Relationships Between the Attributes of Standing Live and Dead Down Trees in Forests of the Lake States

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Abstract.—Refining the understanding of the relationship between a stand's standing live and down dead trees in terms of size, density, and biomass attributes may aid efforts to predict fuel loadings based on standing tree attributes. Therefore, the objective of this study was to compare down dead and standing live tree attributes (size, density, and biomass) for inventory plots and identify any possible relationships. Study results indicate no relationship between down woody material biomass and trees per ha, stand basal area, or a stand mean diameter. There appears to be a defined limit, however, to maximum observed down woody biomass in relation to stand density attributes (basal area and trees per ha). This study suggests that down woody accumulation dynamics result from sudden stand-level disturbances (e.g., blowdowns) and infrequent mortality from gradual stand development obscures and complicates attempts to broadly summarize relationships between a stand's standing live and down dead attributes in forests of the Lake States.

Fuel Prediction

Following the fire season of 2000 in the United States, forest fuel loadings were identified as a knowledge gap in both strategic-scale fire hazard management efforts and small-scale fire incident management activities. Consequently, tremendous effort has been expended to estimate fuel loadings across the United States. Unfortunately, fuel loadings are sampled in most forests only at very low sample intensities. This fact, in combination with the heterogeneous spatial distribution of fuels, results in a relatively insufficient fuel loading dataset with which to estimate fuels at small scales across the Nation. Therefore, efforts have been focused on developing methodologies to predict the fuel loadings for any forest location based on nonfuel attributes such as remotely sensed canopy cover information, digital elevation models, climate data, and standing live tree attributes. Biophysical gradient models (LANDFIRE; www.landfire.gov) (Rollins *et al.* 2004) have enabled the prediction of fuels at finer resolutions; however, the variance associated with these fine-scale estimates may be rather large.

Despite the development of models to estimate relationships between down woody fuels and stand/site attributes, there remains a sizeable knowledge gap in fundamental relationships between down woody fuel loadings and basic stand attributes. How do down woody fuel loadings vary by stage of stand development? How do down woody fuels vary by levels of standing live tree density? How do fuels vary by standing live tree size/density relationships? The inclusion of more fundamental models of stand dynamics and fuel loadings may aid in the construction of sophisticated biophysical models. Therefore, the goal of this study was to refine understanding of the relationship between down woody fuel loadings and stand attributes in forests of the Lake States with specific objectives including (1) to correlate down woody fuel loadings with the number of live trees per acre, live basal area per acre, latitude, and live tree tons per acre, (2) to determine the relationship between the number of down dead and standing live trees per acre with respect to tree size class, and (3) to evaluate the relationship between the number of live trees per acre and total down woody fuel loadings in terms of outliers defining the relationship (99th percentile).

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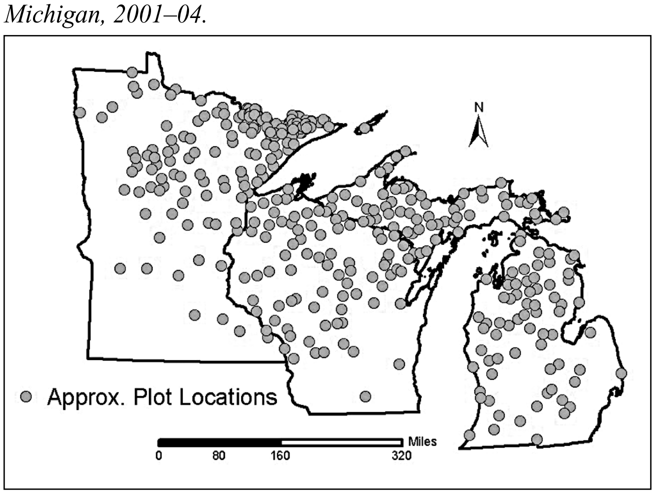
Data/Analysis

Standing tree and down woody fuel data were acquired from the Forest Inventory and Analysis program (FIA) of the U.S. Department of Agriculture Forest Service. The FIA program is responsible for inventorying the forests of the United States, including both standing trees and down woody materials on permanent sample plots established across the study area (Bechtold and Patterson 2005). In the FIA inventory, 378 plots were sampled in forests of the upper Great Lakes States (Minnesota, Wisconsin, and Michigan) from 2001 to 2004 (fig. 1). Both standing live and down dead woody materials attributes were measured on these inventory plots. For details on the establishment and sampling of standing trees by the FIA program, see Bechtold and Patterson (2005). Down woody material sampling methods on FIA plots are detailed by Woodall and Williams (2005). The largest fuels (more than 1,000-hr fuels), with a transect diameter greater than 3.0 in., were sampled on each of three 24-ft horizontal distance transects radiating from each FIA subplot center at 30, 150, and 270 degrees. Data collected for every more than 1,000-hr piece include transect diameter, length, small-end diameter, large-end diameter, decay class, and species. Fine woody debris (FWD) (1-, 10-, and 100-hr fuels) was sampled on the 150-degree transect on each subplot. Fine woody debris with transect diameters less than 0.25 in. and 0.25 in. to 1.00 in (1- and 10-hr, respectively) were tallied separately on a 6-ft slope-distance transect (14 ft to 20 ft on the 150-degree transect). Fine woody debris with transect diameters of 1.00 to 2.99 in (100-hr) were tallied on a 10-ft slope-distance transect (14 ft to 24 ft on the 150-degree transect) (for more information on fuel class definitions, see Deeming *et al.* 1977). Per unit area estimates (tons/acre) for the fuel hour classes followed Brown's (1974) estimation procedures (for further information see Woodall and Williams 2005). Total down woody fuels was a summation of both FWD and coarse woody debris (CWD). Logs per acre estimates were determined using DeVries (1986) estimation procedures.

Figure 1.—*Study plot locations in Minnesota, Wisconsin, and Michigan, 2001–04.*



Pearson's correlation coefficients and associated p-values were estimated between the following plot-level estimates: total woody fuels, live trees per acre, live basal area per acre, latitude, live tree tons per acre, and site index. The means and associated standard errors were estimated for the variables of number of live and down dead trees per acre by standing live tree mean diameter class. Finally, the relationship between the number of live trees per acre and total woody fuel loadings was evaluated by determining the 99th percentile of total woody fuels by live tree biomass classes (10 tons/acre class widths). The relationship between the 99th percentile of woody fuels and midpoint of the live tonnage class was modeled using a linear regression model: $\log_{10}$ (live tree tons) = $\log_{10}$ (total woody fuels).

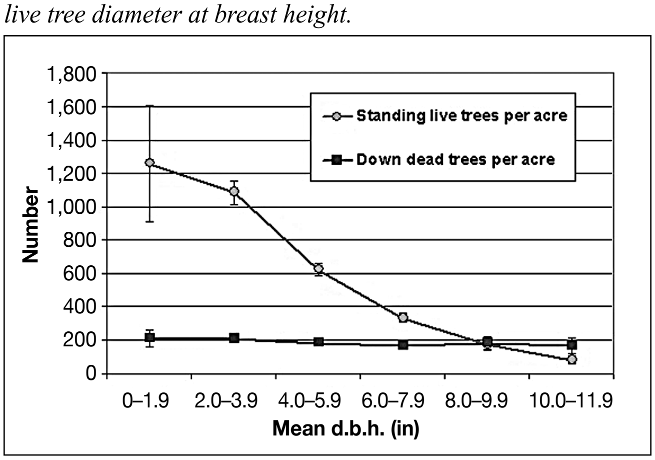
Stand and Site Correlations

Total woody fuels per acre were not strongly correlated with any stand or site attributes. Pearson's correlation coefficients between total fuels and stand/site attributes were live trees per acre -0.10 (p-value = 0.05), live tons/acre -0.08 (p-value = 0.14), live basal area -0.09 (p-value=0.08), site index 0.03 (p-value = 0.60), and latitude 0.08 (p-value = 0.13). These correlations weakly indicate that (1) forests with larger amounts of standing live biomass might have less down dead biomass, and (2) forests on higher quality sites and in higher latitudes with slower decay rates might have higher amounts of dead biomass. More definitive conclusions cannot be made, however, given the weak correlation coefficients and predominantly nonsignificant p-values.

Size/Density Relationships

Standing live trees often exhibit a strong relationship between the maximum number of trees that may occupy a unit area and the average size of those constituent trees (Reineke 1933, Long 1985). As individual trees grow in size, the total number of trees per unit area must decrease to accommodate the growing trees—a process known as self-thinning. The observations in this study exhibited an obvious self-thinning trend: as the mean diameter at breast height of stands increased, the mean number of trees per acre decreased (fig. 2). How does the mean number of CWD pieces per acre change as these stands experience mortality due to self-thinning? Results from this study indicate very little change in the number of CWD pieces per acre as stands progress through stand development (fig. 2). For Lake States forests, the decay rate of fallen trees and the mortality rate (or CWD input rate) may be in equilibrium when viewed in terms of number of trees and CWD pieces. If decay was slowed by colder temperatures, then one might expect more CWD pieces in stands in advanced stages of stand development due to CWD piece accumulation over time. We found this result when we looked at size/density relationships in Lake States forests above and below the 45.5 degree latitude. Given the nearly zero slope of the CWD pieces per acre by standing live tree size, size density relationships of standing live trees may not indicate dead and downed wood resources.

Figure 2.—*Number of trees/logs per acre by mean standing live tree diameter at breast height.*



Live Versus Dead Biomass

There appears to be no relationship between the number of standing live trees per acre and the total woody fuels in study stands (fig. 3). When examined by classes of standing live tree biomass (tons/acre), mean total woody fuels still shows no relationship with a stand's standing live tree density (table 1). There appears to be no practical way to predict total woody fuels based on the standing live tree density for Lake State forests. One relationship, however, is overlooked: the maximum potential amount of fuels appears to be determined by the amount of standing live biomass. When we compare total woody fuels to the number of live trees per acre, there appears to be an outer limit with the maximum amount of fuels negatively related to the number of standing live trees per acre (fig. 3). The 99th percentile of total woody fuels per acre decreases as classes of standing live biomass increase (table 1). A linear regression between the log of 99th percentile of fuels and the log of the midpoint of the standing live tree biomass class had an r-squared of 0.65 with an approximate slope of -1.0. This negative relationship may be viewed conceptually as driven by stand development processes (fig. 4). The left side of this relationship may be occupied by stands that have had recent disturbances that have reduced the amount of standing live tree biomass and greatly increased woody fuels. Conversely, logging or flood events might have reduced both the biomass of standing live and down dead biomass. The right side of this relationship

Figure 3.—*Total woody fuels (coarse and fine woody debris, tons/acre) by number of standing live trees per acre.*

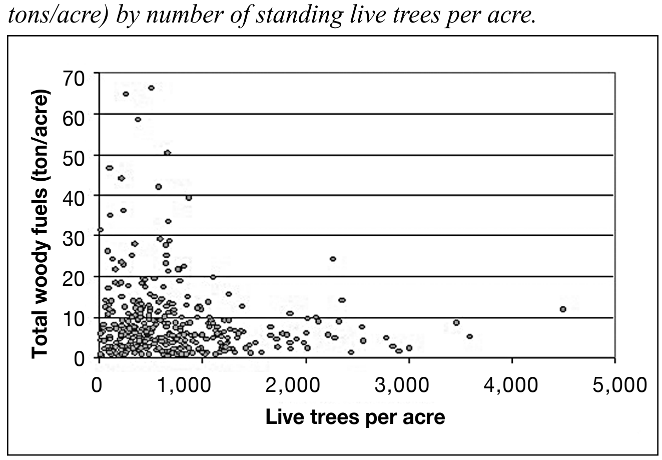
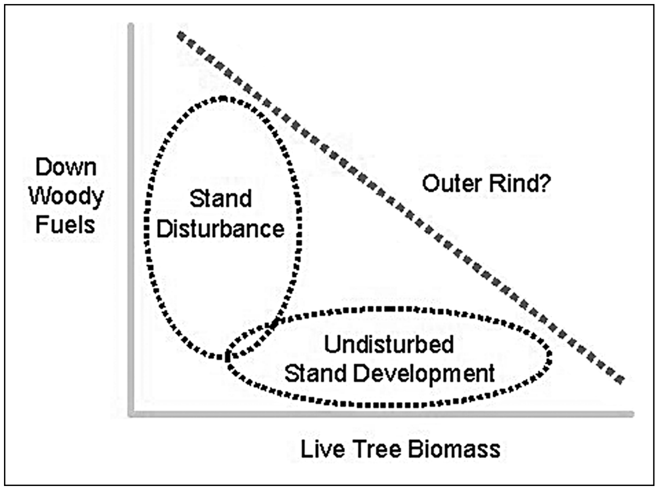


Table 1.—*Mean and 99th percentile of woody fuels (tons/acre) by classes of standing live tree biomass (tons/acre).*

Standing live tree biomass (tons/acre)	Total woody fuels (tons/acre)	
	Mean	99th Percentile
0.0–9.9	8.3	33.4
10.0–19.9	10.1	64.8
20.0–29.9	8.8	66.2
30.0–39.9	7.2	22.4
40.0–49.9	8.6	58.4
50.0–59.9	11.8	46.3
60.0–69.9	8.0	21.6
70.0–79.9	6.7	18.2
80.0–89.9	6.7	10.2
90.0–99.9	9.7	24.1
100.0–109.9	5.2	11.9
110.0–119.9	4.1	5.9

Figure 4.—*Theoretical relationship between standing live tree biomass and down dead fuels in forests of the Lake States.*



may be occupied by stands that have experienced very little disturbance mortality, but rather have density-induced mortality fuel input through stand development processes. These stands may demonstrate a balance between the decay and input of fuels through time as evidenced earlier in this study. Overall, the range in fuel loadings appears to decrease as the standing live tree density increases.

Conclusions

Relationships between standing live and down dead tree attributes in forests of the Lake States are often not statistically significant. Stand and site attributes, such as tree density and site quality, are not strong predictors of any stand's down and dead woody biomass at the stand level. Furthermore, the density of CWD pieces does not follow the same trajectory as the density of standing live trees as mean live tree size at the stand level increases. Despite the lack of live and dead/down tree relationships, standing live tree density may indicate maximum fuel loadings in Lake State forests. This study found a negative relationship between the 99th percentile of woody fuel biomass by classes of live tree biomass. Although the amount of fuels may not be estimated using live tree biomass as an independent variable, live tree biomass may indicate the range of possible fuel loadings—a range possibly driven by stand disturbance and development processes.

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