Use of Expert Systems for Integrated Silvicultural Planning

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Abstract.—The use of silvicultural treatments in hardwood stands presents opportunities for increasing the growth and yield of quality sawtimber and enhancing the suitability of the site for use by numerous species of wildlife. Planners, loggers, and managers must consider multiple aspects of the ecosystem when making silvicultural decisions. In this paper we demonstrate an integrated expert system called FOREX and explain how it can be used to make silvicultural decisions that integrate potential growth and yield, logging technology, economics, wildlife, markets, log prices, and the time value of money.

INTRODUCTION

Owners of forested land are being challenged to meet ecosystem/landscape level goals while meeting personal and financial objectives. This challenge is further complicated by the need for integrated planning, i.e., considering all of the present and potential values and benefits available from forested ecosystems. Information on wildlife habitat, silvicultural practices, logging technology, economic and market factors, and the time value of money must be integrated when deciding how to manage forest lands. The natural process of forest establishment, growth, and development must be studied to better understand the potential values and benefits of proposed silvicultural treatments over time.

Forest ecosystems undergo a series of seral stages that lead to a climax state over time (Odum 1969; Hunter 1990). For example, many ecosystems left undisturbed undergo a series of stages because system changes are constant over time. The vegetation at each stage in the process suits different creatures and different people at different times. As the forest moves through these seral stages, wildlife comes and goes, for example, a thicket-like stand at age 30 will have few grouse and gray fox by age 60. Or a forest stand may be in the pole-timber class for 30 to 50 years as part of its 90- to 200-year rotation age. In this stage, trees of the same species kill each other in competition for light, nutrients, and water (Odum 1969). Also during this phase, many different species of wildlife occupy and use the site (DeGraaf et al. 1991) and also kill each other in a natural struggle for survival (Dasmann 1964; Odum 1969; Hobson et al. 1993; Black 1994). During this period, 30 to 50 years, many plant, tree, and wildlife species can be harvested without stopping or setting back the process.

At some point in this natural process, forests contain fewer but larger trees. These "larger" woods seem to be those that many people want to protect and/or keep constant. But nature does not stand still. In fact, goals for timber production often mimic the natural process of succession. For example, researchers have demonstrated that thinning stands can produce trees that are more valuable and faster growing than those in many unmanaged stands. It is to everyone's advantage to understand and plan for the potential products, values, and benefits that forest stands yield over time. It also is important that managers understand the economic implications of their actions and are able to evaluate the economic tradeoffs that result from alternative silvicultural treatments.

Another major concern of owners is bringing together the volumes of research information on wildlife habitat, stand management, logging technology, economic and market factors, and the impact of time when deciding how to manage their forest land. This challenge is complicated in that the vegetation and various organisms that make up a forest ecosystem survive and reproduce on a site because they have adapted to their physical environment and are able to coexist with one another. When humans disturb this balance by removing vegetation from the site or changing its species composition, the site may no longer be suitable as habitat for certain wildlife species. Managers can avoid much of this potential disruption to wildlife by maintaining the natural/original species composition of the site/stand. This may best be achieved by the use of natural regeneration following disturbance/regeneration versus regenerating the site with artificial methods that favor one species of vegetation over another (Hunter 1990).

A second complication is the lack of decisionmaking software/tools that allow for integration across disciplines. As a result, land owners usually manage their land according to personal experience. Often, the result is the continued implementation of a handful of silviculture practices that may not meet all of the owner's objectives.

We have developed an expert system called FOREX that allows integrated decisionmaking in managing of hardwood forests (LeDoux et al. 1995; 1996; LeDoux 1997). FOREX considers the potential growth and yield, products, and development of a stand over time, economic and market factors, and impacts on wildlife habitat. This system can be applied to all forest types in the Northeast, and currently considers impacts on wildlife habitat for New England forest types. Wildlife data from other forest types and regions will be incorporated into the FOREX database as they become available. In this paper we explain how FOREX can be used to evaluate the flow of potential products, values, and benefits associated with a forested stand over its life.

Description of FOREX

FOREX uses data from simulation runs from a model called MANAGE (LeDoux 1986; LeDoux et al. 1995). The user can obtain information on present net worth (PNW), optimal

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timing of thinning entry, optimal economic stand-rotation age, average diameter at breast height (dbh), volume by grade and value of the trees harvested, and, depending on the cable yarder or ground-based system used, average slope yarding or skid distance, truck class, road class, log-bucking methods, and number of thinnings desired. FOREX also provides information on the effect of harvesting treatments on wildlife habitat. Users can obtain data on the PNW, dbh, and volume required for a specific set of management objectives, and perform a sensitivity analysis that eliminates the need to sort through numerous simulations.

FOREX also can be used to project growth and volume yields, yields of individual wood products, estimate stump-to-mill logging costs, predict cash flows and discounted PNW revenues, project the suitability of habitat for wildlife, estimate optimal periods between thinnings or other silvicultural treatments. From these data, users can gauge the impact of various silvicultural treatments on wildlife and evaluate management tradeoffs such as longer rotations for wildlife versus shorter ones for fiber production.

Stand Conditions Used

For this demonstration, we used a stand from the northern red oak forest cover type. The species mix includes chestnut oak, scarlet oak, black oak, hickories, red maple, and red oak. The average site index is about 70. The stand is 30 years old and contains about 330 trees per acre that are more than 5 inches dbh; the average stand diameter is 6.37 inches dbh. The stand is on moderate to steep slopes and could be harvested by cable or ground-based systems. The site is covered with greater than 25 percent rock cover, has greater than 30 percent forest litter cover, has active seeps, loose soils and small caves, and has at least 50 ft^3/acre of dead and down material on the forest floor. The land has about 20 percent shrub cover and at least 29 percent ground cover. For this demonstration, the management block is assumed to be 300 acres in size for harvesting and wildlife purposes. We input the stand information into FOREX and conducted several consultation runs to determine the potential benefits, costs, and values associated with managing such a stand.

RESULTS

The stand was subjected to thinnings at age 60, 70, and 150, with an optimal rotation age of 160 years. An additional objective of the last thinning at age 150 was to promote advanced regeneration before final harvest. The tract was logged with both cable and ground-based systems (Table 1).

Potential Growth and Yield

The stand would yield 751.20 ft^3 of wood at age 60 with an average dbh of 9.93 inches (Table 1). Thinnings at age 90 and 150 would yield 1,752.58 and 2,132.09 ft^3 respectively, and the final harvest would yield 3,627.75 ft^3. Extending the final harvest to 200 years would yield 4,362.74 ft^3.

Potential Product Yields

At age 60, the product mix consists of a small quantity of grade 3 logs with the remainder in pulpwood (Table 1). The second and third thinnings yield more grade 1 and grade 2 volume. For example, the third thinning and final harvest have high percentages of grade 1 and grade 2 logs. The final harvest has the highest proportion of grade 1 volume because the three previous thinnings favored leaving the best crop trees for final harvest. Extending the final harvest to 200 years would yield a large proportion of grade 1 logs.

Optimal Thinning Entry and Rotation Age

FOREX can be used to estimate the optimal timing of thinning entry. For this demonstration, the optimal thinning schedule is age 60, 90, and 150 with an optimal rotation length of 160 years. The thinnings can be constrained so that they break even or generate a profit before they are considered feasible, that is, the value of the products removed must pay their way to the mills.

FOREX also projects the optimal rotation age given any prior treatment(s). In this case, the stand is thinned at age 60, and the residual stand is projected to age 90 and thinned, and the residual stand at age 90 is projected to age 150 and thinned, and the residual stand at age 150 is projected forward until it reaches the optimal rotation age of 160.

Potential Monetary Yields

FOREX also projects the cash flows and PNW for each combination of thinning entry and optimal rotation. For example, thinning at age 60 would require a subsidy of $123.98 or $105.39/acre for cable and ground-based systems, respectively. Accordingly, data on PNW and cash flow are presented for each thinning, final harvest, or extended rotations. Thinnings at age 90 and 150 are economical, yielding a PNW of $86.40 or $82.53/acre depending on the logging method used.

Management Tradeoffs

FOREX can be used to evaluate/rank alternative management tradeoffs. For example, the optimal rotation at age 160 yields a PNW of $107.65 and $118.09/acre for cable and ground-based harvests, respectively. Extending the rotation to 200 years results in a PNW value of $48.83 and $53.11/acre, for cable and ground-based systems. The tradeoff in PNW represents a reduction of about 55 percent for ground-based harvests, or a net loss of about $1.62/acre/year. Although cash flows for the extended rotation are larger than those from optimal rotations, the time value of money makes future yields worth less in PNW.

Wildlife Habitat Suitability

FOREX links actual stand attributes such as dbh, volume per acre, number of trees per acre, species mix, and other stand/site attributes with guidelines of DeGraaf et al. (1992) to generate lists of potential wildlife species that would find the

Table 1.—FOREX results by treatment for 30-year old northern red oak forest stand

Attribute	Thinning 1[a]	Thinning 2[b]	Thinning 3[b]	Final harvest	Extended rotation
Yarding distance (ft)	600	600	600	600	600
Buck type	1	1	1	1	1
Road class	3	3	3	3	3
Truck class	2	2	2	2	2
Age (years)	60	90	150	160	200
Trees (no.)	57	75	35	51	41
Avg. dbh (inches)	9.93	12.80	19.27	20.43	23.97
Volume (ft^3)	751.20	1752.58	2132.09	3627.75	4362.74
G1 (bd. ft)[c]	0	915.28	6947.64	13543.29	20652.76
G2 (bd. ft)[d]	0	601.00	161.31	402.85	127.81
G3 (bd. ft)[e]	46.67	284.46	758.93	701.66	712.17
G4 (ft^3)[f]	737.33	1320.83	650.75	987.37	813.94
PNW (dollars)[g]	-51.08	49.27	75.17	107.65	48.83
Cash flow (dollars)[g]	-123.98	290.28	2609.22	5021.73	7430.94
PNW (dollars)[h]	-43.42	86.40	82.53	118.09	53.11
Cash flow (dollars)[h]	-105.39	509.03	2864.70	5508.74	8082.38

[a]20 percent of trees/acre removed.
[b]40 percent of trees/acre removed.
[c]G1 = grade 1 volume/acre.
[d]G2 = grade 2 volume/acre.
[e]G3 = grade 3 volume/acre.
[f]G4 = pulpwood/acre.
[g]Cable systems.
[h]Ground-based systems.

site/stand suitable. For example, the 160-year-old stand would yield conditions acceptable to several species of amphibians, birds, mammals, and reptiles (Table 2). Table 3 lists the potential species that would find the site/stand suitable after harvest provided that down logs and tops are left on the site following final harvest. Table 4 shows the potential species that would find the site/stand suitable after final harvest when residual down logs and tops are removed/ utilized after final harvest. Such consultation runs allow users to estimate the suitability of habitat for wildlife and gauge the impact of various silvicultural treatments on wildlife. The lists produced by FOREX were cross-validated using the HAM model (Harvey and Finley 1996).

CONSIDERATIONS FOR USERS

Integrated expert systems can be used to estimate the potential values and benefits associated with the management of eastern hardwoods over time. Managers, planners, and users can obtain detailed information on growth and yield, potential product development, logging costs, potential revenues, suitability of habitat for wildlife, impacts of silvicultural treatments on wildlife, timing of thinning entry and optimal rotation age. Generally, foresters can manage the resource for an array of products and values simultaneously, and users can evaluate economic tradeoffs that result from alternative silvicultural treatments.

Refinements in the data on wildlife, product quality, and other variables are being made, and additions to the knowledge base can be easily incorporated into the FOREX database. FOREX integrates the best information on logging cost, mill prices paid, and similar factors into a user-friendly system that can be used when planning silvicultural treatments.

It is doubtful that expert systems such as FOREX will replace the expertise available at the forest or district level as there is no substitute in the short run for a manager's knowledge of the land, hand-drawn maps, etc. Still, FOREX and other integrated expert systems can be useful in the decisionmaking process and thus contribute to improved management of the nation's forest resources.

Table 2.—Potential species for stand before final harvest

Redback salamander (*Plethodon cinereus*)	Black-capped chickadee (*Parus atricapillus*)
Northern brown snake (*Storeia d. dekayi*)	Tufted titmouse (*Parus bicolor*)
Northern redbelly snake (*Storeia o. occipitomaculata*)	White-breasted nuthatch (*Sitta carolinensis*)
Northern ringneck snake (*Diadophis punctatus edwardsi*)	Brown creeper (*Certhia americana*)
Northern black racer (*Coluber c. constrictor*)	Red-eyed vireo (*Vireo olivaceus*)
Black rat snake (*Elaphe o. obosoleta*)	Blackburnian warbler (*Dendroica fusca*)
Eastern milk snake (*Lampropeltis t. triangulum*)	Scarlet tanager (*Piranga olivacea*)
Northern copperhead (*Agkistrodon contortrix mokeson*)	Brown-headed cowbird (*Molothrus ater*)
Timber rattlesnake (*Crotalus horridus*)	Purple finch (*Carpodacus purpureus*)
Sharp-shinned hawk (*Accipiter striatus*)	Carolina chickadee (*Parus carolinensis*)
Northern goshawk (*Accipiter gentilis*)	Virginia opossum (*Didelphis virginiana*)
Red-shouldered hawk (*Buteo lineatus*)	Masked shrew (*Sorex cinereus*)
Broad-winged hawk (*Buteo platypterus*)	Little brown bat (*Myotis lucifugus*)
Red-tailed hawk (*Buteo jamaicensis*)	Silver-haired bat (*Lasionycteris noctivagans*)
Great horned owl (*Bubeo virginianus*)	Big-brown bat (*Eptesicus fuscus*)
Red-bellied woodpecker (*Melanerpes carolinus*)	Northern red bat (*Lasiurus borealis*)
Yellow-bellied sapsucker (*Sphyrapicus varius*)	Gray squirrel (*Sciurus carolinensis*)
Hairy woodpecker (*Picoides villosus*)	Southern flying squirrel (*Glaucomys volans*)
Eastern wood-pewee (*Contopus virens*)	Northern flying squirrel (*Glaucomys sabrinus*)
Eastern phoebe (*Sayornis phoebe*)	Coyote (*Canis latrans*)
Blue jay (*Cyanocitta cristata*)	Black bear (*Ursus americanus*)
American crow (*Corvus brachyrhynchos*)	Red fox (*Vulpes vulpes*)
Common raven (*Corvus corax*)	White-tailed deer (*Odocoileus virginianus*)
Ruffed grouse (*Bonasa umbellus*)	

Table 3.—Potential species for stand after final harvest (down logs and tops left on site)

Northern brown snake *(Storeia d. dekayi)*	Northern ringneck snake *(Diadophis punctatus edwardsi)*
Northern black racer *(Coluber c. constrictor)*	Black rat snake *(Elaphe o. obosoleta)*
Eastern milk snake *(Lampropeltis t. triangulum)*	Timber rattlesnake *(Crotalus horridus)*
Cooper's hawk *(Accipiter cooperii)*	Golden eagle *(Aquila chrysaetos)*
Blue jay *(Cyanocitta cristata)*	American crow *(Corvus brachyrhynchos)*
Common raven *(Corvus corax)*	Ruffed grouse *(Bonasa umbellus)*
Wild turkey *(Meleagris gallopavo)*	Purple finch *(Carpodacus purpureus)*
Masked shrew *(Sorex cinereus)*	Coyote *(Canis latrans)*
Black bear *(Ursus americanus)*	Red fox *(Vulpes vulpes)*
White-tailed deer *(Odocoileus virginianus)*	

Table 4.—Potential species for stand after final harvest (down logs and tops removed)

Northern ringneck snake *(Diadophis punctatus edwardsi)*	Timber rattlesnake *(Crotalus horridus)*
Cooper's hawk *(Accipiter cooperii)*	Golden eagle *(Aquila chrysaetos)*
Blue jay *(Cyanocitta cristata)*	American crow *(Corvus brachyrhynchos)*
Common raven *(Corvus corax)*	Ruffed grouse *(Bonasa umbellus)*
Wild turkey *(Meleagris gallopavo)*	Purple finch *(Carpodacus purpureus)*
Coyote *(Canis latrans)*	Red fox *(Vulpes vulpes)*
White-tailed deer *(Odocoileus virginianus)*	

LITERATURE CITED

Black, H. C., tech ed. 1994. **Animal damage management handbook.** Gen. Tech. Rep. PNW-GTR-332. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 236 p.

Dasmann, R. F. 1964. **Wildlife biology.** New York: John Wiley and Sons. 231 p.

DeGraaf, R. M.; Scott, V. E.; Hamre, R. H.; Ernst, L; Anderson, S. H. 1991. **Forest and rangeland birds of the United States-natural history and habitat use.** Agric. Handb. 688. Washington, DC: U.S. Department of Agriculture. 625 p.

DeGraaf, R. M.; Yamasaki, M.; Leak, W. B.; Lanier, J. W. 1992. **New England wildlife: management of forested habitats.** Gen. Tech. Rep. NE-144. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 271 p.

Harvey, H. M.; Finley, J. C. 1996. **Stand level assessment—a piece of the biodiversity puzzle.** In: Ecosystem management: translating concepts to practice: 1995 Penn State School of Forest Resources issues conference; 1995; University Park, PA. State College, PA: The Pennsylvania State University, School of Forest Resources: 43-50.

Hobson, S. S.; Barclay, J. S.; Broderick, S. H. 1993. **Enhancing wildlife habitats—a practical guide for forest landowners.** Publ. NRAES-64. Ithaca, NY: Northeast Regional Agricultural Engineering Service, Cooperative Extension. 172 p.

Hunter, J. L., Jr. 1990. **Wildlife, forests, and forestry—principles of managing forests for biological diversity.** Englewood Cliffs, NJ: Prentice-Hall. 370 p.

LeDoux, C. B. 1986. **MANAGE: a computer program to estimate costs and benefits associated with eastern hardwood management.** Gen. Tech. Rep. NE-112. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

LeDoux, C. B.; Gopalakrishnan, B.; Lankalapalli, K. 1995. **FOREX—an expert system for managing even-aged upland oak forests on steep terrain.** In: Gottschalk, K. W.; Fosbroke, S. L. C., eds. Proceedings, 10th central hardwood forest conference; 1995 March 5-7; Morgantown, WV. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 474-480.

LeDoux, C. B.; Gopalakrishnan, B.; Mudiyanur, S. 1996. **Maximizing financial yields while meeting landowner objectives and ecosystem goals.** In: Planning and implementing forest operations to achieve sustainable forests. Proceedings of the joint meeting of the Council On Forest Engineering and International Union of Forest Research Organizations; 1996 July 29-August 1; Marquette, MI. St. Paul, MN: Council on Forest Engineering: 220-226.

LeDoux, C. B. 1997. **Evaluating timber harvesting impacts on wildlife habitat suitability using FOREX.** In: Pallardy, S. G.; Cecich, R. A.; Garrett, H. G.; Johnson, P. S. Proceedings, 11th central hardwood forest conference; 1997 March 23-26; Columbia, MO. Gen. Tech. Rep. NC-188. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 26-35.

Odum, E. P. 1969. **Fundamentals of ecology, 2nd ed.** Philadelphia, PA: W.B. Saunders Co. 546 p.