Extending and Intensifying the FIA Inventory of Down Forest Fuels: Boundary Waters Canoe Area and Pictured Rocks National Lakeshore

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Abstract.—The sampling design for the Forest Inventory and Analysis (FIA) program of the U.S. Department of Agriculture Forest Service allows intensification of fuel inventory sampling in areas of "special interest" and implementation of fuel sampling protocol by non-FIA personnel. The objective of this study is to evaluate the contribution of sampling intensification/extension toward furthering multiscale fire science investigations in two case study areas. In the Pictured Rocks National Lakeshore in Michigan, adoption of FIA's fuel sampling protocols increased inventory efficiencies while linking local fuel estimates to the system of FIA plots. In Minnesota's Boundary Waters Canoe Area, results indicate that 100- and 1,000-hr fuel loadings in wilderness blowdown areas may be twice those of the surrounding forest ecosystem. Both case studies illustrate the potential for the FIA program to provide estimates of fuels and facilitate local fire science initiatives and fuel inventories.

Introduction

The relative severity of recent fire seasons has highlighted the need for a more comprehensive forest fuels inventory across the forest ecosystems of the United States. The dispersal of fire risk mitigation efforts/funding is partially based on the amounts and condition of fuels at various locations. Unfortunately, the disparate efforts and sampling designs used to quantify down forest fuels across the United States has resulted in an inability to compare fuel loadings between forest regions. The down fuel sampling protocols of the U.S. Department of Agriculture (USDA) Forest Service's Forest Inventory and Analysis (FIA) program are applied in a systematic manner across forested regions of the United States, providing for the first standard national inventory (Woodall and Williams 2005). Beyond providing a "strategic-scale" fuels inventory, the sampling intensity of the FIA program's fuels inventory may be augmented to increase fuel estimation precision in areas of "local interest." Additionally, the fuels sampling protocol may be adopted by non-FIA entities so that their resulting fuels estimates may be directly comparable to those from the FIA program. The fuels inventory of the FIA program offers the ability to explore multiscale forest fuels issues through two initiatives described in this study: extension and intensification.

For this study, intensification is defined as increasing the sample intensity from a base Phase 3 intensity of one plot per 96,000 acres (Bechtold and Patterson, 2005). Besides the negative aspects of additional costs and logistics for field sampling and data management, numerous benefits of intensification exist. Intensification reduces the variance of fuel estimates by increasing sample sizes in areas of interest. Because intensification often increases the sample size in localized areas, estimates and analyses can now range in scale from regional to local, therefore increasing the number of analytical opportunities. With locally pertinent fuels data available, FIA can expand its user group through intensification. Because FIA's down woody materials (DWM) inventory was intensified in the Boundary Waters Canoe Area (BWCA) Wilderness of northern Minnesota in 2001, this area can serve as a case study to examine intensification.

We define extension as the process by which non-FIA agencies or individuals use FIA sample protocols for their own inventories. Because these agencies/individuals have no FIA affiliation, sampling usually occurs off the FIA plot system, subsequent estimation procedures (i.e., population estimates) may vary from FIA's. Non-FIA entities that adopt FIA's sample

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protocols may gain numerous benefits. First, field sampling protocols and associated quality assurance procedures are already developed, allowing non-FIA entities to allocate more resources to field sampling and less to sample protocol development. Secondly, because FIA provides base estimators and data management guidelines, non-FIA entities have peer-reviewed estimation procedures on which to base their own analyses. Finally, because the inventories of non-FIA entities use FIA sampling protocols, they may seamlessly link with the larger scale data from FIA and couch their inventory estimates within FIA's. The Pictured Rocks National Lakeshore (PRNL) began using FIA's DWM sample protocol to inventory fuels in 2001; subsequently, this area serves as a case study to examine extension.

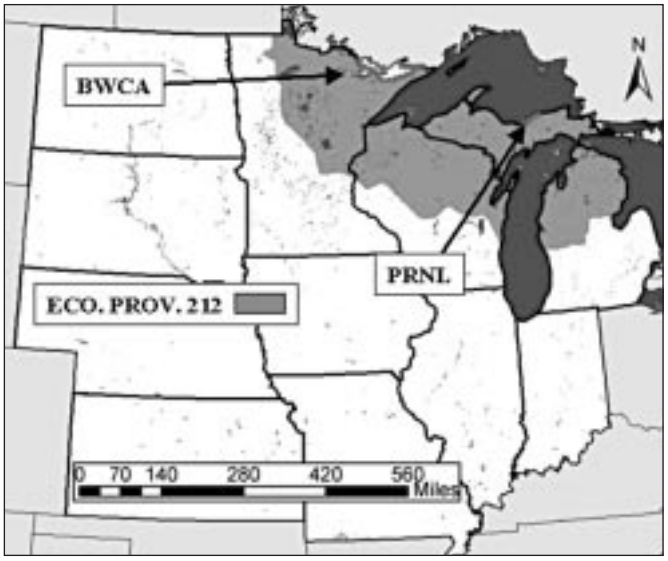
Our goal was to evaluate the contribution of intensification (BWCA) and extension (PRNL) to DWM inventory and analysis objectives. Objectives included (1) estimating and comparing fuel loadings for blowdown and nonblowdown areas of the BWCA, the North Central State region, the Laurentian Mixed Forest ecosystem of the Lake States (Ecological Province 212) (Bailey 1995), and PRNL, (2) exploring multiscale mapping possibilities gained from intensification and extension, and (3) determining what novel, multiscale fuel dynamics information may be obtained from intensification and extension. For this study, local is defined as a distinct area of ownership, management, or ecological uniqueness (i.e., BWCA), and regional is defined as encompassing a political boundary (i.e., State or USDA Forest Service region) or an area of ecological similarity (i.e., ecological province).

Study Sites

The PRNL is located along the south shore of Lake Superior near the town of Munising in Michigan's Upper Peninsula (National Park Service 2003) (fig. 1). PRNL, designated by Congress as the first national lakeshore in 1966, includes 200-foot-high sandstone cliffs and unspoiled beaches/dunes. PRNL consists of 71,397 acres of mixed hardwood and boreal forest types on soils ranging from well-drained sand to hydric. Upland northern hardwoods, including American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), and yellow birch (*Betula allegheniensis*), dominate about 80 percent of PRNL's forest area. Remaining forests are occupied by red, white, and jack pines (*Pinus resinosa*, *P. strobus*, and *P. banksiana*, respectively) on coarse outwash and coastal sands, paper birch (*Betula papyrifera*) and trembling aspen (*Populus tremuloides*) in successional areas, and black spruce (*Picea mariana*), white spruce (*Picea glauca*), and northern white cedar (*Thuja occidentalis*) in poorly drained lowlands. A primary management goal for PRNL is to develop and implement a comprehensive natural resource inventory and monitoring program (National Park Service 2003). Given that nearly 20 percent of PRNL's vegetation are fire-dependent forest communities, the National Park Service has mandated that PRNL preserve and perpetuate fundamental physical and biological processes to the fullest extent possible (National Park Service 2001). Therefore, PRNL intends to inventory forest and fuels conditions and develop a program to reintroduce fire in appropriate forested areas. Additionally, PRNL will compare fuel loads between Federal and non-Federal land within the lakeshore's boundary to assess effects of land management strategies on fuel loads and the potential for cooperative mitigation of hazardous conditions.

The BWCA Wilderness, located in northeast Minnesota, was established as a wilderness area in 1978 and contains 1.084 million acres (Heinselman 1996) (fig. 1). Nearly 18 percent of the BWCA is water with more than 1,000 portage-linked lakes and streams drawing more than 200,000 visitors a year

Figure 1.—*Map of North Central States (white fill), Ecological Province 212 (grey), and BWCA and PRNL.*

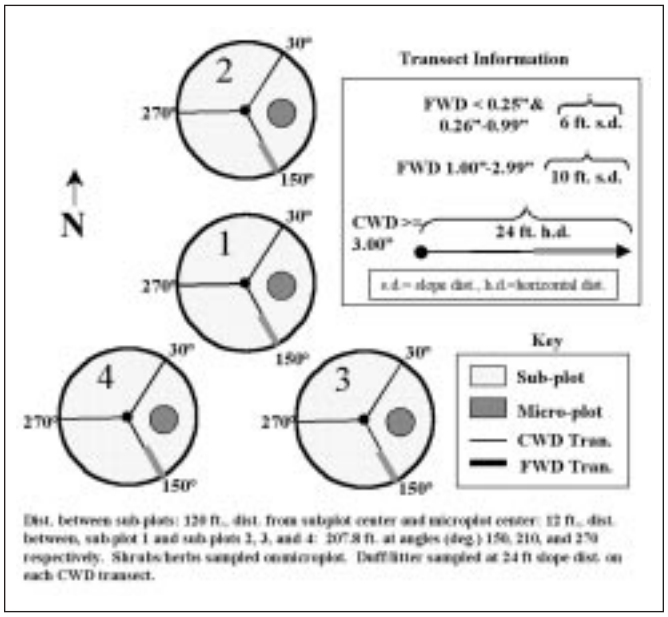


(Heinselman 1996, USDA Forest Service 2001). The forests of the BWCA, an intermix of north-central hardwoods and boreal forests, contain some of the largest tracts of virgin forest in the Eastern United States. (Heinselman 1996, USDA Forest Service 2001). Eighty-one percent of BWCA forests are occupied by upland species of black spruce, northern pines (jack, red, and eastern white), maple, aspen, and paper birch (Heinselman 1996). Black spruce bogs and alder (*Alnus rugosa*)/willow (*Justicia americana*) wetlands occupy the remaining forested areas (19 percent) (Heinselman 1996). Although mostly formed from the parent material of glacial till, soils in the BWCA range from moderately acidic granitic soils to slightly alkaline calcareous clay deposits (Heinselman 1996). The forests of the BWCA have historically been fire-dominated ecosystems with nearly all stands initiated by catastrophic wildfires (Carlson 2001). The historic fire regime that dominated the BWCA was large-scale running crown fires or high-intensity surface fires (Heinselman 1996). Since European settlement began more than a century ago, however, fire suppression activities have increased fire rotation length from 122 years to more than 2,000 years (Heinselman 1996). On July 4, 1999, an unheralded wind storm with winds in excess of 90 miles per hour affected approximately 367,000 acres of the BWCA. (USDA Forest Service 2001). The resulting blowdown substantially increased the volatility and amount of fuel in the BWCA, increasing the probability of wildfire escaping the wilderness (Leuschen *et al.* 2000). Fuel loadings were estimated to have increased from 5–20 tons per acre to 50–100 tons per acre; normal fuel loading in a typical BWCA stand has been proposed as 10 tons per acre (Leuschen *et al.* 2000). Since this wind event, the Superior National Forest has sought to monitor fuel loadings, assess blowdown effects, and mitigate fuel hazards through prescribed burns (USDA Forest Service 2001).

Methods

Varying sample intensities and field crews were used to sample DWM in the North Central States, Bailey's Ecological Province 212 (Bailey 1995), the BWCA (blowdown and nonblowdown), and PRNL. FIA field crews sampled 429 plots in the North Central States with 84 plots in the BWCA (9 in blowdown and 75 in nonblowdown), 131 plots in Ecological Province 212 (outside the BWCA), and 214 plots in the rest of the North Central States (outside Ecological Province 212). PRNL personnel sampled 121 plots in the lakeshore. In this study, we used 1-, 10-, 100-, and 1,000-hr fuels data, along with duff and litter depths, for analysis. Detailed description of the sampling design for DWM is provided by the North Central Research Station (USDA Forest Service 2003) and Woodall and Williams (2005). Briefly, 1,000-hr fuels were sampled on each of three 24-foot horizontal distance transects radiating from each FIA subplot center at 30, 150, and 270 degrees (fig. 2). Down woody pieces with a intersecting transect diameter of at least 3 inches and a length of at least 3 feet were considered 1,000-hr fuels (coarse woody debris [CWD]). Data collected for every 1,000-hr piece were transect diameter, length, small-end diameter, large-end diameter, decay class, species, evidence of fire, and presence of cavities. Fine woody debris (FWD) (1-, 10-, and 100-hr fuels) were sampled on the 150-degree transect on each subplot. FWD with transect diameters of 0.01 to 0.24 and 0.25 to 0.99 inches (1- and 10-hr, respectively) were tallied separately on a 6-foot slope distance transect (14 to 20 feet on the 150-degree transect). FWD with transect diameters of 1.00 to 2.99 inches (100-hr) were tallied on a 10-foot slope-distance transect (14 to

Figure 2.—*Sampling design for the DWM indicator of the USDA Forest Service Forest Inventory and Analysis program.*



24 feet on the 150-degree transect). The nonwoody surface fuels of duff and litter were sampled using an estimate of their respective depths at a 24-foot slope distance along each 1,000-hr transect (for a total of 12 sample points across all four subplots). Slight deviations exist between the 2001 and 2002 DWM sample protocols; the descriptions of these protocols are beyond the scope of this article but are detailed in Woodall and Williams (2005).

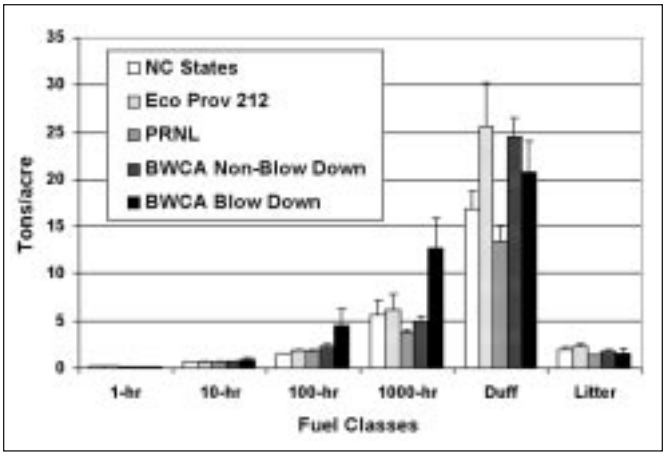
Per unit area estimates (tons per acre) for the fuel hour classes followed Brown's (1974) estimation procedures, while per unit area estimates (tons per acre) for litter and duff were based on average depth among all 12 sample points expanded to tons per acre units. CWD volume estimates were based on DeVries' line-intercept estimators (DeVries 1986). The total basal area (BA) for each sample plot was estimated from the inventory of standing trees conducted by field crews for the Phase 2 of each inventory. The means and associated standard errors were determined for all variables among plots stratified by PRNL, BWCA (blowdown and nonblowdown), Ecological Province 212 (excluding plots in the BWCA and PRNL), and North Central States outside Ecological Province 212. Fuel maps were based on interpolation of plot-level DWM estimates using ordinary kriging with an exponential model. To limit estimation to forested regions, fuel estimates were masked by applying a forest/nonforest map based on the Phase 1 National Land Cover Database (NLCD) imagery (Vogelmann *et al.* 2001).

Results/Discussion

The national inventory of DWM provides context for smaller scale fuel inventories regardless of whether FIA conducted those inventories. Mean plot estimates of fuel classes show that blowdown areas have more than twice the 100- and 1,000-hr fuels than the nonblowdown BWCA area (fig. 3). Before FIA began its national inventory of fuels, any inventory of fuels in the BWCA would have been conducted in isolation with no regional or national context. Most local fuel inventories use unique sample designs, estimation procedures, and data management systems that restrict the direct comparison of local estimates to those regional estimates or estimates from adjoining lands. Through the process of increasing sample intensity in an area of interest (BWCA), however, the FIA program can provide a multiscale assessment of fuels in local areas of interest. For the BWCA, fuel estimates may be compared to estimates from the greater North Central States region and inventories in Ecological Province 212 (fig. 3). Based on interpretation of sample mean standard errors, the means of 100- and 1,000-hr fuel loadings in BWCA blowdown areas are significantly different from those of BWCA nonblowdown areas (fig. 3). Additionally, 100- and 1,000-hr fuels in the BWCA are also greater than those in the rest of the North Central States and Ecological Province 212 (fig. 3). The same benefit of ecological context of local estimates is witnessed with PRNL fuel estimates (fig. 3). Before a consistent regional inventory of fuels was available, PRNL had only an estimate of approximately 4 tons per acre of 1,000-hr fuels (fig. 3). Management decisions and fuel mitigation efforts were based solely on that information with little relation or context of the surrounding forests/ecosystem/biome. Because PRNL used the same sample protocol and estimation procedures as the FIA program (extension), the PRNL data are essentially the same as FIA's and may be linked seamlessly with FIA regional estimates. PRNL management may know that its estimates of 4 tons per acre of 1,000-hr fuels are significantly below those for not only Ecological Province 212, but also for the remainder of the North Central States (fig. 3).

In addition to fuel inventory estimates, intensification/extension provides multiscale mapping capability that enable users to zoom in and out of areas of concern (fig. 4). The base

Figure 3.—*Means and associated standard errors of fuel classes for forested inventory plots in various areas of the North Central States region of the United States.*



sampling intensity of DWM provided by the FIA program allows construction of a regional map of FWD (fig. 4). Because sample intensity was increased in the local area of the BWCA, a smaller scale fuels map may be made for the area and framed within the regional FWD map (fig. 4). Intensification and extension of fuels sampling in local areas may allow local users to spatially appraise fuel loadings while zooming out to larger scales to couch local fuel inventories in regional assessments. Although numerous map-making methodologies are available for creating fuel maps, this study used a geostatistical approach. Regardless of which methodology is selected, the ability to provide context for fuel inventories at various scales (local to regional) may empower decisionmakers with an empirical basis for fire hazard mitigation planning.

Increasing sample intensity at local levels may refine the understanding of the dynamics between fuel and stand attributes. If a fuels inventory is conducted solely at regional scales, an absence of fuel inventories at finer (local) scales will prohibit assessments of local areas of "ecological interest." Because the BWCA experienced a rare wind event, increasing DWM sampling intensity in the wilderness area allowed an examination of the fuel dynamics of this storm in the context of the region. In the BWCA, the volume per acre of 1,000-hr fuels actually decreases with increasing standing live stand basal area (fig. 5). In the PRNL, the volume per acre of 1,000-hr fuels appears to increase with increasing standing live basal area (fig. 5). These trends in 1,000-hr fuels and basal area may be examined in the context of the larger ecosystem. The remainder of the DWM plots in Ecological Province 212 has mean 1,000-hr per acre volumes that increase with increasing stand basal area (BA) in contrast to the trends found in the BWCA (fig. 5). Because the BWCA experienced a massive blowdown, stands that have little standing BA also have large amounts of 1000-hr fuels because most of their standing live BA was converted to 1,000-hr fuels in 1999 (fig. 5). Because this trend in 1,000-hr per acre volumes and BA was not found in the greater forest ecosystem or the PRNL, blowdowns of the severity found in the BWCA are likely to change forest ecosystem stand/fuel dynamics. Furthermore, because of an increasing linear relationship between standing live BA and 1,000-hr fuels in Ecological Province 212, it may be hypothesized that this ecosystem experiences density-induced individual tree mortality or sub acre-scale wind disturbances that increase 1,000-hr fuel volumes in older/greater density stands.

Although intensification and extension data may be seamlessly included with base DWM inventory data for fuel assessments and research, two caveats should be noted. First, extension data should not be used in standard reports or assessments in the FIA program; non-FIA personnel collected the data, and the subsequent data quality cannot be verified (through quality assurance/quality control procedures). Although this caveat does

Figure 4.—*Fine woody debris for selected region of the North Central States with "zoom-in" of Boundary Waters Canoe Area Wilderness based on ordinary kriging of DWM inventory plots masked using a nonforest map based on classified NLCD imagery.*

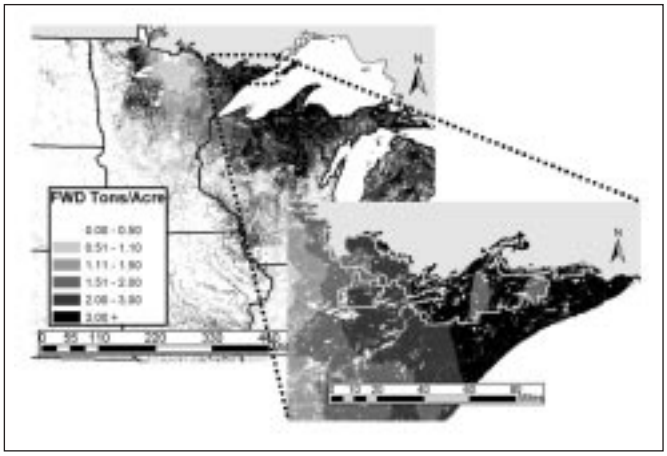
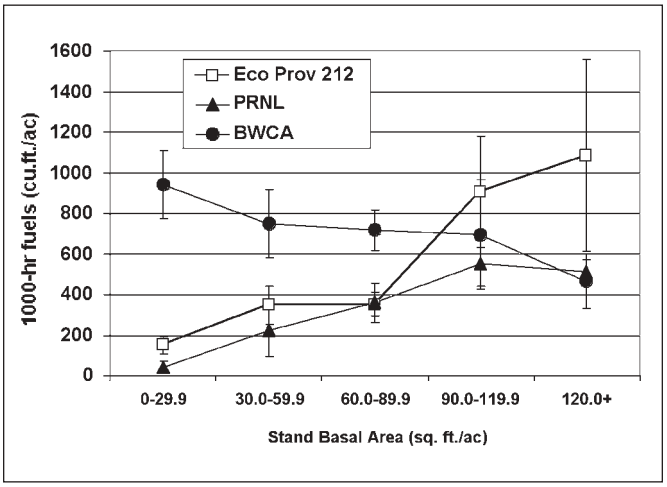


Figure 5.—*Means and associated standard errors of 1,000-hr fuels by total stand basal area for Ecological Province 212, BWCA, and PRNL.*



not preclude use of extension data in FIA research projects, extension data should be explicitly defined and identified. Second, reduced sample and population estimate variances of means in intensification areas are possible. Hypothetically, if 60 plots exist statewide in Minnesota while 84 plots exist in the BWCA, less variance is likely with estimates in the limited area and forest types of the BWCA compared to the rest of the state. Unequal variances across fuel estimates by strata (i.e., forest types) may be acceptable provided variances are explicitly stated and discussed during hypothesis testing and data delivery.

Conclusions

Extension/intensification benefits not only helps meet the objectives of the FIA program, but they also better service FIA's customers. FIA's customer base is expanded by providing data at both regional and local scales that enable individuals/agencies with localized interests to use inventory data. Additionally, research opportunities are expanded because sampling may occur in relatively small areas of ecological interest. Quantification of dynamics between fuel and stand attributes may be refined because intensification may allow investigation of small-scale ecological phenomena such as wind events. For the BWCA, this study's preliminary estimates indicate that 100- and 1,000-hr fuel loadings in blowdown areas may be more than twice those of nonblowdown areas and the rest of the Lake States region. Also, relationships between fuel loadings and stand BA differed between the BWCA and surrounding forest ecosystem, a trend most likely caused by BWCA's recent wind event. For the PRNL, estimates of the lakeshore's fuel loadings appear less than those of surrounding regional forests. Given the current national efforts to assess and mitigate fire hazards at local and regional scales, FIA's DWM inventory may aid fuel management efforts as evidenced by intensification and extension cases in this study.

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