SHIFTS IN RELATIVE STOCKING OF COMMON TREE SPECIES IN KENTUCKY FROM 1975 TO 2004

Christopher M. Oswalt, Jeffrey W. Stringer, and Jeffery A. Turner[1]

Abstract.—Changes in species-specific relative stocking indicate the extent to which a species is either increasing or decreasing in a particular system. Changes in relative stocking values of common tree species in Kentucky from 1988 to 2004 were compared to values calculated for 1975 to 1988. Mean annual increase in relative stocking between 1988 and 2004 was greatest for eastern white pine (*Pinus strobus* L.), boxelder (*Acer negundo* L.), and loblolly pine (*P. taeda* L.), averaging 1.29, 1.25, and 1.06 percent year-1, respectively. Species with an observed decline in relative stocking for both 1975-1988 and 1988-2004 include American beech (*Fagus grandifolia* Ehrh.), scarlet oak (*Quercus coccinea* Muenchh.), northern red oak (*Q. rubra* L.), post oak (*Q. stellata* Wangenh.), black oak (*Q. velutina* Lam.), black walnut (*Juglans nigra* L.), and chinkapin oak (*Q. muehlenbergii* Engelm.). Species with an observed increase in relative stocking over both periods include eastern redcedar (*Juniperous virginiana* L.), boxelder, red maple (*A. rubrum* L.), silver maple (*A. saccharinum* L.), and sugar maple (*A. saccharum* Marsh.). Results suggest that the *Acer* genus has greatly increased over the past 30 years while the *Quercus* genus has continually declined. These results support the generally accepted notion that the eastern deciduous landscape continues to experience replacement of oak with more generalist species such as red maple.

INTRODUCTION

Shifts in species composition herald changes in forest types throughout much of the oak/hickory forest type (e.g., Fei and others 2007). Typical of many states in the eastern United States, Kentucky maintains a high proportion of oak-hickory forests (Smith and others 2004) accounting for approximately 72 percent of the 11.6 million acres of timberland within the state (Turner and others In press). While forest inventory data suggest that the dominance of the oak-hickory forest type continues throughout Kentucky, there is evidence that significant changes in species composition are underway. However, high species diversity and numerous hardwood and softwood associates typical of the oak-hickory forest type are masking changes in species composition.

The degree to which species composition changes indicates the extent to which a particular species is either gaining or losing ground in an ecological system. Such changes may inform scientists and managers both in assessing current status of a forested system and in forecasting probable stand-scale shifts and changes in developmental patterns. Additionally, researchers have concluded that forest health problems can be identified and tracked through the investigation of shifts in species composition.

One way to determine shifts in species composition is through tracking species-specific relative stocking over time. Stocking is generally defined as the amount of growing space that a particular tree occupies in a given unit of land area (Avery and Burkhart 1994, Gansner and others 1996). Specifically, the USDA Forest Service Forest Inventory and Analysis (FIA) program defines stocking as "the degree of occupancy

[1]Forest Resource Analyst (CMO), USDA Forest Service, Southern Research Station Forest Inventory and Analysis, 4700 Old Kingston Pike, Knoxville, TN 37919; Associate Professor (JWS), University of Kentucky, Department of Forestry, 213 T.P. Cooper Building, Lexington, KY 40546-0073; and Forester (JAT) USDA Forest Service, Southern Research Station Forest Inventory and Analysis, 4700 Old Kingston Pike, Knoxville, TN 37919. CMO is corresponding author: to contact, call (865)862-2068 or email at coswalt@fs.fed.us.

of land by trees, measured by basal area or the number of trees in a stand, compared with a minimum standard, depending on tree size, required to fully utilize the growth potential of the land." The FIA definition is based on the original stocking definition presented by Ginrich (1967).

This definition and FIA data were used to define changes of relative stocking values of common tree species in Kentucky from 1988 to 2004. Specific objectives of this investigation included extending the analysis begun by Gansner and others (1995), published in the proceedings of the 10th Central Hardwood Forest Conference, by 1) identifying and quantifying the strength and direction of shifts in relative stocking for common tree species in Kentucky from 1988-2004; 2) comparing current estimates of change with the previously reported estimates from Gansner and others (1995); and 3) identifying long-term and short-term trends in species-specific relative stocking changes.

DATA

Data used in this study were collected by the USDA Forest Service FIA program. Data were obtained from 1099 plots initially measured in 1986-1987 (hereafter 1988) according to FIA procedures for plots with a five-point cluster design with one center point and four satellite points located 98.4 ft north, east, south and west. The same plots were remeasured between 1999 and 2003 (hereafter 2004). The percent forest land in each county influenced the number of remeasured plots located in a given county. As a result, plots per county ranged from one for the counties containing limited forest land to 39 in one of the heavily forested counties (Table 1). The remeasured fixed area plot records allowed for the use of a consistent stocking estimation procedure to be applied to both inventories and comparisons to be made. In addition, estimates of species-specific change in relative stocking were obtained for the period between 1975-1988 from Gansner and others (1995) for comparisons with the estimates derived in the current analysis.

METHODS

Stocking

Species-specific stocking was calculated for both the 1988 and 2004 inventories with the following equation:

$$S_{iklj} = \frac{(b_0 \cdot dbh_{ikjl}^{b_1}) \cdot tpa_{ikjl}}{q_{ik}} \tag{1}$$

where S_{iklj} = stocking value for tree *j* in condition *k* of subplot *l*, plot *i*; dbh_{iklj} = diameter at breast height of tree *j*, subplot *l*, condition *k* of plot *i*; tpa_{iklj} = trees per acre expansion factor of tree *j* on subplot *l*, condition *k* of plot *i*, reflecting the plot size disregarding condition; *qik* = stockability proportion for condition *k* of plot *i* (assumed to equal 1); and b_0 and b_1 = species-specific parameters. Species-specific coefficients were obtained from Tables 2 and 3 in Arner and others (2001).

Relative stocking was calculated for each species at the plot-level by:

$$RS_{hp} = \frac{\sum S_{hp}}{\sum S_{(all)p}} \tag{2}$$

where, RS_{hp} is the relative stocking of species *h* on plot *p*; *S* is the calculated species-specific stocking; and $S_{(all)}p$ is the stocking calculated for all species on plot *p*.

Table 1.—Number of plots remeasured in 2004 and the percent forest land for each county in 2004 within the Commonwealth of Kentucky.

County	Plots	Forest (%)	County	Plots	Forest (%)
Adair	12	44	Larue	3	31
Allen	9	35	Laurel	16	58
Anderson	4	42	Lawrence	18	87
Ballard	5	24	Lee	10	81
Barren	5	19	Leslie	23	91
Bath	5	38	Letcher	20	91
Bell	19	85	Lewis	21	69
Boone	4	31	Lincoln	4	29
Bourbon	3	3	Livingston	10	40
Boyd	6	66	Logan	8	27
Boyle	2	38	Lyon	12	59
Bracken	4	46	Madison	4	27
Breathitt	25	92	Magoffin	24	84
Breckinridge	15	38	Marion	5	34
Bullitt	8	53	Marshall	7	37
Butler	11	53	Martin	15	76
Caldwell	8	28	Mason	7	23
Calloway	10	27	McCracken	9	21
Campbell	3	35	McCreary	11	87
Carlisle	4	28	McLean	2	17
Carroll	3	42	Meade	7	33
Carter	17	76	Menifee	10	77
Casey	13	54	Mercer	2	16
Christian	13	38	Metcalfe	8	36
Clark	2	22	Monroe	5	36
Clay	22	89	Montgomery	2	24
Clinton	6	49	Morgan	15	79
Crittenden	8	35	Muhlenberg	9	42
Cumberland	13	66	Nelson	8	36
Daviess	4	17	Nicholas	2	26
Edmonson	10	57	Ohio	17	48
Elliott	10	71	Oldham	2	22
Estill	10	80	Owen	9	42
Fayette	2	1	Owsley	9	78
Fleming	8	41	Pendleton	7	45
Floyd	19	84	Perry	19	80
Franklin	3	26	Pike	39	84
Fulton	4	18	Powell	8	73
Gallatin	1	37	Pulaski	16	48
Garrard	2	23	Robertson	2	56
Grant	4	37	Rockcastle	14	67
Graves	11	22	Rowan	13	73
Grayson	13	41	Russell	6	40

continued

Table 1.—Number

Green	4	24	Scott	3	21
Greenup	15	75	Shelby	4	19
Hancock	4	50	Simpson	2	6
Hardin	14	31	Spencer	3	35
Harlan	26	92	Taylor	6	36
Harrison	4	18	Todd	6	26
Hart	9	46	Trigg	20	54
Henderson	3	10	Trimble	4	48
Henry	3	30	Union	3	13
Hickman	3	25	Warren	7	24
Hopkins	11	40	Washington	3	27
Jackson	14	78	Wayne	18	72
Jefferson	1	17	Webster	5	29
Jessamine	2	18	Whitley	21	72
Johnson	13	77	Wolfe	11	82
Kenton	3	40	Woodford	3	3
Knott	17	90			
Knox	16	77	Total	1099	

Estimating Change

Change was estimated by comparing species-specific relative stocking for a given plot across both inventories by:

$$SC_{hp} = RS_{1988} - RS_{2004} \qquad (3)$$

where SC_{hp} is stocking change for species *h* on plot *p*.

Average annual change (AAC) was calculated for each species at the plot scale:

$$AAC_{hp} = \frac{SC_{hp}}{RP} \qquad (4)$$

where RP is the time between remeasurements of the plot.

Mean species-specific average annual change AAC_{hp} was calculated for each county in Kentucky. Average annual change calculated for the period between 1988 and 2004 was compared to estimates of average annual change between period 1975 and 1988 reported by Gansner and others (1995). Direction (positive or negative AAC_{hp}) for both periods were compared to detect possible long-term trends in species composition. In addition, change (positive, negative, and no change) was mapped for select species to detect spatial trends in changes.

Table 2—Stocking equation coefficients for each species and number of plots in which a species was postively identified at Time 1 (1988) and Time 2 (2004)

	--------Coefficients --------				
Species	b0	b1	Time1	Time2	Difference
Red maple	0.01105	1.53	306	440	134
Eastern redcedar	0.00946	1.59	108	175	67
Sugar maple	0.00694	1.86	295	358	63
Shortleaf pine	0.00509	1.81	41	73	32
Pitch pine	0.00946	1.59	41	69	28
Boxelder	0.00688	1.86	33	56	23
Yellow buckeye	0.00694	1.86	17	37	20
Shumard oak	0.01119	1.63	5	24	19
Eastern hemlock	0.00313	2.11	27	42	15
Eastern white pine	0.009	1.51	8	15	7
Ailanthus	0.01105	1.53	2	6	4
Balsam poplar	0.01429	1.46	0	3	3
Swamp white oak	0.01119	1.63	3	6	3
Bur oak	0.0025	2	0	1	1
Loblolly pine	0.0068	1.72	8	8	0
Striped maple	0.00694	1.86	1	1	0
American chestnut	0.01105	1.53	1	0	-1
Silver maple	0.01105	1.53	17	16	-1
Osage orange	0.01119	1.63	12	10	-2
Overcup oak	0.01119	1.63	2	0	-2
Cherrybark oak	0.01119	1.63	23	19	-4
Pin cherry	0.01105	1.53	4	0	-4
Eastern cottonwood	0.00688	1.86	11	6	-5
Willow spp.	0.01105	1.53	17	8	-9
Pin oak	0.01119	1.63	23	13	-10
Blackjack oak	0.01119	1.63	15	2	-13
River birch	0.00635	1.89	28	14	-14
Shingle oak	0.01119	1.63	28	13	-15
Post oak	0.01119	1.63	104	76	-28
American sycamore	0.00688	1.86	112	76	-36
American beech	0.00694	1.86	246	199	-47
Scarlet oak	0.01119	1.63	227	161	-66
Chestnut oak	0.01119	1.63	303	235	-68
White oak	0.01119	1.63	527	419	-108
Northern red oak	0.01119	1.63	352	225	-127
Black oak	0.01119	1.63	431	278	-153

RESULTS

In 1988 white oak (*Quercus alba*) occurred on the most plots (527 plots) followed by yellow-poplar (*Liriodendron tulipifera* L.) (448 plots), black oak (*Q. velutina* Lam.)(431 plots), northern red oak (*Q. rubra* L.) (352 plots) and red maple (*Acer rubrum* L.) (306 plots). After remeasurement in 2004, red maple was sampled on the most plots (440 plots) followed by white oak (419 plots), yellow-poplar (383 plots), sugar maple (*A. sacharrum* Marsh.) (358 plots) and black oak (278 plots).

Between 1988 and 2004 the presence of red maple, eastern redcedar, and sugar maple increased significantly (Table 2). Other species that increased in presence were shortleaf (*Pinus echinata* P. Mill.) and pitch pines (*P. rigida* P.Mill.), boxelder (*Acer negundo* L.), eastern hemlock (*Tsuga Canadensis* (L.) Carr.), and eastern white pine (*P. strobus* L.). Species from the oak (*Quercus*) genus had the greatest declines in presence. Five species of oak in particular—black oak, northern red oak, white oak, chestnut oak (*Q. prinus* L.), and scarlet oak (*Q. coccinea* Muenchh.)—were found on approximately 50 fewer plots in 2004 than in 1988 (Table 2). In addition, six other oak species, post oak (*Q. stellata* Wangenh.), shingle oak (*Q. imbricaria* Michx.), blackjack oak (*Q. marilandica* Muenchh.), pin oak (*Q. palustris* Muenchh.), cherrybark oak (*Q. pagoda* Raf.), and overcup oak (*Q. lyrata* Walt.) were identified on significantly fewer plots in 2004 than in 1988.

The 18 species with the largest positive AAC and 18 species with the largest negative AAC between 1988 and 2004 are presented in Figure 1. Species such as eastern white pine, boxelder, and loblolly pine experienced gains in relative stocking of greater than 1 percent year-1. Only eastern cottonwood experienced loses of greater than 1 percent year^{-1}. Oaks averaged losses of 0.02 percent year^{-1}, while maples averaged gains of approximately 0.11 percent year^{-1}. The six most common oaks averaged losses of 0.29 percent year^{-1}. Oaks represented 61 percent of the top 18 species that decreased in abundance.

The relative stocking of 11 species of oak decreased between 1988 and 2004 (Fig. 1). Other species that had significant declines in relative stocking were river birch (*Betula nigra* L.), American sycamore (*Platanus occidentalis* L.), pin cherry (*Prunus pennsylvanica* L.f., and willow (*Salix* spp. L.).

Two genera, *Pinus* (pines) and *Acer* (maples), represented a large proportion of the species that gained in relative stocking between 1988 and 2004. Significant gains were recorded for five maple species and four pine species. The maples were found on many more plots than the pines (Table 2). Red maple, sugar maple, boxelder, striped maple, and silver maple were sampled on 440, 358, 56, 1, and 16 plots, respectively in 2004. While silver maple was recorded on one fewer plot (Table 2) in 2004 than 1988 it exhibited a positive AAC. Shortleaf pine, pitch pine, eastern white pine and loblolly pine were recorded on 73, 69, 15, and 8 plots, respectively in 2004. Other species with significant positive AAC were eastern redcedar (*Juniperus virginiana* L.), balsam poplar (*Populus balsamifera* L.) and the invasive tree-of-heaven (*Ailanthus altissima* (P.Mill.) Swingle).

Arguably the most important analysis is the long-term (1975 to 2004) change in species-specific relative stocking. When compared to similar estimates of AAC for the period between 1975 and 1988, 11 species were found to be experiencing a long-term decline in relative stocking over the combined 30-year period between 1975 and 2004 (Fig. 2). Ten species experienced gains in relative stocking over the same period while 14 species were found to be increasing during one study (1975-1988 or 1988-2004) and decreasing during the other (short-term)(Fig. 2). Long-term declines in relative stocking have been experienced by

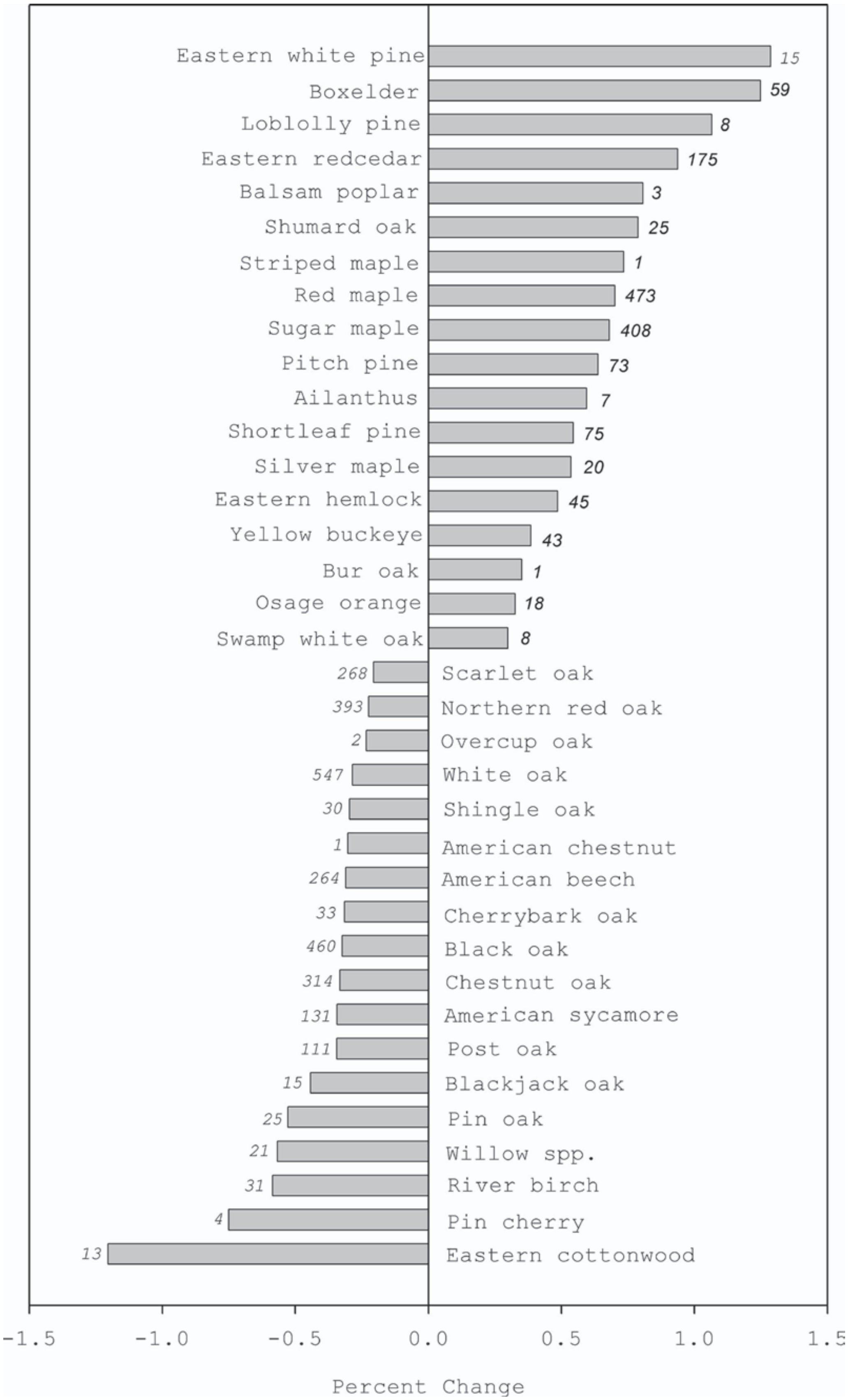

Figure 1.—Average annual change in relative stocking (percent change year^{-1}) of the 18 largest increasing and decreasing forest tree species in Kentucky from 1988-2004. Number of independent plots used in the analysis are in parentheses.

five species of oak, while long-term increases in relative stocking were calculated for four maple species. Species such as pitch, Virginia, and shortleaf pine exhibited short-term increases (Fig. 2). In contrast, species such as white oak, chestnut oak, southern red oak, sassafras (*Sassafras albidum* (Nutt.) Nees), and yellow-poplar have experienced short-term declines in relative stocking.

Species	1975 - 1988	1988 - 2004
American beech Scarlet oak Northern red oak Post oak Black oak Black walnut Chinkapin oak Dogwood Eastern redbud Elm spp. Sweetgum	↓	↓
Pitch pine Black locust Blackgum Hackberry Hickory spp. Shortleaf pine Virginia pine	↓	↑
Sycamore White oak Chestnut oak American basswood Sassafras Southern red oak Yellow poplar	↑	↓
Eastern redcedar Boxelder Red maple Silver maple Sugar maple Yellow buckeye Black cherry Green ash Sourwood White ash	↑	↑

Figure 2.—Direction of average annual change in relative stocking of some common forest tree species for the periods of 1975-1988 and 1988-2004 in Kentucky.

DISCUSSION

The results support the generally accepted notion that the eastern deciduous landscape continues to experience oak replacement by more generalist species such as red maple. Of the tree species that experienced gains in relative stocking between 1988 and 2004, five of the top 13 species that increased in relative stocking were of the *Acer* genus. Three of the five were recorded in considerably more plots in 1988 than in 2004, particularly red maple. Concomitantly, the stocking of numerous oak species decreased across the state. Eleven of the 18 species that declined the greatest in relative stocking were oak species. Five of the oak species (black, northern red, white, chestnut, and scarlet) were observed on 50+ fewer plots in 2004 than in 1988. White oak, northern red oak, and black oak were observed on 100+ fewer plots, indicating significant and widespread decreases in the stocking of numerous oak species.

These trends were reported 10 years ago by Gansner and others (1996). Maples continue to gain while oaks lose ground with respect to relative stocking. The most common species of oak are decreasing in relative stocking at a pace of approximately 0.29 percent year^{-1} and the maples are gaining ground at a pace of 0.11 percent year^{-1}. These rates indicate that some of the most common oak species are being replaced by maples and other species. In fact, a few oak species (bur (*Q. macrocarpa* Michx.), Shumard (*Q. shumardii* Buckl.), and swamp white (*Q. bicolor* Willd.)) had observed gains between 1988 and 2004 along with multiple pine species, eastern hemlock, and the invasive tree-of-heaven.

While some species appeared to have large gains or losses in stocking, (e.g., eastern cottonwood, eastern white pine and loblolly pine) the relatively low number of plots that the species was recorded on must be accounted for and could inflate AAC values. However, the importance of information regarding relatively rare species within a given geographic area is considerable. That is, it is extremely important to know when the presence of a species within a given area drops below the ability for a particular inventory to capture it. For example, in the remeasured plots used in this study American chestnut (*Castanea dentata* (Marsh.) Borkh.) was recorded on one plot in 1988 and not recorded in 2004. On the other hand, while the invasive tree-of-heaven was found on only six plots in 2004 it was recorded on only two plots in 1988, an increase of 200 percent. The implication is that data from large-scale inventories can be used not only to recognize when a species becomes incredibly rare, but also to track increased stocking of nonnative invasive trees.

CONCLUSION

It appears that many early succesional species and advance reproduction-dependent intermediate shade-tolerant species are declining in relative stocking. Concomitantly, many shade-tolerant species and advance reproduction-independent species continue to increase in relative stocking, suggesting general changes in disturbance patterns and an aging forest resource.

ACKNOWLEDGMENTS

The authors would like to thank the many U.S. Forest Service and Kentucky Division of Forestry employees responsible for collecting the data. We would also like to thank the Information Management section of the FIA program for data compilation and processing. This research was funded by the U.S. Forest Service Forest Inventory and Analysis program.

LITERATURE CITED

Arner, Stanford L.; Woudenberg, S.; Waters, S.; Vissage, J.; MacLean, C.; Thompson, M.; Hansen, M. 2001. **National algorithms for determining stocking class, stand size class, and forest type for forest inventory and analysis plots.** Accessed from the FIA Statistics Band Website (http://srsfia2.fs.fed.us/publicweb/statistics_band/stat_documents.htm)

Avery, Thomas E.; Burkhart, Harold E. 1994. **Forest measurements.** Fourth edition. New York, NY: McGraw Hill. 408 p.

Fei, Songlin; Steiner, Kim C.; Finley, James C. 2007. **Stocking equations for regeneration in mixed oak stands.** In: Buckley, David S.; Clatterbuck, Wayne K., eds. Proceedings, 15th central hardwood forest conference. e-Gen. Tech. Rep. SRS-101. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 55-59.

Gansner, David A.; King Susan L.; Arner, Stanford L.; Widmann, Richard H.; Drake, David A. 1995. **Spatial trends in relative stocking point to potential problems in forest health.** In: Gottschalk, Kurt W.; Fosbroke, Sandra L.C., eds. Proceedings of the 10th central hardwood forest conference; Morgantown, WV. Gen. Tech. Rep. NE-197. Radnor, PA: U. S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 1-7.

Gansner , David A.; King Susan L.; Arner, Stanford L.; Drake, David A. 1996. **Mapping shifts in relative stocking of tree species.** Northern Journal of Applied Forestry. 13(2): 92-95.

Ginrich, Samuel F. 1967. **Measuring and evaluating stocking and stand density in upland hardwood forests in the central states.** Forest Science. 13(1): 38-53.

Smith, W. Brad; Miles, Patrick D.; Vissage, John S.; Pugh, Scott A. 2004. **Forest resources of the United States, 2002.** Gen. Tech. Rep. NC-241. St. Paul, MN: U.S. Deptartment of Agriculture, Forest Service, North Central Research Station. 146 p.

Turner, Jeffery A.; Oswalt, C.; Chamberlain, J.; Conner, R.; Johnson, T.; Oswalt, S.; Randolph, K. In press. **Forest resources of Kentucky, 2004.** Resour. Bull. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.