1990

An aspen forest management advisory system

H.M. Rauscher

D.A. Perala

G.E. Host

Recommended Citation

Rauscher, H. M.; Perala, D. A.; Host, G. E. 1990. An aspen forest management advisory system. Aspen Symposium '89 : Proceedings. General Technical Report NC-140. North Central Forest Experiment Station Forest Service, U.S. Department of Agriculture St. Paul, Minnesota.185-194.

AN ASPEN FOREST MANAGEMENT ADVISORY SYSTEM

H. M. Rauscher, D. A. Perala, and G. E. Host[1]

ABSTRACT.--An expert system program is described that advises the user on silvicultural treatments for aspen (Populus tremuloides Michx., P. grandidentata Michx.) stands of given age, site quality, and stocking. Growth models and stocking charts give tabular and graphical updates of projected stand development. Prescription recommendations enable land managers to make informed decisions on silvicultural treatments to obtain their timber, wildlife, and environmental amenity objectives. Hardware requirements: IBM PC AT/386 with hard disk, 640k RAM, and EGA or VGA graphics. Software requirement: MSDOS.

The link between research, professional field experience, and appropriate silvicultural practice in the aspen forest type (as in other types) is fragile and imperfect, but improving. The transfer of technology from the laboratory to the forest has evolved from fragmented and dispersed research notes and papers toward organized, integrated, user-oriented packages. In aspen management, the best example is the superbly detailed and illustrated state-of-knowledge book edited by DeByle and Winokur (1985). Summary handbooks (Brinkman and Roe 1975, Perala and Russell 1983, Shepperd and Engelby 1983, Perala 1986, Davidson et al. 1989), how-to guides (e.g., Steneker 1976, Perala 1977), and video slide tapes (e.g., Perala 1984, Shepperd 1986, Baughman 1988) have condensed the available research knowledge for everyday use. These technology transfer tools are effective but limited because they soon become dated and cannot interact with the user.

Rapidly emerging artificial intelligence technologies are being used to produce advisory systems to overcome these limitations of print technology. By simulating the decision-making logic of human experts, they can provide custom solutions to a large range of complex problems for anyone having access to a microcomputer. Furthermore, they can be updated relatively easily as innovations become available. Knowledge-based systems can integrate standard growth and yield models producing expert decision support systems. The essential improvement that advisory systems offer forest managers, scientists, and students is a way to apply the power of automation to the understanding, application, and management of forestry knowledge in support of teaching, research, and decision making.

Advisory systems must not be viewed as a panacea. They cannot be a substitute for good judgment. They cannot think but can manage the technical details and the large amount of available knowledge that burden even the most expert of land managers.

In this paper we describe an advisory system for the management of aspen in the upper Great Lakes region and highlight the critical data and rules that make it run. The system will be ready for distribution and validation in 1990.

[1]Research Foresters, USDA Forest Service, North Central Forest Experiment Station, Forestry Sciences Laboratory, Grand Rapids MN, 55744

AN ILLUSTRATIVE SESSION

The Aspen Forest Management Advisory System (AS-FMAS) is made up of a number of modules (Fig. 1). A description of a typical cycle through the AS-FMAS will illustrate its use. First, the introductory screens identify the program and explain its purpose to the user. Then module #1 requests the user to enter standard stand description data (Fig. 2). The standard stand description data are asked for at the start of the session, rather than sequentially during the session, to increase operating efficiency. The user should enter as much of the requested information as is available - all, any part, or none. It is up to the advisory system then to analyze the user's input, module #2, and either estimate missing data or ask the user for additional information.

The user is asked next for the geographic location, used by the growth model, of the stand in question (Fig. 3). If the data analysis module requires no further user input to estimate missing data, the program continues to the stand condition analysis, module #3, which determines the health of the aspen stand. Module #3 has not yet been developed for the 1989 version of AS-FMAS, so no input is required. The management objective, module #4, asks the user to select the timber product objective

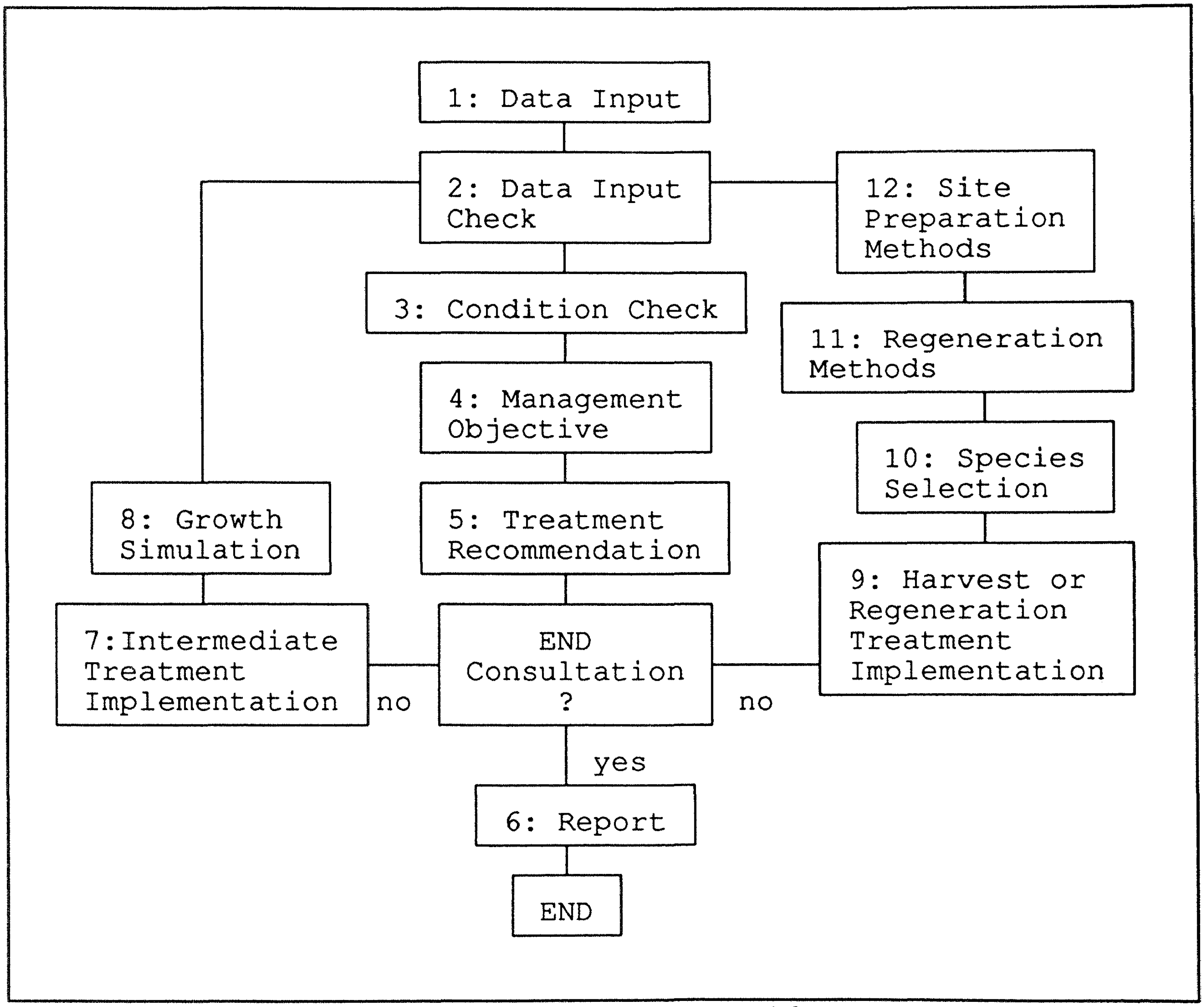

Figure 1.--Conceptual model diagram of AS-FMAS, an even-aged forest management system.

```
Please enter as much data as you can.  Missing data
will be estimated where possible by the expert
system.  You may be asked to provide estimates if
the system cannot.  The better the input the better
the prescription recommendations.
                                        Value
                                      ---------
    AGE (yrs)                     :       20
    AVG. TREE DBH (in)            :      2.9
    BASAL AREA (ft²/ac)           :       70
    TREES PER ACRE (#)            :        0
    SITE INDEX (ft)               :       75
    AREA (acres)                  :       10
    DOMINANT HEIGHT (ft)          :        0
    VOLUME  (cubic ft/ac)         :        0
    VOLUME  (cords/ac)            :        0
    VOLUME  (MBF/ac Scribner )    :        0
```

Figure 2.--Example of initial data entry screen in FMAS (module 1).

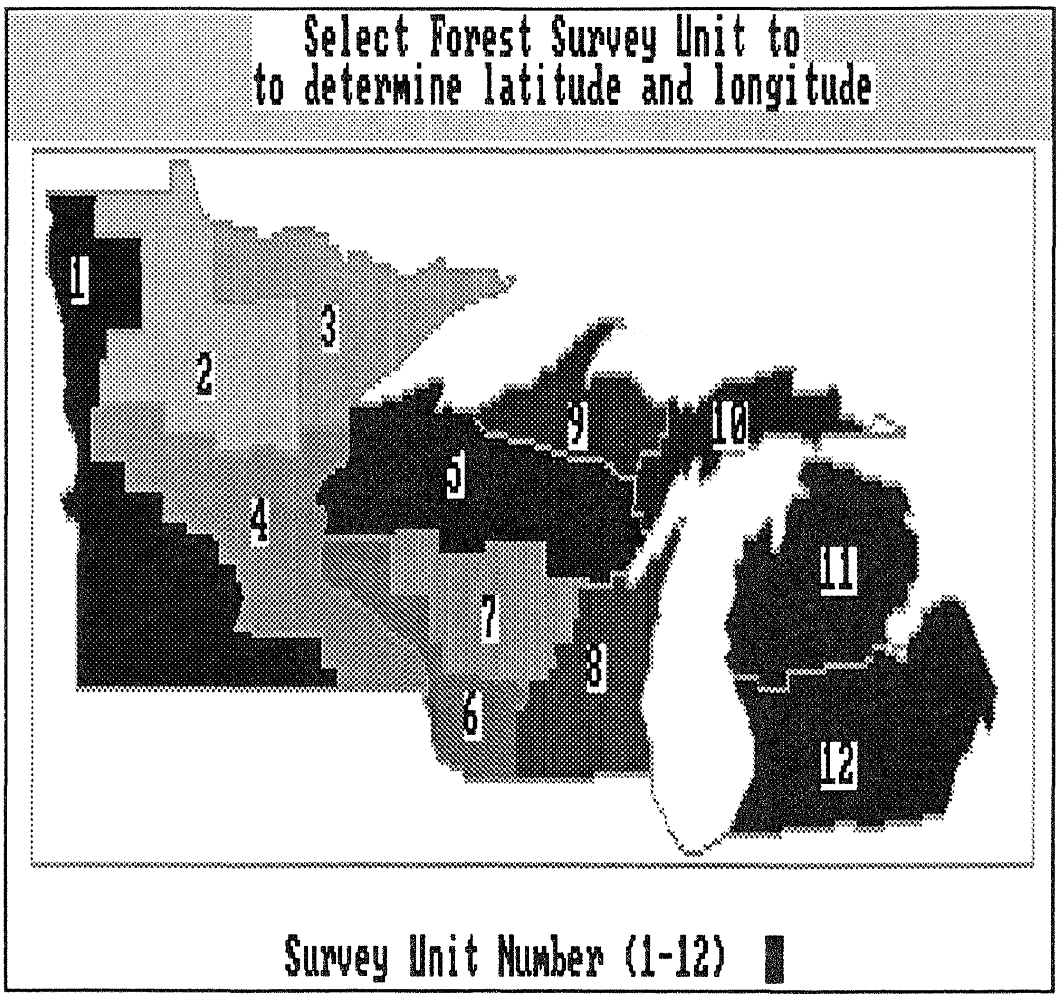

Figure 3.--Map to identify the geographic location of the stand.

for the stand; so the DBH goal for trees at the end of the rotation can be set and the rotation age can be estimated by the advisory system. The product objective is one of the key pieces of knowledge the advisory system needs from the user. The stand description (Fig. 4) then appears, displaying what is known about the stand at this point.

Continuing the program, the user is shown a list of treatment recommendations, module #5, and asked to select one for implementation (Fig. 5). Among the treatment options are conversion or regeneration without harvesting, release, thinning, harvesting, and postponing treatment. The advisory system presents only the treatment options logically possible for a given stand. An approximate "certainty factor", on a scale of 0-100, is reported next to each treatment which allows the user to make qualitative judgments on the advisability of selecting a given recommendation. The user is then shown the logic for recommending the treatment selected (Fig. 6). At this point the user may get a report of the results, module #6, and conclude the consultation.

```
Object Name:  Treatment Recommendation         ROTATION ENDS
THE STAND DESCRIPTION IS FOR YEAR: 2009         IN YEAR: 2015
Latitude: 47.0   Longitude: 94.8                   Recommended
                                              Minimum   Maximum
Covertype .....................: Aspen
Age (yrs) .....................: 40.0
Dbh (in) ......................: 6.1
Basal Area (sq.ft./ac) ........: 107        60        150
Trees per acre ................: 534       295        738
Stocking density class ........: Within recommended levels
Site Index (ft) ...............: 75
Current Height (ft) ...........: 66
Acreage .......................: 10
                                          Specialty
Volume Cubft/ac ...............: 2313    Product Volume
Volume Cds/ac .................: 29        Cubft/ac ....: 0
Volume Mbf/ac (gross).Scribner.: 4.5     Biomass
Volume Mbf/ac (net)...Scribner.: 4.4       Tons/ac green: 99
                                           Tons/ac dry..: 51
Timber product objective ......: Pulpwood
Dbh goal at rotation (in) .....: 7
Rotation age (yrs) ............: 46
```

Figure 4.--Example of the stand status report screen (module 5).

```
The following treatments and their associated confidence
levels have been recommended.  Please select one of these.
                      Recommendations
Certainty factor
             100    Harvest the stand
              20    Postpone treatment
```

Figure 5.--An example of a list of treatment recommendations (module 5).

```
You have selected to:  postpone treatments at this time

We recommend this selection with a certainty factor of: 20

BECAUSE :  Other treatments are recommended with a
           certainty factor of 100, normally one of
           those should have been selected.
```

Figure 6.--An example of a recommendation screen in AS-FMAS (Module 5).

If the user wishes to obtain future recommended treatments for the stand, the consultation may be continued. To illustrate, let us elect to 'Postpone treatment' for this stand. The cycle will go through module #7 where intermediate stand treatment implementation takes no action. Growth simulation, module #8, then asks the user to choose the conditions for stopping the growth and yield program. The user might choose to let the current stand grow until the next thinning is needed, in which case, the advisory system suggests a threshold basal area to trigger the next thinning. This value may be changed by the user if desired. Other choices available for stopping growth, include at a specified rotation age, when mean annual increment culminates, at a specified DBH, or after a specified number of years. Let us choose to grow this stand for another 10 years.

The growth and yield program is then activated to simulate growing the stand for 10 years. Expert systems are essentially static. For simulating changes over time, standard growth and yield models must be used. The result is a hybrid decision support system - part expert system and part simulation model. We developed our aspen growth and yield model specifically for this project; it illustrates the linkage between a conventional simulation model and an expert system. Such linkages are important in creating more useful expert systems in forestry. A stand table (Fig. 7) and a stocking chart (Fig. 8) are among the output screens available to the user upon request.

S T A N D   T A B L E

The expected rotation age is 45 years.
Site Index is 75 feet.

						Pulp		Sawtimber		
			# of					Gross	Net	Resid.
Year	Age	Ht	Trees	Dbh	BA	Cu Ft	Cords	Mbf	Mbf	Cords
2009	40	66	534	6.1	107	2343	30	4.5	4.4	22
2019	50	75	349	7.8	115	3108	39	10.1	9.4	18

Figure 7.--Example stand table output from the growth and yield program.

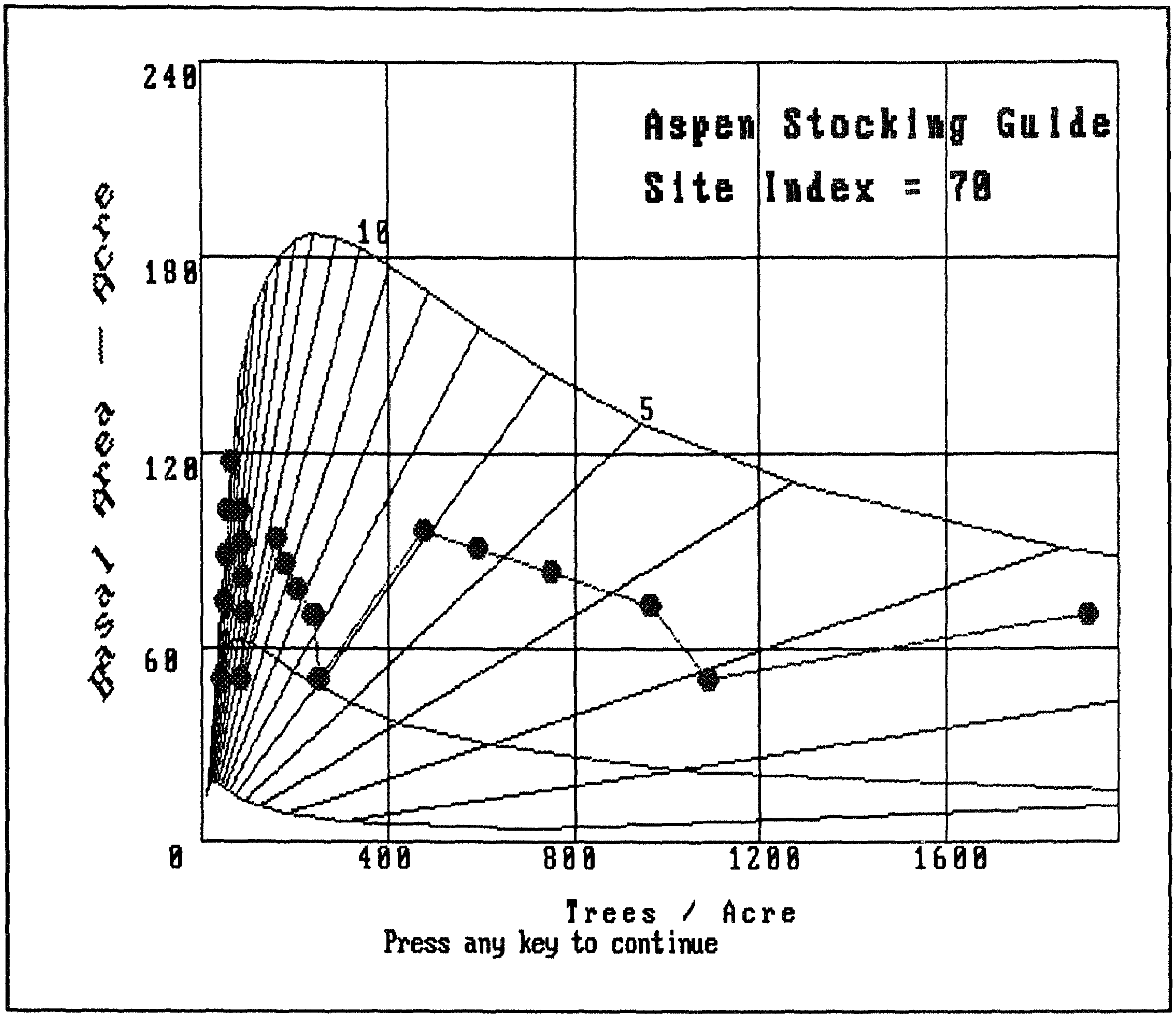

Figure 8.--Stocking guide for aspen.

The advisory system then cycles through selected intermediate stand treatments, under the control of the user, until harvesting is selected as a treatment recommendation. The silvicultural system recommended is clearcut (currently the only option) and the harvesting method, module #9, asks the user to choose one of three options: full-tree, tree-length, or log-length. The species selection, module #10, inquires whether the former species will be used for the next rotation or whether a new covertype will be established. If a new covertype is desired, the advisory system offers the user a species list, ranked by relative preference, from which to select the species or species group to favor. This list is based upon drainage, soil texture, and soil nutrients. If the choice of species is other than aspen, the system advises the user that AS-FMAS does not have recommendations for that species.

When aspen is selected for the next stand, the user is advised by the regeneration method, module #11, that suckering is the only option currently recommended. The advisory system then asks the user to select the timber product objective for the next rotation. Finally, the system helps the user select a site preparation method, module #12, based on drainage, litter conditions, vegetative competition, and other factors. The new stand description is generated and the AS-FMAS cycles back to the data input analysis, module #2, as if the user had entered this young stand from the keyboard. Whenever a treatment recommendation is generated, the user can either terminate the consultation or continue through another cycle. Upon termination, a multi-page report tracing the knowledge used to support the diagnosis is presented to the user. This report is presented by a word processor that can be used to make changes or annotations into the trace file and saved for future reference.

DOCUMENTATION

The decision rules are those used by Perala (1977). The user provides as much data as possible to the program. Missing data is estimated by solving for the item in question after rearranging terms in the normal stand equation (Perala in prep.) as shown below:

$$QMD=7.042*10^{-7}*(Trees/RSD)^{-0.265}*Site^{.632}*Age^{.852}*.995^{Age}*Lon^{-1.18}*1.02^{Lon}*Lat^{5.78}*0.87^{Lat} \quad [1]$$

where QMD=quadratic mean DBH (inches), Trees=density (trees per acre), RSD=relative stocking (decimal), Site=site index (mean height dominants and codominants, feet at 50 years (Lundgren and Dolid 1970), Age=total stand age (years), Lon=longitude and Lat=latitude (degrees). Stand age can also be estimated from equations given by Lundgren and Dolid (1970) if site index and dominant height are given.

The following growth equations (Perala in prep.) project stands into the future:

$$QMD_f=0.191*QMD_o^{0.987}*RSD^{-1.14}*2.573^{RSD}*Age_o^{-1.066}*Age_f^{1.08}*Site^{0.15}*0.998^{Site}*Lat^{0.052}, \text{ and} \quad [2]$$

$$BA_f=9.54*10^{-6}*BA_o^{0.744}*RSD^{-0.922}*2.63^{RSD}*Age_o^{-1.35}*Age_f^{1.524} *Site^{0.624}*0.993^{Site}*Lon^{-0.103}*Lat^{3.08}*0.947^{Lat} \quad [3]$$

where BA=stand basal area (ft^2 per acre) and subscripts "o" and "f" indicate present and future values. These equations were derived by analyzing log-log models applied to published data and tabular values from throughout the native range of aspen. Therefore, regional adjustments are possible by inputting geographic coordinates. These equations are being used temporarily until better ones are developed. Non-linear analyses of models similar to those used by Smith and Brand (1988) will probably provide the final equations.

Stand cubic foot and cord volumes, and biomass, are estimated using Schlaegel's (1975) equations. But four problems had to be solved before these equations could be used. First, Schlaegel's merchantable volume estimates depend on top diameter outside bark (DOB) while industry standards specify inside bark (DIB). This was remedied by developing an equation relating DOB to DIB:

$$DOB=0.041+1.031*DIB, \quad [4]$$

from his data set on file at Grand Rapids. Second, Schlaegel's merchantable volume ratios (MVR) apply only to tree DBH larger than the specified top diameter. Therefore, a modified Weibull nonlinear model (Yang et al. 1978) was fit to the tabular values of Table 158, Brown and Gevorkiantz (1934), to enable us to predict tree distribution by DBH class (DCL) for stands of a given QMD:

$$CFD=1-\exp(-0.2741*QMD^{-4.543}*(DCL+1.006)^{4.89}) \quad [5]$$

where CFD=cumulative frequency distribution (decimal). The third difficulty was that Schlaegel's MVR's are calculated from separate equations for whole top diameters (2 to 7 inches). This did not allow the flexibility needed to calculate MVRs for fractional DOBs predicted from eq. 4. Therefore, an equation was developed from a log-log model fitted to Schlaegel's predicted MVRs,

$$MVR=1-(0.0325*DBH^{-1.5}-0.99*\ln DOB-1.54*DOB*1.22^{DBH}*4.54^{DOB}), \quad [6]$$

to enable calculation of MVR from any DBH/DOB combination.

Finally, Schlaegel requires quadratic mean height (QMH) for calculating stand volumes. Perala (in prep.) provides an equation

$$QMH=9.49*HD^{0.88}*QMD^{0.236}*BA^{-0.0687}*Site^{-0.577}*1.007^{Site} \quad [7]$$

to estimate QMH from more easily gathered dominant height (HD) and other stand data.

Sawtimber volume (board feet, Scribner) is estimated from

$$Saw=0.157*BA7^{1.146}*HD^{0.85}*QMD7^{.995}, \quad [8]$$

where BA7 and QMD7 are stand values derived from a stand table integrated from outputs of eq. 2, 3, and 5 for trees 7 inches d.b.h. and larger. A log-log model was fit to values in Table 157 from Brown and Gevorkiantz (1934). Because sawtimber volume depends so much on freedom from decay, both gross and net volumes are estimated. Net sawtimber volume is derived from gross volume and the equation

$$USR=1-exp(-1*(1.207*Site^{-1.1014}*(Age+12.02))^{5.852}) \quad [9]$$

where USR=usable sawtimber ratio. Table 3 of Zehngraff (1947) provided the data for this nonlinear Weibull model.

Ek and Brodie's equation (1975) is used to estimate the amount of sucker regeneration following harvest and additional site preparation as needed. So far, the growth models (eqs. 2, 3) are only suitable for growing pure (or nearly so) even-aged stands of aspen. One of the critical remaining questions concerns the growth and development of mixed aspen stands, particularly two-storied stands where aspen suckers are sub-dominant to a residual canopy. These situations arise either by default when unmerchantable trees are left after harvesting, or by design ("deferment cutting", see Smith et al. 1989) when selected trees are left for amenity or wildlife purposes. The individual tree growth and mortality equations used in STEMS (Buchman 1979, Buchman and Lentz 1984, Hahn and Leary 1979, Holdaway et al. 1979, Holdaway 1984) will be examined to develop growth models for multi-storied stands.

SUMMARY

From a scientific point of view, the most important contribution of this project was to develop a **knowledge-based model** for aspen management in the upper Great Lakes region. What seemed to be a clear body of knowledge about aspen management was actually inadequately and incompletely defined and organized. Forest management is so complex and unstructured a domain, that creating a conceptual paradigm of the process proved to be a valuable scientific enterprise. It forced critical thinking, helped us generate new hypotheses, and demanded a comprehensive, holistic point of view to organize, synthesize, and thereby, compact the available knowledge. This knowledge-based model also provides a framework into which new research results on aspen stands can be integrated.

From a managerial point of view, we have developed an initial prototype for aspen management. The next stage of development is to extend and enhance the knowledge-base and validate the system so that it can deliver reliable, high quality treatment recommendations. Forest managers should profit from an increased access to specialized aspen management expertise. Through a continual testing-and-use cycle we expect to move this system toward scientific and managerial maturity.

From an educational point of view, the initial prototype of AS-FMAS is ready for study and discussion leading to suggestions for improving the aspen forest management advisory system.

LITERATURE CITED

Baughman, M. 1988. Managing aspen in the Lake States. Slide-cassette tape. Univ. Minn.--USDA Ext. Serv., Inst. Agric. For. & Home Econ., St. Paul, MN.

Brinkman, K.A., and E.I. Roe. 1975. Quaking aspen: silvics and management in the Lake States. USDA Agric. Handbk. 486, Washington, DC. 52 p.

Brown, R.M., and S.R. Gevorkiantz. 1934. Volume, yield, and stand tables for tree species in the Lake States. Univ. Minn. Agric. Exp. Stn. Tech. Bull. 39. 208 p.

Buchman, R.G. 1979. Mortality functions. P. 47-55 *in* A generalized forest growth projection system applied to the Lake States region. USDA For. Serv. Gen. Tech. Rep. NC-94.

Buchman, R.G., and E.L. Lentz. 1984. More Lake States tree survival predictions. USDA For. Serv. Res. Note NC-312. 6 p.

Davidson, R.W., R.C. Atkins, R.D. Fry, G.D. Racey, and D.H. Weingartner. 1989. A silvicultural guide for the Poplar Working Group in Ontario. Ont. Minis. Nat. Res., Toronto, Science and Technology Series Vol. 5. 67 p.

DeByle, N.V., and R.P. Winokur, eds. 1985. Aspen: ecology and management in the western United States. USDA For. Serv. Gen. Tech. Rep. RM-119. 283 p.

Ek, A.R., and J.D. Brodie. 1975. A preliminary analysis of short-rotation aspen management. Can. J. For. Res. 5:245-258.

Hahn, J.T., and R.A. Leary. 1979. Potential diameter growth functions. P. 22-26 *in* A generalized forest growth projection system applied to the Lake States region. USDA For. Serv. Gen. Tech. Rep. NC-94.

Holdaway, M.R. 1984. Modeling the effect of competition on tree diameter growth as applied in STEMS. USDA For. Serv. Gen. Tech. Rep. NC-94. 9 p.

Holdaway, M.R., R.A. Leary, and J.L. Thompson. 1979. Estimating mean stand crown ratio from stand variables. P. 27-30 *in* A generalized forest growth projection system applied to the Lake States region. USDA For. Serv. Gen. Tech. Rep. NC-94.

Lundgren, A.L. and W.A. Dolid. 1970. Biological growth functions describe published site index curves for Lake States timber species. USDA For. Serv. Res. Pap. NC-36. 9 p.

Perala, D.A. 1977. Manager's handbook for aspen in the North Central States. USDA For. Serv. Gen. Tech. Rep. NC-36. 30 p.

Perala, D.A. 1984. Aspen management. Videotape available in 1/2 and 3/4 in. formats. USDA For. Serv., NC For. Exp. Stn., St. Paul, MN.

Perala, D.A. 1986. Aspen management. P. 87-97 *in* Proceedings, Integrated pest management symposium for northern forests, March 24-27, 1986, Madison, WI. Univ. Wisc. Coop. Ext. Serv.

Perala, D.A. in prep. A universal model of aspen growth and yield based on the self thinning rule.

Perala, D.A., and J. Russell. 1983. Aspen. P. 113-115 *in* Silvicultural systems for the major forest types of the United States. R. M. Burns, tech. comp. USDA Agric. Handbk. 445, Washington, DC.

Schlaegel, B.E. 1975. Estimating aspen volume and weight for individual trees, diameter classes, or entire stands. USDA For. Serv. Gen. Tech. Rep. NC-20. 16 p.

Shepperd, W.D. 1986. Silviculture of aspen forests in the Rocky Mountains and Southwest. USDA For. Serv. RM-TT-7. 38 p.

Shepperd, W.D., and O. Engelby. 1983. Rocky Mountain aspen. P. 77-79 *in* R. M. Burns, tech. comp. Silvicultural systems for the major forest types of the United States. USDA Agric. Handbk. 445, Washington, DC.

Smith, H.C., N.I. Lamson, and G.W. Miller. 1989. An esthetic alternative to clearcutting? J. For. 87(3):14-18.

Smith, N.J., and D.G. Brand. 1988. Compatible growth models and stand density diagrams. P. 636-643 *in* Forest growth modelling and prediction. Proc. IUFRO Conf. Aug. 23-27, 1987, Minneapolis, MN. A.R. Ek, S.R. Shifley, and T.E. Burk, eds. USDA For. Serv. Gen. Tech. Rep. NC-120.

Steneker, G.A. 1976. Guide to the silvicultural management of trembling aspen in the prairie provinces. Env. Can. For. Serv. Inf. Rep. NOR-X-164. 6 p.

Yang, R.C., A. Kozak, and J.H.G. Smith. 1978. The potential of Weibull-type functions as flexible growth curves. Can. J. For. Res. 8:424-431.

Zehngraff, P. 1947. Possibility of managing aspen in the Lake States. USDA For. Serv. Lake States Aspen Rep. 21. 23 p.