INTEGRATING REMOTE SENSING AND FOREST INVENTORY DATA FOR ASSESSING FOREST BLOWDOWN IN THE BOUNDARY WATERS CANOE AREA WILDERNESS

Mark D. Nelson, Research Forester
W. Keith Moser, Research Forester
Northern Research Station
USDA Forest Service
1992 Folwell Avenue
St. Paul, MN 55108
Email: mdnelson@fs.fed.us

ABSTRACT

The USDA Forest Service's Forest Inventory and Analysis (FIA) program conducts strategic inventories of our Nation's forest resources. There is increasing need to assess effects of forest disturbance from catastrophic events, often within geographic extents not typically addressed by strategic forest inventories. One such event occurred within the Boundary Waters Canoe Area Wilderness (BWCAW), where a severe windstorm caused extensive damage to the area's forest land. We combined forest inventory data with geospatial datasets derived from satellite remote sensing to assess characteristics of BWCAW blowdown forest area and volume. Net volume per hectare of all live trees was significantly lower in blowdown areas, and damage severity varied by location and forest type. Both plot-level FIA data and satellite image-based data were useful for identifying blowdown forest. Plot-based estimates of blowdown forest area were slightly larger than satellite image-based estimates, but this difference diminished after adjusting for image cloud cover. We present an approach for using remote sensing data for constraining analyses to the approximate vicinity of blowdown damage, coupled with analysis of FIA data stratified by field observations of wind damage.

INTRODUCTION

The Boundary Waters Canoe Area Wilderness (BWCA) is an ecological and recreational resource within the Superior National Forest (SNF), northern Minnesota, USA (Fig. 1). Lakes and rivers along the "boundary", or international border between the United States and Canada, historically were used by Native American peoples as water transportation routes. During 1690 – 1865, these routes also were used by French Canadian fur traders and trappers known as "Voyageurs" (Heinselman, 1996). Giving recognition to these adventurers by name, Voyageurs National Park also encompasses portions of this historic waterway and nearly abuts the western edge of the BWCAW. About half of the land area in the BWCAW and neighboring Quetico Provincial Park in Ontario, Canada, supports unlogged virgin forests and the largest tracts of virgin forest in the eastern united States occur within the BWCAW (Heinselman, 1996). Because of its unique history, ecological condition, and recreational value, the BWCAW was established as a unit of the National Wilderness Preservation System in 1978.

A catastrophic weather event known as the "Boundary Waters-Canadian Derecho" occurred on July 4th (Independence Day), 1999, causing significant damage to tens of millions of trees on 200,000 hectares of forest land within the BWCAW (Frelich, 2002) (Fig. 1) and adjacent Quetico Provincial Park. Derechos are caused by repeated downbursts emanating from thunderstorm cells, producing a pattern of straight line wind damage over a widespread region. Although derechos occur with high frequency in southern Minnesota, they are uncommon in the vicinity of the BWCAW in northern Minnesota. This particular derecho, with winds of at least 80-100 mph, was one of the largest blowdowns ever recorded in North America, similar in size and forest damage severity to category 3 or 4 hurricanes making landfall (Frelich, 2000). Heinselman (Heinselman, 1996) suggests that historic efforts to suppress and exclude forest wildfires resulted in BWCAW forest conditions more susceptible to wind damage and Frelich (2000) provides a preliminary assessment of the BWCAW blowdown event. Trees blown down by this event posed a challenge to canoe campers and produced an increased risk of catastrophic wildfire.

The need by recreationists, local residents, and forest resource managers to understand the extent and severity of forest disturbance within the BWCAW presented a unique challenge and opportunity for the Forest Inventory and Analysis (FIA) Program of the U. S. Forest Service's North Central Research Station (NCFIA). FIA provides strategic inventories of all United States forest land across all ownership categories. The strength of FIA lies in its grid-based plot system, which provides accurate and unbiased design-based estimates of forest land attributes over larger areas. Data collected on these plots include direct measurements of tree diameter and height, as well as various other biotic and abiotic variables. The existence of this database offers many opportunities to provide estimates of current resource status and ecological change at different scales. NCFIA collaborated with SNF to meet the challenge of assessing the effects of a massive blowdown event within the BWCAW. The SNF funded a one-time intensification of FIA's sampling design, which allowed for the collection of more data within the BWCAW than typically is collected by FIA. Moser, et al. (In Press) use FIA data to assess the entire BWCAW, including the blowdown area. Here we discuss the use of remote sensing datasets and geospatial analyses to augment an FIA field plot-based assessment of blowdown damage within the BWCAW. In addition, we compared estimates of blowdown forest area derived from six sources: FIA field plots, FIA field plots within blowdown polygons, FIA field plots within a 5-km buffer surrounding blowdown polygons, a Landsat Thematic Mapper satellite image-based map of blowdown severity, the image-based blowdown severity map adjusted for cloud cover, and a polygon delineation of the image-based blowdown severity map.

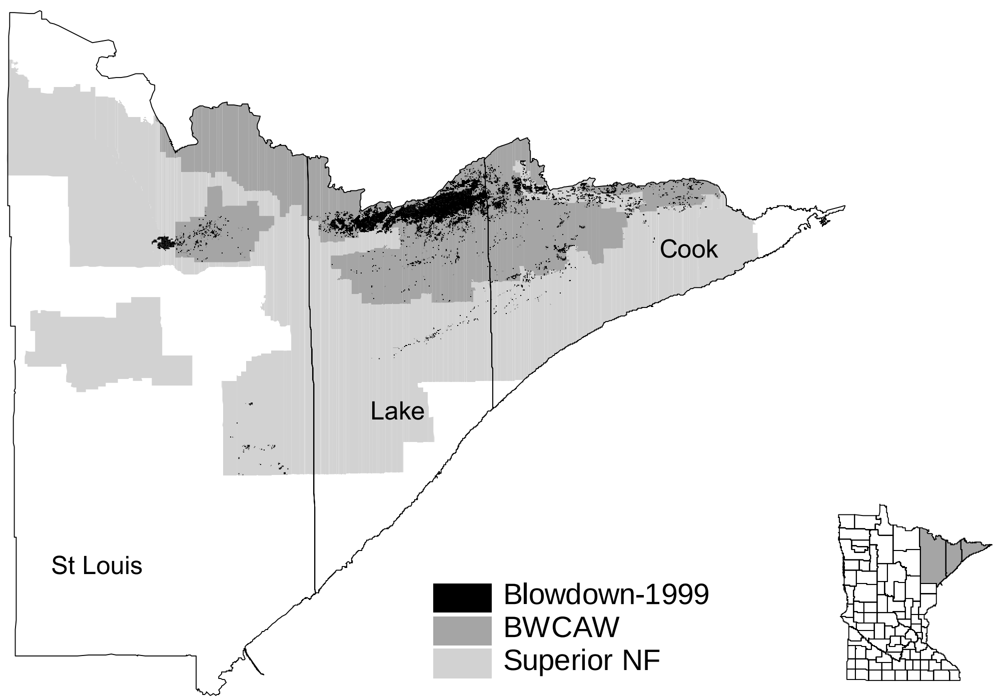

Figure 1. Superior National Forest, BWCAW, and July 4th, 1999 blowdown areas; St. Louis, Lake, and Cook counties, Minnesota, USA.

DATA & METHODS

Study Area

The BWCAW comprises about 440,000 ha (Heinselman, 1996), encompassing portions of Cook, Lake, and St. Louis Counties, MN, USA (Fig. 1). Approximately 72 percent (317,000 ha) of the BWCAW is forest land and 18 percent (77,000 ha) is open water (Moser et al., In Press). Paper birch, quaking aspen, black spruce, jack pine, and eastern white pine comprise the predominant forest types (Fig. 2), and the species are nearly evenly distributed among hardwoods and softwoods (Moser et al., In Press).

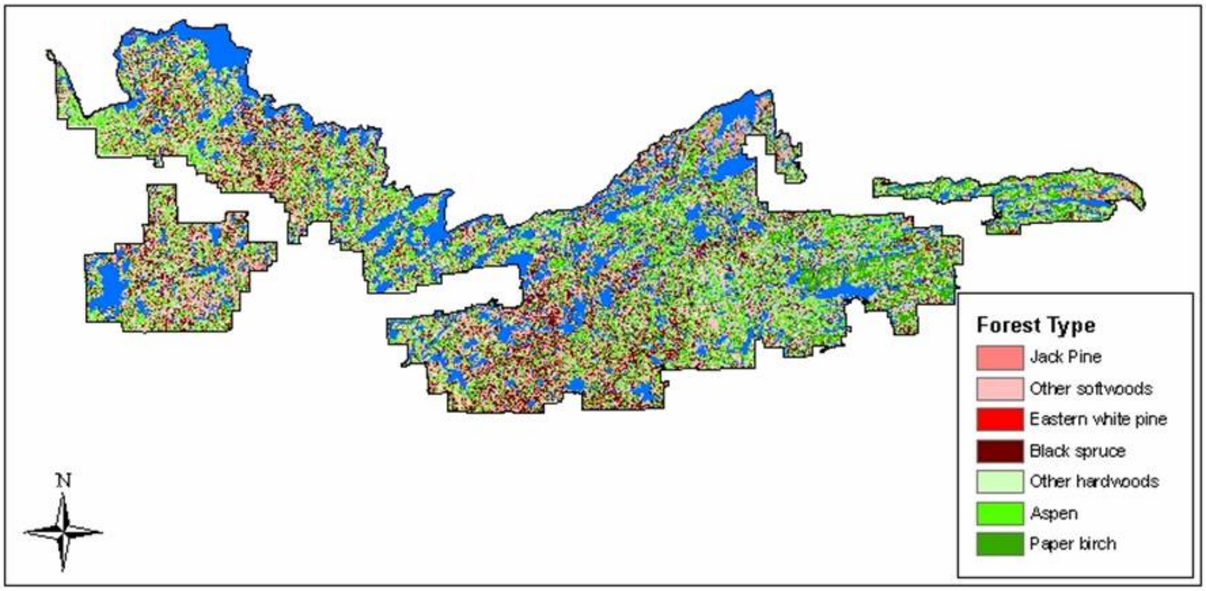

Figure 2. MODIS satellite image-based classification of forest types within the BWCAW, Minnesota, USA (B. Wilson, personal communication).

Satellite Image-based Blowdown Severity

The Resource Assessment (RA) Unit of the Minnesota Department of Natural Resources (MNDNR) produced a 30-m spatial resolution blowdown damage severity map (Minnesota Department of Natural Resources, Internet web application - last accessed 10 July 2006). Pre- and post-blowdown Landsat Thematic Mapper (TM) images from Path 27 Row27 (P27R27) and Path 26 Row 27 (P26R27) were calibrated and subtracted from each other by the RA Unit to produce difference images of forest change. Applying change detection methods developed by the RA for MNDNR's "ChangeView" application (http://www.ra.dnr.state.mn.us/changeview/change_tech.html), change images were used to identify the severity of forest canopy reduction, which ranged from light to heavy (Fig. 3). The distribution of differences in brightness values for corresponding pixels from two dates was used to assign severity classes. Difference values beyond 1.3 standard deviations from the mean (outside the central 80 per cent of the curve) were considered to represent forest canopy change.

Partial cloud cover obscured portions of pre- and post-blowdown imagery from both TM scenes, more so for P26R27, but a relatively small proportion of the storm damage area was obscured by clouds in either pre- or post-blowdown imagery.

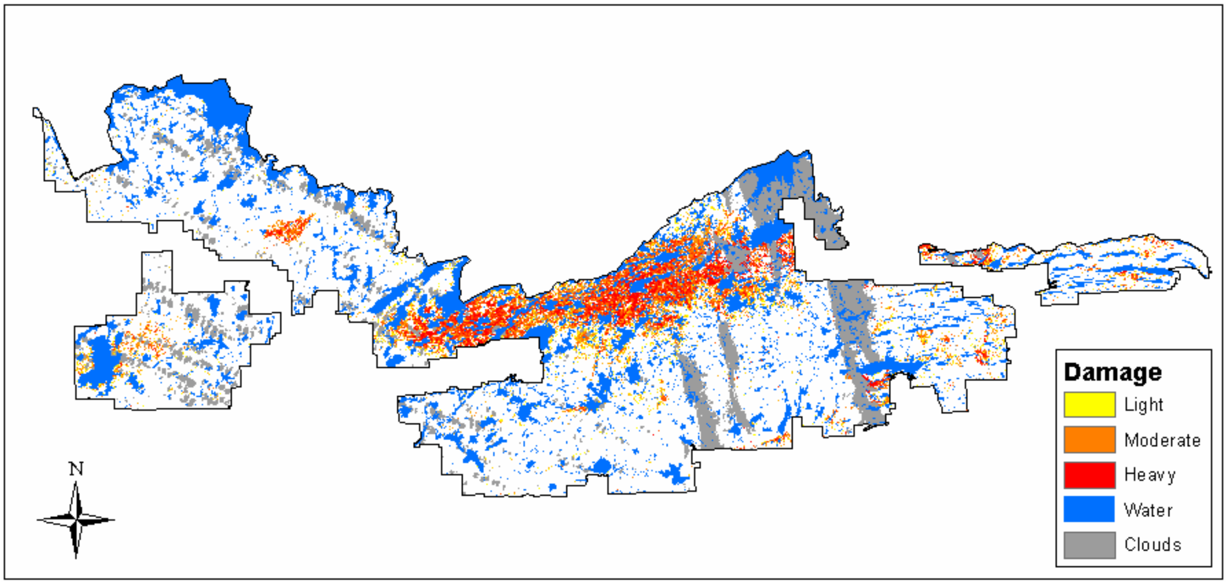

Figure 3. Minnesota Department of Natural Resources, Landsat Thematic Mapper satellite image-based classification of forest canopy change resulting predominately from the July 4th, 1999 blowdown within and surrounding the BWCAW, Minnesota, USA.

Polygon Boundaries

SNF staff provided polygon delineations of SNF, BWCAW, and the perimeters of satellite image-based 1999 blowdown damage areas. A 5-km buffer area surrounding and including the blowdown polygons was created to delineate the general vicinity of the blowdown from surrounding undamaged areas. Geospatial data were maintained and analyzed in a Geographic Information System (GIS) using Universal Transverse Mercator Zone 15N projection, NAD83 datum, and units of measure in meters.

Forest Inventory Feld Data

FIA phase 2 field plot data collected between 1999-2003 (MN cycle 12, subcycles 1-5) were queried from the FIA database (U.S. Department of Agriculture Forest Service, 2006). GIS data layers of inventory plot center locations were created based on global positioning system (GPS) coordinates obtained during field data collection and were used to associate field plots with geospatial datasets via spatial join functions in a GIS. Analysis was restricted to data collected from plots located inside the bounds of the BWCAW (Fig. 4). Tabular attributes indicating whether each plot location occurred inside or outside each geographic area of interest (SNF, BWCAW, blowdown polygons, 5-km buffer surrounding and including blowdown polygons) were added to FIA plot tables. Subsequent tabular estimates of forest volume incorporated the categorical attributes resulting from these spatial joins. Assignment of plots to blowdown or non-blowdown categories was based on a combination of two approaches: 1) field-based observation of disturbance condition (e.g., wind damage), and 2) intersection of plot locations with blowdown forest polygons in a GIS.

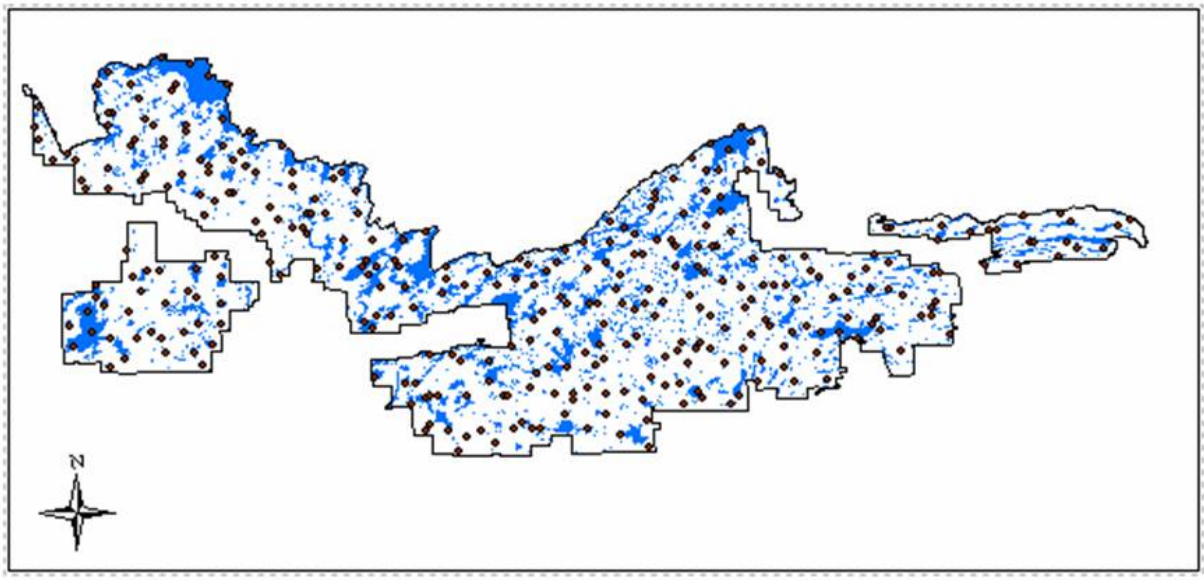

Figure 4. Approximate locations of FIA plots (points) in the BWCAW, Minnesota, USA.

Forest Area Estimates

Satellite image-based estimates of blowdown forest area were calculated as the product of the per-pixel area (900 m^2) and the number of pixels classified as having light, moderate, or heavy damage. The proportion of blowdown forest (0.12) in non-cloudy portions of TM imagery was assumed to represent the overall blowdown proportion across the BWCAW. An image-based cloud-adjusted estimate of blowdown forest area was obtained by multiplying 0.12 by the area of cloud cover within BWCAW and adding this to the area of blowdown not osbscured by clouds. Image-based area estimates are reported for both cloud-adjusted and non cloud-adjusted blowdown forest.

FIA plot-based estimates of blowdown forest area and corresponding estimates of variance were calculated under the assumption of simple random sampling, and were based on field observations of wind damage, weighted by areal proportion of each plot assigned to that damage condition. Paired comparisons of estimates (e.g., inside vs. outside blowdown polygons) were interpreted as being statistically significantly different ($P < 0.05$) when their respective 95 percent confidence intervals were non-overlapping.

No estimate of uncertainty was available for image-based estimates of forest blowdown area. Therefore, differences in area estimates between satellite image-based and plot-based estimates are conservatively reported as significantly different if an image-based estimate fell outside the 95 percent confidence intervals of a plot-based estimate.

Net Cubic Meter Volume per Hectare Estimates

Plot-based estimates of net volume (m^3/ha) of all live trees on forest land were produced for the SNF, BWCAW, blowdown polygons, and 5-km buffer surrounding and including blowdown polygons. Estimates were further stratified by field-level observations of plot condition attributes, including softwoods or hardwoods, forest type and forest type group, and disturbance codes. Variances of these volume estimates, calculated under the assumption of simple random sampling, were used to determine 95 percent confidence intervals which were used as the level of statistical significance. Paired comparisons of estimates (e.g., inside vs. outside blowdown polygons) were interpreted as being statistically significantly different ($P < 0.05$) when their respective 95 percent confidence intervals were non-overlapping. No estimates of forest volume were derived from satellite imagery.

RESULTS

Forest Area Estimates

Figure 5 reveals that the FIA plot-based estimate of BWCAW blowdown forest area (A) was significantly larger than map-based estimates from satellite imagery (D) and from image-derived blowdown polygons (E). However, the plot-based estimate (A) was similar to the cloud-adjusted satellite image-based estimate (F) (Fig. 5). The 5-km buffer-constrained plot-based estimate of blowdown forest area (C) was not significantly different from the plot-based estimate (A), but both of these estimates were significantly larger than the blowdown polygon-constrained plot-based estimate (B) (Fig. 5).

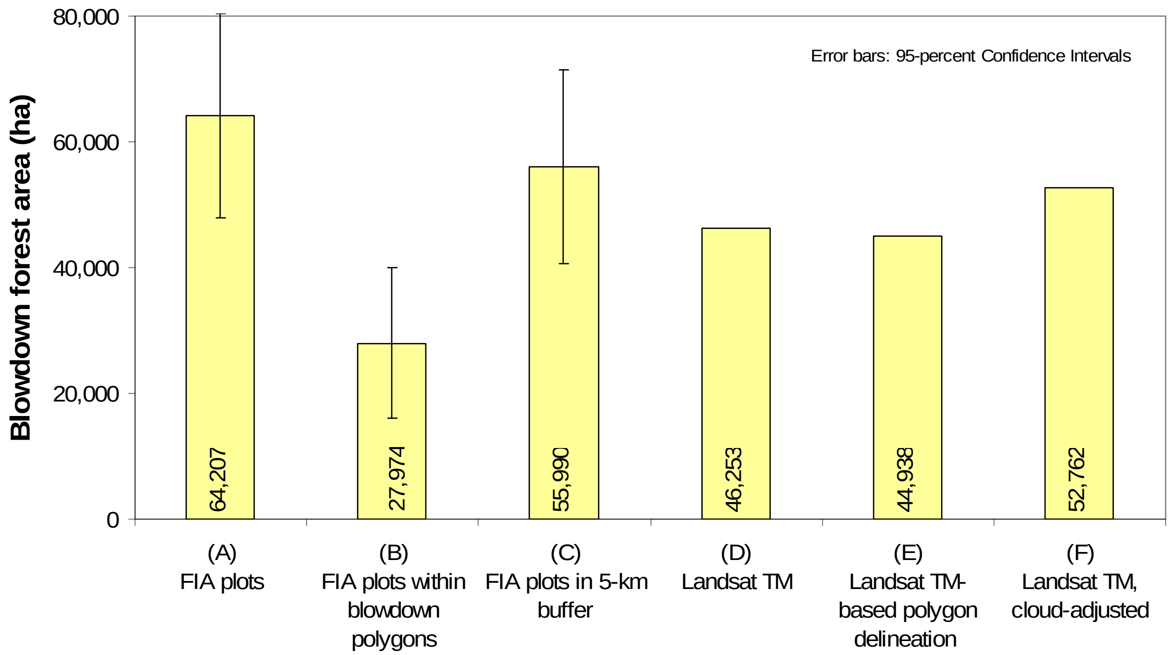

Figure 5. July 4th, 1999 blowdown forest area (ha) in the BWCAW, Minnesota, USA, from field plot-based and image-derived estimates.

Net Tree Volume Estimates

Within BWCAW, forest volume inside the 5-km buffer (74.0 m^3/ha) did not differ significantly from volume outside the 5-km buffer (76.3 m^3/ha). Within the 5-km BWCAW buffer, forest volume was significantly lower within blowdown polygons (56.2 m^3/ha) than outside blowdown polygons (76.4 m^3/ha). Likewise, volume per hectare in hardwoods was significantly lower within blowdown polygons (59.8 m^3/ha) than outside blowdown polygons (81.8 m^3/ha). For other forest type groups, too few FIA plots occurred within blowdown polygons to make statistical comparisons.

Volume estimates within the 5-km buffer area of the BWCAW were significantly lower on forest land with condition-level field observations of wind damage than for undisturbed forest land, for all forest types/groups combined (49.5 vs. 80.8 m^3/ha), softwoods (40.7 vs 70.2 m^3/ha), hardwoods (53.4 vs 92.5 m^3/ha), aspen/birch group (52.4 vs. 89.7 m^3/ha) and aspen type (55.9 vs. 106.2 m^3/ha), respectively (Fig. 6). Too few FIA plots from other forest type groups were available for making comparisons of volume by condition damage codes within the 5-km buffer.

Within the 5-km buffer area of the BWCAW, volume on forest land within blowdown polygons (56.2 m3/ha) appeared slightly larger than volume on forest land with condition-level plot observations of wind damage (49.5 m^3/ha), but the difference was not statistically significantly different.

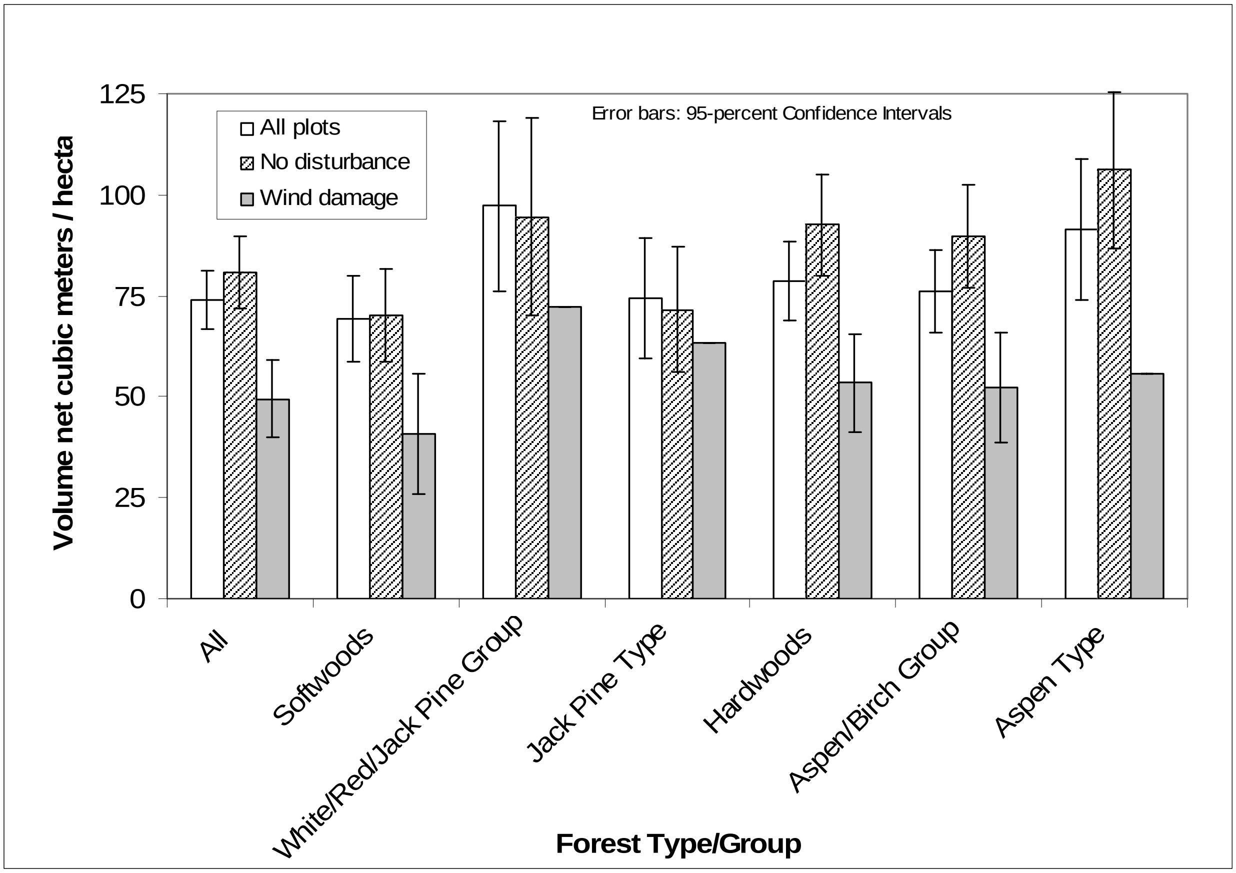

Figure 6. Net volume (m3/ha) of all live trees on forest land within a 5-km buffer surrounding the image-based severity map of July 4th, 1999 blowdown area, in the BWCAW, Minnesota, USA.

DISCUSSION

Overall, BWCAW blowdown forest area differed significantly between field plot- and satellite image-based estimates. However, when blowdown area estimates were adjusted for image cloud cover, the estimates were similar. Plot-based estimates of blowdown forest area differed depending on the approach used for assigning plots to blowdown vs. non-blowdown categories. The approach based on field observations of wind damage resulted in significantly larger estimates of blowdown forest area than the approach based on a spatial join of plots to blowdown polygons. A likely explanation for this is that blowdown polygons encompass a heterogeneous cluster of pixels, some of which are classified as having severe damage, while others have little or no damage. Because some plots located within blowdown polygons have field conditions with little or no wind damage, assigning these undamaged or slightly damaged plots as blowdown plots likely results in overestimates of forest blowdown area within the blowdown class and underestimates in the non-blowdown class.

Within the BWCAW, substantially lower net volumes of all live trees on forest land were estimated in blowdown than in non-blowdown forest land. Furthermore, volumes per hectare of blowdown forest within a 5-km buffer surrounding and including blowdown polygons were lower than non-blowdown forest volumes when using either blowdown polygons or field observations of damage condition for assigning plots to blowdown vs. non-blowdown categories. Blowdown forest volume estimates from these two approaches did not differ significantly from one another, although estimates of blowdown forest area differed between the approaches.

Results generally were as expected, with blowdown estimates exhibiting uneven distribution across the area and among forest types/groups. While plot- and image-based estimates of forest blowdown area were similar after adjusting for clouds, no estimates of forest volume were available from the imagery. Therefore, to consistently and accurately estimate and compare blowdown vs. non-blowdown for both forest area and volume, we recommend using FIA inventory data, stratified by field observations of wind damage, constrained to the approximate vicinity of blowdown damage (e.g., a 5-km buffer). Ongoing studies are being conducted to assess landscape scale susceptibility of forest land to wind damage.

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