to maintain structural and compositional aspects of forest biodiversity. These simulations should provide a good approximation of how well different harvest practices will result in desired structural and

composition features in these forests well into the future. The major product of this project will be preliminary site-based silvicultural guidelines designed to maintain biological diversity in the commercial forests of east-central Minnesota. These guidelines will form a basis for adaptive forest management and contribute to the development and revision of statewide site-based forest management guidelines envisioned by the GEIS Implementation Roundtable.

The forest ecosystem model LINKAGES simulates the birth, growth, and death of trees; soil nutrients; and a variety of aspects of forest structure that are important to biological diversity. This model has been extensively validated and will be used as a tool to assess the effectiveness of different harvest practices in producing desired structural and compositional features in commercial forests. In the course of the project, we will be improving LINKAGES to make it spatially explicit so that the fate of each tree can be simulated. These improvements are funded under a separate grant from the National Science Foundation. The alternative harvest practices to be simulated will be developed by scientists and field foresters, and both groups will participate in preparing the final silvicultural guidelines.

III. Final Work Program Update: Summary

Using data gathered from ten northern hardwood stands within two townships in the Nemadji State Forest, we used LINKAGES to simulate 16 different timber harvest regimes over 400 years on two common soil types and under three climate regimes. Assuming no change in climate over the next 400 years, partial cutting management scenarios with a maximum removal of 30% basal area every 10-20 years would maintain high-quality northern hardwood cover types and commodity timber production. This general guideline, however, should be viewed with caution. First, this simulation is based on the nutrient and water-holding capacity of two similar sandy-loam soil types, and results are likely to differ on other soil types. Second, the simulations address only tree species, not herb and shrub species. Third, maintenance of northern hardwoods (or any forests) on these soils within the Nemadji State Forest is unlikely if the climate warms by 2 degrees C over the next 400 years, as predicted by some climate models.

Nevertheless, a forest management guideline for northern hardwoods on the Nemadji State Forest that recommends partial cutting (trees >30 cm d.b.h.) that removes a maximum of 30% basal area every 20 years is likely to maintain many important structural aspects of the cover type. Where large trees (i.e., > 50 cm d.b.h.) are desirable as part of the forest, lengthening the harvest interval to 30 years is necessary. Lengthening the harvest interval, however, markedly decreases the number of trees available to harvest over the 400 years. Such a guideline represents a starting point for management considerations.

This study also demonstrates that guidelines based on average stands on average soils are inadequate for making the best management decisions at a stand level. In order to choose detailed managemt ptions that are likely to balance timber production and biodiversity maintenance, managers need more information about local ecosystems and how they are likely to respond to management. Textbook prescriptions based on site index are inadequate, and studies such as this one that focus on a few of the many different ecosystem types across Minnesota are not feasible at a large scale. Instead, providing LINKAGES software, training, and support for field managers to use in making management decisions provide the best hope for designing and implementing management strategies that will preserve important forest features and still allow for commodity timber production. LINKAGES is a simple, inexpensive and powerful tool that can be run easily on a 486 desktop computer. Once managers have this tool in hand, we will be able to more readily and accurately identify its strengths and weaknesses and make needed adjustments and/or additions to the program. Some potential improvements to the model may include incorporation of understory species and canopy gap dynamics.

Other important results from the LINKAGES simulation relate to clearcutting and climate change. Clearcutting in these situations causes a shift from the maintenance of northern hardwoods to succession to the aspen cover type. In order to develop soil nitrogen levels, foliage height diversity, and volume of coarse woody debris in these aspen forests that are similar to those in unharvested and partially cut northern hardwoods, a rotation of 80 years is required. These results are especially important given increased harvest of northern hardwoods in the area.

Simulations for forest conditions under different climatic change scenarios were not part of the work plan but was added near the end of the project. The most important conclusion of these simulations is that even under moderate climate change (increase in temperature of 2 degrees C and decrease in precipitation by 10%), the sandy-loam soils of the Nemadji State Forest do not provide the needed moisture capacity to maintain forests. This result has enormous environmental, economic, and social implications for Minnesota.

In preparation for the model simulations, we attempted document patterns of timber harvest across an entire landscape in the Nemadji State Forest (Objective A). We had limited success with this objective, primarily because most of the essential information on past stand management had been discarded by the DNR Forestry field offices several years ago. We did succeed in preparing a landscape analysis covering three township within the Nemadji. In this analysis, we focused the distribution of cover types within the landscape as whole as compared to 1) that within designated old-growth buffer zone and 2) simulated 100-meter buffer zones around streams, roads, and aspen stands. The results showed that old-growth buffer zones were quite different from both the landscape as a whole and from the other buffer zones examined. The old-growth buffers contained virtually no ash, aspen, birch, or northern hardwood cover types but white spruce, black spruce and other wetland types were found in much higher proportions than in other parts of the landscape.

Finally, in hindsight, we would not have spent considerable time and effort searching for records of past forest stand management had we been aware that they no longer existed. This time could have been more profitably spent sampling additional sites and running additional simulations.

An additional report prepared by Cindy Hale of the Natural Resources Research Institute at the University of Minnesota-Duluth will be submitted seperately. This report contains figures and references.

IV. Statement of Objectives:

Objective A. Document forest management practices. We will document actual forest management practices on a large landscape extending over several townships on the Nemadji State Forest. Information gathered on current harvest practices and managed stand parameters will be used in the ecosystem simulations (Objective B). We will produce GIS layers of cover types, current vegetation, streams, roads, and managed study sites, as well as maps of the cover types that surround these features.

Objective B. Assess current and alternative timber harvest practices. Potential long-term effects of harvest practices (silvicultural treatments) on species diversity will be assessed using the forest ecosystem model LINKAGES. Alternative timber harvest practices simulated will be developed in consultation with DNR field foresters. We will examine the potential effects of different harvest practices on structural characteristics important to birds and other wildlife species (foliage height diversity; numbers, volumes, and characteristics of snags, and down logs on the forest floor); soil nitrogen availability; stand productivity; biomass; and tree species diversity. We will also assess the effects of these simulated silvicultural treatments on timber yield by species and diameter class (especially the mix of pulpwood and sawtimber).

Objective C. Develop forest management prescriptions and guidelines that, based on our model runs, maintain key aspects of biological diversity while providing fiber for the forest products industry . We will describe a series of recommended silvicultural prescriptions that maintain key components of biological diversity in the upland forests of east-central Minnesota. These silvicultural practices and their likely outcomes in terms of biodiversity and timber yield will be published in a booklet for distribution to regional forest managers and loggers. Based on these recommendations, we, the scientists and foresters, will develop a draft set forest management guidelines to maintain biological diversity that can be incorporated into statewide forest management guidelines.

Timeline for Completion of Objectives:

7/95 1/96 6/96 1/97 6/97

Objective A - Document forest management practices

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Objective B - Assess current and alternative timber harvesting practices

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Objective C - Develop forest management prescriptions and guidelines

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V. Objectives/Outc... :

A. Title of Objective/Outcome: Document Forest Management Practices

A.1. Activity: Gather data on a large landscape covering several townships in Nemadji State Forest. We will gather data on current vegetation, cover types, streams, roads, old-growth sites, and managed study sites. This information will be summarized and interpreted in a report and published map(s).

A.1.a. Context within the project: Specific information on the pattern of timber harvesting across an entire landscape has rarely been documented in Minnesota. This activity will provide us with the information necessary to choose which existing harvest practices will be modeled using LINKAGES along with the details of these harvest practices. This information will provide a landscape context necessary to develop forest management prescriptions and guidelines.

A.1.b. Methods: We will use forest inventory data, existing records from DNR forestry files, contacts with field foresters, MCBS natural community crosswalks, and field checks to describe the landscape and its components. This information will be summarized in a report and as one or more GIS maps.

A.1.c. Materials: The Natural Resource Research Institute's (NRRI's) GIS laboratory and Cohen's laboratory at St. Paul include PC and Sun computers, digitizing tables, zoom stereoscopes, and other equipment for digitizing data into GIS format and making and analyzing maps. Existing coverages of the area used in other projects will be used whenever possible. Additional air photo coverage of Nemadji State Forest will also be used as needed.

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

A.1.e. Timeline:

	7/95	1/96	6/96	1/97	6/97
Prepare and complete report and map(s)	**************************				

A.1.f. Final Work Program Summary: July 1, 1997
We selected a large landscape consisting of three townships that was located almost entirely on state land in the Nemadji State Forest. During the first few months of the project we spent considerable time and effort attempting to locate DNR stand management records until it become apparent that these records had been discarded several years ago due to lack of storage space. We then shifted the emphasis of this objective to perform a landscape analysis focusing on the distribution of cover types in the landscape as a whole as compared to 1) those in designated old-growth buffer zones and 2) simulated 100-meter buffers zones around streams, roads, aspen stands. For this analysis we used GIS data layers (including stand cover type, roads, and streams) provided by DNR Forestry in Brainerd.

Our results indicated that old-growth buffer zones are quite different from both the landscape as a whole and from the other buffer zones examined: The old-growth buffers contained virtually no ash, aspen, birch, or northern hardwood cover types but white spruce, black spruce and other wetland types were found in much higher proportions than in other parts of the landscape.

B. Title of Objective/Outcome: Assess current and alternative timber harvesting practices .

B.1. Activity: Simulate harvesting practices using the forest ecosystem model LINKAGES and assess potential effects of harvesting on timber yield, stand structure, tree species diversity, habitat (especially for bird species), productivity, soil nitrogen availability, snags and down logs, and other old-growth characteristics that are important for biological diversity.

B.1.a. Context within the project: This activity will use a well-validated ecosystem model to explore the range of possible silvicultural methods and their potential effect on the ecosystem processes that sustain both timber yield and diversity. Data from old-growth forests will be used to validate the model further and to choose various old-growth attributes to be assessed in the simulations.

Relationship to modeling in the LCMR Project : *Minnesota Forest Bird Diversity Initiative (Subd. 7(d)):* The modeling efforts in the Forest Bird Project rely primarily the model LANDIS. LANDIS simulates bird habitat relations at a landscape scale. This project, however, simulates structural and compositional features of forests at the site or stand level. Also, this project addresses structural and compositional features that are important to a variety of plants and animals, not just birds.

B.1.b. Methods: We shall simulate a full range of silvicultural prescriptions from clearcutting to selection cutting and various combinations using the forest ecosystem model LINKAGES (Pastor and Post 1986, Cohen and Pastor 1991, Pastor and Mladenoff 1994). LINKAGES simulates the birth, growth, and death of all trees greater than 1.43 cm dbh in 1/12 ha plots, along with the return of litter from these trees, its decay, and release of nitrogen for subsequent plant growth. In a normal run, many plots (20-100 or more) are simulated to scale up to a stand. Growing season degree days, soil water availability, and evapotranspiration are calculated from monthly rainfall and temperature and soil water retention characteristics. Light availability to each tree is a function of leaf biomass of all taller trees. The presence of available seed trees, degree days, soil water availability, and light limit recruitment of new individuals. Degree days, soil water availability, soil nitrogen availability, or light, whichever is most restrictive, limit the growth of each individual tree. The probability of a tree dying increases with age and slow growth. Litter from shed leaves, roots, and dead wood is returned to the soil at the end of each year to begin decaying the following year. The above-ground population dynamics are thereby extended into the soil environment by tracking changes in the carbon and nitrogen contents of litter. This model therefore simulates the effect of different tree species on ecosystem processes. The model has been extensively validated against independent data on second growth and old-growth forests of Minnesota, Wisconsin, Michigan, and Ontario (Pastor and Post 1986, 1988, 1993, Pastor et al. 1987, Cohen and Pastor 1991, Pastor and Mladenoff 1993). LINKAGES differs from the forest growth model used in the GEIS in that it explicitly simulates interactions of trees with their climatic, soil, and biological environments, and the effects that different tree species and stand structures have on animal habitat, particularly that for birds.

Several recent developments of this model are of interest to this project: 1) We have implemented a timber harvesting routine that allows the user to design any harvesting strategy by specifying the proportion of basal area to be removed from any one or all of 10 cm diameter classes in any or all species on site and by specifying rotation age. The harvesting routine also allows for mixing harvesting strategies during different stand entries. Pastor and Mladenoff (1993) used this harvesting routine to show that a mixture of clearcutting and partial harvests in alternative stand entries might maintain biodiversity equivalent to that of old growth forests as well as provide a mix of both sawtimber and pulpwood for a diversity of markets. 2) Under separate funding from the National Science Foundation to Cohen and Pastor, we are further implementing and improving a more spatially detailed version of this model in which the exact location of each plot (and therefore the approximate location of each tree) is specified and seeds are dispersed across the site according to the location of potential seed trees. These improvements will allow us to more accurately simulate silvicultural practices such as seed tree and shelterwood cuttings. 3) Also under funding from NSF, we are using the model to simulate bird habitat for a variety of species in forests of the Lake Superior Region. In this endeavor, we are cooperating with Dr. Gerald Niemi and using data collected under the current LCMR project on bird species

diversity. In fact, this summer we collected data to evaluate model performance in simulating bird habitat and population densities in one of the square mile plots established by this other LCMR project. Thus, the current expenditure of $80,000 on this objective makes use of over $500,000 worth of research funded by complementary projects.

We shall simulate a range of possible silvicultural prescriptions using soils data, stand data, and weather data from the prospective field sites. We shall develop the simulations in consultation with local field foresters. We shall examine the effect of simulated silvicultural treatments on timber yield by species and diameter class (especially the mix of pulpwood and sawtimber), stand productivity and biomass, structural characteristics important to birds and other wildlife (foliage height diversity, number, species, and size of snags, amount of down logs on the forest floor), soil nitrogen availability, and tree species diversity.

These simulations should be the basis for demonstration timber sales conducted on the Nemadji State Forest as part of a separate project. Such timber sale boundaries should be permanently marked so that long-term monitoring of specific applications of these silivicultural prescriptions can be carried out.

B.1.c. Materials: Most of the budget allocated for this objective will be spent on salaries of a graduate student or programmer and partial support of John Pastor's and Yosef Cohen's time. No major purchases are anticipated. Supplies such a magnetic marking stakes, flagging tape, and computer diskettes will be purchased

B.1.d. Budget: $80,000
Balance: $0

B.1.e. Timeline:	7/95	1/96	6/96	1/97	6/97
Develop simulations		****	****	**	
Field evaluation			****	****	

B.1.f. Final Work Program Summary: July 1, 1997
<u>Stand selection and sampling</u>. We selected northern hardwood stands within two townships within the Nickerson Moraine Complex to provide baseline data for the

model runs. These townships were selected because they were similar in soil and landform types and because they contained both mature and old-growth northern hardwood forest stands. Five northern hardwood stands were sampled in each townships to provide soil and stand information for model runs.

Field Work. Field work consisted of field checking a large number of potential sites and sampling 10 of these sites for structural and compositional features. We sampled stands using 2m x 100m belt transects; four to eight transects were located in a stratified random manner within 20-meter intervals throughout each stand. The number of transects in each stand was determined by stand size. Within each transect, the species, dbh, canopy position, and visual indicators of rot were recorded for all trees greater than 10cm dbh. The following data were recorded for hollow logs and snags greater than 10 cm dbh: the species, dimensions, decay state, and per cent hollow. Leaf area index was measured at three sample points along each transect.

Simulations. We used information on the two major soil types (Ahmeek sandy loam and Cloquet sandy loam) present in our sample stands to run LINKAGES. For each simulation, 20 plots were simulated; the results presented here represent an average of 20 plots for each different combination of parameters. Each simulation covered a period of 400 years.

To validate the model for the sites, we ran a total of eight simulations. When we used a starting point of bare ground on Ahmeek sandy loam, the model always predicted the development of a forest dominated by Red Pine (*Pinus resinosa*) and White Pine (*Pinus strobus*) with a small component of aspen (*Populus* spp.). These stands were of very low productivity with basal areas under 12 sq. m/ha. When Cloquet sandy-loam soil parameters were used, the pine and aspen species were co-dominant, with sugar maple and other northern hardwood species present in the seedling and sapling size classes but never making it into the canopy class. Basal area remained under 12 sq. m/ha. When these stands were harvested under a wide range of prescriptions, from clear cuts to partial cutting, they inevitably succeeded to aspen-dominated cover types with small pine components. In order for a northern hardwoods cover type to become established on these stands from bare ground, the soil moisture parameters had to reach a field capacity of 35.0 cm and wilting point of 16.5 cm. With these soil conditions, a northern hardwoods cover type was established. Once northern hardwoods became established, soil nitrogen levels increased dramatically as did productivity with basal area ranging from 45 to 65 sq. m/ha.

Once the model was validated, we ran 42 simulations starting with a composite northern hardwood stand created from the field data collected. These runs

simulation of a wide variety of management scenarios described below. We also did seven additional model runs incorporating the predicted effects of climate change due to increasing levels of CO_2. Results of these simulations were compared to information on old-growth northern hardwood and maple-basswood forests gathered as part of two previous LCMR projects on old-growth forests.

No Harvest Scenarios. When simulations were run with no harvesting and an original stand composition of northern hardwoods, on both the Ahmeek and Cloquet soil types, the stands remained northern hardwood. Available nitrogen levels, basal area and woody debris volumes increased to old-growth stand levels within 80 to 100 years. Available nitrogen continued to increase to 400 years while basal area and woody debris volumes oscillated at or above old-growth stand levels. Under the no harvest scenario foliage height diversity initially decreased and then increased to a consistently high level after 50 to 100 years. Meanwhile, tree species diversity initially increased and then dramatically decreased to consistently low levels.

Partial Cutting and Thinning. We simulated a variety of harvesting scenarios:

Partial Cutting at 10,20,30, & 40 years with 10, 20, & 30% removal of trees > 30 cm d.b.h.,

Thinning at 40 & 50 years with 50% removal of trees between 10-30 cm d.b.h.,

and a combination of the two.

In the various partial cutting scenarios the frequency of entry had little to no affect on the resultant parameters, whereas the percent of removal had notable effects. In general, a 10% to 20% removal of >30 cm d.b.h. trees as frequently as every 10 years yielded approximately the same parameter levels as those seen in the no harvest scenario. At a removal level of 30%, available nitrogen, basal area and woody debris volumes decreased from the levels of the no harvest scenario; lengthening the time between removals did not compensate for these changes. All partial cutting scenarios exhibited diversity indices and successional trends similar to that of the no harvest scenario with the continuation of the northern hardwoods cover type, low tree species diversity, and high foliage height diversity. Thinning alone or the combination of thinning and partial cutting yielded parameters comparable to those already reported.

Clear Cutting. The various clear cutting scenarios (intervals of 40, 50, 60, and 80 years) yielded parameters that were increasingly divergent from the no harvest scenario as the length of rotation decreased. At a rotation of 80 years, available nitrogen levels approximated or were slightly lower than that seen in the no harvest scenario. Basal area and woody debris volumes oscillated in accord with the rotation age. Basal area values decreased in all clear cut rotations of less than

80 years, as compared to no harvest levels. Even at an 80 year rotation, basal area reached the approximate level of the no harvest stands just as it is cut again. Woody debris exhibited a pattern similar to that of basal area with the exception that for the 80 year rotation woody debris volumes reached levels much higher than the no harvest scenario in the later 30-40 years of the rotation. In all rotation lengths foliage height diversity decreased to zero at the time of the cut and then increased until the next cut. Only in the 80 year rotation did it reach a level comparable to the no harvest stands. Conversely, tree species diversity generally remained high, as compared to the no harvest scenario, even at an 80 year rotation. Clear cutting, irrespective of the rotation length, caused a shift in succession trajectory from the maintenance of the northern hardwood cover type to an aspen cover type.

Harvest Levels. The quantity and type of timber produced under partial cutting versus clear cutting management scenarios varied greatly. By definition, the partial cutting scenarios only harvested trees >30 cm d.b.h. and only a certain percent of the total trees were removed. Two species, sugar maple (*Acer saccharum*) and yellow birch (*Betula alleghaniensis*), accounted for the majority of trees harvested under the partial cutting scenarios. Smaller numbers of basswood (*Tilia americana*), red oak (*Quercus rubra*, aspen) and paper birch (*Betula papyrifera*) were also harvested. With partial-cut stand entries every 10 years, the majority of all trees harvested were in the 30-40 cm size class. Only sugar maple had any appreciable numbers of trees harvested in the 40-50 cm size class. No trees were available for harvest in size classes >50 cm. Lengthening stand entry intervals to 30 years produced a greater percent of the total number of trees in larger size classes. However, the yield over 400 years of total number of tree was much lower). The Cloquet soil type was more productive than the Ahmeek soil type. However, the two soil types yielded the same distribution of species and size classes for harvest.

Clear cutting scenarios produced pulp trees as compared to saw timber trees produced in the partial cutting scenarios. This was true even at rotation lengths of 80 years. On the Ahmeek soil type the pulp wood harvested was dominated by sugar maple in the 10-20 cm size class. On the Cloquet soil type there was higher productivity overall with a mix of sugar maple, yellow birch and red oak in size classes from 10 cm to 30 cm making up the majority of trees harvested. A small proportion of aspen in size classes from 40 cm to 60 cm were also harvested.

Climate Change. On both soil types, when both an increase in temperature of 2° C and a decrease of 10% in precipitation was simulated over 400 years, there was a precipitous drop in basal area after 100 years, which continued until virtually no trees existed at 300 years. Related parameters including woody debris, foliage

height diversity and available nitrogen also dropped while tree species diversity increased. Only when an increase in temperature of 2° C was coupled with no decrease in precipitation over 400 years did the simulated forested cover types remained intact. However, basal area decreased dramatically, followed by a comparable decrease in woody debris. Foliage height diversity and available nitrogen decreased and tree species diversity increased slightly, as compared to the no climate change scenario. Successional patterns were the same as previously reported in the various management scenarios. The northern hardwood cover type was preserved in the no harvest and partial cutting scenarios. The same successional trend towards aspen dominated cover types reported earlier was seen in these clear cutting scenarios.

Discussion. Model validation simulations produced white and red pine forests, which were the dominant, historic cover types in the area. In many areas, harvesting of the pine forests in the early 1900's was followed by succession to northern hardwoods forests. The simulations demonstrated that once northern hardwoods are established they are persistent so long as catastrophic removal of the canopy does not occur. If several seasons following the large scale pine harvests were slightly wetter than average, yet still within the standard deviation for current precipitation levels, conditions would have been sufficient to initiate and maintain the northern hardwoods cover type.

The two diversity measures, foliage height diversity and tree species diversity were inversely related. Under no harvest or low intensity partial cutting scenarios foliage height diversity is high, whereas tree species diversity is low. The inverse is true under high harvest levels. These two measures cannot be maximized simultaneously in a given stand. Thus, the goal of maintaining high levels of both indices becomes a landscape scale issue requiring a mixture of management throughout the forest matrix.

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C. Title of Objective/Outcome: Develop forest management prescriptions and guidelines that maintain key aspects of biological diversity while providing fiber for the forest products industry.

C.1. Activity: Develop forest management prescriptions and guidelines.

C.1.a. Context within the project: Forest management prescriptions and guidelines are the most important outcomes of this project. Unless the field tests and model simulations are translated into specific recommendations, the research outlined here will remain an academic exercise.

C.1.b. Methods: The requirement for specific new prescriptions and management guidelines will be assessed following completion of objective A, Document Forest Management Practices. New guidelines will be developed for northern hardwood forests based on the model simulations and plots in the field. The model simulations are currently based on specifications of number of trees to be cut in different size classes for different species at different stand entries. This is the general nature of the silvicultural prescriptions that are currently incorporated into timber sales. Therefore, it is a relatively straightforward procedure to transform the different model simulations into alternative management guidelines to meet specific biodiversity objectives through timber sales.

We shall also demonstrate the use of the model to the state and local foresters and make copies available for use on their own personal computers (most versions require only an IBM 386). It is our belief that the best

decisions are made in the field by the local foresters and that the model can be used as a tool for exploring alternative management prescriptions to meet state and federal guidelines.

C.1.c. Materials: No special materials are needed. There will be copying (and perhaps printing) and distribution costs for dissemination of information through reports, etc..

C.1.d. Budget: $40,000
Balance: $806

C.1.e. Timeline:

	7/95	1/96	6/96	1/97	6/97
Develop recommended prescriptions				*******	
Prepare management guidelines				***********	

C.1.f. Final Work Program Summary: July 1, 1997
Assuming no change in climate over the next 400 years, partial cutting management scenarios with a maximum removal of 30% basal area every 10-20 years would maintain high-quality northern hardwoods cover types and commodity timber production. This general guideline, however, should be viewed with caution. First, this simulation is based on the nutrient and water-holding capacity of two similar sandy-loam soil types, and results are likely to differ on other soil types. Second, the simulations address only tree species, not herb and shrub species. Third, maintenance of northern hardwood (or any forests) on these soils within the Nemadji State Forest is unlikely if the climate warms by 2 degrees C over the next 400 years, as predicted by some climate models.

Nevertheless, a forest management guideline for northern hardwoods on the Nemadji State Forest that recommends partial cutting (trees >30 cm d.b.h.) that removes a maximum of 30% basal area every 20 years is likely to maintain many important structural aspects of the cover type. Since large trees (i.e., > 50 cm d.b.h.) are often desirable as part of a forest, lengthening the harvest interval to 30 years is necessary. Lengthening the harvest interval, however, markedly decreases the number of trees available to harvest over the 400 years. This guideline represents a starting point for management considerations.

This study also demonstrates that guidelines based on average stands on average soils are inadequate for making the best management decisions at a stand level. In order to choose detailed management options that are likely to balance timber production and biodiversity maintenance, managers need more information about local ecosystems and how they are likely to respond to management. Even where the goal is to emphasize biodiversity, managers must choose what elements to promote. For example, management for increased foliage height diversity is likely to result in a decrease in tree species diversity. Moreover, textbook prescriptions based on site index are inadequate, and studies such as this one that focuses on a few of the many different ecosystem types across Minnesota are not feasible at a large scale. Instead, providing LINKAGES software, training, and support for field managers to use in making management decisions provide the best hope for designing and implementing management strategies that will preserve important forest features and still allow for commodity timber production. LINKAGES is a simple, inexpensive and powerful tool that can be run easily on a 486 desktop computer. Once managers have this tool in hand, we will be able to more readily and accurately identify its strength and weaknesses and make needed adjustments and/or additions to the program. Some potential improvements to the model may include incorporation of understory species and canopy gap dynamics.

VI. Evaluation: The ultimate success of this project will rest upon the extent to which the forest management prescriptions and guidelines become part of on-the-ground forest management activities and the extent to which these prescriptions produce the desired results with respect to maintaining biological diversity. The immediate success of the project can be assessed by whether the project produces forest management prescriptions and guidelines that are useful for forest managers, either for direct implementation or as examples than can be modified to fit circumstances in other parts of the state. This project has the potential to reduce the negative effects of timber harvest on wildlife and biological diversity in large areas of Minnesota's forests. Complete evaluation of the ultimate success of this project will require site monitoring over many decades. Such monitoring is well-beyond the 2-year time scale of this project.

VII. Context within field: The recently completed Generic Environmental Impact Statement on Timber Harvesting and Forest Management in Minnesota (GEIS) predicted significant negative effects on forest biological diversity from continued and increasing timber harvest unless current forest management practices are modified. Although a variety of alternative silvicultural practices have been suggested under the mantle of "New Forestry", the effects of these practices on the structure and composition of the resulting forest is uncertain. Simulations of different silvicultural practices based on the extensively validated model LINKAGES provides the best approach for assessing the potential impacts of these practices on biological diversity.

The recently completed GEIS, while a landmark document, is best viewed as a first approximation toward improved timber harvesting and forest management recommendations. The forest growth model used in the GEIS has been the industry and regulatory standard for the past several decades in which the major objective of forest growth modeling has been short-term forecasts of timber supply. The GEIS model assumes that site productivity is fixed, and so it cannot realistically simulate the long-term beneficial or adverse effect of harvesting on future productivity. The model also has not been calibrated for old-growth forests because of lack of data. Today's forest management objectives must take into account the long-term effects of harvesting on future site productivity, biodiversity, and the maintenance of valuable old-growth characteristics. This need requires a more sophisticated model that can simultaneously predict timber yield concurrently with harvesting effects on habitat structure, diversity, and nutrient cycling. This integrated model is precisely what LINKAGES has been developed to provide (Pastor and Mladenoff 1993). LINKAGES makes several improvements over the GEIS model, as detailed above (Objective B). This project will provide a key test of LINKAGES and will help develop management guidelines that have a stronger biological and ecosystem basis.

VIII. Budget context:

A. July 1, 1993 - June 30, 1995: Drs. Pastor and Cohen have been using the model LINKAGES to simulate forest bird habitats in the Great Lakes Region. This research is funded by a grant from the National Science Foundation. They have also tested LINKAGES using data gathered by the 1993 LCMR Forest-Bird Diversity Initiative Project ($500,000) and collected new data on a square mile field plot developed as part of that project. The current project will also use data on old-growth forest characteristics gathered by the 1993 LCMR Old-Growth Forest Project ($250,000) and the 1991 LCMR Old-Growth Forest Project ($150,000).

B. July 1, 1995 - June 30, 1997: Under funding from the National Science Foundation ($200,000), Pastor and Cohen are developing a more spatially detailed version of LINKAGES (see B.1.b.).

XI. Dissemination: Forest management prescriptions and guidelines will be distributed statewide through the entity designated by the legislature to coordinate the implementation of the GEIS. We anticipate distribution of materials to federal, state, county, and private forest managers. Results of the research will be presented at national and regional scientific and professional meetings. Documentation of forest management activities and results of the simulations will be submitted to appropriate refereed journals.

X. Time: This project will be completed within two years.

XI. Cooperation: The program manager will spend 70% of his time on this project, and will have primary responsibility for Objective C but will be involved in all aspects of the project. Dr. John Pastor of the Natural Resources Research Institute and Dr. Yosef Cohen will be principle investigators for Objectives A and B. Dr. Pastor will devote 15% of his time to the project; Dr. Cohen will devote 15% of his time. Most of the work on objectives A and B will be done by a full-time graduate student or programmer supervised by Dr. Pastor. Jerry Langworthy and other DNR Field Foresters in the Hinckley and Moose Lake Areas will be involved in all aspects of the project, especially the field work and coordination. Because a number of DNR field foresters will be involved, time estimates for their participation are not provided below.

Amount of time involved:

	Total	Objective A	Objective B	Objective C
Project manager	70%	25%	25%	20%
Dr. Pastor	15%	4%	8%	3%
Dr. Cohen	15%	4%	8%	3%

XII. Reporting Requirements: Semiannual six-month work program update reports will be submitted not later than January 1, 1996, July 1, 1996, January 1, 1997, and a final six-month work program update and final report by June 30, 1997.