Use of Damage Surveys and Field Inventories to Evaluate Oak and Sugar Maple Health in the Northern United States

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Abstract: *Oak species (Quercus spp.) and sugar maple (Acer saccharum) are substantial components of the forest ecosystems in the 24-state region spanning the northern U.S. During recent decades, both damage surveys and forest inventories have documented declines of sugar maple and oak health. In order to more fully assess the status of oak and sugar maple health, we examined correlations between damage detected by aerial survey data, a soil dryness index, and field-based forest conditions. Study results indicated that aerial damage surveys were correlated with an overstory attribute: percent standing dead basal area. Additionally, we present a state-level analysis as an example of how this study could be replicated for inclusion in a Forest Inventory and Analysis state report.*

Keywords: FIA, forest health, aerial damage surveys, oak decline, sugar maple decline, *Acer saccharum*, *Quercus* spp.

Introduction

Oak species (*Quercus* spp.) and sugar maple (*Acer saccharum*) are substantial components of the forest ecosystems in the 24-state region spanning the northern U.S. During recent decades, both forest inventories and aerial damage surveys have documented declines in sugar maple and oak health.

It has been suggested that North America's oak forests may be in an extended period of poor growth and susceptibility to invasive pests and droughts (Kessler 1992), a situation that has been a national forest health problem since 1960 (Thomas and Boza 1984). Oak decline results from the interaction of predisposing stress factors (defoliating insects, drought, frost/ice damage, poor

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site quality, and advanced tree age) and secondary disease and insect pests (root fungi, canker fungi, and insect borers) (Lawrence et al. 2002, Manion 1991, Starkey and Oak 1989). These many stresses eventually weaken oak trees, resulting in sparse foliage, thin crowns, crown dieback, reduced radial growth, and eventually death (Lawrence et al. 2002). Oak decline has been observed throughout most of the range of oak in the eastern United States, but has been most problematic in midwestern states (e.g., Missouri: Dwyer et al. 1995). Because oak decline is a complex etiological combination of predisposing, inciting, and contributing factors (Manion 1991, Oak et al. 1996), there is need for baseline data, long-term studies, and new analytical procedures (Kessler 1989, Nebeker et al. 1992, Oak et al. 1996).

Similarly, numerous reports of sugar maple decline or dieback have been recorded over the last 50 years. Sugar maple decline has been associated with insect defoliation, drought, unbalanced soil nutrition (particularly a lack of calcium, magnesium, and potassium), stand density, and midwinter thaw/freeze events (Horsley et al. 2000, Houston 1999, Long et al. 1997). Sugar maple trees in decline are characterized by a slow loss of crown vigor, dieback of fine twigs, and reduced radial increment over a period of years, often ending in death (Horsley et al. 2002). Houston (1999) found that crown dieback and death result when at least one predisposing stress event reduces resistance to invasion by opportunistic, secondary organisms that kill tissues. Episodes of sugar maple decline have been observed across the northern U.S.: Wisconsin in the 1950s, Massachusetts in the 1960s, New York and Vermont in the 1980s, and Pennsylvania in the 1980s and 1990s (Horsley et al. 2002).

Two inciting factors that have been attributed to oak and sugar maple decline are insect defoliation and drought. At least one past study integrated forest inventory data with aerial damage survey data to assess tree health (Morin et al. 2004) but never at the landscape-level geographic scale. Likewise, previous studies have cited drought as a factor affecting sugar maple (Drohan et al. 2002, Horsley et al. 2000, Payette et al. 1996) and oak health (Dwyer et al. 1995, Starkey and Oak 1989, Stringer et al. 1989, Tainter et al. 1984) in localized areas.

The goal of this study was to compare aerial damage surveys and a soil dryness index with field inventories of sugar maple and oak forests in the 24-state region of the northern U.S. The study had four objectives: 1) to assess the current status of oak and sugar maple health across the study area, 2) to examine correlations between the number/frequency damages identified through aerial and ground surveys with the ratio of standing dead basal area of oak and sugar maple (based on forest inventories), 3) to examine correlations between soil dryness index and the ratio of standing dead basal area of oak and sugar maple (based on forest inventories), and 4) to suggest opportunities for supplementing Forest Inventory and Analysis (FIA) state and regional reports with forest health assessments using damage survey data.

Methods

Forest Inventory Data

The FIA program of the U.S. Department of Agriculture, Forest Service, the only congressionally mandated national inventory of U.S. forests, conducts a three-phase inventory of forest attributes of the country (Bechtold and Patterson 2005). The FIA sampling design is based on a tessellation of the United States into hexagons approximately 2,428 ha in size with at least one permanent plot established in each hexagon. In phase 1, the population of interest is stratified and plots are assigned to strata to increase the precision of estimates. In phase 2, tree and site attributes are measured for forested plots established in each hexagon. Phase 2 plots consist of four 24-ft fixed-radius subplots on which standing trees are inventoried.

For assessment of current forest attributes, inventory data collected from 2002 to 2006 were used with a total of 16,689 inventory plots included in the oak analysis and inventory data collected from 2001 to 2006 were used with a total of 8,722 inventory plots included in the sugar maple analysis. This study's 24-state study region includes CT, DE, IL, IN, IA, KS, ME, MD, MA, MI, MN, MO, NE, NH, NJ, NY, ND, OH, PA, RI, SD, VT, WV, and WI. Plots were included in the analyses if at least three trees of the species of interest greater than 1-inch diameter at breast height (d.b.h.) were measured.

Aerial and Ground Survey Data

The national Forest Health Monitoring (FHM) program was initiated by the U.S. Forest Service in 1990 to monitor, assess, and report the status of and trends in forest health across the Nation. The survey component of FHM detection monitoring consists of aerial and ground surveys to detect damage in the form of tree defoliation, mortality, and damage as associated with the occurrence of damaging insects, diseases, windthrow, and other biotic and abiotic forest disturbances (Conkling et al. 2005).

Aerial surveys supply a landscape-level overview of forest health conditions at a relatively low cost (McConnell et al. 2000). Forest defoliation usually is documented by a remote-sensing technique known as sketch-mapping. A sketch-map is created while flying in an aircraft and observing damage and outlining its location on topographic maps. Sketch-mapping is an acquired and difficult skill that is somewhat subjective because human observers must rely on their judgment in identifying and delineating damaged areas.

All available aerial survey data for the 24-state region were acquired for 1997-2005. The aerial survey damage polygons were limited to include only types of damage that would be expected to affect oak and sugar maple growth and/or mortality; most of the recorded damages were from defoliators (gypsy moth, *Lymantria dispar* L., for oak and forest tent caterpillar, *Malacosoma disstria* Hubner, for sugar maple). Using a GIS, the FIA plots were overlayed with the aerial survey damage polygons to assign each plot with the number of times it received damage during the 9-year period.

Due to differing levels of effort and spending among states, the detail and quality of the survey data vary across the 24-state study area. Therefore, a subset of states deemed to have high quality survey data were selected for the study (Table 1). Pennsylvania was also chosen for an independent analysis as an example for FIA state reporting.

Table 1: List of states with high quality survey data.

Oak Analysis	Sugar Maple Analysis
Massachussetts	
Minnesota	Michigan
Missouri	Minnesota
New Hampshire	Missouri
New Jersey	New Hampshire
Pennsylvania	New York
Vermont	Vermont
West Virginia	

Soil Dryness Index

Patterns related to soil water content are often a primary factor related to tree stress and thus to insects and diseases (Elliott and Swank 1994, He and Richard 2000). The soil dryness index (DI), originally named the "natural soil wetness index" (Schaetzl 1986), is a measure of the long-term wetness of a soil. The DI concept was first initiated by Hole (1978) and Hole and Campbell (1985). It indicates the amount of water that a soil contains and makes available to plants under normal climatic conditions. The DI ranges from 0 to 99. The higher the DI, the more water the soil can supply to plants. Sites with a DI of 99 are, essentially, open water. A soil with a DI of 1 is thin and dry enough to be almost bare bedrock. This layer was obtained and intersected with the FIA plots (R. Schaetzl, 2007, pers. commun.). The DI values were binned into three categories (0-33, 34-66, 67-99) for analysis (Fig. 1).

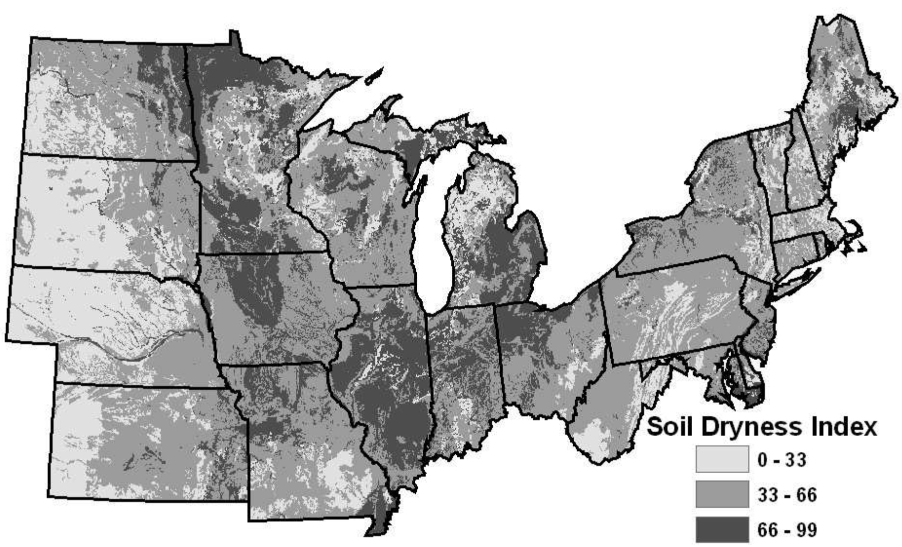

Figure 1: Map of soil dryness index.

Analysis

Spatially interpolated maps of host density and percent standing dead were produced on a 5-km by 5-km raster via a moving-window average of FIA plot values and were visually compared to the damage survey maps and soil dryness index map. One-way analysis of variance (ANOVA) was used to test the relationship of percent standing dead host material on number of damages and soil dryness index (PROC ANOVA, SAS Institute Inc. 2004). Additionally, a general linear model (PROC GLM, SAS Institute Inc. 2004) was employed to evaluate percent standing dead host material as a function of the number of damages, the soil dryness index, and the interaction between the two. Visual inspections and statistical analyses were conducted for the high quality damage survey states and for Pennsylvania separately.

Results

Oak

Oak is a critical component in forest ecosystems across the study area (Fig. 2 and Table 2). Mortality events, many presumably attributed to oak decline, over the past two decades (Lawrence et al. 2002, Manion 1991, Starkey and Oak., 1989) have led to pockets of elevated levels of standing dead oak biomass (Fig. 3 and Table 2). Based on visual inspection there appears to be some general coincidence of areas with elevated standing dead oak (Fig. 3) and recorded damage (Fig. 4); this is especially evident in Missouri, New Jersey, Pennsylvania, West Virginia, and Wisconsin.

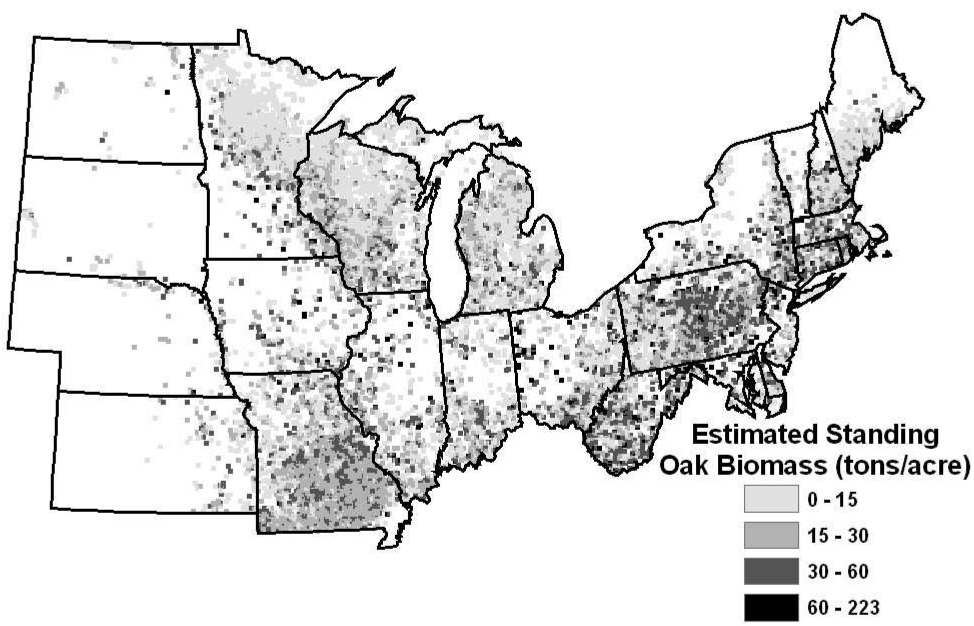

Figure 2: Map of estimated oak biomass across the 24-state study area (FIA data from 2002 to 2006).

Table 2: Mean and standard error (SE) of oak biomass and percent standing dead oak biomass by state

State	N	Oak Biomass (tons/acre)	SE (%)	Percent Standing Dead Oak Biomass	SE (%)
Delaware	47	19.9	3.572	7.2	2.190
Missouri	3189	23.7	0.304	3.8	0.165
Wisconsin	2932	15.4	0.316	3.4	0.207
Rhode Island	55	27.7	3.308	3.2	1.191
Maryland	98	25.2	2.583	3.0	0.997
Illinois	660	21.5	0.794	3.0	0.400
Connecticut	113	31.1	2.253	2.7	0.748
Iowa	295	20.7	1.057	2.6	0.648
Michigan	2187	15.6	0.383	2.2	0.179
Pennsylvania	1805	28.4	0.613	2.2	0.208
Kansas	154	15.5	1.162	2.0	0.730
Indiana	622	19.3	0.805	1.8	0.357
Minnesota	1663	12.7	0.398	1.8	0.194
New Jersey	84	26.2	2.865	1.7	0.789
New Hampshire	242	18.7	1.617	1.6	0.465
Massachussetts	178	26.5	1.774	1.6	0.410
West Virginia	502	29.9	1.136	1.6	0.280
Maine	444	11.8	0.691	1.4	0.335
Ohio	675	22.5	1.023	1.0	0.197
New York	536	23.0	1.104	0.9	0.226
Vermont	42	17.1	2.441	0.8	0.448
Nebraska	65	20.1	1.944	0.0	0.000
North Dakota	60	15.2	1.764	0.0	0.000
South Dakota	41	14.1	2.401	0.0	0.000

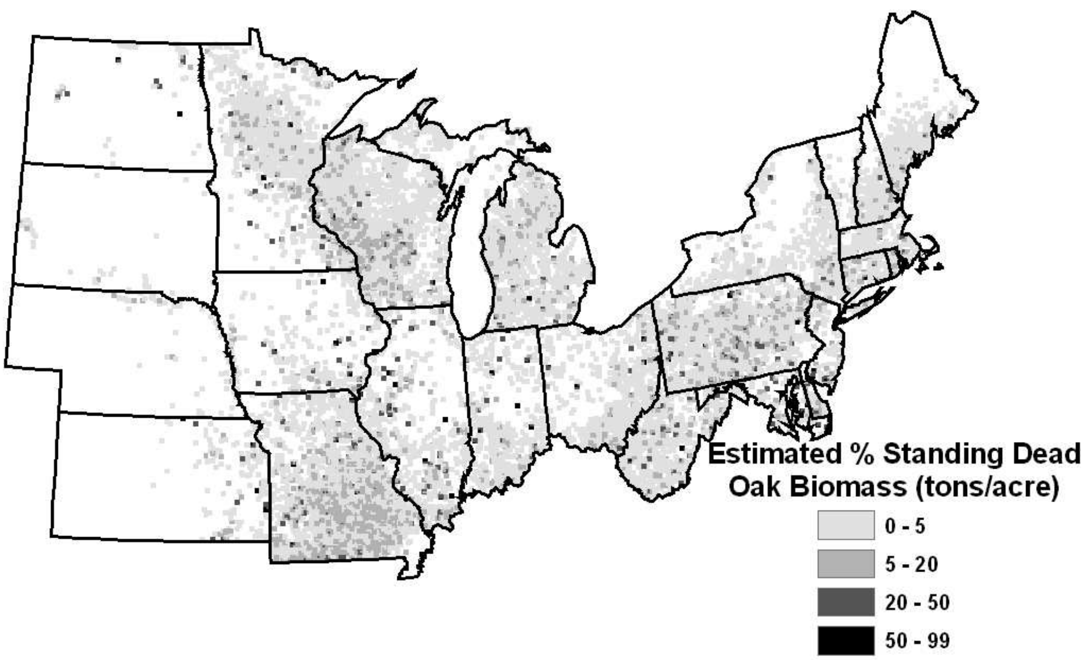

Figure 3: Map of estimated percent standing dead oak biomass across the 24-state study area (FIA data from 2002 to 2006).

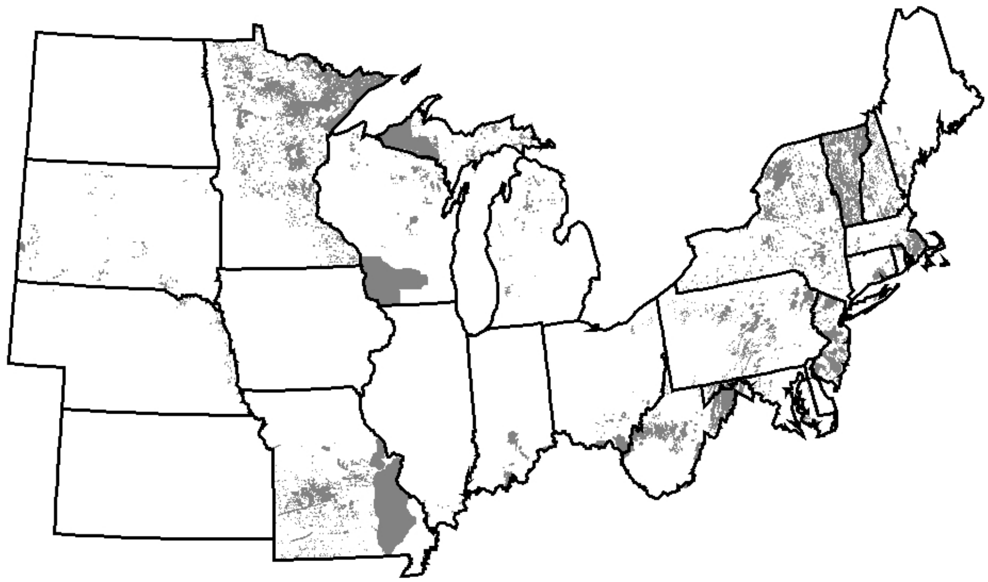

Figure 4: Map of damages expected to affect oak across the 24-state study area (survey data from 1997 to 2005).

One-way ANOVA models between percent standing dead oak biomass and years of damage (p=0.0001; Fig. 5) and between percent standing dead oak biomass and DI category (p=0.0001; Fig. 6) were statistically significant and linear in nature. Additionally, in a general linear model, years of damage (p=0.0025) and DI (p=0.0016) were significant independent predictors of percent standing dead oak biomass; the interaction between the two was not significant.

Figure 5: Percent standing dead oak biomass against years of damage across the 24-state study area.

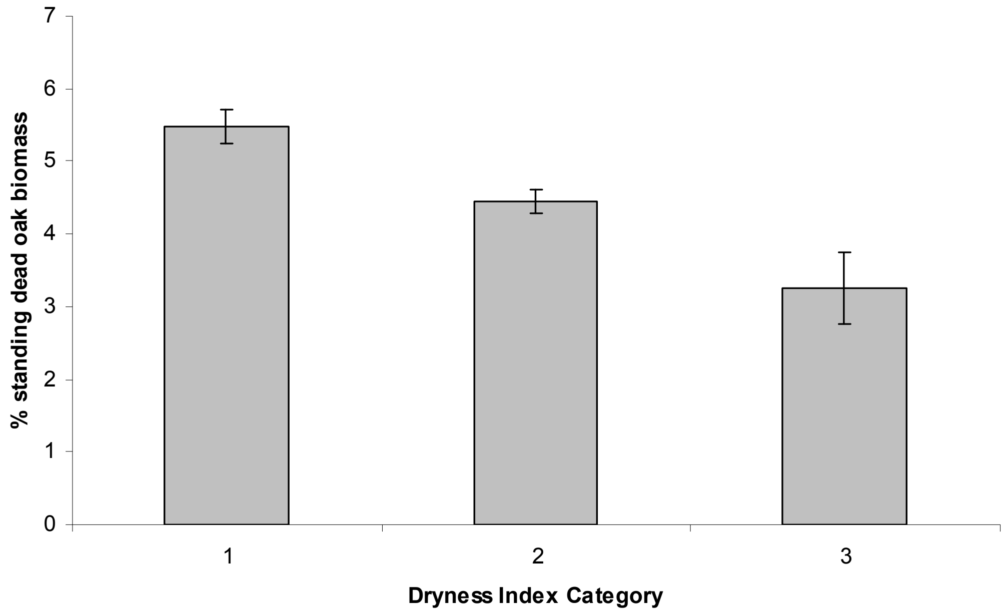

Figure 6: Percent standing dead oak biomass against dryness index category across the 24-state study area.

Sugar Maple

Sugar maple is a vital species in the forests across the study area (Fig. 7 and Table 2). Areas of elevated levels of standing dead sugar maple basal area (Fig. 8 and Table 2) are evident. Much of this mortality over the past five decades is seemingly related to sugar maple decline (Horsley et al. 2002). A visual inspection reveals a general coincidence of areas with elevated standing dead sugar maple (Fig. 8) and recorded damage (Fig. 9); this is especially evident in New York, Vermont, New Hampshire, and Massachusetts.

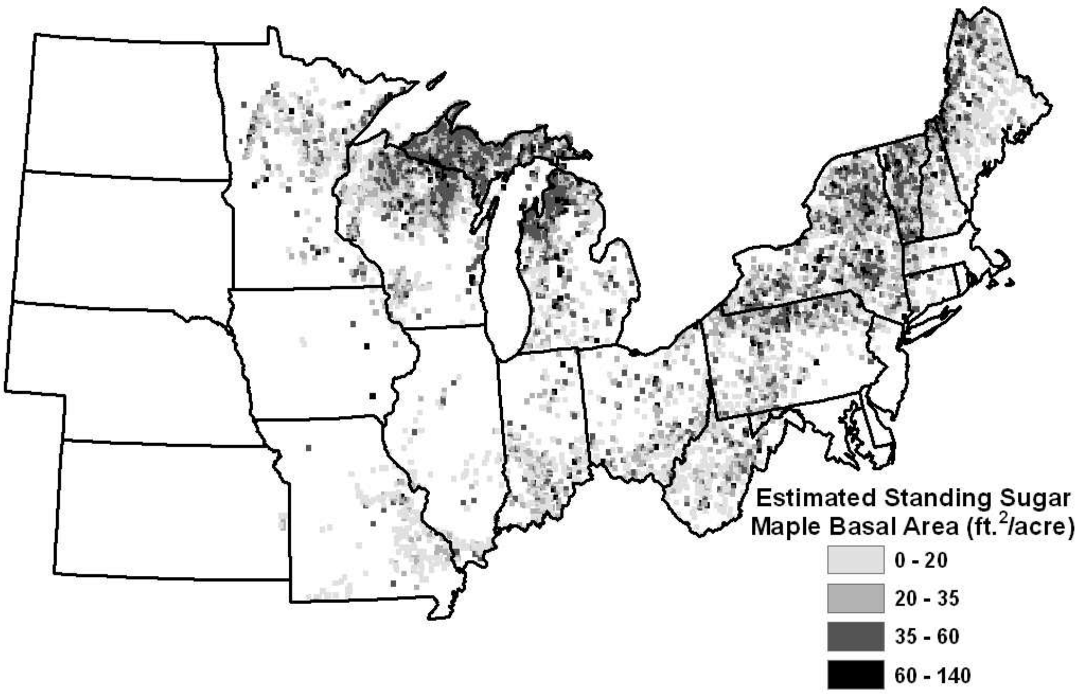

Figure 7: Map of estimated sugar maple basal area across the 24-state study area (FIA data from 2002 to 2006).

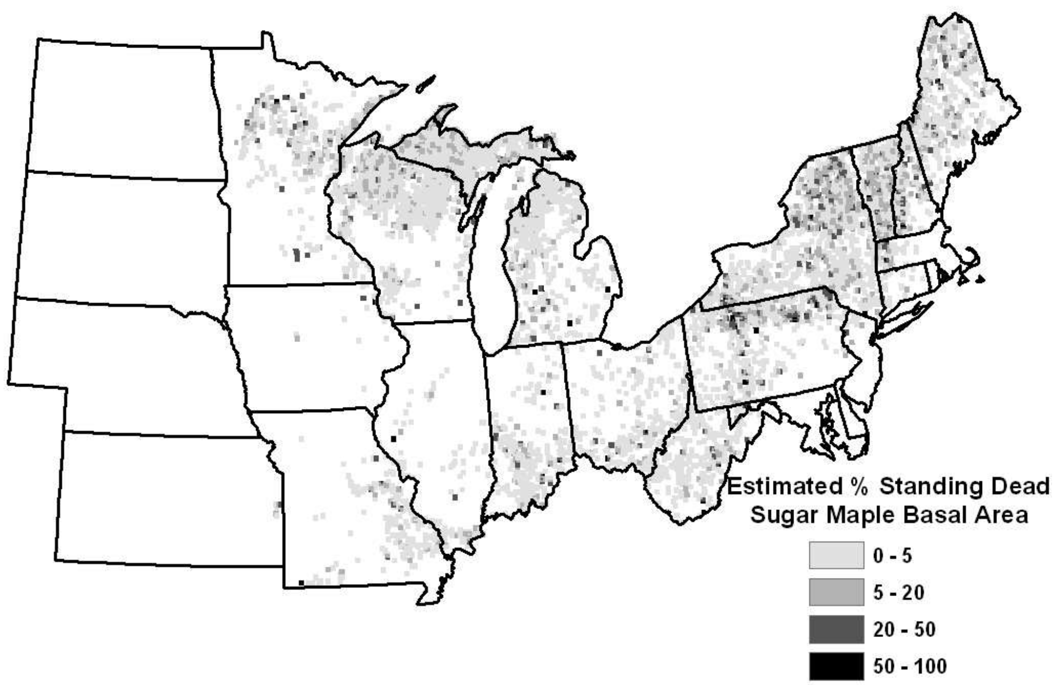

Figure 8: Map of estimated percent standing dead sugar maple basal area across the 24-state study area (FIA data from 2002 to 2006).

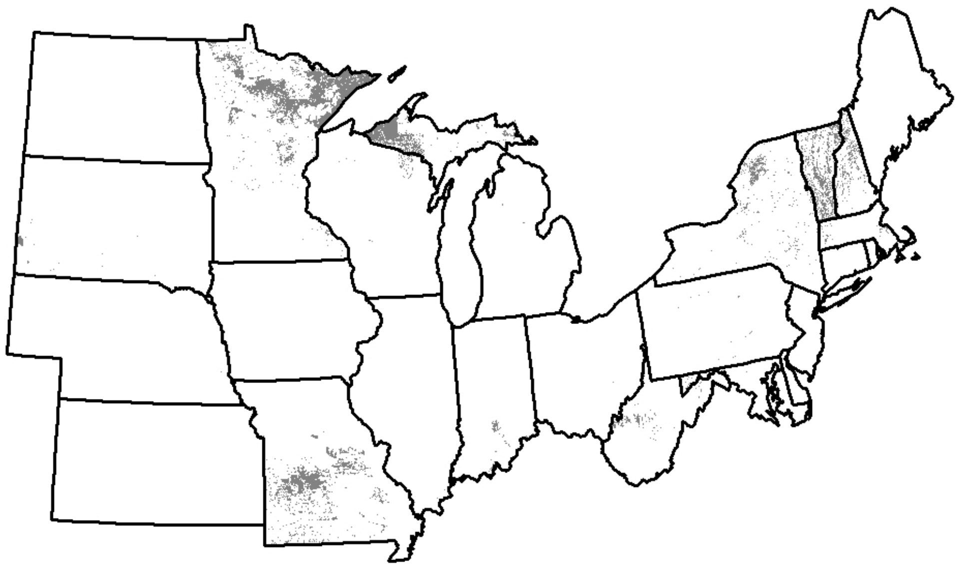

Figure 9: Map of damages expected to affect sugar maple across the 24-state study area (survey data from 1997 to 2005).

A one-way ANOVA model between percent standing dead sugar maple basal area and years of damage (p=0.0019; Fig. 10) was statistically significant and linear. A one-way ANOVA between percent standing dead sugar maple basal area and DI category (p=0.0007; Fig. 11) was also statistically significant although the relationship was not linear. In a general linear model, years of damage (p=0.0006) was a significant independent predictor of percent standing dead sugar maple basal area; DI and the interaction between years of damage and DI were not significant.

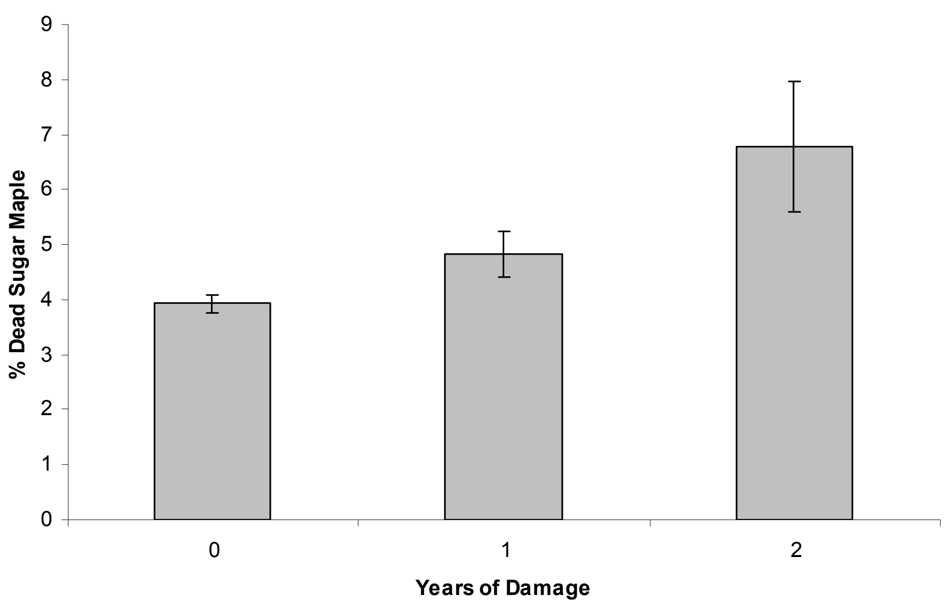

Figure 10: Percent standing dead sugar maple basal area against years of damage across the 24-state study area.

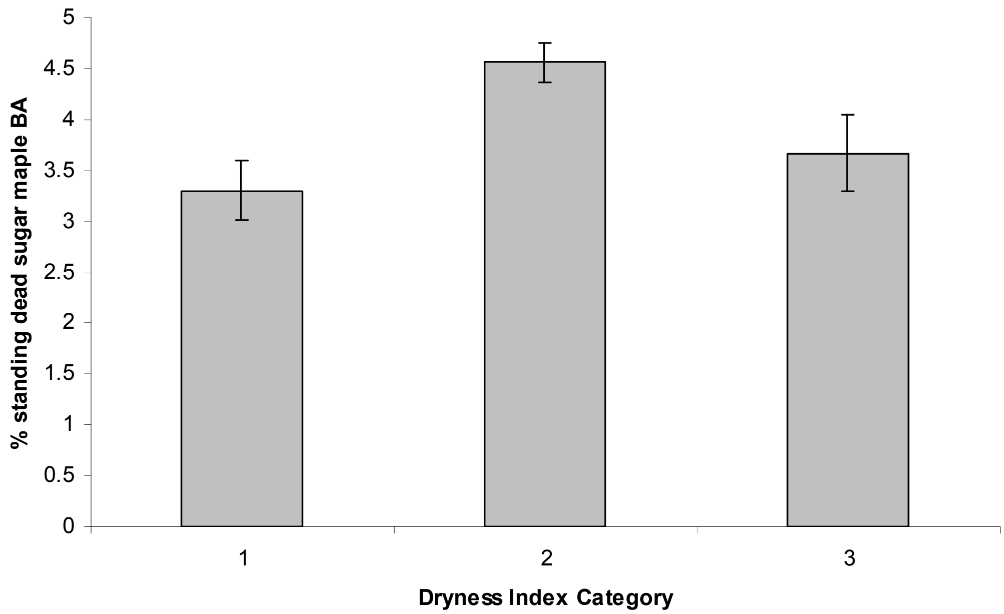

Figure 11: Percent standing dead sugar maple basal area against dryness index category across the 24-state study area.

Pennsylvania – An Example of an Analysis for an FIA State Report

Oak is the most abundant genus in Pennsylvania and is very important from an ecological and economic standpoint. Elevated levels of standing dead oak biomass (Fig. 12) exist in specific areas across the state. There appears to be some general coincidence between these areas and recorded damage (Fig. 13). A one-way ANOVA model between percent standing dead oak biomass and years of damage (p=0.0001; Fig. 14) was statistically significant and linear. A one-way ANOVA between percent standing dead oak biomass and DI category (p=0.0007; Fig. 15) was also statistically significant although the relationship was not linear. In a general linear model, years of damage (p=0.0136) and DI category (p=0.0026) were significant independent predictors of percent standing dead oak biomass; the interaction between years of damage and DI was not significant.

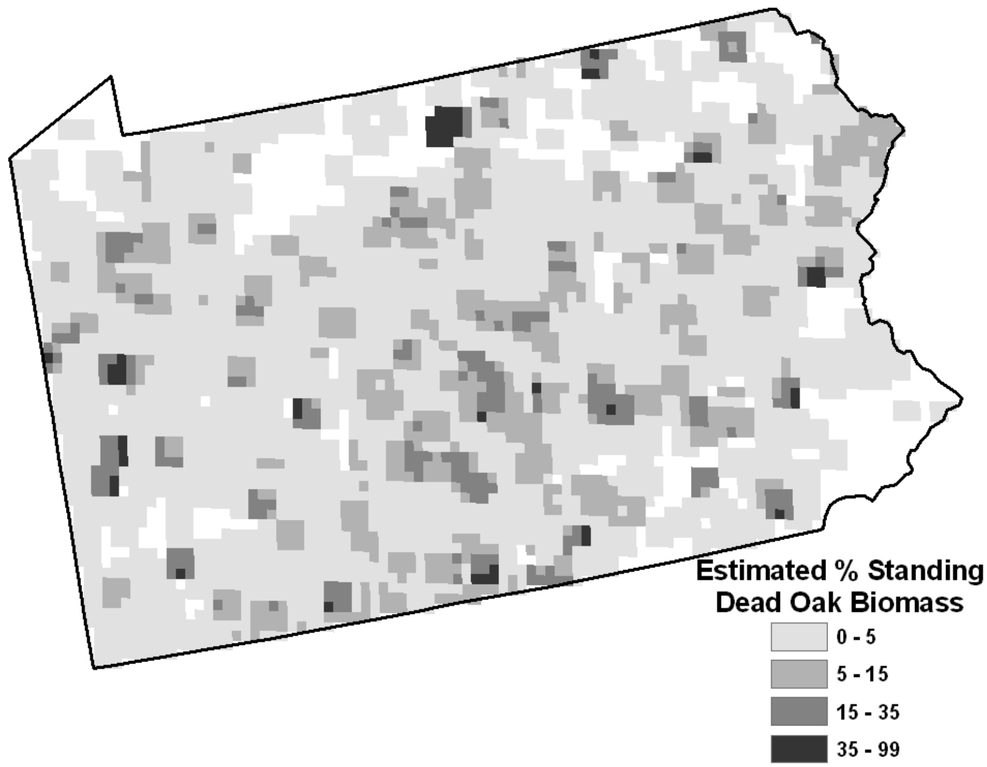

Figure 12: Map of estimated percent standing dead sugar maple basal area in Pennsylvania (FIA data from 2002 to 2006).

Figure 13: Map of damages expected to affect oak in Pennsylvania (survey data from 1997 to 2005).

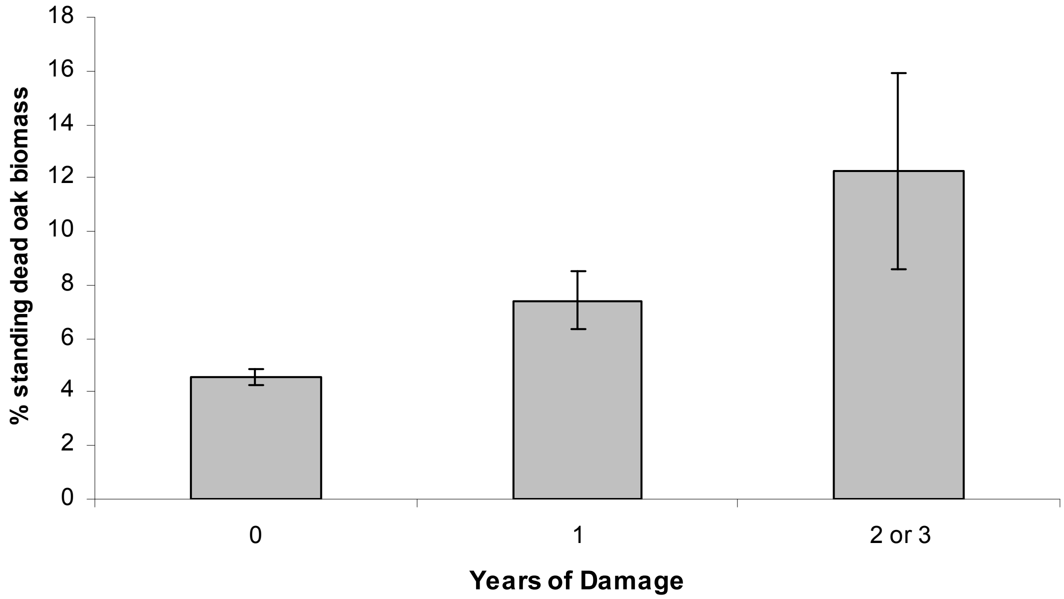

Figure 14: Percent standing dead oak biomass against years of damage in Pennsylvania.

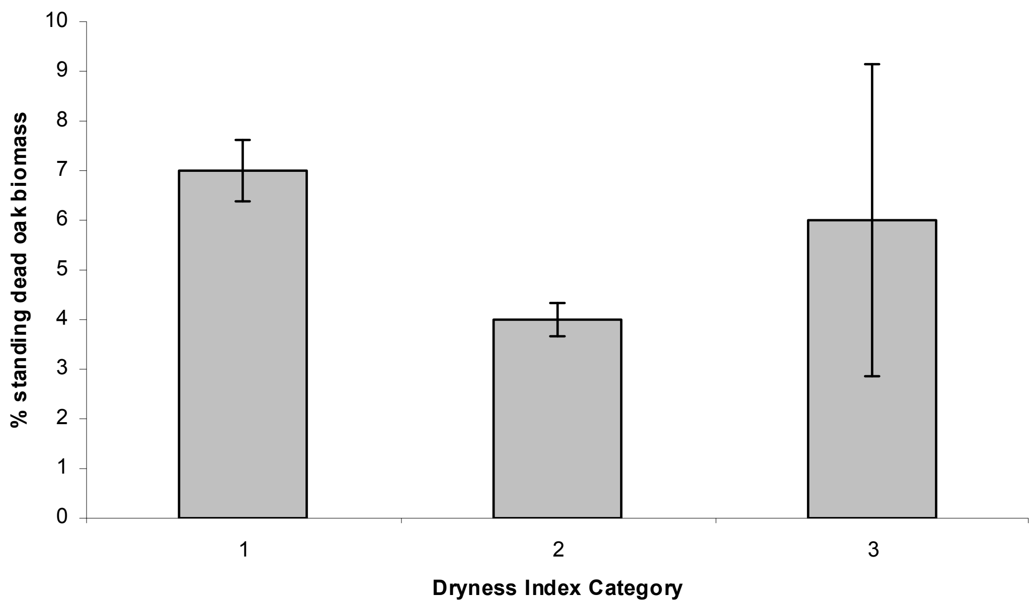

Figure 15: Percent standing dead oak biomass against dryness index category in Pennsylvania.

Discussion and Future Direction

Many FIA national, regional, and state reports include maps of various characteristics of the forest resource. Maps of mortality and/or standing dead trees are often presented with little more than anecdotal evidence to support spatial patterns. The spatial data used in this study provide an opportunity to relate levels of mortality or standing dead to potential causal factors. Quantification of these relationships is valuable from a land management perspective because it will allow managers to predict the impact of defoliation and/or significant drought events on important forest species. The potential is there for FIA analysts to use the damage survey datasets as an ancillary source for resource analysis, but caution is recommended due to the inconsistency of data collection between states.

Future work is underway to expand the scope of this study to include FIA phase 3 variables including crown dieback, crown density, and soil chemistry measures. Adding the crown measures as dependent variables will provide further insight into the relationship among tree health, damage, and soil dryness. Furthermore, soil nutrition has been cited as an important factor in sugar maple decline (Horsley et al. 2000, Long et al. 1997). Measures of available calcium and magnesium in soil samples from phase 3 plots will be related to sugar maple crown health and percent standing dead basal area. Although the soil dryness index provided a measure of drought potential, it did not account for actual levels of precipitation. Therefore, precipitation is another important factor that we plan to add to future analyses. Finally, we plan to compare spatial patterns of standing dead and/or mortality from FIA plots to areas of predicted mortality highlighted by the U.S. Forest Service's Forest Health Protection national risk map (Krist et al. 2007).

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Literature Cited

Bechtold, W.A.; Patterson, P.L., eds. 2005. Forest Inventory and Analysis National Sample Design and Estimation Procedures. Gen. Tech. Rep. SRS-GTR-80. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 85 p.

Conkling, B.L.; Coulston, J.W.; Ambrose, M.J. eds. 2005. Forest health monitoring: 2001 national technical report. Gen. Tech. Rep. SRS-81. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 204 p.

Drohan, P.J.; Stout, S.L.; Petersen, G.W. 2002. Sugar maple (*Acer saccharum* Marsh.) decline during 1979-1989 in northern Pennsylvania. Forest Ecology and Management. 170(1): 1-17.

Dwyer, J.P.; Cutter, B.E.; Wetteroff, J.J. 1995. A dendrochronological study of black and scarlet oak decline in the Missouri Ozarks. Forest Ecology and Management. 75: 69-75.

Elliott, K.J.; Swank, W.T. 1994. Impacts of drought on tree mortality and growth in a mixed hardwood forest. Journal of Vegetation Science. 5(2): 229-236.

He, F.; Richard, D.P. 2000. Density-dependent effects on tree survival in an old growth Douglas fir forest. Journal of Ecology. 88(4): 676-688.

Hole, F.D. 1978. An approach to landscape analysis with emphasis on soils. Geoderma. 21: 1-13.

Hole, F.D.; Campbell, J.B. 1985. Soil landscape analysis. Totowa, NJ: Rowman and Allanheld. 196 p.

Horsley, S.B.; Long, R.P.; Bailey, S.W.; [et al.]. 2000. Factors associated with the decline disease of sugar maple on the Allegheny plateau. Canadian Journal of Forest Research. 30(9): 1-14.

Horsley, S. B.; Long, R. P.; Bailey, S. W.; [et al.]. 2002. Health of eastern north American sugar maple forests and factors affecting decline. Northern Journal of Applied Forestry. 19(1): 34-44.

Houston, D. R. 1999. History of sugar maple decline. In: Horsley, S.B.; Long, R.P., eds. Sugar maple ecology and health: Proc. international symposium; 1998 June 2-4; Warren, PA. Gen. Tech. Rep. GTR-NE-261. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station: 19-26.

Kessler, K.J., Jr. 1989. Some perspectives on oak decline in the '80's'. In: Rink, G.; Budelsky, C. A., eds. Proc. 7th central hardwood conference; 1989 March 5-8; Carbondale, IL. Gen. Tech. Rep. NC-GTR 132. St. Paul, MN: U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station: 25-29.

Kessler, K. J., Jr. 1992. Oak decline on public lands in the Central Forest Region. Res. Note RN-NC-362. St. Paul, MN: U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station. 4 p.

Krist, F.J., Jr.; Sapio, F.J.; Tkacz, B.M. 2007. Mapping risk from forest insects and diseases. FHTET 2007-06. Fort Collins, CO: U.S.Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team. 115 p.

Lawrence, R.; Moltzan, B.; Moser, W.K. 2002. Oak decline and the future of Missouri's forests. Missouri Conservationist. 63: 11-18.

Long, R.P.; Horsley, S.B.; Lilja, P.R. 1997. Impact of forest liming on growth and crown vigor of sugar maple and associated hardwoods. Canadian Journal of Forest Research. 27: 1560-1573.

Manion, P. D. 1991. Tree disease concepts, 2nd ed. Upper Saddle River, NJ: Prentice Hall Career & Technology. 416 p.

McConnell, T.J.; Johnson, E.W.; Burns, B. 2000. A guide to conducting aerial sketchmapping surveys. FHTET 00-01. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team. 88 p.

Morin, R.S., Jr.; Liebhold, A.M.; Gottschalk, K.W. 2004. Area-wide analysis of hardwood defoliator effects on tree conditions in the Allegheny plateau. Northern Journal of Applied Forestry. 21(1): 31-39.

Nebeker, T.E.; Ammon, V.D.; Boyle, C.R.; [et al.]. 1992. Oak decline: a comparison of study results from different areas of the south. Tech. Bull. 183. Mississippi State, MS: Mississippi Agricultural and Forestry Experiment Station. 19 p.

Oak. S.; Tainter, F.; Williams, J.; Starkey, D. 1996. Oak decline risk rating for the southeastern United States. Annals of Forest Science. 53: 721-730.

Payette, S.; Fortin, M.J.; Morneau, C. 1996. The recent sugar maple decline in southern Quebec: probable causes deduced from tree rings. Canadian Journal of Forest Research. 26: 1069-1078.

SAS Institute Inc. 2004. SAS OnlineDoc® 9.1.2**.** Cary, NC: SAS Institute.

Schaetzl, R.J. 1986. A soilscape analysis of contrasting glacial terrains in Wisconsin. Annals of the Association of American Geographers. 76: 414-25.

Starkey, D.A.; Oak, S.W. 1989. Site factors and stand conditions associated with oak decline in southern upland hardwood forests. In: Rink, G.; Budelsky, C.A., eds. Proc. 7th central hardwood conference; 1989 March 5-8; Carbondale, IL. Gen. Tech. Rep. NC-GTR 132. St. Paul, MN: U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station: 95-102.

Stringer, J.W.; Kimmerer, T.W.; Overstreet, J.C.; [et al.]. 1989. Oak mortality in eastern Kentucky. Southern Journal of Applied Forestry. 13: 86-91.

Tainter, F.H.; Fraedrich, S.W.; Benson, D.M. 1984. The effect of climate on growth, decline, and death of northern red oaks in the western North Carolina Nantahala Mountains. Castanea. 49(3): 127-137.

Thomas, W.D.; Boza, C.A. 1984. The oak decline complex. Journal of Arboriculture. 10: 170-177.