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Distribution and growth of autumn olive in a managed forest landscape

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A B S T R A C T

Autumn olive (*Elaeagnus umbellata*) poses significant challenges for forest managers. The ability to predict when and where this species will become a problem would allow managers to more effectively prioritize control efforts and implement the most efficient management practices available. Several studies have sought to determine which key factors lead to greater abundance of exotic, invasive plants on certain sites and their spread at multiple scales. Previous research suggests that disturbances and increased light can be important. The overall goal of this research was to identify factors associated with forest road edges that are most important in facilitating autumn olive. Specific objectives were to: (1) document site factors significantly related to the presence and success of autumn olive, (2) investigate the hypothesis that southern aspects have greater abundance, patch depth and growth of autumn olive than other aspects, (3) examine the hypothesis that there is a negative relationship between the abundance and height of autumn olive and the abundance and height of native species, and (4) determine if the relationship between autumn olive abundance and height and the abundance and height of other invasive species is positive. Densities of autumn olive, native woody species, and other woody exotic, invasive species in different size classes were quantified in plots located along forest-road edges having northern, southern, eastern, and western aspects. Slopes, elevation, road opening width, canopy cover, and basal area were also quantified at each plot location. In addition, presence and absence of autumn olive, slope, elevation, canopy cover, and road canopy closure were quantified at randomly selected points along major and minor gravel roads within the study area. Larger autumn olive were most abundant along edges with southern aspects and patches of autumn olive were deepest on edges with northern and southern aspects. Autumn olive height and abundance were positively related to the height and abundance of both native and exotic, invasive woody plants. Slope, elevation, road canopy cover, road opening width, and road type were found to be important factors influencing autumn olive establishment and success. As a result, these factors may prove useful in the development of habitat suitability models and GIS-based risk maps that managers could use to more effectively address this invasive species.

1. Introduction

Autumn olive (*Elaeagnus umbellata*) is an important, exotic, invasive shrub that is often ubiquitous along road edges. This species is native to Asia, and was introduced to North America in the 1830s. It was originally planted on disturbed sites to provide cover and food for wildlife and stabilize the soil (Darlington and Loyd, 1994; Fowler and Fowler, 1987). The dark green leaves with silvery, orange-flecked undersides readily stand out among native plants in the central hardwood forest landscape. Autumn olive attains heights up to 7 m (Kohri et al., 2011), but more typically reaches 4.5 m in the Southeast (Darlington and Loyd, 1994) with upright, arching, or a mixture of upright and arching growth forms. Typically single-stemmed as a seedling, the plant has the potential to produce multiple stems from the main root as it becomes older. Both the branches and the main bole produce sharp spines up to 2.54 cm in length.

Autumn olive produces light yellow, campanulate, clustered flowers beginning in early spring. The flowers develop into small brown or olive green drupes that turn bright red in late summer. Generally, berry production begins in individuals aged 3–5 years (Fowler and Fowler, 1987). Berries of autumn olive persist on the branches into winter and provide a steady food supply for birds and small mammals when other sources of sustenance are less abundant (Darlington and Loyd, 1994; Fowler and Fowler, 1987; Kohri et al., 2011). Once fruits are consumed and the arils are removed, 99% of autumn olive seeds germinate within 6 days

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(Kohri et al. 2002). An autumn olive 5 cm in diameter can produce approximately 5000 fruit annually, and larger individuals can produce as many as 10,000 berries in a season. Kohri et al. (2011) reported that frugivorous birds in Japan preferentially consume autumn olive fruits over the fruits of other species such as multiflora rose (*Rosa multiflora*) and Oriental bittersweet (*Celastrus orbiculatus*), creating opportunities for greater spread to, and proliferation in, favorable locations. Most autumn olive seed is dispersed within 200–300 m of the parent plant (Kohri et al., 2011).

Autumn olive often forms dense patches once it becomes established, and can competitively exclude native forest species within these patches (Catling et al., 1997). With its propensity to spread laterally and to arch, the crowns of autumn olive are particularly effective in shading out competitors. Once present in an ecosystem, autumn olive's ability to fix nitrogen (Darlington and Loyd, 1994; Schlesinger and Williams, 1984) has the potential to impact other plant species and ecosystem processes. Ultimately, the addition of autumn olive into a native forest ecosystem has the potential to impact forest dynamics and long-term development.

In actively managed forests impacted by silvicultural practices such as thinnings, timber harvests, and prescribed burning, a primary concern is that well-established roadside populations of autumn olive will serve as a source of propagules that will disperse into and dominate more interior forest areas. Yates et al. (2004) reported 0.39 autumn olive stems/m^2 in interior understories and 0.84 stems/m^2 along roadsides and other edges. Although twofold, this difference was not statistically significant. In a similar comparison, Sanford et al. (2003) reported that cumulative 2-year survival of autumn olive seedlings planted in understory areas was 62%, while that of seedlings planted in open areas was 88%. This difference in survival was not statistically significant, but the autumn olive seedlings planted in interior forest understories had significantly less height growth, biomass, and leaf area than the seedlings planted in open areas (Sanford et al., 2003). These results suggest that although autumn olive can establish and grow in the understory of interior forest areas, the largest and most fecund individuals are likely to be produced in open conditions along roads and in adjacent forest areas impacted by silvicultural practices and other disturbances.

Due to the competitive effects of autumn olive and its ability to invade forests adjacent roadside populations, a greater understanding of factors leading to the development of extensive populations of large, seed-producing individuals is needed. Tools such as GIS-based risk maps would enhance the ability of managers to predict where these important source populations are likely to develop, thereby increasing the efficiency of their detection and management. Variables such as aspect, slope, elevation, and canopy cover can be obtained from topographical maps, remote sensing, and GIS coverages, and lend themselves to the development of invasive plant habitat suitability models (Crall et al., 2013) required to develop risk maps.

Previous research has resulted in several hypotheses concerning key variables that can facilitate or hinder exotic invasions. Roads are widely recognized as an important conduit for the establishment and spread of invasive species (Flory, 2006; Forman and Alexander, 1998; Ibañez et al., 2009; Mortensen et al., 2009; Watkins et al., 2002; Yates et al., 2004). In addition, forest ecosystems adjacent to roads have a higher probability of containing exotic species (Forman and Alexander, 1998). In exotic plant invasions, the aspect of the forest-road edge has been suggested to alter biotic and abiotic site factors based on differences in photosynthetically active radiation (Burgess and Sharpe, 1981; Chen et al., 1995), which, in turn, influence the likelihood of exotic plant establishment (Fraver, 1994). In the northern hemisphere, southern aspects receive longer periods of direct sunlight than northern aspects (Burgess and Sharpe, 1981, Chen et al., 1995, Fraver, 1994, Gehlhausen et al., 2000, Matlack, 1993; Palik and Murphy, 1990), which could facilitate invasions by exotic plants. This hypothesis was supported by results obtained by Fraver (1994) in North Carolina, in which greater numbers of exotic plant species occurred on forest edges with a southern aspect than on those with a northern aspect.

In terms of biotic site factors, increased native plant diversity has been hypothesized to partially limit the degree to which invasive plants proliferate at a given site (Davies et al., 2007; Elton, 1958; Lodge, 1993; Lonsdale, 1999). The basis for this hypothesis is that there are fewer niches available for exotic, invasive plants when native plant diversity is high. Empirical data, however, have shown that the relationship between the diversity and abundance of native species and exotic, invasive plants can be negative, positive (Davies et al., 2007; Howard et al., 2004) or insignificant. An alternative hypothesis that may explain negative relationships between exotic and native plants is that native plants are outcompeted by the invasive species, thereby decreasing their diversity and abundance (D'Antonio et al., 1998; Greene and Blossey, 2012; Meiners et al., 2001).

Finally, several hypotheses have been developed concerning the importance of disturbances in facilitating exotic plant invasions across many types of sites (Bergelson et al., 1993; McGlone et al., 2009). Recent disturbance often enhances the availability of resources such as light (Spence et al., 2011). Disturbances can also create more favorable seedbed conditions for invasive plants. The removal of leaf litter was demonstrated to enhance the spread of Japanese stilt grass (Oswalt and Oswalt, 2007). Further, Marshall and Buckley (2008a) found that the rate of spread of Japanese stilt grass increased substantially with leaf litter removal combined with mineral soil disturbance. Although Japanese stilt grass is ranked as shade-tolerant (Barden, 1987; Winter et al., 1982), increases in the height and abundance of this species with decreasing canopy cover have also been reported (Marshall and Buckley, 2008b; Winter et al., 1982), suggesting the importance of the combination of both canopy and soil disturbance in the success of this exotic, invasive species. Garlic mustard (*Alliaria petiolata*), a species well known for its ability to invade shaded understories, has been shown to produce greater total biomass in environments with increased amounts of light (Meekins and McCarthy, 2000; Myers et al., 2005). As a result, it can be argued that this species is also likely to benefit from canopy disturbance. If site factors such as canopy disturbance benefit multiple invasive species across a range of site types, it follows that the abundance and performance of one invasive species will be positively related to the abundance and performance of others.

The overarching goal of this research was to identify basic factors correlated with increased autumn olive patch size, stem density, and height along forest roads. Particular emphasis was placed on variables that could readily be used to develop invasion risk maps for this species. Specific objectives were to (1) document site factors significantly related to the presence and success of autumn olive, (2) investigate the hypothesis that southern aspects have greater abundance, patch depth and growth of autumn olive than other aspects, (3) examine the hypothesis that there is a negative relationship between the abundance and height of autumn olive and the abundance and height of native species, and (4) determine if the relationship between autumn olive abundance and height and the abundance and height of other invasive species is positive.

2. Materials and methods

2.1. Study site

Autumn olive was studied on Chuck Swan State Forest and Wildlife Management Area (CSSFWMA), a contiguous 9997 ha tract