SILVICULTURAL TREATMENTS TO REGENERATE PRINCIPAL SPECIES IN THE FLAT ROCK FOREST COMMUNITY

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Abstract—Principal indicator tree species of the Flat Rock Forest Community include Virginia pine (*Pinus virginiana* Mill.), eastern redcedar (*Juniperus virginiana* L.), and post oak (*Quercus stellata* Wangenh.). These species are unusual for forests occurring adjacent to large rivers in the central and southern Appalachian Mountains, but the thin, dry soils typical of the Flat Rock communities preclude other mesic species. As the Flat Rock forests are invaded by riparian tree species such as green ash (*Fraxinus pennsylvanica* Marshall), American sycamore (*Platanus occidentalis* L.), yellow poplar (*Liriodendron tulipifera* L.), and red maple (*Acer rubrum* L.), the indicator species decline. A study was established to determine the effectiveness of cutting, prescribed burning, and herbicide application to create conditions more favorable for the regeneration of the target species and discourage the less desirable riparian vegetation. Treatments were effective in favoring Flat Rock species in the overstory and understory. Over the 2-year study period, seedling numbers increased across all treatments, including controls. This was attributed to above-average precipitation during both growing seasons following treatment.

INTRODUCTION

The Flat Rock Forest Community is a minor, but locally significant, plant community found in unique locations along major rivers in the Appalachian Mountains (McDonald and Trianosky 1995). Characterized by low biodiversity and harsh sites with little soil over hard sandstone bedrock, these plant communities are maintained by frequent flooding that removes soil rather than deposits sediments. As a result, the plant community is floristically simple, with early successional species dominating. In the absence of flooding, as is the case on the New River below the Bluestone Dam in Summers County, WV, soil accumulates; organic matter, fertility, and water-holding capacity increase; and the site is invaded by both exotic and riparian species. Traditional overstory species in the Flat Rock Forest Community, eastern redcedar (*Juniperus virginiana* L.), Virginia pine (*Pinus virginiana* Mill.), and post oak (*Quercus stellata* Wangenh.), are reduced over time.

Maintaining the Flat Rock Forest Community has become a primary management objective of the National Park Service (NPS) New River Gorge National River. The NPS owns nearly 21,000 ha along the New River in West Virginia (Mahan 2004) and preserving native species and habitats is a primary concern. In light of observed species changes in the Flat Rock Forest Community, the NPS has agreed to test a series of silvicultural practices designed to reduce the overstory and understory composition of upland, riparian, and exotic species. These practices also were designed to facilitate regeneration of the Flat Rock indicator species: eastern redcedar, Virginia pine, and post oak.

OBJECTIVES

The objectives of this experiment were to evaluate the effects of various silvicutural treatments on overstory and understory composition of key species groups in the Flat Rock Forest Community and to determine the effect of silvicultural treatments on species composition and density of regeneration of key species groups in the Flat Rock Forest Community.

PROCEDURES

Study Area

The study was conducted on Brookside Island, located on the New River in Summers County, WV (N 37° 38', W 80° 50'). The New River originates in North Carolina and flows north for approximately 400 km, joining the Gauley River to form the Kanawha River. The New River drains an area of 11,136 km^2.

Field Plot Layout and Measurements

The study site was established in the Sub-mesic Virginia Pine Forest Community. This community most resembles the transition from a typical Flat Rock community to a mature riparian forest. Changes in vegetation structure and composition resulting from the applied treatments would be most apparent in this area. Within the Sub-mesic Virginia Pine Forest Community, nine plots were established, each 24 by 24 m in size. All plots were located at least 15 m inland from the New River to avoid exposed bedrock and the influence of high water levels. Each plot is separated by at least an 8-m buffer to prevent any overlap between treatments.

Within each sample plot, overstory trees > 5 m in height were measured for d.b.h. (diameter at breast height) and height. Each overstory plot was divided into a series of nested subplots for understory and regeneration evaluation. Four 6 x 6-m subplots were established for understory assessment, which included trees and shrubs between 1 and 5 m in height. Recorded measurements included species and d.b.h. for trees, while species and number of individuals were recorded for shrubs.

Within each understory subplot, two 1-m^2 sub-subplots were established to sample regeneration, for a total of eight regeneration sub-subplots in each overstory plot. The regeneration stratum was defined as trees and shrubs between 0 and 1 m in height. Regeneration measurements included species and number of individuals.

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Silvicultural Treatments

Three treatments, each randomly replicated three times, were imposed on the sample plots. The first treatment (light) involved a thinning in which undesired species in the overstory were cut, retaining only eastern redcedar, Virginia pine, post oak, and other species identified by the NPS staff. This treatment was applied to plots 3, 6, and 8. In June of 2001, trees were cut and the slash distributed over the sample plots or relocated to plots scheduled for burning. Two herbicide treatments were also applied to the light treatment. Pathway™ (picloram; 2,4-dichlorophenoxyacetic acid) was applied at a rate of 18.9 L/ha to stumps after cutting to prevent sprouting. Two months later, Brushmaster® [isooctyl (2-ethylhexyl) ester of 2,4-dichlorophenoxyacetic acid; 2-ethylhexyl ester of (+)-R-2-(2,4-dichlorophenoxy) propionic acid; Dicamba] was directly applied to any emerging hardwood species at a rate of 9.5 L/ha.

The second treatment (heavy) included a thinning, an herbicide application as previously described, and a low-intensity prescribed burn, which was applied in April of 2002. This treatment was applied to plots 2, 4, and 7. A prescribed burn plan was prepared by the NPS and used in the implementation of the heavy treatment. This plan provided guidelines for acceptable weather conditions for the day of burning as well as the desired burn characteristics such as rate of spread and flame length. Environmental conditions on the day of burn, including wind speed (km), temperature (°C), wind chill (°C), relative humidity (percent), heat index (°C), and dew-point (°C), are reported in table 1. The specific prescribed burn characteristics for each plot, including duration of burn (min), distance between drip torch lines (m), and flame height by fuel type (m), are presented in table 2.

The third treatment was a control, used for reference, with no active management. The control treatment was assigned to plots 1, 5, and 9.

Post-Treatment Measurements

Post-treatment vegetation was sampled for each plot during the summers of 2002 and 2003. Overstory assessment included all tree species ≥ 5 m in height. D.b.h. (cm) and height (m) were measured for each tree. Basal area/ha (BA/ha) was used to calculate dominance. Density was calculated as the number of stems/ha.

The understory was sampled using trees and shrubs that were 1 to 5 m in height. Dominance and density were calculated by species group for the understory tree stratum. For each understory tree species, diameter was recorded and relative dominance, relative frequency, and relative density were calculated. The regeneration stratum was evaluated by measuring the density of each tree and shrub species. Relative density and relative frequency were also calculated for each species. Importance values (IVs) were calculated by averaging the mean relative dominance, relative density, and relative frequency (Mueller-Dombois and Ellenberg 1974).

Data Analysis

The effects of the silvicultural treatments, light (thinning/herbicide) and heavy (thinning/herbicide/prescribed burn) as compared to control (no treatment), on the composition and density of tree species were studied by analysis of variance using a completely randomized design. Tree and shrub species were grouped into four categories including riparian, upland, target, and exotic. Each of the three treatments was applied three times at random to the nine plots. Replications from each treatment were compared to determine significant differences, followed by mean separation using the Tukey HSD (honestly significant difference) test (Zar 1999). All percent data were arcsine transformed prior to analysis.

Table 1—Environmental conditions for prescribed burn applied in April of 2002 on Brookside Island, Summers County, WV

Environmental condition	Plot		
	2	4	7
Wind (*km/h*)	6.4	2.3	3.5
Temperature (*°C*)	19.3	19.5	15.4
Wind chill (*°C*)	19.8	19	15.3
Relative humidity (*%*)	18	14	27
Heat index (*°C*)	18	16.2	13.6
Dew point (*°C*)	-5	-4.9	-4

Table 2—Burn characteristics for prescribed burn applied in April of 2002 on Brookside Island, Summers County, WV

Prescribed burn characteristics	Plot		
	2	4	7
Burn order	3	2	1
Duration of burn (*min*)	20	30	50
Rate of spread (*km/h*)	0.072	0.048	0.288
Distance between drip-torch lines (*m*)	1	1.5-2	N/A[a]
Flame heights (m):			
Grass	0.1-0.4	0.1-0.2	0.08-0.1
Light debris	0.3-1.8	0.3-0.8	0.3-0.38
Heavy debris	0.6-1.2	0.6-1.2	0.6-0.8

[a] Drip-torch lines were sparse due to sufficient fuel loads to carry across plot 7.

RESULTS AND DISCUSSION

The effects of silvicultural treatments on the IVs of overstory species groups are presented in table 3. The purpose of the treatments was to promote the target species while discriminating against the other species groups. Two years following treatment, the IVs of target species in both silvicultural treatments were significantly > in the control treatment. IVs for the target species in 2003 averaged 100 percent in the light treatment, 99 percent in the heavy treatment, and 82 percent in the control (table 3). This shift in importance came largely at the expense of the upland species, which were significantly reduced by both treatments.

Similar to the overstory, the applied silvicultural treatments caused significant effects on the IVs of species groups in the understory (table 4). For example, in 2003, 2 years after the treatments, IVs of riparian species in the treated plots were significantly lower than in the control, while the IVs of the target species were signficantly higher in the treated plots than

Table 3—Mean importance value of the three species groups (riparian, target, and upland) in the overstory stratum sampled annually in July of 2000, 2002, and 2003 on Brookside Island, Summers County, WV

Treatment	Species group	N	Importance value Mean[a] 2000	2002	2003	S.E. 2000	2002	2003
			percent					
Control	Riparian	3	2.3 a A	2.4 a A	2.4 a A	1.3	1.2	1.2
	Target	3	83.0 a A	81.0 a A	82.4 a A	6.3	6.9	8.2
	Upland	3	14.7 a A	16.7 a A	15.2 a A	5.0	6.1	7.2
Heavy	Riparian	3	2.6 a A	0.0 a A	0.0 a A	1.3	0.0	0.0
	Target	3	83.6 a A	99.5 b B	99.4 b B	5.6	0.5	0.6
	Upland	3	13.9 a A	0.5 b B	0.6 b B	4.6	0.5	0.6
Light	Riparian	3	0.6 a A	0.0 a A	0.0 a A	0.6	0.0	0.0
	Target	3	75.5 a A	100.0 b B	100.0 b B	7.6	0.0	0.0
	Upland	3	23.9 a A	0.0 b B	0.0 b B	7.8	0.0	0.0

[a] Means followed by the same letter are not significantly different at $\alpha = 0.1$ level. (Note: a = within each species group and between treatments; A = within each treatment and between years).

Table 4—Mean importance value of the four species groups (exotic, riparian, target, and upland) in the understory stratum sampled annually in July of 2000, 2002, and 2003 on Brookside Island, Summers County, WV

Treatment	Species group	N	Importance value Mean[a] 2000	2002	2003	S.E. 2000	2002	2003
			percent					
Control	Exotic	3	0.0 a A	0.0 a A	0.0 a A	0.0	0.0	0.0
	Riparian	3	51.2 a A	51.1 a A	55.5 a A	9.5	3.5	11.2
	Target	3	16.4 a A	16.6 a A	18.8 a A	9.2	6.5	12.3
	Upland	3	32.5 a A	32.2 a A	25.6 a A	6.8	3.2	2.4
Heavy	Exotic	3	0.0 a A	0.0 a A	0.0 a A	0.0	0.0	0.0
	Riparian	3	35.1 a A	6.9 b B	9.8 b AB	6.9	6.9	4.9
	Target	3	16.9 a A	88.0 b B	79.1 b B	5.4	12.0	8.6
	Upland	3	48.0 a A	5.1 a B	11.2 a B	8.2	5.1	6.9
Light	Exotic	3	0.0 a A	0.0 a A	2.0 a A	0.0	0.0	2.0
	Riparian	3	32.5 a A	14.4 ab A	9.2 b A	11.4	14.4	4.7
	Target	3	11.9 a A	58.4 b A	68.6 b A	3.3	22.1	16.3
	Upland	3	55.7 a A	27.2 a A	20.3 a A	13.6	14.5	11.4

[a] Means followed by the same letter are not significantly different at $\alpha = 0.1$ level. (Note: a = within each species group and between treatments; A = within each treatment and between years).

in the control. In the heavy treatment, the pre-treatment IV for target species was 16.9 percent, while 2 years after treatment it was 79.1 percent, a significant increase. Similarly, in the light treatment the IV of the target species increased from 11.9 percent to 68.6 percent (table 4).

The understory shrub stratum was not as diverse as the overstory and understory tree strata, with two species groups identified, exotic species and upland species (table 5). The heavy treatment significantly reduced the importance of the upland shrubs, from 94 percent prior to treatment to 33 percent 2 years post-treatment. The IVs of exotic species did not differ either over time or across treatments. The highest IV for exotic species was 31 percent in the control treatment in 2003. The shrub stratum was affected by all the silvicultural treatments, including cutting, herbicide application, and fire. Thus, the shrub stratum was the first to show significant differences between the light and heavy treatments.

The effects of silvicultural treatments on IVs and densities of regeneration species groups are shown in tables 6 and 7. The importance values of the dominant species groups, target and upland, were unaffected by the silvicultural treatments (table 6). The treated plots, however, did show a significant increase in the importance of exotic species, from 0 in 2000 to 15 percent in the heavy treatment to 4 percent in the light

Table 5—Mean importance value of the two species groups (exotic and upland) in the understory shrub stratum sampled annually in July of 2000, 2002, and 2003 on Brookside Island, Summers County, WV (note: riparian shrub species were not present in the understory stratum)

			Importance value					
			Mean[a]			S.E.		
Treatment	Species group	N	2000	2002	2003	2000	2002	2003
			percent					
Control	Exotic	3	18.4 a A	25.0 a A	30.5 a A	9.4	12.6	15.7
	Upland	3	81.6 a A	75.0 a A	69.5 a A	9.4	12.6	15.7
Heavy	Exotic	3	6.5 a A	0.0 a A	0.0 a A	3.3	0.0	0.0
	Upland	3	93.5 a A	0.0 b B	33.3 a AB	3.3	0.0	33.3
Light	Exotic	3	3.7 a A	0.0 a A	0.0 a A	3.7	0.0	0.0
	Upland	3	63.0 a A	0.0 b A	0.0 a A	31.6	0.0	0.0

[a] Means followed by the same letter are not significantly different at $\alpha = 0.1$ level. (Note: a = within each species group and between treatments; A = within each treatment and between years).

Table 6—Mean importance value of the four species groups (exotic, riparian, target, and upland) in the regeneration stratum sampled annually in July of 2000, 2002, and 2003 on Brookside Island, Summers County, WV

			Importance value					
			Mean[a]			S.E.		
Treatment	Species group	N	2000	2002	2003	2000	2002	2003
			percent					
Control	Exotic	3	0.0 a A	1.6 a A	3.2 a A	0.0	1.6	1.7
	Riparian	3	16.7 a A	13.2 a A	25.0 a A	8.7	5.2	7.8
	Target	3	17.8 a A	35.8 a A	24.2 a A	11.3	3.8	7.9
	Upland	3	65.5 a A	49.3 a AB	47.6 a B	6.9	3.5	1.4
Heavy	Exotic	3	0.0 a A	15.4 b B	5.4 a A	0.0	5.5	0.8
	Riparian	3	19.7 a A	5.6 a A	12.7 a A	17.1	1.1	4.7
	Target	3	26.6 a A	30.3 a A	28.7 a A	1.8	10.2	1.5
	Upland	3	53.7 a A	48.6 a A	53.2 a A	16.9	7.9	4.0
Light	Exotic	3	0.0 a A	4.1 ab B	3.7 a AB	0.0	0.7	2.7
	Riparian	3	17.8 a A	7.3 a A	19.3 a A	13.4	1.8	1.6
	Target	3	24.5 a A	38.2 a A	23.8 a A	8.7	5.0	3.1
	Upland	3	57.7 a A	50.4 a A	53.2 a A	12.1	2.8	4.8

[a] Means followed by the same letter are not significantly different at $\alpha = 0.1$ level. (Note: a = within each species group and between treatments; A = within each treatment and between years).

treatment in 2001, a significant increase in both cases. Interestingly, the number of seedlings increased significantly in all treatments, including the control, over the course of the study (table 7). For example, in the heavy treatment, target species increased from 15,417 seedlings/ha in 2000 to 49,167 seedlings/ha in 2003, a significant increase. However, during this same time period, the number of seedlings of the upland species also increased significantly, from 18,333/ha to 89,167/ha. In the control plots, the number of riparian and upland seedlings also increased significantly. This increase was attributed to the greater than normal precipitation during the study period, which influences seed abundance and germination and establishment success. The long-term average precipitation for Summers County, WV, is 94 cm per year. However, annual precipitation was 123 cm in 2002 and 133 cm in 2003.

CONCLUSIONS AND RECOMMENDATIONS

(1) Both thinning and herbicide treatments are effective in favoring desired species over the invading upland and riparian species. (2) Prescribed burning does not appear to significantly improve the responses over thinning and herbicide application alone, although target seedling density increased significantly after burning. (3) Exotic species composition in the regeneration stratum increased, but not significantly. This should be carefully monitored and control strategies implemented if the invasion increases significantly. (4) Numbers of seedlings increased significantly in all treatments, including the controls, over the 2-year study period, due to favorable moisture conditions. It is expected that, due to more favorable light levels in the treated plots, over time survival will be higher in the treated plots.

Table 7—Mean density of the four species groups (exotic, riparian, target, and upland) in the regeneration stratum sampled annually in July of 2000, 2002, and 2003 on Brookside Island, Summers County, WV

			Density					
	Species		Mean[a]			S.E.		
Treatment	group	N	2000	2002	2003	2000	2002	2003
			number of stems/ha					
Control	Exotic	3	0 a A	1,667 a A	2,500 a A	0	1,667	1,443
	Riparian	3	2,917 a A	6,667 a A	33,750 a B	1,502	2,732	10,777
	Target	3	8,750 a A	36,250 a A	47,083 a A	7,535	6,960	20,276
	Upland	3	19,583 a A	32,917 a A	64,583 a B	5,320	4,229	833
	Total		31,250	77,500	147,917			
Heavy	Exotic	3	0 a A	23,333 a A	7,500 a A	0	18,348	2,165
	Riparian	3	13,750 a A	2,500 a A	16,667 a A	13,130	722	8,427
	Target	3	15,417 a A	34,583 a AB	49,167 a B	3,975	9,419	6,821
	Upland	3	18,333 a A	51,667 a AB	89,167 a B	4,229	18,559	14,866
	Total		47,500	112,083	162,500			
Light	Exotic	3	0 a A	2,500 a A	5,000 a A	0	722	3,819
	Riparian	3	6,667 a A	3,750 a A	19,167 a A	5,465	1,250	5,512
	Target	3	10,417 a A	42,500 a A	34,583 a A	7,372	10,897	11,235
	Upland	3	14,167 a A	34,167 a A	66,250 a B	4,696	4,410	5,204
	Total		31,250	82,917	125,000			

[a] Means followed by the same letter are not significantly different at $\alpha = 0.1$ level. (Note: a = within each species group and between treatments; A = within each treatment and between years).

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