EVALUATION OF SAPLING HEIGHT AND DENSITY AFTER CLEARCUTTING AND GROUP SELECTION IN THE MISSOURI OZARKS

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Abstract.—Silvicultural decisions often affect the development and characteristics of a stand. Silvicultural regeneration events can have immediate and gradual impacts on stand development. The objective of this study was to evaluate the effects of two silvicultural regeneration methods, clearcutting and group selection, on the composition of trees that are likely to recruit to the canopy within stands near the end of the regeneration period. We compared the mean density of saplings among 16-year-old clearcuts and 18-year-old group openings that were above height thresholds based on the 90th percentile of all sampled individuals on exposed or protected aspects within each treatment. The calculated percentiles provide a framework to determine whether the canopy that surrounds group selections causes a significant loss in productivity or desired species. We found significant treatment and aspect interaction ($p = 0.032$) for hickories and a significant treatment effect for red oaks ($p = 0.004$) and white oaks ($p < 0.001$). Our results provide valuable information about the effects of clearcutting and group selection on stand development.

INTRODUCTION

Historical ideologies for upland hardwood forest management have centered on the use of even-age silviculture systems (Roach and Gingrich 1968). In the Missouri Ozarks, these systems were largely successful at regenerating timber species such as oaks (Johnson 1993). More recently interest in multi-aged forests and management objectives has increased beyond commercial optimization to include wildlife habitat and aesthetics. This has led agencies such as the Missouri Department of Conservation (MDC) to enact policy changes that encourage canopy retention during regeneration, such as clearcutting with reserves or shifts to uneven-age practices of single-tree and group selection. Few studies have, however, contrasted the impacts of clearcutting and uneven-age management practices on species composition and density in the Missouri Ozarks.

Although oak regeneration is a complex process that has been a concern of land managers throughout the eastern United States, the evidence suggests that a wide variety of silvicultural practices can successfully regenerate oaks in the Missouri Ozarks because of the unique accumulation of oak seedlings (Dey et al. 1996, Liming and Johnston 1944). Oaks sprout vigorously after top-kill, contributing to the success of oak regeneration with the use of even-age silvicultural systems such as clearcutting. In contrast, Pioneer Forest in southeastern Missouri has used modified single-tree selection for uneven-age management with evidence of successful oak regeneration through 40 years of management (Loewenstein et al. 2000). The capacity of oaks to sprout and grow quickly is reduced, however, with increased overstory retention. An experiment examining the survivability and growth of oak stump sprouts in the Missouri Ozarks

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determined that single-tree harvesting resulted in significantly greater stump sprout mortality than group selection and clearcutting (Dey et al. 2008). Subsequent effects of harvesting practices on regeneration dynamics and stand development are not well understood. Site conditions also affect regeneration outcomes after harvest. Variable solar radiance caused by site aspect can be a contributing factor in regeneration success of oaks (Collins and Carson 2004). Thus, the effects of silvicultural practices on regeneration may vary by aspect.

The objective of this paper is to compare the density (stems per hectare) of the regenerating cohort after clearcutting and group selection in the Missouri Ozark Highlands. Our analyses focused on the tallest 10 percent of trees in both treatments to highlight individuals that are most likely to achieve canopy dominance. The effectiveness of each regeneration method is evaluated across protected and exposed aspects for six prevalent species groups, shortleaf pine, and the combination of all species present.

METHODS

Data were collected from the Missouri Ozark Forest Ecosystem Project (MOFEP), which encompasses more than 3,700 ha in the Current River watershed in Carter, Reynolds, and Shannon counties of southeastern Missouri (Kabrick et al. 2000). MOFEP is a long-term, landscape-scale experiment that was designed as a randomized complete block by MDC in 1989 to evaluate the effects of forest management on ecosystem composition, structure, and function (Shifley and Brookshire 2000).

The MOFEP study design includes three blocks, each with site replicates of even-age management, uneven-age management, and no management treatments. The even-age regeneration method (clearcutting with reserves) and uneven-age regeneration methods of single-tree selection and group selection were applied in 1996. The size of the group openings varied by aspect, with a diameter of one standard tree height (21.3 m) on exposed slopes and two standard tree heights (42.6 m) on protected slopes. The variation in harvest size was designed to allow one-third full sunlight at plot center for maximum photosynthesis of oak saplings (Dey et al. 2010, Law and Lorimer 1989).

The original MOFEP study design included 648 circular, 0.2-ha plots in a nested design for sampling vegetation composition and structure (Jensen 2000). The species, height, and diameter at breast height (d.b.h.) of each tree greater than 11.43 cm d.b.h. were recorded in each plot. In addition, four 0.02-ha plots were nested within each plot and the species, height, and d.b.h. were recorded for all trees, shrubs, and woody vines with d.b.h. measurements greater than 3.81 cm and less than 11.43 cm (Jensen 2000). Centered on each 0.02-ha subplot, one 0.004-ha circular plot was nested to collect species, height, and d.b.h. of trees, shrubs, and woody vines taller than 1 m and with a d.b.h. less than 3.81 cm (Jensen 2000). Clearcut plots were last sampled in 2012 (age 16).

The original MOFEP plots were randomly located (with stratification, see Shifley and Brookshire 2000) before the various harvest treatments were applied, and the proportion of plots that were located within a group opening was low. Moreover, the proportion of a plot that was actually within the opening varied among those plots that did occupy group-selection openings. Therefore, a more explicit sample of group-selection openings within the MOFEP framework was commissioned. We randomly selected 74 group selections. Within each, we established a similar sampling design of 0.004-ha plots nested within 0.02-ha plots. Data for this study were recorded in 2014 (age 18) and included the aspect of each plot and the species, height, and d.b.h. of all individuals taller than 1 m and with a d.b.h. greater than 3.81 cm. We used data from the

74 group selection 0.02-ha subplots along with data from 18 clearcut 0.02-ha subplots that included the same measurements collected in 2012 (age 16).

The 47 species encountered in clearcuts and the 36 species in group selections were condensed into six species groups: hickories (e.g., *Carya tomentosa* and *C. glabra*); maples (*Acer rubrum and A. saccharum*); mixed hardwoods (e.g., *Juglans nigra, Prunus serotina,* and *Ulmus rubra*); red oaks (e.g., *Quercus coccinea, Q. rubra,* and *Q. velutina*); white oaks (e.g., *Q. alba, Q. muehlenbergii,* and *Q. stellata*), and others (e.g., *Rhus copallina* and *Vaccinium arboreum*). We created an additional category for shortleaf pine (*Pinus echinata)*. These species groups are derived from the original MOFEP establishment report (Brookshire and Dey 2000). Because the clearcut and group selection plots were sampled in different years (ages 16 and 18, respectively), we standardized tree height at 16 years after harvesting for each treatment. To accomplish this, we first calculated annual height increment as each individual's height at sampling divided by the number of years since harvest and then multiplied the annual height increment by 16.

We selected the 90th percentile height as a threshold indicator of the most competitive trees in the regenerating cohort to allow comparison of densities among the regeneration treatments that would not be possible if we focused our analyses on a fixed number of trees per hectare. Within each treatment we used all sampled individuals to determine the 90th percentile heights for clearcuts on exposed (90th percentile = 7.406 m) and protected (90th percentile = 8.189 m) sites and for group selections on exposed (90th percentile = 7.707 m) and protected (90th percentile = 8.631 m) sites. Clearcut 90th percentile thresholds were also applied to group selection data to directly ascertain the differences in regeneration density, composition, and heights of individuals of the two treatments.

We calculated the average number of trees per hectare above the 90th percentile height values at the plot level for each species group. To determine treatment effects, we calculated the following response variables:

1. Clearcut^{CC90}: average number of trees per hectare in the clearcuts that met the 90th percentile height threshold calculated from clearcut plots
2. Group^{CC90}: average number of trees per hectare in group selections that met the 90th percentile height threshold calculated from clearcut plots
3. Group^{GP90}: average number of trees per hectare in group selections that met the 90th percentile height threshold calculated from the group selection plots

Each response variable was calculated using data from the exposed and protected sites separately. We calculated species group percent composition for aspect within clearcuts and group openings and for all treatments and aspects above the 90th percentile. We examined the fixed effects of harvest treatment, aspect, and the interaction of treatment and aspect using randomized complete block analysis of variance, using site block as a random effect. We determined statistical significance with $\alpha = 0.05$ and conducted analyses using SAS 9.3 (SAS Institute, Cary, NC).

Table 1.—Mean and maximum heights for all sampled individuals

	Clearcut				Group selection harvest			
	Exposed		Protected		Exposed		Protected	
Species group	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum
	meters							
Hickories	8.4	10.3	10.3	13.2	12.1	17.7	12.4	22.9
Maples	8.2	9.6	9.9	12.6	9.6	10.6	10.9	15.0
Mixed hardwoods	8.4	11.1	9.3	12.2	10.5	15.4	11.5	15.9
Red oaks	9.9	17.1	10.4	14.3	10.3	14.4	10.9	13.6
Shortleaf pine	8.7	9.5	0.0	0.0	9.7	12.4	0.0	0.0
White oaks	8.8	18.3	9.9	13.9	9.4	13.0	10.7	18.1
Others	7.6	7.6	9.4	10.1	0.0	0.0	0.0	0.0

RESULTS

The tallest mean heights for each species group, excluding others, were within group selections. Because of the absence of individuals on protected slopes, shortleaf pine had a greater mean height within exposed group selections than exposed clearcuts (Table 1). Within clearcuts, red oaks had the tallest mean height (10.4 m) followed by hickories (10.3 m) and white oaks (9.9 m) (Table 1). Hickories (12.4 m) and mixed hardwoods (11.5 m) had the tallest mean heights within group selections (Table 1). The tallest oaks were found within exposed clearcuts, and hickories, maples, and mixed hardwoods had higher maximum heights in group selection harvests.

Mixed hardwoods were the most common species group of both treatments and aspects when all individuals were considered (>31 percent) (Fig. 1A). White oaks were the second most abundant (>17 percent) aside from maples within the protected aspect of clearcuts (23 percent) (Fig. 1A). The others species group were comparable to red oaks for all sampled individuals (Fig. 1A), but within the 90th percentile, red oaks contribute a much greater percentage to the overall composition (Fig. 1B). Above the 90th percentile, the red oak group is more common within clearcuts than group selections, and red oaks are more common on the exposed aspect of each treatment than on the protected aspect (Fig. 1B). The white oak group makes up at least 22 percent of all stems across all aspects and treatments above the 90th percentile. Shortleaf pines are found only on the exposed aspect of each treatment, and the greatest abundance of shortleaf pine is within Group^{GP90} (Fig. 1B).

When analyzed across all species, we found significant treatment ($p < 0.001$) and aspect ($p = 0.048$) effects on the number of trees per hectare taller than the 90th percentile. Clearcuts^{CC90} resulted in significantly more trees per hectare than Group^{CC90} and Group^{GP90} (Fig. 2A). There was no significant interaction between aspect and treatment ($p = 0.114$) when all species were included. Hickories were the only species group to exhibit a significant interaction between treatment and aspect ($p = 0.032$) (Fig. 2B). Aspect had a significant effect on density for maples ($p = 0.014$) and mixed hardwoods ($p = 0.001$) (Fig. 2C and Fig. 2D), and there was a significant treatment effect for red oaks ($p < 0.001$) (Fig. 2E) and white oaks ($p < 0.001$) (Fig. 2G). Shortleaf pine and others exhibited no significance in regards to treatment, aspect, or the interaction of treatment and aspect (Fig. 2F and Fig. 2H).

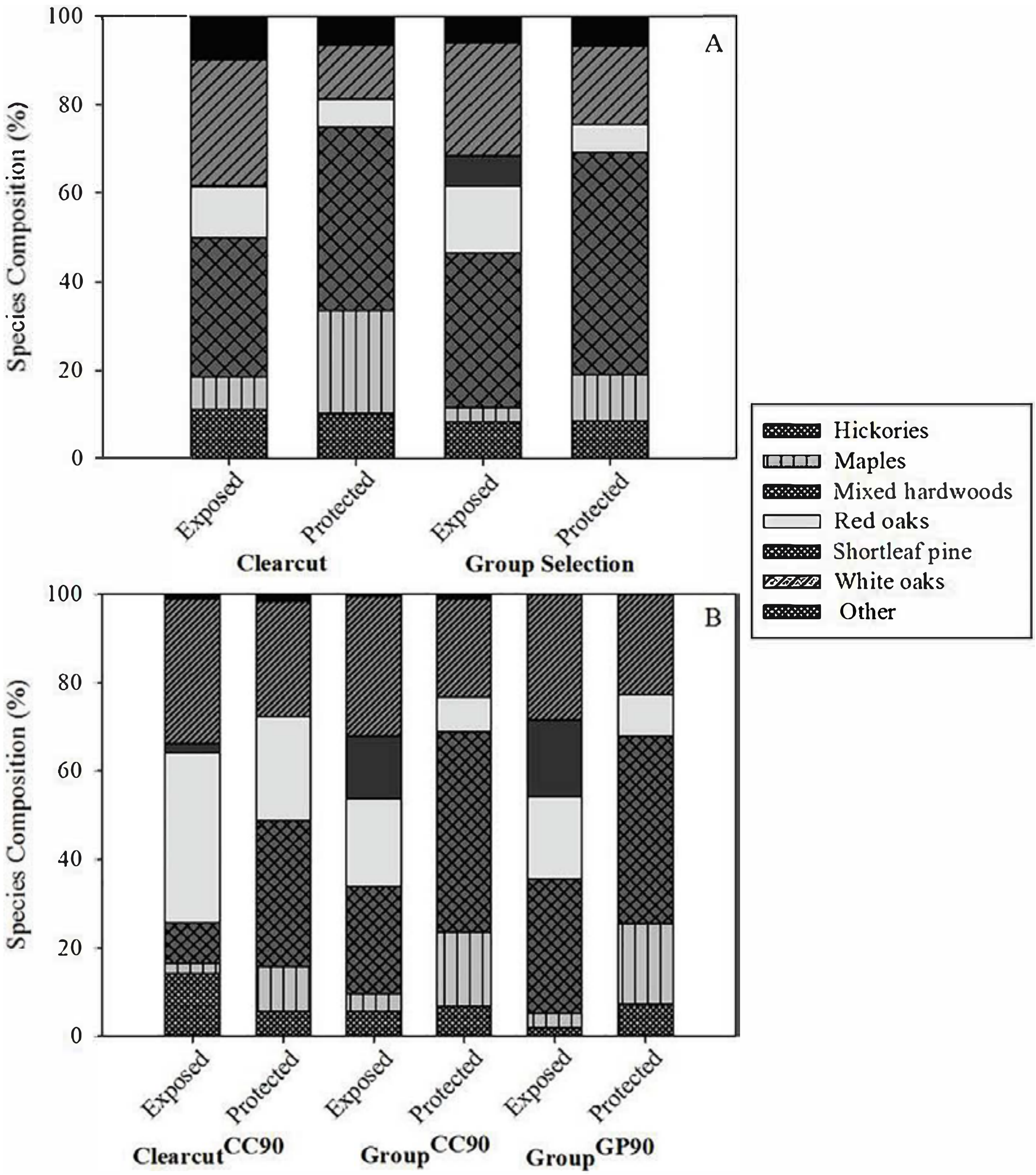

Figure 1.—Species composition (percentage of all stems present) for (A) exposed and protected sties by treatment using all trees present, and (B) exposed and protected sites of all individuals greater than the 90th percentile threshold used in this study.

Clearcutting produced a lower 90th percentile height threshold on both exposed (7.39 m) and protected (8.12 m) sites compared to the group selection harvests on exposed (8.67 m) and protected (9.71 m) sites, and this resulted in greater densities within clearcuts for all species aside from shortleaf pine (Fig. 2B-2H). Group^{CC90} had greater densities for all species compared to Group^{GP90}, and Group^{CC90} had densities greater than clearcut^{CC90} for maples and mixed hardwoods (Fig. 2B-2H).

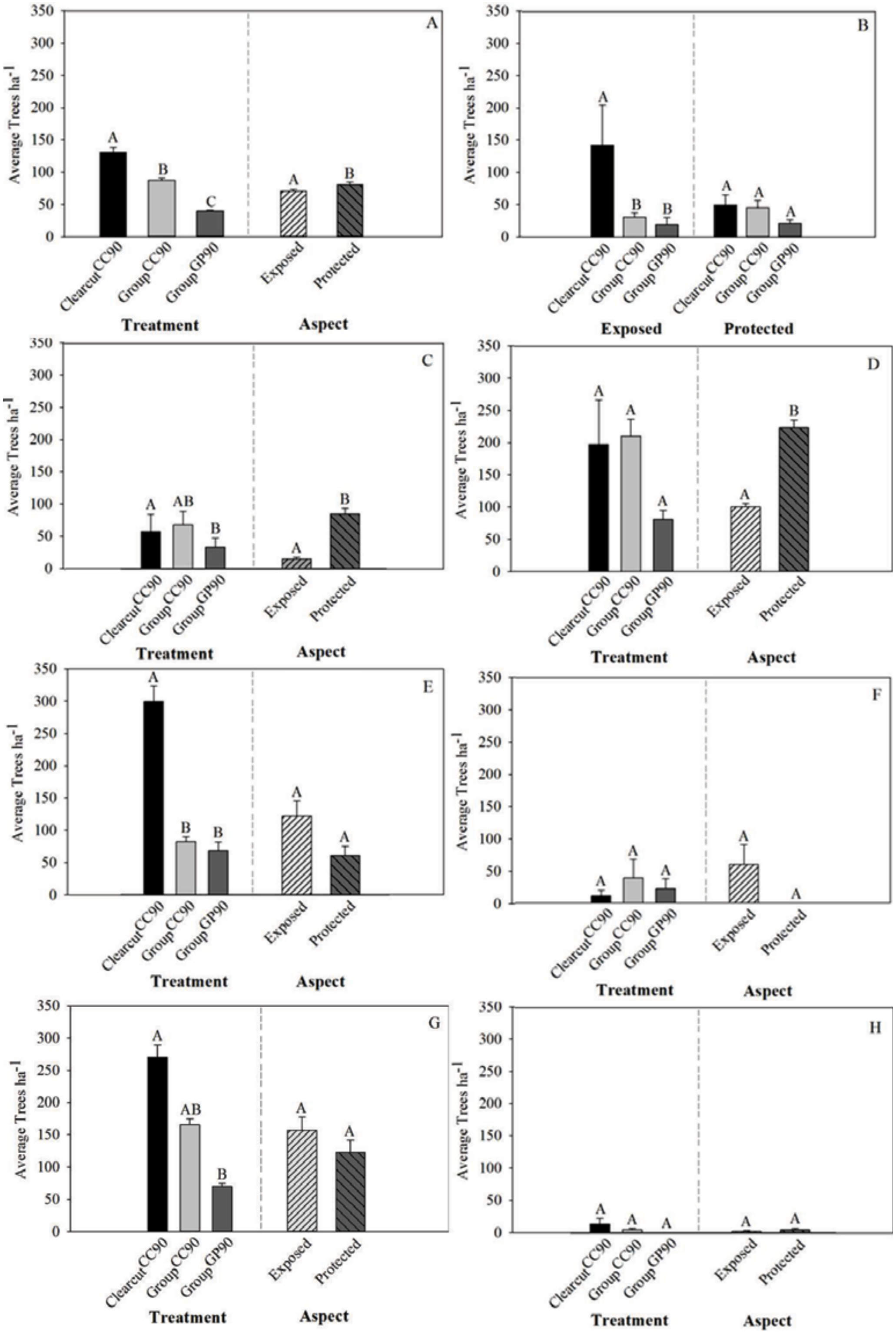

Figure 2.—Average trees per hectare above 90th percentile on protected and exposed aspects for all species and groups: (A) total; (B) hickories; (C) maples; (D) mixed hardwoods; (E) red oaks; (F) shortleaf pine; (G) white oaks; (H) others. Threshold^{CC90} exposed = 7.4066 and protected = 7.707 m. Threshold^{GP90} exposed = 8.189 m and protected = 8.6314 m. The significance (α = 0.05) denoted within graph B indicates significance within each aspect. Within treatment and aspect classes, significantly different (α = 0.05) densities are denoted by differing letters above error bars.

DISCUSSION

Even-age management has been recommended for regenerating oaks on upland sites in the Central Hardwood Forest region (Roach and Gingrich 1968), and the results of our study indicate that clearcutting resulted in the greatest density of oaks that are most likely to achieve canopy dominance. Species diversity was greatest within clearcuts, but the population of the tallest trees was dominated by fewer species than in group openings. The reduction in light levels reaching the regeneration in group openings is a likely factor in the reduction of oak species density. Species composition as a result of group selection did not vary greatly from clearcuts, however. The most notable difference between treatments was the decrease in density for almost every species group in group openings.

The 90th percentile thresholds for heights were similar for each aspect, but group selection thresholds were higher than clearcuts on both aspects. Collins and Carson (2004) found that *Q. alba* showed significant differences in density across aspects, but our white oak species group did not exhibit the same trend. Density of stems in the red oak and white oak species groups did not differ between aspects of the same treatment. The mean heights of all species except shortleaf pine and others were highest in protected group openings. The greater quantity of small trees in clearcuts resulted in higher mean heights in group selections for all species groups except the others group. The elevated 90th percentile thresholds of the group selections were possibly a result of having fewer small trees than in the clearcuts to skew the distribution, which perhaps accelerated the treated area through stand development. If a greater quantity of small trees is the cause, the existence of these smaller trees could be a result of variable budburst phenology, but additional analysis will be required to determine if this is a source of variability (see Hunter and Lechowicz 1992). In addition, competition within the shaded group selections could be the cause of more growth resources attributed to stem elongation.

Our analyses did not take into account sapling locations within the groups and examined only the averages of each plot sampled. Regenerating oaks near plot center may have received the optimum sunlight for growth (Minckler et al. 1973) and were capable of performing similarly to oaks within the clearcuts, but oaks closer to the group edge were subject to greater shading from the mature canopy. Examining the growth and location of trees within the group selections would yield valuable information on the success of group selection in promoting individuals across the selection as well as on the utility of additional treatments such as thinning the forest matrix that surrounds a group selection (Lhotka and Stringer 2013).

Group openings were not placed or shaped selectively to encourage any one species group to dominate. The effect of the treatment may increase with deliberate placement and shape and could be further enhanced by cultural practices such as thinning to accomplish management objectives (Miller et al. 1995). The evaluation of group selection success could have been improved by pretreatment sampling to compare species composition before and after management actions.

CONCLUSION

The Missouri Ozarks are well suited for oak regeneration, and the structure and composition of the regenerating stand depend largely on the composition of the mature canopy before a regeneration event (Dey et al. 1996). Our findings suggest that group selection could be a viable alternative to clearcutting despite significantly different densities after clearcutting and group selection. Although even-age management resulted in the greatest number of stems per hectare of oak species, oaks also dominated the recruiting cohort in group openings. Consideration of management objectives such as aesthetics, economics, and specific wildlife requirements may discourage clearcutting, and group selection harvest appears to be a viable alternative for forest management to succeed in meeting the goals of myriad stakeholders.

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