Assessment of Black Ash *(Fraxinus nigra)* Decline in Minnesota

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Abstract.—Black ash *(Fraxinus nigra)* is an important component of wetland forests throughout the Upper Midwest and northeastern United States and is highly valued for paneling, furniture, and basketry. Decline of black ash has been noted with increasing frequency, although no detailed studies of the pattern of decline across the region have been done. From analyses of Forest Health Monitoring aerial sketchmapping data, an association was found between dieback and decline of black ash and proximity to city, county, and State roads. In addition, relationships between growth and mortality levels of black ash and climatic, edaphic, and physiographic factors were found through analyses of U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) field plot data collected in Minnesota between 1977 and 2005. FIA data were limited, however, in revealing factors that could have caused the decline, such as damage from biotic and abiotic agents.

Introduction

Black ash *(Fraxinus nigra)* is present throughout the Upper Midwest and northeastern United States and is often found in lowland or swamp hardwoods forest types (Erdmann *et al.* 1987). Black ash also grows on more well drained and mesic sites. Black ash seed is an important food for game birds, song birds, and small mammals, and the twigs and foliage are used by white-tailed deer and moose. Black ash wood has limited commercial uses; it is highly valued for paneling, furniture, and specialty products. In addition, black ash wood is ideal for Native American basketry because it is strongly ring porous and the wood can be easily separated into basket splints (Benedict 2001). In recent years, the availability of quality basket trees has diminished because of black ash decline (Benedict 2001).

Black ash decline and relatively high levels of tree mortality have been observed throughout the range of black ash in recent years and at times throughout past decades (Croxton 1966, Livingston *et al.* 1995, USDA Forest Service 2004). For example, in 2004, more than 27,000 acres of black ash trees were reported to be affected by dieback and decline in Minnesota (Northeastern Area State and Private Forestry 2005). Declining trees typically exhibit sparse crowns, twig dieback, epicormic sprouting, and slow growth. The cause of black ash decline is unknown but was thought to be related to past drought conditions (Livingston *et al.* 1995), subfreezing winter temperatures with little snow cover, or late spring frosts (USDA Forest Service 2004). Black ash is a shallow-rooted species and, as such, is susceptible to the effects of varying water table levels and winter freeze-thaw injury. We identified several other hypotheses for black ash decline—advanced stand age, damage from biotic agents, hydrologic changes from road development, and road salt runoff.

The objectives of this study were to use Forest Service forest inventory and analysis (FIA) data and Forest Health Monitoring (FHM) data to assess the pattern and extent of black ash decline in Minnesota and to relate decline occurrence and variation to mapped landscape-scale climatic, physiographic, and edaphic data.

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Methods

Aerial Survey Data

Aerial survey data collected in Minnesota in 2004 were obtained from the FHM Aerial Survey Results Viewer (Northeastern Area State and Private Forestry 2005). Dieback and decline polygons in the black ash cover type were joined to three Minnesota Department of Transportation roads layers—major interstates and trunk highways, county and State roads, and city streets—using ArcGIS. A field containing distance values from the dieback/decline polygons to roads was added to the data tables during the joins. Random points equal in numbers to the dieback/decline polygons were generated within the black ash cover type previously determined by the Minnesota Gap Analysis Program. In a manner similar to the dieback/decline polygons, the random points were spatially joined to each of the three roads layers and distance from roads was calculated for each. Numbers of dieback/decline polygons and numbers of random points at distances from roads at 150-ft intervals between 0 and 9,990 ft were analyzed using contingency tables and the likelihood ratio statistic.

Public Inventory Data

TREE, PLOT, and CONDITION data tables were obtained for four Minnesota FIA inventory cycles initiated between 1977 and 2005—cycles 4, 5, 12, and 13 (FIA 2006). For cycles 12 and 13, black ash tree data from the tables were filtered to include only plots that were coded as black ash forest type. Black ash tree data from cycles 4 and 5 were filtered to include only plots coded as the elm/ash/cottonwood group because the codes were not specific to black ash forest type. Mean mortality, diameter at breast height (d.b.h.), and dead tree-to-live-tree ratios for each of the four FIA inventory cycles were derived from the TREE tables, averaged on a plot basis, and used as response variables. FIA variables, ASPECT, OWNCD, OWNGRPCD, PHYSCLCD, RDDISTCD (2003 and 2005 cycles only), SITECLCD, SLOPE, TRTOPCD, and WATERCD (2003 and 2005 cycles only), were used as potential predictors of black ash growth and mortality (see table 1 for variable definitions). The data were analyzed with a generalized linear model and Fisher's least significance difference. In addition, numbers of

Table 1.—*Statistically significant associations of public forest inventory and analysis data in four inventory cycles and black ash (a) dead-to-live tree ratio and (b) diameter at breast height (d.b.h.).*

FIA Variable	Cycle							
	1977 era	1990 era	2003	2005	1977 era	1990 era	2003	2005
	(a) Dead-to-live tree ratio				(b) d.b.h.			
OWNCD[a]				X[b]	X			
OWNGRPCD						X	X	
PHYSCLCD			X	X			X	
SITECLCD		X			X		X	
TRTOPCD		X	X	X		X	X	X
SLOPE						X		
ASPECT								
RDDISTCD	NA[c]	NA			NA	NA		
WATERCD	NA	NA			NA	NA		

[a] *OWNCD = owner (National Forest System; U.S. Fish & Wildlife Service; other Federal, State, county/municipal; private).*
OWNGRPCD = owner group (Forest Service; other Federal, State, and county/municipal; private).
PHYSCLCD = physiographic class (1977- and 1990-era cycles [xeric, mesic]; 2003 and 2005 cycles [dry ridge tops, deep sands, flatwoods, rolling uplands, moist slopes, narrow flood plains, broad flood plains, other mesic, swamps/bogs, small drains, wet bays, beaver ponds, boggy bays, other hydric]).
SITECLCD = site productivity class (cubic feet/acre/year) (165 to 224, 120 to 164, 85 to 119, 50 to 84, 20 to 49, 0 to 19).
TRTOPCD = physical opportunity to improve stand conditions by applying management practices (regeneration without site preparation, regeneration with site preparation, stand conversion [e.g., undesirable species], thin seedlings and saplings, thin poletimber, other stocking control [e.g., remove undesirable material], other intermediate treatments [e.g., fertilize, prune], clearcut harvest, partial cut harvest, salvage harvest, no treatment).
SLOPE = slope angle (percent).
ASPECT = slope direction (degree).
RDDISTCD = horizontal distance to improved road (feet) (2003 and 2005 cycles [less than or equal to 100, 101 to 300, 301 to 500, 501 to 1000, 1,001 to 2,640, 2,641 to 5,280, 5,281 to 15,840, 15,841 to 26,400, greater than 26,400]).
WATERCD = water on plot (2003 and 2005 cycles [none, small permanent streams or ponds; deep swamps, bogs, marshes; temporary streams; flood zones; other temporary water]).
[b] *X = a statistically significant association (P<0.05).*
[c] *NA = not available.*

trees in damaging agent categories (AGENTCD) were summarized for all four cycles, and counts of tree damage types (DAMTYP1) were summed for the 2003 and 2005 cycles. Damage types (DAMTYP1) were not recorded in the 1977 and 1990 cycles. Plot coordinates for all public inventory data are adjusted to ensure that the FIA plot data cannot be linked to individual landowners, so the true coordinates for the public data were not available.

True Coordinate Inventory Data

Data collected in Minnesota from 1,605 black ash trees measured in the 1990-era cycle and remeasured in the 2003 cycle were accessed from the FIA Spatial Data Services center in St. Paul, MN. The data included the true plot coordinates which were spatially joined with several ancillary datasets—county boundaries (Minnesota DNR 2003a), ecological subsections (Minnesota DNR 1999), temperature and precipitation (PRISM Group 2006), STATSGO soils data (NRCS 2006), the National Wetlands Inventory (NWI) (Minnesota DNR 2003b), and the National Hydrography Dataset (NHD) (USGS 2005). Spatial relationships of black ash growth and mortality among State climate divisions, ecological subsections, and counties were analyzed using contingency tables, the likelihood ratio statistic, and StatXact software. SAS software and linear regression were used to determine relationships between growth and mortality variables of black ash and mean temperature, mean precipitation, and STATSGO soil characteristics.

Results

Aerial Survey Data

Black ash dieback/decline polygons were significantly closer to city streets ($P = 0.030$) and to county and State roads ($P < 0.001$) than were random black ash points. Distances to highways were similar between dieback/decline polygons and random points ($P = 0.341$).

Public Inventory Data, 1977 Era

Mean d.b.h. differed by SITECLCD (table 1) and was smallest in the lowest productivity class (20 to 49 cf/ac/yr); most declining and nondeclining trees (85 percent) were on sites in the lowest productivity class. Mean d.b.h. differed by OWNCD (table 1) and was significantly larger on private land than on State land ($P = 0.050$) (table 1). Neither mean d.b.h. nor dead-to-live tree ratio was associated with ASPECT, OWNGRPCD, PHYSCLCD, SITECLCD, SLOPE, or TRTOPCD. Damaging agents were found to affect 20 percent of the trees, and the most common damaging agents were disease (13 percent) and fire (3 percent).

Public Inventory Data, 1990 Era

Dead-to-live tree ratio differed by SITECLCD ($P < 0.001$) (table 1), and the largest mean ratio was on medium productivity sites (85 to 119 cf/ac/yr). Most declining and nondeclining trees (88 percent) were on the poorest sites (20 to 49 cf/ac/yr). Dead-to-live tree ratio ($P < 0.001$) and d.b.h. differed by TRTOPCD ($P < 0.001$) (table 1), and the smallest dead-to-live tree ratios and the smallest mean d.b.h. were on sites requiring thinning treatments. Mean d.b.h. was positively related to increasing SLOPE values ($P < 0.001$) (table 1). Mean d.b.h. also differed by OWNGRPCD ($P = 0.053$) (table 1) and was largest on private land and smallest on National Forest land. Neither mean d.b.h. nor dead-to-live tree ratio was associated with ASPECT, OWNCD, or PHYSCLCD. Damaging agents were recorded on 14 percent of the trees, and, similar to the 1977-era cycle, the most common damaging agents were disease (5 percent) and fire (3 percent).

Public Inventory Data, 2003

Dead-to-live tree ratio ($P < 0.001$) and mean d.b.h. ($P < 0.001$) differed by TRTTOPCD (table 1). The largest mean dead-to-live tree ratio was on sites requiring the greatest degrees of treatment (e.g., stand conversion, regeneration with site preparation), and the smallest mean d.b.h. was on sites requiring stand conversion or thinning. Dead-to-live tree ratio ($P < 0.001$) and mean d.b.h. ($P = 0.006$) also differed by PHYSCLCD (table 1). The largest mean dead-to-live tree ratios were in hydric classes, such as beaver ponds and swamps and bogs, and the smallest mean ratios were in mesic and xeric classes—moist slopes and dry ridge tops. Similarly, black ash on sites with beaver ponds had a smaller mean d.b.h. than black ash on dry ridge tops or moist slopes. Mean d.b.h. also differed by SITECLCD ($P = 0.005$) (table 1); the smallest mean d.b.h. and the least mean stand ages were in the largest productivity class (120 to 164 cf/ac/yr). Most declining and nondeclining trees (84 percent) were on sites in the poorest productivity class (20 to 49 cf/ac/yr). Mean dead-to-live tree ratio differed by OWNGRPCD (table 1) and was significantly larger on Forest Service land than on State or local government or private land (P = 0.050). Neither mean d.b.h. nor dead-to-live tree ratio was associated with ASPECT, OWNCD, RDDISTCD, SLOPE, or WATERCD. The most common damaging agent on dead trees was unknown (47 percent), and the most frequent damage types were dead terminals (3 percent) and conks or decay (2 percent).

Public Inventory Data, 2005

Dead-to-live tree ratio differed by OWNCD (P = 0.016) (table 1); the largest mean dead-to-live tree ratio was on county- or municipal-owned land, and the smallest was on National Forest land. Dead-to-live tree ratio differed by PHYSCLCD (table 1) and was significantly greater on narrow flood plains (P = 0.050) than on any other physiographic class. In addition, mean d.b.h. differed by TRTOPCD (P < 0.001) (table 1), and black ash on sites requiring stand conversion or regeneration with site preparation had smaller mean d.b.h. than black ash on sites with other TRTOPCD codes. Dead-to-live tree ratio also differed by TRTOPCD (table 1) and was significantly greater (P = 0.050) in stands requiring site preparation for regeneration than in stands with adequate stocking levels. Most declining and nondeclining trees (78 percent) were on sites in one of the poorest productivity classes (20 to 49 cf/ac/yr). Neither mean d.b.h. nor dead-to-live tree ratio was associated with ASPECT, OWNGRPCD, SITECLCD, RDDISTCD, SLOPE, or WATERCD. Unknown (21 percent) and logging or human (21 percent) were the most common damaging agents on dead trees, and, similar to the 2003 cycle, the most frequent damage types were dead terminals (5 percent) and conks or decay (3 percent).

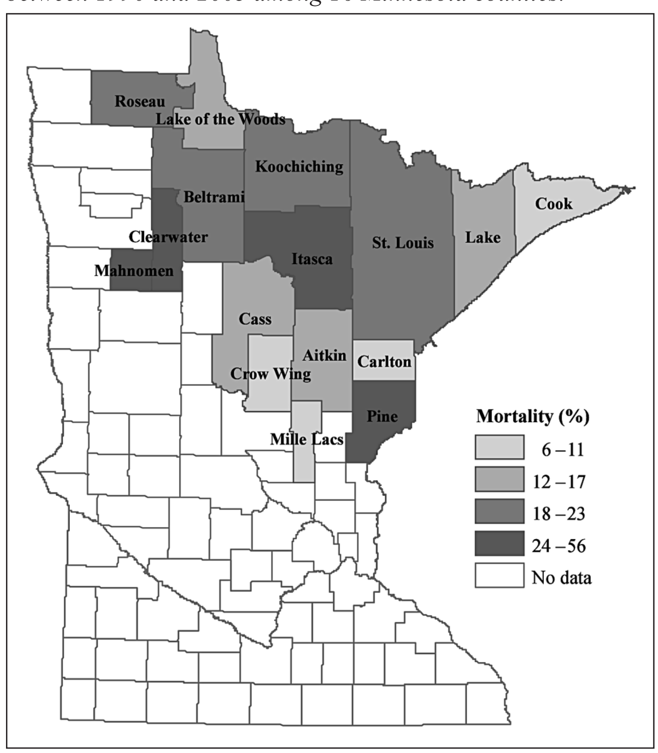
True Coordinate Inventory Data, 1990 Era and 2003

Black ash mortality increased by 18 percent between 1990 and 2003, and levels of mortality were spatially concentrated. Mortality differed among 16 counties (P < 0.001) (fig. 1) and was greatest in Mahnomen County (56 percent) and was least in Crow Wing and Mille Lacs Counties (6 percent and 7 percent, respectively). Mortality also differed among five Minnesota climate divisions in 1990 (P ≤ 0.001) but was similar among divisions in 2003 (P = 0.176). Mortality between 1990 and 2003 was largest in the Central (24 percent), Northwest (23 percent), and North Central (15 percent) Divisions. d.b.h. also differed among climate divisions in 1990 (P = 0.052) and in 2003 (P = 0.006), and the mean d.b.h. was largest in the Central Division in both time periods. In 1990, differences in black ash mortality (P = 0.02) existed among 20 ecological subsections, and the greatest mortality was in the Mille Lacs Uplands subsection. Mortality was similar among ecological subsections (P = 0.540) in 2003.

Between 1990 and 2003, change in d.b.h. was significantly greater in Upland than in palustrine/lacustrine NWI classes (P = 0.004). Similarly, between 1990 and 2003, change in d.b.h. increased as distance from a water-saturated NHD class (swamp) increased (P = 0.029).

Although significant relationships between black ash mortality and STATSGO soils variables, such as Pnddep (depth of surface water ponding on the soil), Clay (clay content), and Kffact (susceptibility of soil particles to detachment and movement by

Figure 1.—*Differences in levels of black ash tree mortality between 1990 and 2003 among 16 Minnesota counties.*



water), were observed, little of the variation was explained for tree mortality in the 1990 cycle ($R^2 = 0.10$) or the 2003 cycle ($R^2 = 0.02$). Between 1990 and 2003, change in black ash d.b.h. was significantly related to the STATSGO variable Bd (moist bulk soil density) and to mean temperature, but again little of the variation was explained ($R^2 = 0.03$).

Discussion

Black ash decline was associated with multiple, interacting factors. For example, black ash growth and survival were affected by site characteristics, such as physiographic features, including topography, soils, and wetness; weather conditions; land ownership; and proximity to city, State, and county roads. Generally, black ash growth and survival were poorer on flat, water-saturated sites of low quality. A positive relationship also existed between black ash decline and proximity to city, county, and State roads; several factors could contribute to this relationship. Road construction can alter the natural hydrologic flow through black ash stands and result in stagnant, standing water which can adversely impact tree growth and survival. Other factors include high levels of road deicing salt spray and runoff on land adjacent to roads in the winter. Road salt spray causes bud death and twig dieback in deciduous trees, and high levels of soil salt can damage leaves and reduce tree growth and vigor (Johnson and Sucoff 1999). In addition, road salt can decrease the cold hardiness of plants (Sucoff and Hong 1976). Vegetation near roadways can also be exposed to damaging pollutants from car and truck emissions.

Increases in black ash d.b.h. over time were negatively related to water-saturated classes in the NWI and NHD datasets, but no association occurred with black ash d.b.h. increases and the FIA plot water class (WATERCD). The difference may be due to disparity of scale because the WATERCD is on a point basis and both the NWI and NHD data are polygon based. In addition, the FIA water class definitions are different from definitions used by NWI and NHD. WATERCD is defined as a water body less than 1 acre in size or a stream less than 30 feet wide, whereas, definitions for water class in the NWI and NHD datasets do not include size limitations. Similarly, significant positive relationships existed between numbers of FHM dieback/decline polygons and proximity to city streets and county and State roads, but no associations existed between growth and mortality variables and the FIA distance to roads class. Again, a disparity of scale exists between the datasets. In addition, FHM dieback/decline variables and FIA growth and mortality variables are not interchangeable. Differences in mean d.b.h. among land ownership classes also could be due to varying geographic locations, management types, stand ages, legacies of land acquisition, or other unidentified causes.

The most common damage types recorded on black ash trees were dead terminals and decay. Disease and unknown causes were the most frequent damaging agents associated with black ash. It is difficult to meaningfully compare damaging agent codes and damage types from different FIA inventory cycles because methods have changed over time. For example, before 2000, damaging agents were coded for all trees. Beginning in 2000, however, the variable was collected for only dead and removed trees. In addition, data are collected in all seasons, and the ability to discriminate among types of tree damage and between damaged and undamaged trees differ depending on the season. Wetland species, such as black ash in Minnesota, are much easier to survey in the winter when the ground and surrounding water features are frozen and easier to traverse. It is very difficult, however, to differentiate damaged from undamaged trees in the winter because of the lack of foliage. In addition, decline results from complex interactions among multiple factors, so no one code or combination of codes could be expected to be sensitive enough to reliably distinguish declining from nondeclining trees.

In summary, FIA growth and mortality data proved valuable for discriminating among several factors that could be associated with black ash decline, such as physiographic and edaphic classes, but no FIA variables were found to separate declining trees from nondeclining trees. Many of the tree and plot characteristics used in this study could be easily derived from publicly available FIA data. The advantage of the true-coordinate FIA data is that it can be joined to various geospatial layers, and previously undetermined relationships may be revealed.

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