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Potential for regenerating major and minor ash species (*Fraxinus* spp.) following EAB infestation in the eastern United States

Joshua J. Granger *, John M. Zobel, David S. Buckley

Department of Forestry, Wildlife and Fisheries, University of Tennessee, Knoxville, TN 37996, USA

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ABSTRACT

Incidentally introduced in 2002, the expansion of emerald ash borer (EAB) led to widespread ash mortality throughout the eastern United States. A great deal of effort has been invested in containing and controlling this forest invasive species, whereas the ability to regenerate ash from extant seedling and sapling populations following the initial EAB invasion has received less attention. Using recent data available from the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis program (FIA), we quantified ash seedling and sapling regeneration counts across FIA forest type groups containing white, green, black, blue, pumpkin, and Carolina ash. In addition, all other seedling and sapling species in these stands were quantified to determine overall species composition of the regeneration and the potential for inter-specific competition. Ash seedlings and saplings represented the greatest proportion of regeneration across most forest type groups containing mature ash. Top competitors of ash tended to be far less economically and ecologically valuable. If retaining ash in current stands remains a management goal, and provided that an effective biological control for EAB is identified and established across infested areas, the success of extant ash seedlings and saplings into larger size classes will depend on silvicultural treatments designed for controlling inter-specific competition across stand cohorts.

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1. Introduction

Originally identified in Detroit, Michigan and Windsor, Ontario in 2002, the emerald ash borer (EAB; *Agrilus planipennis* Fairmaire) has quickly spread across the eastern United States and killed millions of ash (*Fraxinus* spp.) trees (Poland and McCullough, 2006). Inadvertently introduced from Asia, few efforts have proven effective in slowing the spread of this forest pest and reducing its impact on native ash populations. Upon infestation and regardless of initial tree health, a stand can lose nearly 100% of its mature ash trees in just three to five years (Gandhi et al., 2008). Despite heavy losses of larger sapling and mature trees, ash seedlings and small saplings often survive.

As a common component of natural forest systems, the loss of ash has major economic and ecological consequences. Ash has been a major source of sawtimber in the United States representing 7.5% of annual harvests. Based on an estimate of over 8 billion forest ash trees in the United States, the value of the genus has been estimated at $282.3 billion (Poland and McCullough, 2006). Ecologically, ash provides wildlife with shelter, browse and seeds, which are consumed by a variety of birds, small mammals, and insects (Schlesinger, 1990). Several ash species tolerate frequent inundation in swamps, alluvial floodplains, and pond margins where stand diversity is limited. As a result of their prominence, several ash species are key regulators of hydrological processes and community assembly in these systems (Ellison et al., 2005; Slesak et al., 2014).

There are three major and three minor ash species commonly recognized in the eastern deciduous forests. The two most abundant and widespread ash species are white ash (*Fraxinus americana* L.) and green ash (*Fraxinus pensylvanica* Marsh.). Though similar in appearance, the two species differ greatly in site requirements. White ash is commonly located on moist uplands and dry to mesic woodlands but is rarely a major component of forest canopies. Green ash is frequently found on mesic, poorly drained bottomlands, and along riparian corridors where it is often a major canopy component (Hardin et al., 2001; Poland and McCullough, 2006). Black ash (*Fraxinus nigra* Marsh.) is the third major ash and is found in nearly pure stands within deciduous swamps in the northern Great Lakes Region and Canada (Hardin et al., 2001; Tardif and Bergerson, 1999) (Fig. 1). Blue ash (*Fraxinus quadrangulata* Michx.), the first of the minor ash species, is common within the Ohio and Upper Mississippi river valleys and is generally associated with dry, rocky, limestone uplands. Carolina ash (*Fraxinus caroliniana*

* Corresponding author.
E-mail address: grangerjosh@hotmail.com (J.J. Granger).

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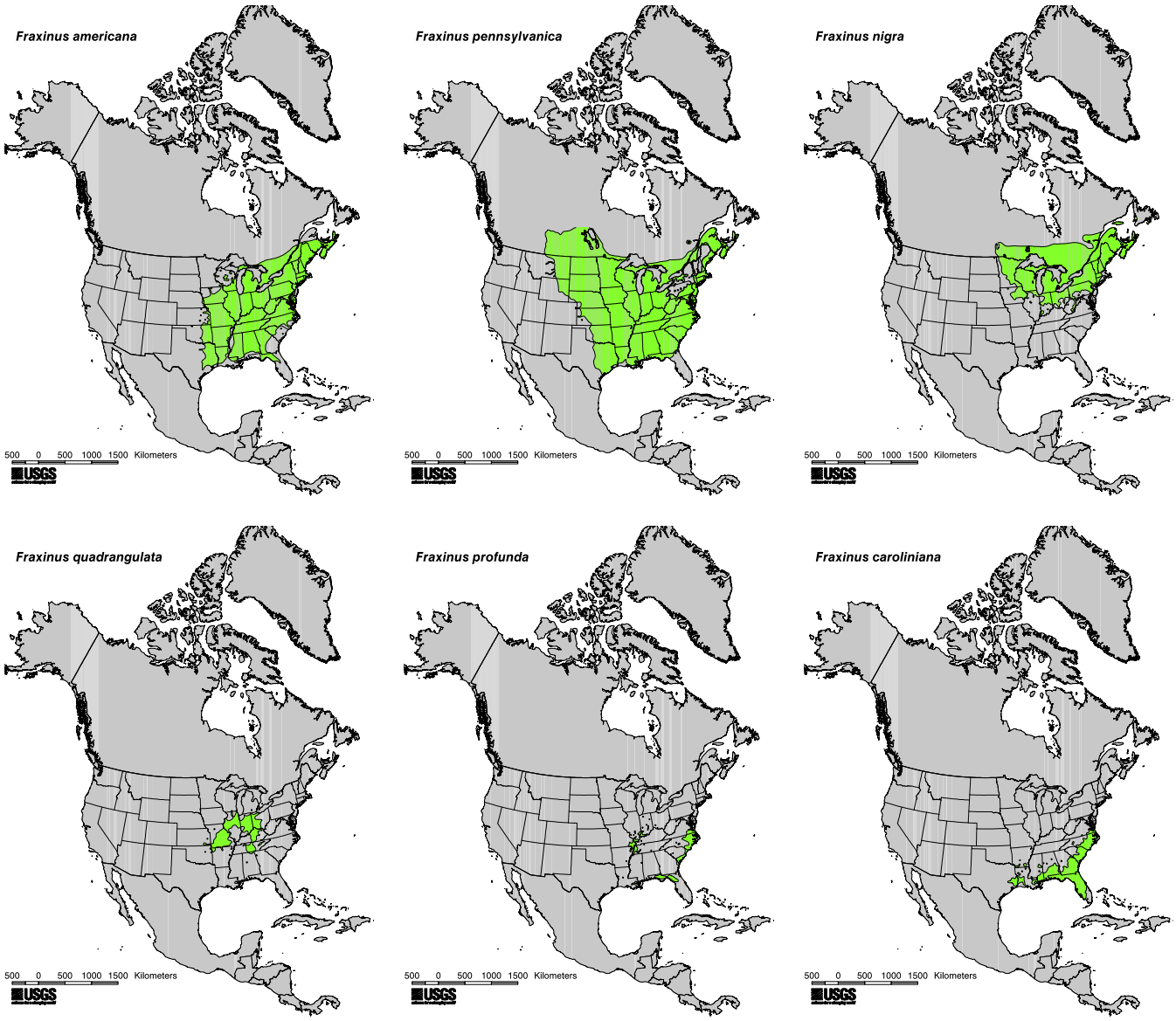

Fig. 1. Distribution maps of white ash (*Fraxinus americana*), green ash (*Fraxinus pennsylvanica*), black ash (*Fraxinus nigra*), blue ash (*Fraxinus quadrangulata*), pumpkin ash (*Fraxinus profunda*), and Carolina ash (*Fraxinus caroliniana*). Source: USGS map based on Atlas of United States trees by Elbert L. Little, Jr.

Mill.) and pumpkin ash (*Fraxinus profunda* (Bush) Bush) have more discontinuous ranges and are restricted to swamps, ponds, bottomlands, and coastal plain communities within the eastern and southeastern United States. Pumpkin ash also occurs along streams and rivers within the Ohio and Upper Mississippi river valleys (Hardin et al., 2001; Nesom, 2010a, 2010b) (Fig. 1).

Over the past two centuries, the exponential increase in the introduction of forest pests and pathogens in North America has resulted in large changes in forest structure and function in conjunction with host mortalities (Liebhold et al., 1995; Gandhi and Herms, 2010). Some of the most devastating of introductions include pests such as the European bark beetle (*Scolytus multistriatus* Marsh.), which has served as the principal vector of Dutch elm disease (*Ceratocystis ulmi* Buism.). This disease has been responsible for the loss of over 200 million mature elm (*Ulmus* spp.) trees native to the eastern half of the United States beginning in the early 1920s (Gandhi and Herms, 2010). The Hemlock woolly adelgid (*Adelges tsugae* Annand) and Balsam woolly adelgid (*Adelges piceae* Ratzeburg) have caused widespread mortalities in Appalachian forests containing hemlock (*Tsuga* spp.) and fraser fir (*Abies fraseri* (Pursh) Poir) since the mid 1980s (Orwig et al., 2002; Ellison et al., 2005; Small et al., 2005; Pauley and Clebsch, 1990; Hollingsworth and Hain, 1991). Further, American chestnut blight (*Cryphonectria parasitica* (Murrill) Barr) killed approximately 3.5 billion American chestnut (*Castanea dentate* (Marsh.) Borkh.) trees in North American between the years 1920 and 1940. While these pests and pathogens have long altered the forest ecosystems of eastern North America, the recent introduction and spread of EAB presents both challenges and opportunities. In the case of all ash species native to eastern North America, susceptibility to EAB and the continued loss of mature ash trees from forest communities will challenge our ability to conserve genetic diversity and maintain ecosystem services and functions.

We examined the hypothesis that extant ash regeneration is sufficiently abundant and diverse in both seedling and sapling stages of regeneration to adequately recruit ash back into stands as ash overstories succumb to EAB. In contrast to the lack of data during earlier forest pest introductions, extensive regional and

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