United States
Department of
Agriculture

Forest Service

**Northeastern
Research Station**

Research Paper NE-719

Modeling the Regeneration of Northern Hardwoods with FOREGEN

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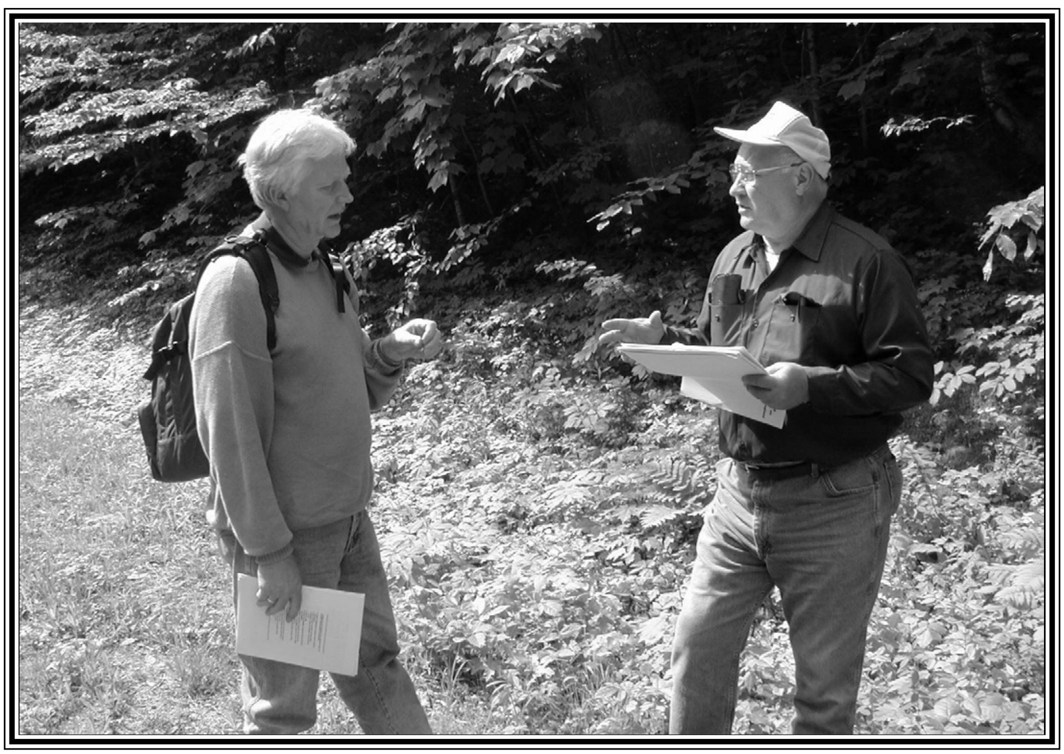

Abstract

FOREGEN is a simulator that models the regeneration of openings in northern hardwood stands that range in size from clearcuts of 2,000 by 2,000 feet to single-tree openings of 25 by 25 feet. The model incorporates random effects related to seed development, dispersal, germination, seedbed conditions, advanced regeneration and weather. Users can specify options on stand age, species composition, size of opening, harvesting in winter vs. summer, mechanical scarification, seed trees, advanced regeneration, and stump treatment for red maple. The output is percent species composition of the established regeneration 3 years after harvest. Although variation is high due to the stochastic elements incorporated into the model, FOREGEN produces realistic results that are in line with expectations on regenerating the northern hardwood forest. FOREGEN should be useful in assessing regeneration options, as input into growth simulators, and as an educational tool.

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Manuscript received for publication 19 November 2001

Cover Photo

Dr. Dale Solomon, right, discusses the regeneration of northern hardwoods with Professor Burghard von Lüpke of the Institute of Silviculture at the University of Göttingen, Germany.

Published by:

USDA FOREST SERVICE
11 CAMPUS BLVD SUITE 200
NEWTOWN SQUARE PA 19073-3294

April 2002

For additional copies:

USDA Forest Service
Publications Distribution
359 Main Road
Delaware, OH 43015-8640
Fax: (740)368-0152

Visit our homepage at: **http://www.fs.fed.us/ne**

Introduction

Numerous growth models have been developed for forest types in the Northeast, including FIBER (Solomon et al. 1986, 1995), SILVAH (Marquis and Ernst 1992), NE-TWIGS (Hilt and Tech 1989), OAKSIM (Hilt 1985), and models by Hansen (1984) and Hansen and Nyland (1987). All of these project the growth of overstory existing trees, but some are less effective when modeling the regeneration phase (Schuler et al. 1993). Some models ignore regeneration; others make simplified assumptions about ingrowth into the main stand or use regression equations to predict ingrowth based on site and stand conditions (Larsen et al. 1997; Shifley et al. 1993; Solomon et al. 1995). To our knowledge, the only detailed regeneration model that applies somewhat to northeastern forest types is one that was developed for the North-Central United States (Monserud and Ek 1977; Monserud 1987). This model was used within the framework of FOREST, a distance dependent, individual-tree growth simulator.

Modeling efforts for other forest types include those of Pukkala and Kolström (1992), who reported the simulated effect of parent trees on seed dispersal for pine regeneration, and Dey et al. (1996a), who accounted for sprouting and survival failures in modeling the regeneration of five oak species. ACORn, a program developed by Dey et al. (1996b), predicted the development of hardwood species in the Ozark Highlands. Other regeneration models were developed by Belcher et al. (1982) for the North-central Region and by Ferguson and Carlson (1993) and Tomback et al. (1993) for conditions in the West. Peterson and Carson (1996) presented conceptual models of forest regeneration in Northeastern North America. They concluded that none adequately considers ranges of disturbance characteristics and forest conditions at the time of disturbance.

In the early 1970's, we developed a detailed regeneration model for even-aged northern hardwoods in New England based on numerous studies on the Bartlett Experimental Forest in New Hampshire. This Monte Carlo model incorporated as much random variation as possible in the major variables, and was concerned primarily with the steps required to regenerate clearcuttings of specified dimensions. Because of its size and inefficiency, the model was not published, but we decided to revise it in light of the growing interest in sustainable forest practices and the need for accurate long-term forest projections. The model now has a more efficient and modern framework, and includes additional options for regenerating uneven-aged stands.

FOREGEN, currently written in Fortran 90, includes as much of the available data as possible on regenerating northern hardwood stands in New England. We have tried to avoid using assumptions that have not been fully documented, and have attempted to incorporate as much unexplained variation as possible that might affect the course of the regeneration process. We also provide practical, silvicultural options in the revised version of FOREGEN. The process includes and is based on random effects related to seed development, dispersal, germination, seedbed conditions, advanced regeneration and weather. Users can specify options on stand age, species composition, size of opening, harvesting in winter vs. summer, mechanical scarification, seed trees, advanced regeneration, and stump treatment for red maple. The output is percent species composition of the established regeneration 3 years after harvest. The current model can be used as a stand-alone regeneration simulator, and also can be linked to growth simulators such as FIBER. Tabular imputation models were developed in Minnesota for similar purposes by Ek et al. (1996).

Overview

Regeneration following a harvest operation in northern hardwoods usually originates from four sources: (1) new seedlings from seed disseminated during or after the harvest, (2) advance regeneration present at harvest (Leak and Wilson 1958), (3) new seedlings from older seed buried in the soil (Graber and Thompson 1978), and (4) new stump sprouts or root suckers from sources on the harvest site (Solomon and Blum 1967). The new seedlings consist primarily of paper birch (*Betula papyrifera*), yellow birch (*B. alleghaniensis*) and white ash (*Fraxinus americana*). Previous work showed that regeneration from these species can be represented in a matrix framework that is computationally similar to an absorbing Markov chain (Leak 1968). The primary variables in this matrix are: flower and seed production; dispersal distance; a variety of seedbed criteria defined by seedbed materials, sun/shade exposure, and a wet or dry spring; and the development (germination, survival) of seedlings on each environmental condition. This matrix forms the basis for simulating the regeneration of paper birch, yellow birch, and white ash (Table 1).

The advance regeneration consists of beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), small proportions of red maple (*A. rubrum*) and white ash, along with some red spruce (*Picea rubens*) and hemlock (*Tsuga canadensis*). Pin cherry (*Prunus pensylvanica*) develops from buried seed, while aspen (*Populus* spp.) and beech arise primarily from root suckers. The most common shrubs are *Rubus* spp. and hobblebush (*Viburnum alnifolium*). In FOREGEN, numbers of advance and new stems are inserted based on available regeneration records for given stand and seedbed conditions, or users can specify these amounts. Numbers of red maple stump sprouts are inserted based on numbers and sizes of red maple trees cut during the

Table 1.—Regeneration matrix and initial vector showing probabilities (+) for transitions from transient states and certainties (p=1) for absorbing states

	State																												
Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Initial Vector	+																												+
Transition Matrix																													
1. Seed developed		+	+	+	+	+	+	+	+	+	+	+																	
Dispersal (ft)																													
2. 0-50													+	+	+	+	+	+	+	+	+	+	+	+	+				
3. 50-100													+	+	+	+	+	+	+	+	+	+	+	+	+				
4. 100-150													+	+	+	+	+	+	+	+	+	+	+	+	+				
5. 150-200													+	+	+	+	+	+	+	+	+	+	+	+	+				
6. 200-250													+	+	+	+	+	+	+	+	+	+	+	+	+				
7. 250-300													+	+	+	+	+	+	+	+	+	+	+	+	+				
8. 300-350													+	+	+	+	+	+	+	+	+	+	+	+	+				
9. 350-400													+	+	+	+	+	+	+	+	+	+	+	+	+				
10. 400-450													+	+	+	+	+	+	+	+	+	+	+	+	+				
11. 450-500													+	+	+	+	+	+	+	+	+	+	+	+	+				
12. 500+													+	+	+	+	+	+	+	+	+	+	+	+	+				
Seedbeds[a]																													
13. SWM																										+	+	+	
14. NWM																										+	+	+	
15. SDM																										+	+	+	
16. NDM																										+	+	+	
17. SWH																											+	+	+
18. NWH																											+	+	+
19. SDH																											+	+	+
20. NDH																											+	+	+
21. SWL																											+	+	+
22. NWL																											+	+	+
23. SDL																											+	+	+
24. NDL																											+	+	+
25. Unproductive																											+	+	+
26. Good stem																										1			
27. Dead stem																											1		
28. Nongerminate																												1	
29. Seed aborted																													1

[a]Seedbed conditions = S (shade), N (sun), W (wet), D (dry), M (mineral), H (humus), L (litter).

harvesting operation; aspen root suckers are predicted from the percentage of aspen in the harvested stand. The final output from the model is the percent species composition (based on stem numbers) of the established regeneration 3 years after harvest.

Beginning at 50 feet on a side, clearcut openings can be expanded in increments of 50 feet up to 2,000 by 2,000 feet. Small, single-tree, cleared openings (25 by 25 feet) can be regenerated to simulate uneven-aged management.

Simulation Process

Rather than presenting detailed flow charts, we will describe the simulation process in narrative form.

Seed Production

Seed production is simulated by first drawing a separate seed-year rating for yellow and paper birch. The population of seed years consists of 10 numbers:

1 2 2 2 3 3 3 4 4 5

Table 2.—Seed production in pure stands, by species, stand age, and seed year

Species	Stand age	Seed production				
		Heavy	Good	Medium	Poor	Failure
	years	*millions per acre*				
Paper birch	30-50	6.9-8.6	5.1-6.9	3.4-5.1	1.7-3.4	0.0-1.7
	50-90	32.0-40.0	24.0-32.0	16.0-24.0	8.0-16.0	0.0-8.0
	90+	32.0-40.0	24.0-32.0	16.0-24.0	8.0-16.0	0.0-8.0
Yellow birch	30-50	1.2-1.5	0.9-1.2	0.6-0.9	0.3-0.6	0.0-0.3
	50-90	6.8-8.6	5.1-6.8	3.4-5.1	1.7-3.4	0.0-1.7
	90+	10.8-13.5	8.1-10.8	5.4-8.1	2.7-5.4	0.0-2.7
White ash	30-50	0.6-0.8	0.5-0.6	0.3-0.5	0.2-0.3	0.0-0.2
	50-90	0.7-0.9	0.6-0.7	0.4-0.6	0.2-0.4	0.0-0.2
	90+	1.0-1.2	0.7-1.0	0.5-0.7	0.2-0.5	0.0-0.2

This artificial population represents the proportion of years in each of five seed-abundance categories (unpublished data on file at Northeastern Research Station,Durham, NH):

Seed Year	Proportion of Years
1. Heavy	0.10
2. Good	0.30
3. Medium	0.30
4. Poor	0.20
5. Failure	0.10

In the absence of specific information, the same distribution of seed years was used for white ash.

Given the seed year, the number of seeds produced per acre by a pure stand of each species is based on the data in Table 2 (unpublished data on file at Durham, NH). This table was derived partly from measured seed production in stands of known species composition, and partly by subdividing the known range in seed production into the five classes (heavy-failure).

Actual seed production by species is determined by taking a random observation from the appropriate range in Table 2 and multiplying by the decimal composition of that species in the harvested stand.

During seed production, seed loss from insects, diseases, or climatic factors is appreciable. Bjorkbom (1971) reported that 14 to 47 percent of paper birch seeds were discolored or empty. The comparable amount for yellow birch is 20 to 50 percent, mostly from insects (Shigo and Yelenosky 1963). Random numbers drawn from these ranges provide estimates of seed abortion and, conversely, seed development, which are inserted in the basic regeneration matrix (Table 1).

Dispersal

Following winter cutting (August 15-May 15), we assume that the seed is dispersed uniformly over the harvest area from harvested and border trees. Following a summer clearcutting, seed for new regeneration must come from the border stand. Available data indicate that birch seed falls at the rate of about 6.0 feet per second (Baker 1950); ash seed fall is slightly faster. Average falling time is computed by dividing crown height (currently based on site index and age) by falling time. During this falling time, seeds travel a distance that we have approximated by average wind velocity. A population of wind velocities is stored in the program (Table 3). Sixty samples of velocity and direction are drawn to represent a dispersal period of 60 days. Then, the average wind velocity from each cardinal direction is computed. Seed dispersal characteristically follows a negative exponential distribution:

$$F(x) = 1 - e^{-r x}$$

where the parameter r is the reciprocal of the average wind velocity or the average horizontal travel distance. Integration over 50-foot intervals provides estimates of the dispersal probabilities incorporated into the regeneration matrix (Table 1).

Seedbed Conditions

Seedbed materials are important for germination, particularly for the birches. Measurements after logging operations in northern hardwoods under snowfree

Table 3.—Percentage of days with wind from four cardinal directions (based on historical daily averages during August-December at Concord, NH)

Velocity (mph)	North	East	South	West	All
0-2	1	1	1	2	5
2-4	5	3	8	8	24
4-6	8	4	12	6	30
6-8	3	1	5	8	17
8-10	3	1	4	5	13
10-12	1		1	5	7
12-14	1			1	2
14-16				1	1
16-18				1	1
All	22	10	31	37	100

conditions or light snow cover provided information on the natural occurrence (in percent) of five classes of seedbed materials (Marquis and Bjorkbom 1960):

Material	Average	Range
Mineral	9	5-17
Humus	23	13-30
Slash	13	13
Unproductive	3	0-9
Litter	52	31-69

The simulator randomly selects percentages of mineral, humus, and unproductive seedbed within the indicated ranges, sets the slash proportion at 0.13, and computes the percentage of litter seedbed as a residual.

Where a mechanical scarification operation is implemented, the proportion of the area scarified is set as the percentage of mineral soil; the remaining area is proportioned deterministically according to the average percentages in the previous tabulation.

Another aspect of seedbed condition relates to moisture and shade. Germination and early survival are highly dependent on the occurrence of wet or dry spring rainfall. Past work showed that a May-June rainfall of 6 inches or more (total for both months) has no negative effects on germination (Marquis et al. 1964). Thus, we assumed that fewer than 5 inches of rainfall would bring about the dry conditions that are known to affect first-year germination and survival. Local records for New Hampshire records showed that the probability of a May-June rainfall of fewer than 5 inches was 0.26. The average for the period is about 8 inches. The simulator draws a random number between 0.0 and 1.0 to determine the occurrence of wet or dry conditions.

The border stand on the south side of a clearcutting casts shade for about 25 feet (Marquis 1965a). Thus, seed dispersed from the south edge has about a 50-percent chance of encountering a shaded seedbed within the first 50-foot dispersal distance. In addition, in a small clearcut, significant amounts of seed from the north border and smaller amounts from the east and west borders may encounter shaded conditions.

On the basis of these considerations, probabilities are developed by 50-foot dispersal distances for encountering sun vs. shade, a wet vs. dry season, and a given seedbed material. These combined probabilities are entered into the regeneration matrix (Table 1).

Germination and Survival

Once a seed has been dispersed to the various seedbed conditions defined earlier, the next step is to determine the chances this seed will produce a good stem, dead stem, or nongerminate, and then insert these probabilities into the basic regeneration matrix. The probability of a good stem is computed as the probability of germination times the probabilities of survival during the first growing season, first winter, second growing season, and second winter. The probability of nongermination is taken as 1.0 minus the probability of germination. The probability of a dead stem is equated to 1.0 minus the probabilities of a good stem or a nongerminate. Germination and survival percentages for paper and yellow birch are shown in Tables 4 and 5. Survival for both birches was estimated at 61 to 76 percent for the first winter and 96 to 100 percent for the second growing season (unpublished data on file at Durham, NH).

Table 4.—Percent germination for paper and yellow birch, by shading, spring moisture, and seedbed conditions

Shading	Spring moisture	Seedbed				
		Mineral	Humus	Litter	Slash	Unproductive
				Paper Birch		
Shade	Dry	5.2-11.6	0.0	0.0	0.0	0.0
Shade	Wet	17.2-38.1	1.9-15.7	0.4-6.6	0.0	0.0
Sun	Dry	1.0-3.0	0.0	0.0	0.0	0.0
Sun	Wet	9.4-28.6	0.0-15.4	0.0-7.2	0.0	0.0
				Yellow Birch		
Shade	Dry	4.2-7.4	0.0	0.0	0.0	0.0
Shade	Wet	4.4-31.8	1.9-15.7	0.4-6.6	0.0	0.0
Sun	Dry	0.0-1.0	0.0	0.0	0.0	0.0
Sun	Wet	5.0-33.0	0.0-15.4	0.0-7.2	0.0	0.0

Table 5.—Estimated survival (percent) for paper and yellow birch during the first growing season, by shading and seedbed conditions

Shading	Seedbed		
	Mineral	Humus	Litter
Shade	29-94	55-92	18-84
Sun	7-88	0-56	0-60

Comparable probabilities for white ash were developed similarly, though the data are more limited. Germination of white ash ranges from about 1.3 to 8.4 percent, while estimated survival into the second growing season is 89 to 99 percent (unpublished data on file at Durham, NH). Random samples from these ranges are used to estimate the probabilities of a good stem, dead stem, or nongerminate.

Advance, New, and Vegetative Stems

The simulator provides an option for incorporating known amounts of advance, new, and vegetative regeneration, or allowing the program to enter these quantities. Under the latter option, the simulator chooses numbers of stems within the ranges shown in Table 6 (Marquis 1965b), depending on whether the stand is even-aged and less than 90 years old or uneven-aged (or at least 90 years old). A weighted average is computed between disturbed and undisturbed stem numbers based on the proportions of mineral + humus seedbed (disturbed) and the proportion of litter, slash, and unproductive seedbed (undisturbed).

Numbers of red maple stump sprouts are determined by first estimating average stand diameter from stand age:

$$D = 1.89211 + .06811 \text{ (Age)}$$

In a stand 90 years old or more, the mean diameter is set at 13 inches. Then, numbers of trees per acre is estimated by:

$$\text{Log (base 10) } N = 3.469767 - .145636 \times D + .0032868 \times D^2$$

Then, numbers of stumps per acre on the harvested area is found by multiplying by percent composition of red maple. Numbers of sprouts per stump equals (Solomon and Blum 1967):

$$\text{Log(base 10) } N{+}1 = 0.779 + .134 \times D - .007 \times D^2$$
$$SD = .077$$

Drawing a value from a normal random-number generator and multiplying by numbers of stumps gives an estimate of sprouts per acre.

Numbers of aspen root suckers are predicted from the percentage of aspen basal area in the stand to be harvested based on data in Graham et al. (1963). Aspen root suckers are presumed to replace pin cherry in the new stand at a rate of one aspen stem for two pin cherry stems, i.e., each aspen stem eliminates two pin cherries from the new stand.

Calculations

After the regeneration matrix is complete (for paper birch, yellow birch, and white ash taken separately), it is

Table 6.—Advanced and volunteer stem density 3 years after patch clearcutting in even-aged and uneven-aged stands on disturbed and undisturbed seedbeds

Species	Even-aged		Uneven-aged	
	Disturbed	Undisturbed	Disturbed	Undisturbed
	thousands per acre			
Sugar maple	2.1-3.8	4.9-7.1	23.0-28.3	6.7-35.9
Beech	4.4-7.1	2.9-6.0	8.9-11.1	6.4-13.0
Red maple	5.3-7.3	2.3-4.5	3.0-3.1	0.9-1.1
White ash	2.2-3.4	1.3-1.8	5.1-5.4	0.0-1.9
Pin cherry	21.8-23.7	11.4-23.5	5.0-7.7	4.7-9.0
Striped maple	0.1-0.9	1.0-2.2	3.0-3.1	1.2-5.0
Aspen	0.6-1.4	0.0-1.0	0.8-1.7	0.0
Other	5.2-10.9	9.6-13.2	15.5-28.2	0.8-5.9

taken to the fourth power and then premultiplied by the initial vector. This results in a 1 by 29 vector with the probability of each seed producing a good stem, dead stem, or nongerminate in cells 26 to 28, respectively. Multiplication by the number of seeds per species per acre provides an estimate of numbers of stems per acre in the good, dead, and nongerminating categories. For winter cutting, this average number of seeds per acre is simply the average seed production per species. For summer cutting, the average is developed by averaging the seeds that fall on each dispersal distance from the edge of the clearcutting. The numbers of regeneration stems from each direction are computed and summed to produce an estimate of the total regeneration per acre on the harvest area. The final output is percent composition of the regeneration based on stem numbers.

To realistically simulate regeneration in small openings, only tolerant advanced regeneration from Table 6 is allowed in the shaded southern border of a 100-foot opening, but birches, ash, aspen, pin cherry, and other species (approx. 90 percent *Rubus*) are regenerated as usual in the rest of the opening. If any opening dimension is 50 feet, only half the predicted numbers of intolerants (paper birch, aspen, pin cherry, or other) are allowed. At 25 by 25 feet (a single-tree opening), only tolerant regeneration is allowed.

Input Data

The data required to run the program consist of:

1. The initial species composition (decimal) in the stand to be harvested.

2. Initial stand age.

3. Harvest season: summer or winter.

4. Cutting area dimensions: NS and EW dimensions in multiples of 50 feet, or 25 by 25 feet.

5. Seed trees reserved on the cutting area: numbers per acre and average diameters of paper birch, yellow birch, and white ash.

6. Percent of the harvest area machine scarified.

7. Red maple stump treatment (to prevent sprouting): yes or no.

8. Advanced and volunteer growth (optional): numbers per acre of beech, sugar maple, red maple, white ash, pin cherry, striped maple, aspen, and other.

9. Site index (sugar maple):

Examples

To provide some indication of the output from the simulator, several options on summer vs. winter, harvest area, and wet vs. dry spring are summarized in Table 7 based on 10 runs per option. These runs are for a stand 80 years old with 10 percent basal area in paper birch, yellow birch, and white ash; 20 percent in beech, sugar maple, and red maple, and 5 percent in aspen and other species. The range within option represents random variation due to seed years, seedbeds, and dispersals. Even with this variation there are logical differences among options related to seed dispersal-germination-survival conditions. Dry spring conditions produced noticeably less birches in the species composition. Large openings generally produced less birch trees than 50- by 50 or 100- by 100-foot openings, especially for summer harvests. Single-tree openings (25 by 25 feet) regenerated to tolerant and semi-tolerant species. Other differences, not reflected in Table 7, occur in stands older than 90 years, where the proportions of pin cherry

Table 7.—Range in predicted species composition as a percentage of total stem density 3 years after harvest

Harvest season	Harvest area	Spring moisture	Species composition[a] PB	YB	WA	BE	SM	RM	PC	STR	ASP	Other
	(ft)											
Summer	1,000 x 1,000	Dry	0	0	4	9-11	10-11	10-12	32-39	3	4	22-24
		Wet	3-4	1	4-5	8-10	10-11	10-11	31-37	2-3	3	20-24
	100 x 100	Dry	1-2	0	4-5	11-12	12	11-14	27-35	4	3	20
		Wet	13-19	4	3-4	8-9	10-11	11	22-29	2-3	2-3	15-18
	50 x 50	Dry	1-2	1	5-8	19-20	20-23	21-22	12-15	6-7	1	8
		Wet	12-17	10-11	5-6	14-16	17-18	17-18	8-11	3-5	0	5-6
Winter	1,000 x 1,000	Dry	2-3	0	4-7	9-10	10-11	9	35-38	2-3	3	20-21
		Wet	11-13	9-13	4-7	7-8	7-9	7-9	24-30	2	3	15-18
	100 x 100	Dry	3-4	0-1	3-9	10-12	12-14	10-11	25-34	3-4	3	19
		Wet	18-34	5	2-3	7-10	8-9	8-10	20-23	1-2	2-3	11-16
	50 x 50	Dry	2-3	1-2	4-11	19-20	23-24	17-21	11-15	5-7	0-1	8
		Wet	11-19	8-9	4	16-19	17-18	19	9-10	3-4	0-1	4-6
Both	25 x 25	Either	0	0	0	27-32	28-30	26-31	0	5-7	0	6-7

[a]PB = paper birch, YB = yellow birch, WA = white ash, BE = beech, SM = sugar maple, RM = red maple, PC = pin cherry, STR = striped maple, ASP = aspen, Other = other species.

[b]Stand basal area before harvest was PB, YB, WA (each 10%); BE, SM, RM (each 20%); ASP, Other (each 5%).

and other species are lower due to the decline of viable buried seed. In these older stands, the proportion of birches and ash trees tends to rise due to increased seed production. Species composition of the harvested stand is another option that significantly changes the predicted regeneration composition due to the influence of seed production and aspen, beech, and red maple sprouts or root suckers.

Applications

This regeneration simulator is an attempt to duplicate most of the details of the regeneration process, and is based on a fairly extensive data base. However, there are many areas that obviously need added refinement and more data, and there remains much unexplained variation in the process. It would be overly optimistic to suggest that FOREGEN would accurately predict the outcome of a particular harvesting operation. In this sense, the model is humbling: we included much data on the regeneration process but still cannot accurately reproduce the events that control a specific regeneration operation.

However, FOREGEN mimics "real" situations with respect to the average effects of size of opening, seed year, scarification, advance regeneration, and weather conditions, as well as the extreme variability inherent in the regeneration process. The effects of these factors are modeled realistically and should provide forest managers with suitable guidelines on the general outcome of harvesting practices (if not the actual numbers). Another application possibility is in teaching silviculture and ecology, providing students with some introduction into the range of ecological factors, and their variability, that influence stand regeneration.

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Describes the stochastic model FOREGEN that simulates regeneration in openings in northern hardwood stands that range in size from clearcuts of 2,000 by 2,000 feet to single-tree openings of 25 by 25 feet. The model incorporates the effects of seed development, dispersal, germination, seedbed conditions, advanced regeneration, and weather. Users can specify options on stand age, species composition, size of opening, harvesting in winter vs. summer, mechanical scarification, seed trees, advanced regeneration, and stump treatment for red maple. The output is percent species composition of the regeneration 3 years after harvest.

Keywords: FOREGEN, regeneration, model, simulator, northern hardwoods.

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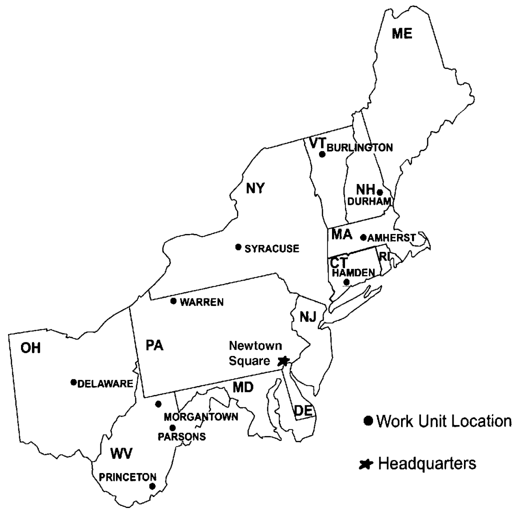

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