EFFECTS OF PRESCRIBED BURNING ON ECOSYSTEM PROCESSES AND ATTRIBUTES IN PINE/HARDWOOD FORESTS OF THE SOUTHERN APPALACHIANS

James M. Vose
USDA Forest Service
Coweeta Hydrologic Laboratory
Otto, NC 28763

ABSTRACT

Pine-hardwood ecosystems in the southern Appalachians are in a serious state of decline due to the combined effects of fire exclusion, abusive land practices, and drought related insect infestations. A silvicultural treatment termed "fell and burn" is applied as a best management practice (BMP) in an attempt to restore the diversity and productivity of these ecosystems. A multi-investigator study was initiated to assess the effects of this treatment on ecosystem processes and attributes. Results showed that felling and burning had positive effects on vegetation diversity and nitrogen (N) cycling, while soil erosion rates were unchanged. Losses in total aboveground N pools were larger than observed with other silvicultural practices (e.g., stem only and whole tree harvest) due to the consumption of foliage and forest floor. A more complete assessment will require a long-term approach where potential N additions from N-fixation and other sources are quantified.

INTRODUCTION

Fire is used as a silvicultural tool in pine-hardwood ecosystems in the southern Appalachians. Stands receiving this treatment typically consist of mixtures of pitch pine (Pinus rigida Mill.), scarlet and chestnut oak (Quercus coccinea Muenchh. and Quercus prinus L.), red maple (Acer rubrum L.), and a dense understory of mountain laurel (Kalmia latifolia L.). These ecosystems are most prevalent on xeric sites (i.e., south/west aspect ridge sites). While the pine/hardwood ecosystem is limited in extent (e.g., < 5% of the landscape in the southern Appalachians), it is a unique vegetation type that provides important habitat for both flora and fauna.

Changes in pine/hardwood ecosystems in the southern Appalachians have been quite dramatic, particularly in the past 20 years. The combined effects of abusive land practices (e.g., high grade logging, grazing), fire exclusion, and drought have left many of these stands in poor condition. For example, selective logging through the early 1920's has resulted in a sparse (i.e., 200 stems/ha) and low quality hardwood overstory. In addition, pre-suppression wildfires are thought to have played a major role in maintaining a pine component in these ecosystems by providing mineral soil for seed germination and reducing mountain laurel density and vigor in the understory (Barden and Woods 1976, Van Lear and Johnson 1983). Fire exclusion, combined with drought related southern pine beetle infestations, has resulted in significant reductions in overstory pine and increased mountain laurel in the understory (Smith 1991, Vose et al. in press). These poor conditions have prompted the use of cutting, burning, and planting (referred to as fell and burn) to restore the productivity of these ecosystems.
The fell and burn treatment was first described by Abercrombie and Sims (1986) for forests in the southern Appalachian pinelands of South Carolina. There, merchantable timber was removed, remaining stems were felled after leaf out, and sprouts and logging slash were burned in mid-summer. In the southern Appalachians of North Carolina, the best management practice (BMP) involves cutting all vegetation (merchantable products are removed) in early spring, burning sprouts and felled material in the early fall, and planting white pine (Pinus strobus L.) on a wide spacing (5 x 5 m) in late winter. White pine is planted because it has high growth rates, it is resistant to southern pine beetle, and at least until recently (Vose et al. in press), it was unknown whether natural regeneration would provide enough pine to re-establish a pine/hardwood mixture in these ecosystems. Sites are burned when conditions are likely to promote a high intensity, but low severity fire. Guidelines to achieve these results are: 1000-hr fuels > 25% moisture, 1-hr fuels dry but forest floor wet (>50% moisture), 10-hr fuels between 10-12% moisture, and 10-hr fuels in uncut areas > 14% moisture (Swift et al. 1993). These types of conditions often occur 30-60 days after cutting and 3 days after heavy rain (Abercrombie and Sims 1986). The ignition technique is a backfire along the top and flanks of the watershed to provide a protective zone, followed by a headfire ignited along the lower boundary. Desired short-term benefits from burning include a substantial reduction in aboveground material to facilitate planting, reduced vigor of competing vegetation (especially mountain laurel), and maintenance of an intact forest floor. The desired long-term benefits are a productive and diverse mixed pine/hardwood ecosystem.

While this treatment had been used with at least qualitative success in the southern Appalachians of North Carolina, there were numerous questions regarding potential impacts on long-term site productivity, soil erosion, stream chemistry, and vegetation diversity. To address these questions, a long-term multi-investigator study was initiated by scientists and cooperators at the U.S. Forest Service Coweeta Hydrologic Laboratory (Swift et al. 1993). The objective of that study was to assess the impacts of the fell and burn treatment on ecosystem processes (Figure 1). In this paper, I will summarize the ecosystem effects of prescribed burning from the Coweeta study and other associated studies in the southern Appalachians. I will also compare those effects with other common silvicultural practices in the southern Appalachians.

METHODS AND MATERIALS

In this paper, I will summarize the results of several studies. Specific methods of each of those studies are available in the published literature so only a brief summary will be provided here. A comprehensive assessment of ecosystem-level effects of fell and burn was recently published in a series of journal articles (i.e., Swift et al. 1993, Vose and Swank 1993, Elliott and Vose 1993, Knoepp and Swank 1993, and Clinton et al. 1993) and details of the overall study design are provided in Swift et al. (1993). These studies used a replicated, paired watershed approach, where plots were established on control and treatment watersheds and responses to burning were assessed for a variety of ecosystem attributes (e.g., vegetation, forest floor, and soil sampling for changes in total N, soil N cycling, soil solution N, erosion, etc.). A heavy emphasis was placed on N because these sites typically have low N availability (Knoepp and Swank 1993) and N most commonly limits forest ecosystem productivity. Related studies include longer-term vegetation responses (Clinton et al. 1993) and the potential use of the fell and burn technique for natural pine regeneration and pine/hardwood ecosystem restoration (Vose et al. in press).

RESULTS AND DISCUSSION

Qualitative assessments of the effects of felling and burning on a variety of ecosystem processes and attributes are summarized in Table 1. The following sections provide details of those effects.
Table 1. Generalized effects (0 = minimal response, + = positive response, - = negative response) of burning on ecosystem properties.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Response</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation Diversity</td>
<td>+</td>
<td>Clinton et al. 1993</td>
</tr>
<tr>
<td>Nutrient Pools</td>
<td>-/0</td>
<td>Vose &amp; Swank 1993</td>
</tr>
<tr>
<td>Erosion</td>
<td></td>
<td>Swift et al. 1993</td>
</tr>
<tr>
<td>Stream Quality</td>
<td></td>
<td>Knoepp &amp; Swank 1993</td>
</tr>
<tr>
<td>Nitrogen Cycling</td>
<td>+</td>
<td>Knoepp &amp; Swank 1993</td>
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</tbody>
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Effects on Vegetation

The combination of felling all woody vegetation and burning downed material resulted in complete vegetation consumption. Re-vegetation was quite rapid, however, with new plants appearing on the site within 2-weeks after burning (Swift et al. 1993). For woody vegetation, sprouting was the major recovery mechanism, while with herbs and grasses, recovery resulted from a combination of re-growth of residual plants and the establishment of new individuals from windblown or buried seed (J.M. Vose, personal observation). In the first year after burning, vegetation biomass ranged from 250 to 3000 kg ha⁻¹. The large variation in post-burn vegetation biomass was reflective of the combined effects of variation in pre-burn vegetation amount and composition, and fire severity. Areas with the greatest post-burn vegetation biomass were typically those which had a large amount of pre-burn vegetation and lower severity fires.

To obtain a longer-term perspective, a chronosequence approach was used to assess vegetation impacts 13-years after treatment (Clinton et al. 1993). Here, we emphasized changes in vegetation diversity relative to unburned stands, and assessed the effectiveness of this treatment in reducing mountain laurel vigor. Results of this study showed that the fell and burn treatment increased vegetation diversity relative to unburned stands (i.e., Shannon-Wiener Diversity Index = 3.24 for burned stands vs. 2.86 for unburned stands) and most of the increased diversity was due to overstory trees and herbs. Mountain laurel vigor was reduced sufficiently to allow a diverse hardwood and pine overstory; however, mountain laurel continued to influence stand structure and species composition. For example, overstory density was negatively related to mountain laurel basal area, indicating that mountain laurel restricted regeneration and establishment of overstory species.

Effects on Aboveground N Pools

One of the primary objectives of the fell and burn treatment is to reduce the amount of material on the site to facilitate planting. However, a potential negative effect of reducing this material is the loss of site nutrients. This is particularly true of N which volatilizes at relatively low temperatures and is lost to the atmosphere. In addition, burning also consumes forest floor which is a large reservoir of the most readily available N. Maintaining an intact forest floor is also important for minimizing soil erosion.

In the Coweeta study, we quantified total N losses from aboveground material and identified contributing sources. Total N losses ranged from 190 to 480 kg ha⁻¹ across the three watersheds (Vose and Swank 1993). The most important pools were large wood (>10 cm dbh) and forest floor (Figure 2). In the
short term, losses from the forest floor are the most significant because forest floor decomposition provides a major source (e.g., 50%) of available site N (Monk and Day 1988). Losses from wood were even greater; however, the immediate significance of these losses is not as important as forest floor losses because wood N is released slowly in decomposition. Wood N losses (as well as other nutrients) may be more significant in the long run, particularly if fires occur frequently. Currently, there are no guidelines for recurrence intervals in these ecosystems, but the period between burns should allow for adequate replenishment of site N through atmospheric deposition, biological fixation, and increases in soil N transformations. Assuming N additions of 15-20 kg ha yr\(^{-1}\) (Swank 1984), N losses from burning would be replaced in 20-30 years.

Effects on Soil Erosion

Even though side slopes ranged from 35 to 45%, there were no appreciable amounts of soil erosion after the fell and burn treatment. Only two of ten sediment traps on burned areas collected material and in these, the total amount was < 1 m\(^3\) (Swift et al. 1993). Most of the material collected was in organic form (e.g., charcoal). Several factors limited the amount of erosion on these sites. First, the forest floor was not completely consumed. Most importantly, the humus layer (Oa + Oe) remained mostly intact. Second, not all of the downed material was consumed in the fire (i.e., consumption ranged from 50 to 60% [Vose and Swank 1993]). Hence, there were several natural barriers and traps preventing long distance sediment transport. Finally, the site revegetated rapidly—within 1-yr after burning, vegetation covered 23% of the sites (Swift et al. 1993).

Effects on Soil and Stream N

Cutting and burning resulted in significant increases in total soil N in the upper 20 cm on two of three sites 1-yr after burning (Knoepp and Swank 1993). Ammonium (NH\(_4^+\)) generally increased on all sites, while nitrate (NO\(_3^-\)) responses were inconsistent. Mechanisms for increased NH\(_4^+\) in the soil include downward movement and deposition of volatilized N from aboveground materials and increased mineralization (Knoepp and Swank 1993). Increases in soil N and mineralization rates were greatest on the site that burned with the greatest intensity. Hence, some of the variability in response among sites was due to variation in fire intensity. Although sometimes statistically significant, many of the soil changes did not result in large quantities of additional N becoming available for plant growth (Knoepp and Swank 1993). Therefore, it is unlikely that these short-term changes will offset N losses due to burning aboveground material. Although stream NO\(_3^-\) increased eight-fold after cutting and burning (Knoepp and Swank 1993), stream NO\(_3^-\) concentration was still quite low (e.g., < 0.08 mg L\(^{-1}\)) even at peak values. These responses indicate that there are no substantive losses of site N in streams, and hence, no detrimental effects on streamwater quality.

Comparison of N Effects with Other Silvicultural Treatments

Losses of aboveground N from the fell and burn treatment were often greater or equal to losses from either whole tree harvest or stem only harvest (Figure 3). For example, in hardwood forests at Coweeta, N losses were 59 and 277 kg ha\(^{-1}\) for stem only and whole tree harvest, respectively (Mann et al. 1988). The primary reason for the lower N losses in the harvesting treatments is that foliage and forest floor, which represent relatively large N pools, remain on the site.

Clearcutting (with or without whole tree harvest) also stimulates soil N cycling processes. Total N increased almost two-fold in the upper 10-cm soil depth in the first year after clearcutting at Coweeta (Waide et al. 1988). Similar to patterns observed in the fell and burn treatment, NH\(_4^+\) increased measurably. In contrast to the results from felling and burning, consistent increases in soil NO\(_3^-\) were
also observed (Waide et al. 1988). Whole tree harvesting and clearcutting at Coweeta resulted in consistent increases in both N mineralization and nitrification.

Clearcutting results in relatively small increases in stream N losses. At Coweeta, losses in the first year were elevated < 0.3 kg ha\(^{-1}\) and never exceeded 1.3 kg ha\(^{-1}\) over a 5 year response period (Swank 1988). The primary reason for low N losses after cutting in the southern Appalachians is that vegetation regrowth is rapid and N is stored in the early successional vegetation. The same is probably true after felling and burning, even though one of the objectives of burning is to reduce the vigor and amount of regrowth.

Using Fire as a Restoration Tool

White pine is planted on the fell and burn sites because it has higher productivity and is more resistant to pine beetle attack than native pines species (e.g., pitch pine, virginia pine, shortleaf pine) that typically occur on these dry sites. Additionally, it was unknown whether natural regeneration of native pines would provide the stocking necessary to achieve a mixed pine/hardwood stand. Comparison of native pine density on fell and burn sites, wildfire sites, and untreated stands showed that the fell and burn treatment promotes regeneration comparable to wildfires (Figure 4; Vose et al. in press). Hence, the fell and burn treatment may also be a useful tool to regenerate native pines and restore or maintain a pine component in these ecosystems.

CONCLUSIONS

Use of BMP's in the fell and burn treatment results in few negative effects on ecosystem processes and attributes. Vegetation diversity and nutrient cycling processes were generally increased and there were no negative effects on soil erosion. One potential concern is the impact on overall site N, where losses exceed those from other silvicultural practices in the southern Appalachians. However, a long-term perspective is required to fully assess these losses because of potential mitigation from increased N-fixation (symbiotic and asymbiotic) as a result of burning.

LITERATURE CITED


Figure 1. Schematic of Coweeta prescribed burn study design and measurements.
Figure 2. Source of aboveground N loss from the fell and burn treatment. Values are averaged from three replicate watersheds. Other includes sprouts, herbs, and grasses.
Figure 3. Comparison of aboveground N losses from three silvicultural practices in the southern Appalachians.
Figure 4. Understory yellow pine density for burned and unburned stands.
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