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Use of Prescribed Burning to Restore Jack Pine Ecosystems in the Great Lakes Region

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Introduction

In the 1960s, after decades of fire suppression, land managers and ecologists developed the attitude that fires are a natural part of many ecosystems, rather than a purely destructive force (Johnson & Miyanishi 1995). Prescribed burning is a management technique that evolved from this shift in attitude, and has been used in a variety of fire-dependent ecosystems including prairies, savannas, and forests. Today, the reintroduction of fire is often considered necessary, because long-term suppression is assumed to have changed the character of many fire-dependent ecosystems. The decision to reintroduce fire, however, is often based on a general notion of fire as a historically-important process that implicitly should be introduced. Although such a premise has merits, the use of prescribed burning as a restoration tool is only advisable to achieve specific goals (Johnson & Miyanishi 1995).

Our current knowledge of prescribed burning has developed largely since the 1970s, usually in the form of technical literature that is not always read by managers and ecologists. Of the existing literature on the use of prescribed fire in the restoration and management of intact vegetation, most pertains to select grassland and savanna ecosystems (Johnson & Miyanishi 1995). By far the majority of the prescribed burning literature has been generated from silvicultural studies of site regeneration after forest harvesting (e.g. Chrosciewicz 1974, McRae 1979; Johnson & Miyanishi 1995). Such information can be useful if one has the simple goals of reducing slash fuel (i.e. limbs and other residual woody debris resulting from harvesting operations) for safety or planting, or the regeneration of a particular species. Information generated by silvicultural studies is not equally useful for the purpose of restoring all natural ecosystems (e.g.Ahlgren 1970; Johnson & Miyanishi 1995). Under pre-European settlement conditions, different ecosystems at different successional states likely experienced fire of varying frequencies and intensities depending on the community structure and composition, climate, topography and other factors.

For the purposes of this review, I will contrast the use of prescribed burning in the restoration of two fire-dependent ecosystems for which jack pine (Pinus banksiana Lamb.) is the canopy dominant: jack pine forest, and jack pine savanna. This contrast will illustrate that the restoration goals of prescribed burning will differ even between ecosystems with similar canopy composition. Managers considering the use of prescribed burning should not assume that the successful use of a given fire prescription in one ecosytem would justify its application in another (Johnson & Miyanishi 1995). Fire prescriptions and standards for evaluating success may differ even for two apparently similar wooded ecosystems.

Ecosystem descriptions

In pre-European settlement times, jack pine forests and savannas occupied a much larger portion of the Great Lakes landscape (Ontario, Minnesota, Michigan, and Wisconsin) than they do today. Remaining today are only 3% of the original 13,520 km2 of Great Lakes jack pine forest and only tiny remnants of the original 20,000 km2 of jack pine savanna (Vora 1993; Frelich 1995).

The vegetation of jack pine forests and savannas differ primarily in the species composition of the understory, and the spacing of canopy trees. The canopy of jack pine forests is closed. Jack pine forest stands usually originate when a catastrophic fire burns a pre-existing stand, leading to stand reinitiation. The trees are densely spaced (1000/ha) and often even-aged (Weber 1987). Aspen (Populus sp.), oaks (Quercus sp.) and white pine (Pinus strobus L.) sometimes accompany the jack pines as canopy co-dominants. The subcanopy of jack pine forest often includes cherry (Prunus sp). A variety of shade tolerant species prevail in the understory, depending upon soil type (Minnesota Department of Natural Resources, Division of Parks and Recreation 1995). Shrubs and forbs common in the understory include blueberry (Vaccinium sp.), hazel (Corylus americana Walter), sweet fern (Myrica sp.), bracken fern (Pteridum aquilinum [L.] Kuhn.), and trailing arbutis (Epigaea repens L.) (Vora 1993; MNDNR, Div. of Parks and Recreation 1995). In jack pine savannas, trees are sparsely-spaced (<10% canopy cover). A few small oaks and shrubs are scattered throughout. The understory in jack pine savanna is dense relative to that of jack pine forest. Understory grasses and forbs in jack pine savanna include big bluestem (Andropogon gerardii Vitman), little bluestem (Schizachyrium scoparium [Michx.] Nash), Indian grass (Sorghastrum nutans [L.] Nash), blazing star (Liatrus sp.), and the occasional grape fern (Botrychium sp.) (Vora 1993; MNDNR, Div. of Parks and Recreation 1995).

Fire-dependence in jack pine ecosystems

As a forest or savanna canopy dominant, jack pine possesses a number of particularly fire-dependent characteristics. Both ecosystems depend upon fire to prevent succession to another vegetation type. Jack pine usually has serotinous cones, which require the interaction of the heat of fire with the cones' thermal conductivity in order to open and disperse seeds (McRae 1979; Johnson & Gutsell 1993). Once seeds are dispersed, jack pine requires bare mineral soil or an extremely thin duff layer in order to germinate successfully and to become established (McRae 1979; Thomas & Wein 1985). A scattered duff layer consisting of senesced vegetation of a depth <2.5 cm benefits jack pine germinants by being both penetrable for the root and slowing moisture loss. Chrosciewicz (1974) demonstrated a negative exponential relationship between post-burn duff layer depth and jack pine seedling germination and growth, with thin residual duff (0.5 cm deep) providing the best combination for the two response variables.

Jack pine is only one component of the jack pine forests and savannas. Other structural and compositional components of the jack pine communities also rely on fire. The amount of many shrubs and forbs is reduced after fire, while other species may increase dramatically following a burn (e.g. sedges (Carex sp.), sweet fern (Comptonia sp.)) (Ahlgren 1970). Immediately following a post-harvest burn, transitory seed-producing species invade, including geranium (Geranium bicknellii Britt.),willow-herb (Epilobium angustifolium L.), and knotweed (Polygonum cilinode Michx.), all of which decline in abundance 3-5 years later (Ahlgren 1970).

Overall percent cover of herbaceous plants is lower for years following a burn. High soil temperatures (1500_F) during a fire may be responsible for the reduction in percent cover of shrubs (Ahlgren 1970). In an unharvested jack pine forest, soil microorganisms generally decrease in number and activity immediately after a prescribed burn, but sharply increase later in the first post-fire growing season (Ahlgren & Ahlgren 1965). The microbial response may have implications for nutrient cycling, symbioses with plants, and soil structure.

Although much information exists about the effects of post harvest prescribed burning in post-jack pine forests, less is available about the success of the technique in jack pine savanna. A few attempts have been made in this regard, including one pilot project in the Moquah Barrens of the Chequamegon National Forest in Wisconsin (Vora 1993), and one currently underway in St. Croix State Park, Minnesota (Minnesota Department of Natural Resources, Division of Parks and Recreation 1995). In contrast to the quantitative descriptions of post-fire vegetation and soil microbe recovery in cut-over jack pine forests, information from the jack pine savanna restorations is largely anecdotal. In the Moquah Barrens, after the first burn the Washburn District Timber Management Assistant commented that the treated area "looks really good" (Vora 1993). Vora (1993) offers a supplemental description of the burned area: "The unit has some pine barrens characteristics, and looks like a barrens." Vora goes on to describe the scattered trees and patches of seedlings that colonize after the burn, but appears not to have quantified the response.

Implementation of prescribed burns

A prescribed burn is one that is carried out with a precise statement of a fire's behavior (intensity, duff consumption, rate of spread, and frequency), along with a description of the desired ecological effects and restoration goals (Johnson & Miyanishi 1995). Most information available in technical manuals on prescribed burning deal with the management of the fire itself, ignoring the effects of the fire on the ecosystem of interest. Future prescriptions should pay more heed to ecological information if they are to be more useful for restoration.

It is not possible to develop universally-applicable fire prescriptions, but there are some general guidelines for carrying out safe and effective burns. A variety of weather conditions must be met. Wind speed must be $\leq$ 8 mph, the relative humidity must be at least 30% and rising, and the fuel moisture content must be at least 10% within the area to be burned, and 2-4% higher in areas that are not to be burned (USDAFS 1974). These guidelines can be adjusted based upon the goals of the restoration and the ecosystem in which it is being conducted. For example, afternoons may be considered a good time to burn if the relative humidity is consistently around 40%, and the wind speed is < 10 mph (Ahlgren 1970). A burn conducted in the early morning or evening may be subjected to a higher relative humidity, which in turn could reduce fire intensity (McRae 1978).

A variety of different firing patterns can be used, each with advantages and disadvantages depending upon the goals. Headfires and backfires are two examples of commonly-used firing patterns. Headfires move rapidly in the direction of the wind, and are often used to dispose of slash rapidly (Ahlgren 1970). As a more rapid practice, costs associated with headfires are less than for backfires. Disadvantages of headfires include the danger that they will burn out of control, and the minimal reduction of the duff layer (Ahlgren 1970). Backfires on the other hand, burn much more slowly, with the fire line burning into the wind rather than with it. Backfires are more costly than headfires, but may be less dangerous and more effective at consuming the duff layer. Backfires may also kill shrubs and small trees more effectively (Ahlgren 1970). For any prescribed burn pattern, the establishment of a fire barrier, bereft of fuel, is necessary for the purpose of containing the fire (USDAFS 1974). Pre-existing roads or wide trails can be used for this purpose.

During the burn, detailed observations about the fire's behavior need to be recorded. Fire intensity is among the most relevant fire variables for ecosystem response. Fire intensity (kW/m) is the heat generated at the flaming front, and is a function of low heat of combustion, fuel consumed, and rate of spread (Johnson & Miyanishi 1995). Intensity can be quantified in a few different ways, but perhaps the most straight-forward is in relation to flame length:

$$I = 259.83L^{2.174}$$

where I = intensity and L = flame length (length along the flame) (Alexander 1982). In contrast to commonly-used classifications of prescribed burns as "hot," or "light," quantification of intensity along with a description of fire behavior can help managers to refine burn prescriptions especially as they relate to desired restoration outcomes.

As a restoration technique, prescribed burning in jack pine ecosystems has a number of advantages over other methods. Compared with a number of mechanical site preparation techniques designed to reduce competition and create good seed bed conditions, prescribed burning is more economical even for a small area (McRae 1979). Mechanical site preparation may also cause soil compaction, an effect that prescribed burning may not have. Herbicides could be periodically applied in jack pine ecosystems, potentially killing a portion of the vegetation as effectively as fire. Herbicide treatments would not create the same type of seedbed as fire, because dead vegetation would remain on the site rather than being consumed as fuel. Although either mechanical or herbicide treatments might mimic some of the effects of fire, neither would have the effect of stimulating seed dispersal from jack pine's serotinous cones. Prescribed burning may also uniquely impact nutrient cycling in jack pine communities (Weber 1987; Stergas & Adams 1989). Herbicide or mechanical treatments, for example, might result in a slow release of nutrients from killed vegetation throughout the decomposition process. Fire might result in a short-term net loss of nutrients from the ecosystem, particularly of nitrogen, which might be volatilized during or leached soon after the fire.

Linking fire prescriptions with restoration goals

Based on historical evidence, jack pine forests and savannas probably were maintained naturally by very different fire regimes. Dense, even-aged jack pine forests were probably maintained by intense, infrequent fires (i.e. every 40-50 years). Some evidence exists that if a stand-replacing fire occurs in the early stages of jack pine forest development (<20 years old), nutrient cycling may be impaired, which might lower stand productivity and lead to site degradation. Jack pine savannas, on the other hand, may have been maintained by light, frequent burns (i.e. every 10-20 years) that maintained their quality of openness. In a study of a New York jack pine savanna, fire did not appear to adversely affect macronutrient cycling, even within only 20 years after a burn (Stergas & Adams 1989).

In both jack pine savannas and forests, seed production and prescribed burns should be considered together. Between 17 and 23 seed trees/ha may be required to produce sufficient quantities of seed for the natural regeneration of jack pine forest (Ahlgren 1970). A few seed trees/ha might produce adequate amounts of seed for natural jack pine regeneration in a savanna. If care is not taken to coordinate available seed with desired restoration goals, the fire prescription must include artificial seeding or planting shortly after the burn.

A careful evaluation of prescribed burning effects upon the target community should be conducted in conjunction with each burn in any ecosystem, but too often this requirement is not met. Silvicultural applications are an exception to this deficiency. Success, defined as jack pine regeneration, is often well-defined and well-documented (e.g. Ahlgren 1970). A successful burn for a jack pine forest ecosystem restoration might include a stand killing fire that initiates not only jack pine regeneration but ultimately also important understory species. Prescribed burning goals and measures of success should differ in a jack pine savanna ecosystem depending on its status. A savanna ecosystem from which fire has long been excluded might require an initial thinning of trees to savanna densities either with a hot burn or by harvesting. The fire prescription in this case would include killing a certain percentage of trees and shrubs, shifting the composition of the understory toward a desired species mixture. A fire prescription for an intact savanna system might simply strive to maintain the understory species mixture and canopy openness.

In order to evaluate the success of a prescribed burn with respect to specific restoration goals, careful pre-and post-fire measurements must be taken, along with a detailed study of the burn itself. In jack pine ecosystems, measures of seed availability, basal area, and species composition for different vegetation, are all examples of vegetation variables that should be quantified before and after a prescribed burn. Thickness of the duff layer and fuel availability should be measured before and after a burn as a means of quantifying direct effects of the fire upon available organic matter. Additional measures of pre-and post-fire microbial communities, soil, and foliar nutrient content would supplement the vegetation data, possibly explaining some of the trends in terms of nutrient losses or gains as a result of fire.

Few studies have actually quantified any of the above variables both before and after a prescribed burn. Even fewer studies have actually linked specific aspects of fire behavior with specific fire effects on ecosystem structures and processes (McRae 1979; Johnson & Miyanishi 1995). Detailed quantification of such fire variables as intensity should be conducted during a burn, both at the stand level and at a finer scale. Such observations can be matched with whether a burn meets specific restoration goals. If the burn does not achieve the goals in the desired amount of time, burn parameters can be adjusted on the next occasion.

Fine-tuning a burning prescription can only be accomplished if precise fire measurements are linked with ecosystem response. This link generally has been neglected since the adoption of prescribed burning as an accepted management tool in the 1960s. Managers today should strive to enhance our use of prescribed burns in jack pine ecosystems by carefully relating fire behavior and ecosystem response, rather than treating the technique as an inherently useful reintroduction of a historical process.

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