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Variability and persistence of post-fire biological legacies in jack pine-dominated ecosystems of northern Lower Michigan

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ABSTRACT

On the dry, flat, jack pine (*Pinus banksiana* Lamb.)-dominated ecosystems of the northern Lake States and eastern Canada, wildfire behavior often produces narrow, remnant strips of unburned trees that provide heterogeneity on a landscape historically shaped by stand-replacing wildfires. We used landscape metrics to analyze a chronosequence of aerial imagery to examine these "stringers" of mature trees within historical wildfires in northern Lower Michigan. Our major objective was to describe the natural range of variability of stringer patterns and their persistence and change during the fire-free interval. Field studies were then used to examine stringer composition and structural variability. Stringers were found to occur in all fires >1000 ha, in about one-third of wildfires >80 ha, but never in fires <80 ha, likely because of the lack of fire intensity on smaller fires that is necessary for stringers to be formed. Stringers were typically composed of many small, well-aggregated patches that represented 3–14% of the area within the burn perimeter, and stringer formation was relatively independent of pre-fire forest structure or composition. Stringer patterns changed mostly in the first decade after the fire that created them and then stabilized. Major changes that occurred in stringer patterns after this period were most often due to human activities, highlighting their natural persistence through the fire-free interval. The historical persistence and importance of these features also highlights their importance on modern fire-prone landscapes, particularly in northern Lower Michigan where a high proportion of land management is focused on jack pine plantations for breeding habitat for Kirtland's warbler (*Dendroica kirtlandii* Baird), an endangered species.

1. Introduction

Biological legacies are well documented as being important for forest ecosystem recovery following stand-replacing disturbances (Franklin et al., 2000). Post-disturbance legacies in forests are often considered to be small components of the prior vegetation, such as green trees, surviving plant parts (including propagules), dead wood, organic soil, and other surviving organisms (Harmon et al., 1986; Maser et al., 1988). Entire patches of mature forests that survive a disturbance are common on many landscapes and may be thought of as ecosystem-level biological legacies that provide refugia and allow persistence of many species while the surrounding landscape recovers from the disturbance (Perry and Amaranthus, 1997). Such patches are critical for the continuity they provide between the pre-disturbance and post-disturbance ecosystems, and play important roles as seed sources (White and Mladenoff, 1994), species habitat (Carey and Johnson, 1995), and in ecosystem function (Franklin et al., 1981; Spies, 1997). Biological legacies in general have important implications for the conservation of biological diversity where forest landscapes are heavily disturbed (Lindenmayer and Franklin, 2002).

Biological legacies are often explicitly addressed in ecological forestry, which emphasizes a wide range of ecological values – such as forest biodiversity and ecosystem processes – as well as timber production (Seymour and Hunter, 1999). Ecosystem-level biological legacies represent important contributions to structural complexity and heterogeneity on landscapes where silvicultural practices are geared toward mimicking natural disturbance regimes (Franklin et al., 1997; Hunter, 1999). This type of legacy is particularly important on landscapes characterized by stand-replacing wildfires, where individual surviving trees within the fire perimeter are uncommon.

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Stand-replacing wildfires have historically shaped the structure of dry, sandy, jack pine (*Pinus banksiana* Lamb.)-dominated ecosystems of the northern Lake States and eastern Canada (Whitney, 1987). Forest composition in this region is dominated by jack pine where fire interval is relatively short (30–50 years) and fire severity is stand-replacing (Whitney, 1987; Simard and Blank, 1982; Frelich, 2002). Fire behavior during large wildfire events on these flat outwash plains has been documented to preserve long, narrow strips of unburned trees arranged parallel to the direction of fire spread (Fig. 1; Haines, 1982; Foster, 1983; Simard et al., 1983; Arseneault, 2001). The mechanisms behind the creation of these unburned strings of trees (also called "tree crown streets" (Haines, 1982); hereafter termed "stringers" for brevity) is unclear. Physical laboratory experiments (Haines and Smith, 1983) and field observations during fire events (Haines, 1982; Simard et al., 1983) have attributed stringer formation to horizontal-roll vortices that develop in a parallel orientation to the wind direction (Haines and Smith, 1983). These horizontal roll vortices create a strong downward draft that effectively "blows out" the flames along their length, protecting trees at the base of the downward movement from lethal heat. The stringers are often (although not always) formed near the successive flanks of the fire as it spreads, and thus can mark the fire perimeter as the fire develops (Arseneault, 2001). Horizontal roll vortices (and associated stringers) have been also documented in other regions and ecosystem types where stand-replacing fires occur, including general boreal forests (Foster, 1983), ponderosa pine (*P. ponderosa* Douglas ex C. Lawson) forests in Arizona, pinyon pine (*P. edulis* Engelm., *P. monophylla* Torr. & Frém., *P. quadrifolia* Parl. ex Sudw.) forests in California (Haines and Smith, 1983), pocosin and pond pine (*P. serotina* Michx.) in North Carolina (Wade and Ward, 1973), and in sawgrass (*Cladium* spp.)-dominated ecosystems in the Everglades (Klukas, 1972). Another potential explanation for stringer formation is that the flanks of spot fires ahead of the main fire front under burn the surface beneath live trees, protecting them from consumption when the main fire front burns over the spot fire area (P. Huber, pers. obs.). Despite the prevalence of stringers in many regions and ecosystem types, their natural range of variability in frequency, size, shape, composition, and longevity after formation has thus far never been examined, making it difficult to incorporate these biological legacies into silvicultural prescriptions for jack pine-dominated ecosystems within an ecological forestry context (e.g., Corace et al., 2009).

The jack pine-dominated ecosystems of Michigan, Wisconsin, and Ontario constitute the breeding grounds for the federally endangered Kirtland's warbler (*Dendroicus kirtlandii* Baird). Kirtland's warblers nest exclusively under young, dense, patchy stands of jack pine historically created by wildfires (Whitney, 1987; Comer et al., 1995; Probst et al., 2003) for only a short window of time before abandoning them due to successional changes in stand structure (Probst, 1986). Given the effectiveness of fire suppression in the region, the Kirtland's Warbler Recovery Plan (Byelich et al., 1976) encouraged the creation and management of jack pine plantations to ensure a continuous supply of suitable habitat on a rotational basis (Probst and Weinrich, 1993; Kepler et al., 1996). This multi-agency management of jack pine plantations has increased warbler populations from about 400 birds in 1971 to nearly 3600 birds today (unpublished annual census data).

Kirtland's warbler breeding habitat management presents an informative case study for the occurrence and importance of post-wildfire biological legacies and their inclusion into intensive and extensive silvicultural prescriptions (Corace and Goebel, 2010). In most jack pine plantations created for warbler habitat, trees are specially arranged in an "opposing wave" pattern to incorporate grassy openings (~0.1 ha) that mimic wildfire-generated tree patterns to a degree (Byelich et al., 1976; Probst, 1988). The Strategy for Kirtland's Warbler Management (USDA Forest Service, 2001) and other research (Probst, 1988; Corace et al., 2010a) recommends the maintenance of biological legacies such as snags and even stringers within warbler plantations; these legacies are increasingly recognized as important for structural and biological diversity and thus use of these lands by species other than Kirtland's warbler (Byelich et al., 1976; Probst, 1988; Corace

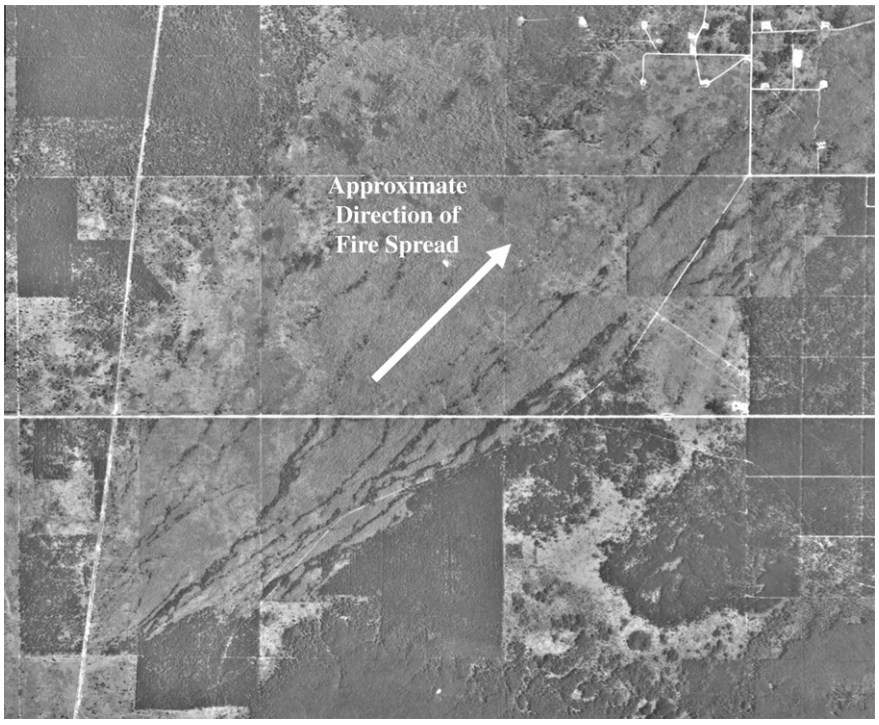

Fig. 1. Stringers (darker bands within lighter burned area) located within the perimeter of a portion of the 1968 Fletcher Fire in Kalkaska County, Michigan (photo date 1973). Note that stringers are oriented parallel to the direction of fire spread and are composed of variable-sized patches of unburned trees that are arranged into long strips.