Adaptation of FIBER for Forest Inventory and Analysis Growth Projections in the State of Maine

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Abstract.—The model FIBER (Forest Increment Based on Ecological Rationale) was selected by the Technical Review Team on the Sustainability of Timber Supplies in the State of Maine to construct yield information using USDA Forest Service Forest Inventory and Analysis (FIA) field data. FIBER habitat criteria based on soil characteristics, species composition of overstory, and adjusted understory trees were used to classify FIA plots compared to the past and present records of the FIA inventory forest typing. Yield curves based on ecological classification and species compositional succession were constructed for input into the model ATLAS (Aggregate Timberland Assessment).

Scientifically based practices are critical and a required component of forest policy for the State of Maine. Sustaining a viable forest is economically essential to address the recreational needs and provide for an adequate timber industry supply. Thus, policy makers are required to consider levels of timber harvest that are sustainable, both biologically and economically. The use of regional planning and policy application models is one method of combining structure and regulation to ensure continuance of the "Maine Woods" for future generations to enjoy. Cooperation between the Maine State Forest Service and the U.S. Department of Agriculture (USDA), Forest Service, Northeastern Research Station has initiated a statewide study using Forest Inventory and Analysis (FIA) inventory plot data to assess present and future forest conditions in developing policy recommendations for the State of Maine. A technical review team, comprised of scientists and individuals from industry, the Forest Service, universities, and public interest groups, has chosen the FIBER 3.0 model (Forest Increment Based on Ecological Rationale) (Solomon *et al.* 1995) to grow the mixed species stands and generate yield curves based on six ecological classifications using the FIA plots.

The construction of the FIBER model (Solomon *et al.* 1986) is based on a regional database across northern New York and New England to Nova Scotia. The two-stage matrix model structure captures the changes in different species growth rates and species succession for different ecological classifications that occurs during stand maturation. These classes are indicative of the *probable* climax or late succession overstory species composition, which is theoretically determined by a set of biophysical relationships (Leak 1982). This classification is analogous to natural habitats that state the predominant overstory/understory of *potential* climax vegetation originating in the western United States (Daubenmire 1952, Pfsister and Arno 1980). By growing plot level data in FIBER to stratify all timberlands into the six ecological types, an ecologically based timber supplies projection can be produced.

The 1995 FIA survey for Maine utilized a sample of 2,698 plots and subplots inventorying roughly 17 million acres of timberland in the state. The forest types and forest-type groups from the FIA inventories are not directly comparable with the ecological classification in FIBER. Therefore, the FIA forest types were placed into FIBER classes for analysis. Table 1 shows that from the three different inventories, the acreage in each forest type changed over time. The USDA Forest Service defines forest type as "a classification of forest land based on the species that form a plurality of live-tree basal-area stocking" (Griffith and Alerich 1996). The forest types of Maine's woods, and even the algorithms used to define them, have changed rather significantly over the last 4 decades (Powell and Dickson 1984). These species changes, softwoods decreasing and hardwoods increasing, are due to both natural processes and human disturbance. Therefore, the FIA plots need to be reclassified into the most appropriate FIBER habitats.

This paper is a preliminary overview of the process used to adapt the ecological model FIBER and FIA forest types to produce realistic growth and yield curves. These yield curves, by ecological habitats, were input for the ATLAS (Aggregate Timberland Assessment) projection model (Mills and Kincaid 1992) to match timber supply with timber demand.

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Table 1.—*FIBER habitat compared with FIA forest type by timberland area for 1971, 1982, and 1995*

FIBER habitat	Forest type	Forest Inventory and Analysis 1971	1982	1995
		- - - - Million acres	- - - -	
Sugar maple/	Sugar maple/beech/yellow birch	3.1	3.1	3.9
Ash	Black cherry	—	—	.1
		(3.1)[1]	**(3.1)**	**(4.0)**
Beech/Red	Red maple/northern hardwoods	1.2	1.2	1.5
Maple	Pin cherry	—	.1	.1
	Mixed northern hardwoods	.6	.5	.8
		(1.8)	**(1.8)**	**(2.4)**
Oak/	Oak/pine	—	—	.5
White pine	Oak/hickory	.3	.4	.3
	Pine/hemlock	1.4	1.6	.7
		(1.7)	**(2.0)**	**(1.5)**
Cedar/	Tamarack	.1	.1	.1
Black spruce	N. white cedar	1.4	1.6	1.3
	Black spruce	.2	.3	.2
	Elm/ash/red maple	.3	.2	.4
		(2.0)	**(2.2)**	**(2.0)**
Spruce/fir	Balsam fir	1.7	1.1	1.8
	Red spruce	1.1	1.2	.9
	Spruce/fir	3.7	3.3	1.5
	White spruce	.2	.2	.2
	Aspen/birch	1.0	1.5	2.2
		(7.7)	**(7.3)**	**(6.6)**
Hemlock/red spruce	Hemlock	.5	.6	.5
		(.5)	**(.6)**	**(.5)**
	TOTAL	**16.8**	**17.0**	**17.0**

[1] Values in parentheses are subtotals.

METHODS AND RESULTS

The 1995 FIA database contains 183 variables including past (1982 inventory) and current tree list information as well as regeneration data tallied in the 1995 remeasurement. To analyze 2,698 stands, modifications to FIBER 3.0 and to the FIA forest typing of inventory plots were required in a flexible inventory program since FIBER 3.0 is designed as a single-stand analytical tool. Therefore, FlexFIBER 4.xx (Brann and Solomon unpublished) was developed to handle batch processing of stands by ecological habitats to produce yield data files for ATLAS. We ran all 2,698 timberland plots through the FlexFIBER model to generate independent overstory habitat assignments.

The habitat algorithm in FIBER 3.0 looks at the percentages of the basal area by tree species in the existing forest stand that, through an association to different soil characteristics, are indicative of successional trends. An initial assignment by FIBER led to a different distribution of FIA timberland acres in table 2, acknowledging that 135 plots had less than 5 square feet of basal area required by the model and therefore were not included in this first phase distribution of acreage.

Table 2.—*Phase I classification of 1995 Forest Inventory and Analysis timberland acreage into six FIBER ecological habitats*

Ecological habitat	Acres	Acres	Hardwood basal area
		- - - *Percent* - - -	
Beech/Red Maple	2,367,769	14.6	91
Cedar/Black Spruce	2,851,104	17.6	19
Hemlock/Red Spruce	1,629,054	10.0	34
Oak/White Pine	2,248,710	13.9	47
Spruce/Fir	5,188,685	32.0	36
Sugar Maple/Ash	1,930,294	11.9	92

The model was further adapted in FlexFIBER 4.xx to consider understory tree species composition. The understory trees (<4.5 inches) on a plot are normally not considered as an input to the FIBER 3.0 model. The FIA data contained understory species information, and an assignment of ingrowth species into each ecological habitat was made. Profile, by habitats, of all 2,698 timberland plots were sorted by FIBER using the number of trees by species per acre in the understory in addition to the past FIA forest type classification. This adjustment allows for a more accurate description of ingrowth, which might have been overlooked using only the overstory stand. This was particularly important as a means of accurately following species succession in spruce/fir habitats, which currently have a high level of red maple (*Acer rubrum L.*), aspen (*Populus spp.*), and northern white cedar (*Thuja occidentalis L.*) stocking.

Plots were then divided into three groups for each of the six ecological classifications. To address the differences between the overstory and understory assigned by the FIBER model, the groups were classified as plots that had: a) agreement between the understory and overstory (1,201 plots); b) different understory and overstory assignments (1,362 plots); and c) no overstory and did not fall into the above two groups (135 plots).

After looking through the 1,201 plots that had agreement between overstory and understory, we felt that the data describing these plots provided few opportunities to improve this subset. So instead, we focused on plots with disagreement between the overstory/understory and plots with no overstory recorded.

In a two-step process, 1,497 (1,362 + 135) plots were considered for habitat reassignment. In the first step, we grouped the different overstory and understory by FIBER habitat classifications. Then, using a list of 12 plot-level variables of current and past FIA forest types, soil-based habitat information, parent material, moisture class, elevation, measures of volume, and species composition, plots were classified (table 3). The sorted plots by FIBER habitat and past FIA forest type, within a given FIBER habitat, could be profiled while also allowing plots with like variables to be listed together. Of the 1,362 plots scrutinized, 823 remained in the initial FIBER habitat classification. This process allowed for different species and different growth rates of the same species to aggregate on plots where regeneration was not the same species composition as the existing stand overstory. Spruce-fir habitats that are heavily harvested usually regenerate to hardwoods; however, the plots should not be classified as hardwood habitat but as spruce-fir, since species succession will return the stand to spruce-fir composition over time. After examining the remaining plot variables over time and the tree list data, it became apparent that some general guides could be developed to move groups of plots with similar characteristics into more appropriate FIBER habitat classifications, especially since the model FIBER follows species succession during stand maturation. For example, it seemed that many quality sites, Sugar Maple/Ash plots (past FIA type of Maple-Beech-Birch, mesic soils, Sugar Maple/Ash understory) did not have the basal area requirements for Sugar Maple/Ash habitat. While somewhat subjective, we recognized the persistence of a Sugar Maple/Ash understory on mesic soils, as well as the homogeneity of many of the plots, and reassignment was made to Sugar Maple/Ash. Fundamental understanding of existing timber types and reflection on the actual plot data and species changes over time became the basis for the development of guides for placing plots into habitat classification when the plot overstory and understory do not agree. The following guides and guides in table 3 were applied to the understory classification that resulted in changing the remaining 539 plots. Within a FIBER type, these rules were intended to be hierarchical. In application, however, there were few, if any, cases where these guides were in conflict.

Table 3.—*Forest Inventory and Analysis plot level variables used in the reclassification of FIA forest types into FIBER habitats*

Overstory habitat	Plot ID	FIBER understory	Current FIA type	Past FIA type	Soil-based habitat	Parent[1] material	Moisture[2] class	Elevation	BioPhysical	Total net volume	AGS[3]	Hardwood	2 Story stands
								Meters		*ft³*	*Percent*	*Percent*	
BE/RM	17-307-1	SF	Aspen	Aspen		3	4	275	Western Mountains	2114	87.0	13.0	0
	3-262-1	SF	SM/BE/Birch	Aspen	SM/ASH	2	3	220	Aroostook Lowland	651	100.0		0
	9-195-1	SF	RM/Northern Hardwoods	Balsam Fir		4	4	50	East Coastal Region	995	100.0	0.0	0
CE/BS	3-274-1	BE/RM	Black Spruce	Black Spruce	CE/BS	6	5	185	Aroostook Lowland	2830	96.3	3.7	0
	27-126-1	BE/RM	SM/BE/Birch	Hemlock	SM/ASH	1	3	145	Central Interior	770	97.8	2.2	0
	25-684-1	BE/RM	Northern White Cedar	Northern White Cedar	CE/BS	6	5	150	Western Foothills	1161	60.8	39.2	0
OAK/WP	17-314-1	BE/RM	Northern Red Oak	Northern Red Oak	OAK/WP	2	2	170	Southwest Interior	537	89.3	10.7	0
	13-96-1	BE/RM	White Pine/ Hemlock	White Pine	OAK/WP	3	2	80	Central Interior	1492	97.9	2.1	0
SPRUCE/ FIR	25-740-1	BE/RM	Red Spruce	"Unrecorded"	SP/FIR	4	4	370	Aroostook Hills	2900	98.4	1.6	0
	29-15-1	BE/RM	RM/Northern Hardwoods	Balsam Fir	BE/RM	2	3	70	Eastern Lowlands	644	73.2	26.8	0
SM/ASH	3-68-1	BE/RM	SM/BE/Birch	Mixed Northern Hardwood	SM/ASH	1	3	400	Aroostook Hills	1598	100.0	0.0	0
	17-5-1	BE/RM	SM/BE/Birch	SM/BE/Birch	SM/ASH	2	3	185	Western Mountains	2077	98.3	1.7	0

[1] Parent material: 1 = compact till; 2 = loose till; 3 = sand and gravel; 4 = silt and clay; 5 = alluvium; 6 = organic
[2] Moisture class: 1 = very dry; 2 = dry; 3 = mesic; 4 = wet; 5 = very wet
[3] AGS = Acceptable Growing Stock

Guides Used to Supplement Assignment of Fiber Habitat Classification for Plots with Disagreement Between Overstory and Understory Species Composition.

SUGAR MAPLE—ASH HABITAT:

Plots with Sugar Maple—Ash FIBER understory and Sugar Maple—Ash soil were placed in Sugar Maple—Ash habitat. This applies across all FIBER habitats, and supersedes other guides (changes 82 plots).

BEECH—RED MAPLE HABITAT:

1. Plots with Spruce—Fir FIBER understory and a fir, red-white spruce, or cedar past FIA type were placed in Spruce—Fir habitat (changes 35 plots).
2. Plots with Spruce—Fir FIBER understory and an intolerant hardwood past FIA type (aspen, paper birch) were placed in Spruce—Fir habitat. If the past FIA type is unrecorded, the current FIA type can be substituted (changes 44 plots).

CEDAR—BLACK SPRUCE HABITAT:

1. Plots with red-jack-pitch pine FIA type were placed in Oak—White Pine. This is due to FIBER soil and site categories of these pines and having growth rates similar to tamarack (changes 7 plots).
2. Plots with Spruce—Fir FIBER understory and fir, red-white spruce past FIA type were placed in Spruce—Fir habitat. If past FIA type is unrecorded, current FIA type can be substituted (changes 144 plots).
3. Plots with hardwood FIBER understory (Beech—Red Maple, Sugar Maple—Ash) and tolerant hardwoods for both FIA types were placed in Beech—Red Maple habitat (changes 3 plots).
4. Plots with Hemlock—Red Spruce FIBER understory and hemlock or red spruce FIA types were placed in Hemlock—Red Spruce habitat (changes 3 plots).
5. Plots with Spruce—Fir FIBER understory and an FIA type other than cedar, black spruce, or tamarack were placed in Spruce—Fir habitat, unless soils are Cedar—Black Spruce. If soils are Cedar—Black Spruce, then no change (changes 42 plots).

HEMLOCK—RED SPRUCE HABITAT:

1. Plots with Sugar Maple—Ash soils and past FIA type of any northern hardwoods were placed in Beech—Red Maple habitat. Current FIA type can be substituted if past FIA type is not available. Plots with Sugar Maple—Ash soils and Sugar Maple—Ash FIBER understory have already been assigned Sugar Maple—Ash (changes 29 plots).
2. Plots with Beech—Red Maple or Sugar Maple—Ash FIBER understory and FIA types of any northern hardwoods (or current if past is unrecorded) were placed in Beech—Red Maple habitat (changes 16 plots).

OAK—WHITE PINE HABITAT:

1. Plots with Hemlock—Red Spruce FIBER understory and a hemlock or red spruce past FIA type (or current if past is unrecorded) were placed in Hemlock—Red Spruce habitat (changes 10 plots).
2. Plots with Sugar Maple—Ash soil and "non-Oak" for both FIA hardwood types were placed in Beech—Red Maple habitat (changes 21 plots).
3. Plots with Beech—Red Maple FIBER understory and "non-Oak" for both FIA hardwood types were placed in Beech—Red Maple habitat (changes 21 plots).

SPRUCE—FIR HABITAT:

1. Plots with Beech—Red Maple or Sugar Maple—Ash FIBER understory, and both FIA hardwood types (can substitute current FIA type if past is unrecorded) were placed in Beech—Red Maple habitat (changes 61 plots).
2. Plots with Sugar Maple—Ash soils and both FIA hardwood types were placed in Beech—Red Maple habitat (changes 16 plots).

Also, in this second phase, the assignment of the 135 plots was made using the same 12 plot descriptor variables and tree list data. However, plots were placed individually in habitats without guides being explicitly stated. Because of the absence of an overstory, the FIBER understory from the initial run, soil, and the past forest type were utilized to assign habitat. The Phase II assignment, while different from the FIA typing and initial FIBER assignment, produced an objective refinement of the distribution of the total timberland acres as listed in table 4.

The staff conducted a third phase at a higher level of resolution to correct plots they felt either were not or could not be captured correctly by Phase I or II. The same 12 variables scrutinized in earlier assessments, supplemented by subjective criteria of the tree list

Table 4.—*Phase II Reclassification of 1995 Forest Inventory and Analysis timberland acreage into six FIBER ecological habitats using overstory and understory trees*

Ecological habitat	Acres	Acres	Hardwood basal area
		Percent	*Percent*
Beech/Red Maple	2,876,515	17.0	77
Cedar/Black Spruce	1,599,084	9.4	15
Hemlock/Red Spruce	1,447,076	8.5	30
Oak/White Pine	1,928,361	11.4	43
Spruce/Fir	6,599,835	38.9	36
Sugar Maple/Ash	2,501,361	14.8	87

inspections of the FIA data, were used to distribute timberland acreage (table 5). This distribution reflects a higher percentage of Spruce/Fir, Sugar Maple/Ash, and Beech/Red Maple acres than the initial FIBER or Phase II assignments. Also, lower percentages of Cedar/Black Spruce, Hemlock/Red Spruce, and Oak/White Pine acres were the result of moving the less than obvious plot assignments into the other three habitats. FIBER was then used to estimate yields by management units and intensities and was used in the ATLAS timber supply analysis.

Attempting to understand the accuracy of our current distribution, it is helpful to look at past FIA inventories for Maine in the 1950's, 1960's, and 1970's. Catastrophic attacks by the spruce budworm in 1970-80 caused excessive mortality (Solomon and Brann 1992). Salvage of that mortality and excessive harvesting to prevent windthrow changed species compositions and ground cover types for future FIA inventories. For this reason, the current forest habitat classification is confounded, and data from earlier inventories must be incorporated to follow the species' successional trends over time. For example, the 1959 FIA inventory (Ferguson and Longwood 1960) recorded 8.4 million acres of spruce-fir type group as compared to the 1995 FIA inventory of 6 million acres. Although the FIA forest typing algorithms have changed since 1959, it is safe to say that harvest activity over the past 3 decades has promoted a higher level of stocking in both hardwoods and northern white cedar, while decreasing plots stocked with spruce and fir. However, many of these stands have a strong component of spruce and fir in the understory and, in many cases, reflect the successional tendency of these sites. Our approach uses the convenience of FIBER's batch level processing with the valuable understory, ecological, and forest type information from FIA to follow forest tree species growth and succession through time.

CONCLUSION

With Maine's timberland acres aggregated into these six ecological types, yield curves based on a variety of harvesting intensities and silvicultural regimes within different management units were constructed. FIBER was used to project the FIA inventory timberland plots data (except the 135 without an overstory). FIBER produced updated inventory estimates every 5 years and constructed a time series file of the projected inventory. The time series files were used to develop yield tables by the above ecological habitats and volume classes for ATLAS. In using the FIBER ecological habitats as a stratification, the

Table 5.—*Final distribution of 1995 Forest Inventory and Analysis timberland acreage by ecological habitat as adjusted and supplemented by tree list inspections*

Ecological habitat	Acres	Acres	Hardwood basal area
		Percent	*Percent*
Beech/Red Maple	3,187,980	18.8	73
Cedar/Black Spruce	1,612,559	9.5	14
Hemlock/Red Spruce	1,290,525	7.6	31
Oak/White Pine	1,290,311	7.6	42
Spruce/Fir	6,909,619	40.8	35
Sugar Maple/Ash	2,661,238	15.7	86

ATLAS model results extend beyond current species inventoried, while allowing the consequences of alternative silvicultural regimes and stand maturation to be modeled. Classification of FIA plots into a FIBER habitat during the field data collection would improve future processing. Phase I and II are within different management units being incorporated into FlexFIBER 4.xx for application in Maine, New Hampshire, New York, and Vermont.

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