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Tree regeneration in black ash (*Fraxinus nigra*) stands exhibiting crown dieback in Minnesota

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ABSTRACT

Crown dieback and mortality of black ash (*Fraxinus nigra*) has been noted across the range of the species in North America for several decades. Causes of dieback and mortality are not definitive, but may be related to spring drought or excessive moisture. Where black ash is the dominant tree species in the forest, continued dieback and mortality may result in open, non-forest systems in the future. There is only limited research that has examined tree regeneration in black ash-dominated forests and none in stands experiencing dieback and mortality. Such studies are needed to better understand likely successional dynamics of impacted stands. Our objective was to quantify tree regeneration of black ash and other species in stands with and without crown dieback and mortality, to elucidate potential successional trajectories with decline and loss of black ash. We assessed 54 stands in Minnesota exhibiting a range of black ash crown dieback and mortality. Dieback and mortality in the black ash sapling layer were positively correlated with the same condition in the overstory, suggesting that saplings may not replace dead overstory trees. The next most abundant sapling-sized species was speckled alder, a non-canopy species, indicating that replacement tree species for black ash are not currently abundant. Black ash seedling densities were generally low, suggesting that a pool of advance regeneration is not available to replace black ash. Other canopy potential species were limited in the seedling layer, while abundance of shrubs was generally high. Our results suggest a high potential for loss of a tree layer in these stands and conversion to open, shrub dominated systems.

1. Introduction

Extensive crown dieback of black ash (*Fraxinus nigra* Marsh.) has been observed throughout its range in recent decades (Croxton, 1966; Trial and Devine, 1994; Livingston et al., 1995; USDA Forest Service, 2004; Palik et al., 2011). Symptoms include thinning crowns, epicormic branching, twig and branch dieback, and occasionally small, discolored leaves (Trial and Devine, 1996).

Crown dieback of black ash has an unknown disease etiology. Most dieback episodes do not seem to be associated with a specific disease or insect pest. Researchers working in Maine presented preliminary evidence suggesting that the onset of widespread dieback of black ash (called brown ash in their study) was correlated with severe May drought (Livingston et al., 1995; Livingston and White, 1997). Stronger evidence has shown that dieback is positively correlated with depth to a restrictive soil layer that may perch water and also with relative site wetness index (Trial and Devine, 1994; Palik et al., 2011), although it still could be triggered by a drought on these typically wet sites.

It is not clear that crown dieback always results in mortality, as black ash uses branch abscission to recover from stress (Kozlowski, 1991; Pallardy, 2008). As such, trees with dieback potentially could recover. However, in an earlier study, we did find generally higher percentages of standing dead black ash in stands with greater crown dieback (Palik et al., 2011).

Black ash stands with extensive crown dieback and/or recent mortality face an uncertain successional future, largely because regeneration dynamics and successional development after natural disturbance or harvesting have not been well studied in this ecosystem. Limited research suggests that seedling densities of black ash after clearcutting can be reasonably high (Peterson, 1989), with the expectation that the species will be a large component of the new forest after a stand replacement disturbance. We are aware of no studies that have examined tree regeneration in black ash dominated forests after natural disturbance, including dieback. However, an examination of black ash seedlings in hardwood swamps after emerald ash borer (*Agrilus planipennis*) mortality found densities of black ash seedlings to be sufficient for replacement of dead

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overstory trees, despite the species being a relatively minor component in these forests (Kashian and Witter, 2011). Erdmann et al. (1987) did suggest that black ash reproduction is almost entirely absent on better sites without canopy disturbance and that best seedling development occurs at around 45–50% of full sunlight. Moreover, they indicate that black ash readily sprouts from cut stumps. One could hypothesize from this information that crown dieback and mortality in black ash stands may result in new regeneration of black ash seedlings and, potentially, new sprouts from remnant stumps.

Given the large geographic extent of crown dieback and (sometimes) mortality of black ash in portions of its range (not caused by emerald ash borer), there is a need to better quantify regeneration characteristics and potential successful trends in declining stands. With this need in mind, we quantified regeneration status of black ash and other tree species in stands with and without crown dieback and mortality in the overstory. We asked the following questions: (1) is black ash regenerating and potentially replacing itself in these stands; and (2) what other species of advance regeneration are present in stands with crown dieback.

2. Methods

2.1. Study sites

This study was conducted in five counties in northeastern Minnesota. A total of 54 black ash stands were selected from a larger pool, without prior knowledge of their health condition. The criteria for stand selection included: (1) large enough to establish a minimum of three 0.02 ha circular plots spaced linearly 45 m apart (center to center) on a transect running through the stand; (2) no evidence of recent cutting in the stand; (3) no large artificial openings, ditches, roads, or trails through the stand; and (4) dominated by mature trees. Each study site was located on a National Wetlands Inventory (NWI) map, from which wetland status was determined (i.e., palustrine wetland or upland). Given the large number of sample stands, their wide geographic distribution, and their diverse ownerships, we had no detailed information on establishment histories or detailed age structures, other than to note that they were likely second-growth stands.

2.2. Field methods

During the growing seasons (mid-June to mid-August) of 2006 and 2007, 3–5 0.02 ha circular plots (depending on stand size) were established in each stand along a transect running through the stand perpendicular to the nearest access road. The center of the initial plot was placed approximately 45 m from the road center, so that the plot was within the stand proper and did not encompass ditching along the road. Subsequent plot centers were spaced 45 m apart.

In each plot the species and diameter, at 1.4 m height (dbh), of all live overstory trees (dbh $\geqslant$ 10 cm) and subcanopy/sapling trees (2.5 cm $\leqslant$ dbh < 10 cm) were recorded. The health condition of each black ash in these size classes was recorded as healthy, experiencing dieback, or dead. If a live tree had >15% of crown volume currently dead (excluding epicormic branches) it was considered to be experiencing dieback, otherwise it was considered healthy. Seedlings of black ash was tallied in each plot by two size classes ($\leqslant$0.5 m tall; >0.5 m tall to <2.5 cm dbh).

The combined abundance of woody understory species, other than black ash, that were <2.5 cm dbh was assessed using an index based on a visual estimate of the following attributes: (1) coverage over the entire plot (1 = <5% of the plot, 2 = 5–35%, 3 = 35–65%, and 4 = >65%), (2) density where it occurred in the plot (1 = sparse, 2 = medium, 3 = dense),and (3) height (1 = <1 m, 2 = 1–1.5 m, 3 = >1.5 m). The numerical value for each attribute was summed for a cumulative value for each plot. The summed index values for plots could potentially range from 3 to 10, based on combinations of the three attribute scores. Plot index scores were averaged for each stand. The dominant (up to five) species contributing to the index score on a plot (other than black ash) were recorded. We use these qualitative data to derive a general sense of importance of species other than black ash, but do not compare them to quantitative data statistically.

2.3. Data analysis

After confirming non-normal data distributions, Mann–Whitney Rank Sum tests were used to compare several variables between wetlands and uplands, including percentages of black ash that were healthy, exhibiting crown dieback, or dead. An alpha of 0.05 or less was considered significant for these tests.

Percentages of healthy, dying back, and dead black ash trees in stands were compared between overstory and sapling layers using Pearson correlations, after verifying distributional parametric assumptions. Pearson correlation also was used to relate densities of black ash seedlings to percentages of dying back and dead black ash in the overstory. For these analyses, an alpha value of 0.05 or less was considered significant.

3. Results

3.1. Forest composition

The overstory (stems with dbh $\geqslant$ 10 cm) of the 54 stands was strongly dominated by black ash which comprised around 80% of total density in both NWI classified uplands and wetlands (Table 1). The density of other species was generally very low, but did vary somewhat between uplands and wetlands (Table 1).

The sapling layer (2.5 $\leqslant$ dbh < 10 cm) was black ash dominated, with the species comprising 32% and 43% of total density in NWI wetland and upland sites, respectively (Table 2). Densities of other canopy capable tree species in the sapling layer were, individually, very low (Table 2). Speckled alder (*Alnus incana*) was abundant on both upland and wetland sites, while balsam fir and mountain maple (*Acer spicatum*) were moderately abundant on upland sites. Uplands had higher densities of trembling aspen and sugar maple saplings than wetlands (Table 2).

3.2. Crown dieback and mortality of overstory and sapling black ash

The percentage of healthy overstory black ash (dbh $\geqslant$ 10 cm) and those with crown dieback varied continuously among stands

Table 1
Density of trees (dbh $\geqslant$ 10 cm) by major species and NWI wetland system in black ash stands (n = 54).

Species	Wetland (n = 38)	Upland (n = 16)
Black ash	646 (211)[a]	564 (157)
American elm	14 (31)	14 (33)
Balsam fir	47 (85)	7 (14)
Balsam poplar	12 (25)	8 (25)
Green ash	15 (38)	25 (41)
White cedar	35 (124)	3 (8)
Trembling aspen	3 (12)	22 (39)
Sugar Maple	0.4 (3)	21 (74)
Red maple	4 (14)	5 (9)
Other species	31 (47)	13 (15)
Total	808 (262)	681 (179)

[a] Stems per hectare (±) 1 standard deviation.

Table 2
Density of saplings (2.5 ⩽ dbh < 10 cm) by major species and NWI wetland system in black ash stands (n = 54 stands).

Species	Wetland (n = 38)	Upland (n = 16)
Black ash	605 (537)[a]	512 (430)
American elm	56 (88)	46 (64)
Balsam fir	150 (233)	42 (89)
Balsam poplar	46 (176)	1 (4)
Mountain maple	105 (289)	13 (26)
Trembling aspen	11 (42)	54 (88)
Speckled alder	754 (877)	350 (684)
Sugar maple	3 (14)	41 (98)
Red maple	12 (34)	38 (88)
Willow	18 (34)	44 (122)
Other species	114 (145)	50 (40)
Total	1874 (1136)	1191 (837)

[a] Stems per hectare (±) 1 standard deviation.

from near 0% to almost 100% (Fig. 1). There were lower mean percentages of healthy trees and a higher mean percentage of trees with dieback on NWI wetland sites compared to upland sites, but the differences were not significant ($p \geqslant 0.1$). Percentage of dead black ash in the overstory ranged from 0% to 50% among stands, with a higher range of dead trees on NWI wetlands sites compared to upland sites, although means were not significantly different between wetlands and uplands ($p = 0.5$) (Fig. 1).

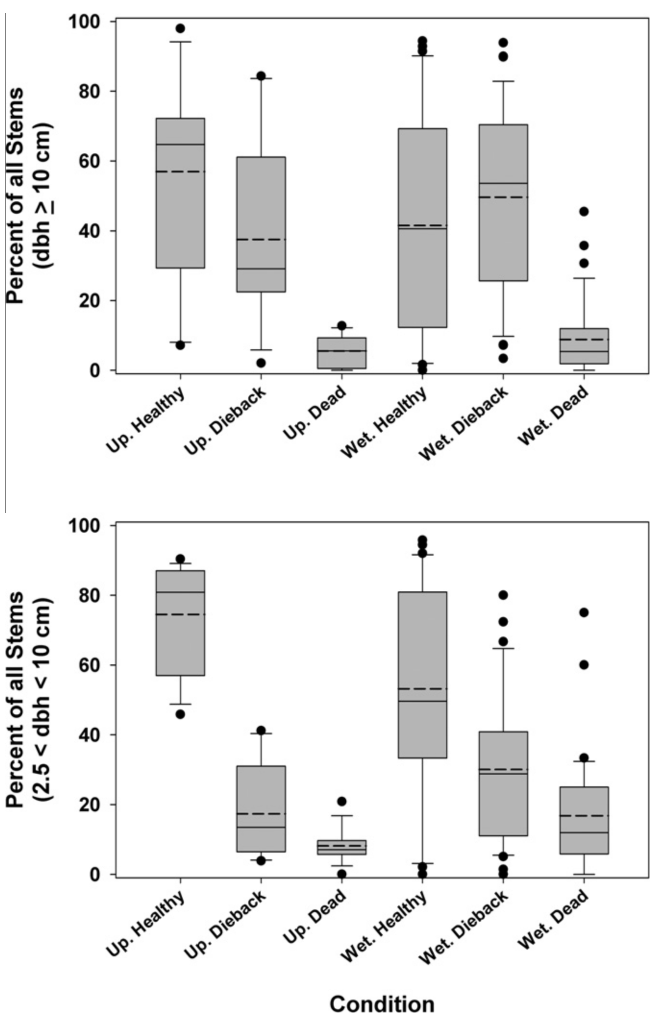

Fig. 1. Percentages of black ash overstory trees (dbh ⩾ 10 cm) that were healthy, experiencing dieback, or dead in 54 stands within palustrine wetlands (n = 38) and uplands (n = 16). Each box plot shows the mean (dashed horizontal line), the median (solid horizontal line), the 10th, 25th, 75th, and 90th percentiles, and outliers beyond the 10th and 90th percentiles.

The percentage of healthy saplings (2.5 cm ⩽ dbh < 10 cm) and those with crown dieback also varied continuously among NWI wetland sites, from 0% to 98% and 0% to 82%, respectively (Fig. 1). The ranges of both healthy saplings and those with dieback were much narrower on upland sites (45–90%, 5–42%, respectively). Mean percentage of healthy saplings was significantly higher on upland sites ($p = 0.012$), while the mean percentage of stems with dieback was marginally significantly higher on wetland sites ($p = 0.05$). Percentage of dead saplings ranged from 0% to 20% on uplands and 0% to 75% on wetlands, but was largely less than 35% overall. Mean percentage of dead saplings was marginally significantly higher on wetland sites than uplands ($p = 0.05$) (Fig. 1).

Percentage of trees with crown dieback in the sapling and overstory layers were positively correlated ($r = 0.72$, $p < 0.0001$). Moreover, percentage of saplings with dieback was positively correlated with percentage of dead trees in the overstory ($r = 0.56$, $p < 0.0001$). Percentage of dead trees in the sapling layer was not significantly correlated with percentage of dead trees in the overstory, after removing two outliers stands that had unusually high sapling mortality ($r = 0.23$, $p = 0.1$). Percentage of dead trees in the sapling layer was positively correlated with percentage of dieback in the overstory, both with and without the two outliers ($r = 0.40$, $p = 0.003$ with outliers; $r = 0.46$, $p = 0.0007$ without outliers). Relationships of health status between the overstory and sapling layers did appear to differ between NWI wetlands and uplands, due to the greater range of dead and dying back saplings on wetland sites.

3.3. Black ash seedlings and overstory health

Densities of small (<0.5 m tall) and large (⩾0.5 m tall and dbh < 2.5 cm dbh) black ash seedlings varied widely among stands, particularly in NWI uplands (Fig. 2). Overall, seedling densities were low, averaging around 500 stems/ha for the small size class and 1000 stems/ha for the large size class. There was no significant correlation between densities of seedlings and percentage of overstory trees with dieback or that were dead (p = 0.2–0.6).

3.4. Competing understory vegetation

Mean abundance index of woody species in the understory ranged from 4 to 10 among stands (Fig. 3). Seventy-two percent of stands had a mean index of seven or greater, indicating a fairly dense, well distributed, and tall understory layer. Moreover, this layer was overwhelmingly dominated by shrub species (Fig. 4). Speckled alder, raspberry (*Rubus* spp.), and beaked hazel (*Corylus cornuta*) were the three most abundant species in most stands. Canopy potential tree species (other than black ash) were rarely noted in this survey and were limited to two species; black cherry (*Prunus serotina*) in two stands and yellow birch (*Betula alleghaniensis*) in one stand (Fig. 4).

4. Discussion

We asked two questions related to regeneration of tree species in black ash stands experiencing crown dieback and mortality. First, is black ash regenerating and potentially replacing itself in these stands? Our results suggest limitations on self-replacement in stands with extensive crown dieback and/or dead black ash.

In general, black ash sapling densities were low, although similar to results from an earlier study in central Minnesota (Weber, 1985). However, in both studies, sapling densities were on the or-

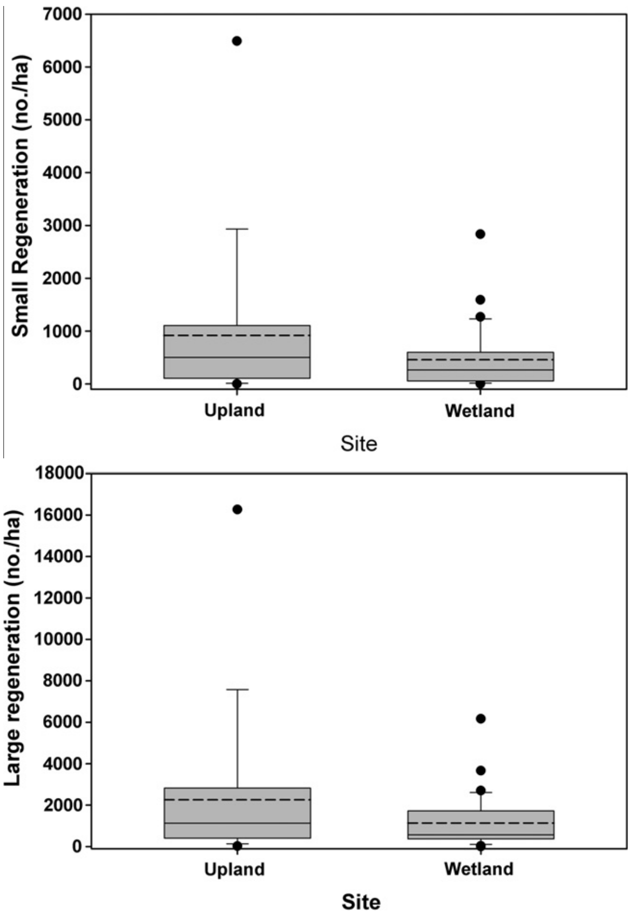

Fig. 2. Densities of small (<0.5 m tall) and large (⩾0.5 m tall and <2.5 cm dbh) black ash seedlings within palustrine wetlands (n = 38) and uplands (n = 16). Each box plot shows the mean (dashed horizontal line), the median (solid horizontal line), the 10th, 25th, 75th, and 90th percentiles, and outliers beyond the 10th and 90th percentiles.

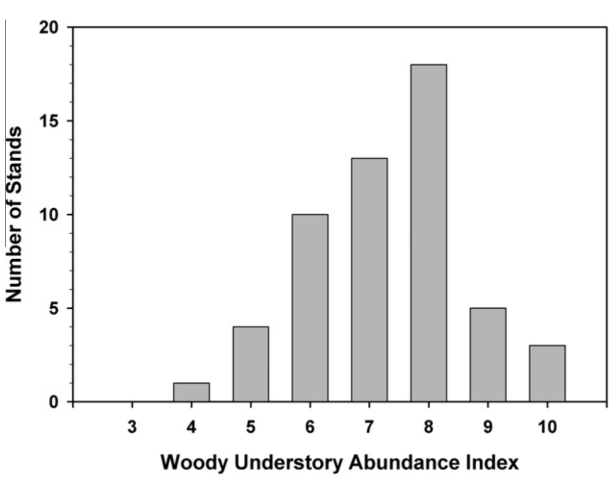

Fig. 3. Frequency (number of stands of 54 total) of woody understory (<2.5 cm dbh) abundance index scores in black ash stands. Potential index scores could range from 3 to 10.

der of 2–3 times lower than reported for northern Quebec (Tardif and Bergeron, 1992; Tardif et al., 1994). Moreover, percentages of saplings with dieback were positively correlated with percentages of overstory trees that were dying back or were dead, and percentage of dead saplings was positively correlated with percentage of

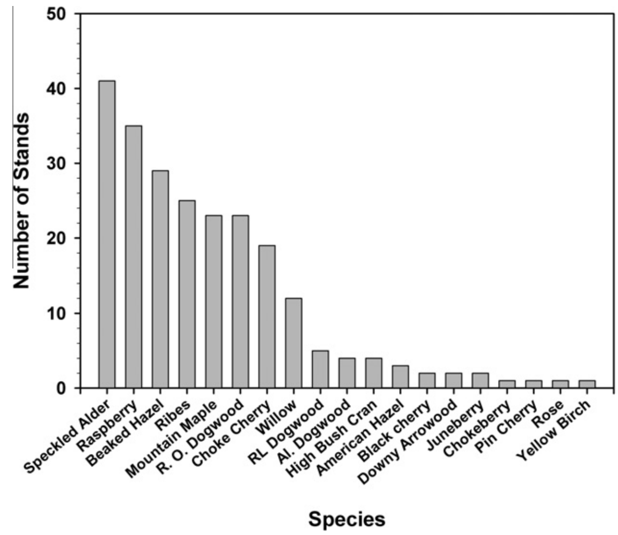

Fig. 4. Frequency (number of stands of 54 total) of woody understory species (<2.5 cm dbh) occurrence, within the top five most abundant species, in black ash stands.

overstory black ash with dieback. In other words, the greater the amount of dieback and mortality in the overstory, the greater the amount of the same in the sapling layer, such that the number of healthy saplings may not be sufficient to replace overstory black ash as they die, although this can only be verified with longer term monitoring. Dieback and mortality in a sapling layer are not unusual when there is competition for resources and perhaps herbivory occurring, but it is also possible that the unknown factors resulting in health problems in the overstory are impacting the sapling layer as well. Black ash seedlings were generally limited in most stands. Both small (<0.5 m tall) and large (>0.5 m tall, but <2.5 cm dbh) seedling densities were low, averaging around 500/ha and 1000/ha, respectively. Other studies in black ash dominated stands reported higher densities on average. For instance, Weber (1985) found mean densities of 8100/ha and 1450/ha for large and small seedlings, while Peterson (1989) reported densities of 4900/ha and 3333/ha for small and large seedlings, respectively. These amounts were deemed sufficient to sustain black ash dominance in these stands. In emerald ash borer (EAB) impacted swamps in Michigan, where black ash comprised only about 15% of overstory basal area, Kashian and Witter (2011) reported 8 to 18-fold (depending on year) higher densities of small black ash seedlings (<0.5 m) than in our study, while densities of larger seedlings were similar to the values we report. They also felt that these densities would be sufficient to sustain a future population of overstory black ash, if mortality from EAB were to discontinue.

In our study, there were no increases in large or small seedling densities with higher percentages of dieback or mortality in the overstory, as might occur if light was limiting the establishment or survival of black ash seedlings. The generally lower densities of seedlings that we found, compared to similar studies, and the lack of increases in densities with a more open overstory, suggest limited self-replacement of black ash from the seedling layer in stands with black ash mortality. However, the potential for self-replacement could improve if seedling densities were to increase substantially in association with an episodic recruitment event.

We also asked what other tree species are present in our study stands and might these replace black ash? Black ash makes up about 80% of stems in the overstory and individually other species occurred at low densities. Consequently, current canopy stems other than black ash will not contribute substantially to replacement. The trend in the sapling layer is not appreciably different than in the overstory. While black ash makes up a lower percentage of total saplings stems (32% and 43% on wetlands and uplands, respectively), individually other canopy potential tree species occurred in low densities. Our results for both the overstory and sapling layers are consistent with those from other black ash ecosystems in the region (Kurmis and Kim, 1989). Moreover, the most abundant woody species other than black ash was speckled alder, a species that does not reach canopy sizes in these ecosystems. Consequently, there does not appear to be substantial replacement potential of dead or dying black ash from current sapling layer species, suggesting the potential for conversion to an open shrubland condition in the future.

Except for black ash, we examined the woody regeneration layer in only a semi-quantitative way using an index of abundance that integrated density, spatial distribution, and height of an understory layer. Based on this index, our results suggest a generally high potential for competitive inhibition of black ash seedlings and, in fact, regeneration of any potential canopy species. The majority of stands had abundance indices of 7–10 (the maximum score), indicating a dense, well distributed, and tall understory layer. More importantly, there were only three stands that had canopy potential tree species in high enough abundance to be noted in this survey. Moreover, the species observed, black cherry and yellow birch, are generally not abundant in any forest type in the region, including black ash ecosystems. In contrast, mirroring results from the sapling layer, speckled alder was generally highly abundant, as were raspberries and beaked hazel. Collectively, these results suggest limited potential for dead and dying black ash to be replaced by canopy potential tree species that currently reside in the understory/regeneration layer.

5. Management implications

Crown dieback and mortality were high in many of the stands we examined. While the causes of the current dieback and mortality events are not clear (Palik et al., 2011), both were significantly higher on wetland versus upland sites, suggesting an underlying hydrologic contributor (e.g., overly wet conditions or overly dry conditions on wet sites). Regardless of the cause, the apparent limited potential for black ash self-replacement and the currently limited abundance of other canopy potential tree species suggest that loss of forest cover in impacted stands is a possibility. This conclusion is based on a one-time evaluation of crown conditions and regeneration; longer-term observation is needed to elucidate actual responses. However, the regeneration bottleneck that we observed may actually be exacerbated in the future if loss of overstory trees continues and, in turn, if this leads to upward fluctuating water tables due to loss of transpiration. Higher water tables for longer periods of the growing season would likely result in regeneration failures (Erdmann et al., 1987). Moreover, loss of seed sources with overstory mortality will limit new seedling establishment in the future (Kashian and Witter (2011). If mortality of trees with crown dieback continues or increases, and given the limited amount of natural advance regeneration of black ash and other replacement tree species, it may be prudent plan for artificial regeneration of other species. Removal of currently healthy black ash without first securing regeneration in a stand is likely to only hasten conversion of these forests to shrubs, or potentially grasses or sedges.

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