Group Selection Opening Effects on Regeneration Decades after Harvest

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Abstract.—Forest managers and researchers have proposed group selection as a complementary system to conventional, uneven-aged management in temperate hardwood forests with the goal of counteracting declines in forest diversity (Eyre and Zillgitt 1953, Leak and Sendak 2002, Neuendorff et al. 2007). The intended goals for group openings in this selection system are to establish new age classes and use opening size to influence essential resources and microclimates in openings to complement the desired species composition of regeneration (Coates and Burton 1997, Grubb 1977, Lhotka et al. 2018). Yet few long-term studies provide group selection outcomes (Coates and Burton 1997, Kern et al. 2017).

INTRODUCTION

These findings present tree regeneration results from two long-term group-selection experiments implemented in northern hardwood forests in the western Great Lakes region.

METHODS

We used two experiments: (1) Divide Canopy Gap Study (DCGS), Chequamegon-Nicolet National Forest, Forest County, Wisconsin (N 45°56', W 88°59') and (2) Yellow Birch Legacy-tree Project (YBLP), Michigan Technological University's Ford Center and Forest, Baraga County, Michigan (N 46°37', W 88°29') (Table 1).

The DCGS has a randomized, complete-block design. Treatments were six size classes of harvest-created, circular-canopy openings (Table 1). The remainder of the study site was thinned (except in the reference [0 m] sites where no harvesting occurred). The YBLP has a completely randomized design. In 2003, the study area was surveyed for dominant and codominant yellow birch and 69 were randomly selected to serve as centers of four size classes of harvest-created, circular-canopy openings and reference sites (0 m, Table 1). The species selection for legacy-tree retention was yellow birch (*Betula alleghaniensis* Britton) because this historically important species is scarce in the area. Legacy-tree retention maintains overstory presence and seed source in the stand over multiple cutting cycles. The remainder of the study site was treated with single-tree selection.

We used regenerating tree species, size, and density over time to study composition and density, sapling structure and composition, and failed regeneration patches across opening size classes at each experiment. Accompanying studies of browse were conducted for each site. Exclosures were maintained for a short, early period at the DCGS and in a gap study of similar duration at and near the YBLP. Data were analyzed by experiment. For details on methods, see Knapp et al. 2019a, Knapp et al. 2019b, Knapp et al. 2021, VanderMolen et al. 2021, and VanderMolen and Webster 2021.

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Table 1.—Study design and site details for two long-term group selection experiments in northern hardwood forests of the western Great Lakes, United States

Study design and site characteristics	Divide Canopy Gap Study (DCGS)	Yellow Birch Legacy-tree Project (YBLP)
Location	Northern Wisconsin, United States	Upper Michigan, United States
Habitat type	ATD	ATD
Soil type	sandy loam	silt loam
Known management history since 1900	Unmanaged since clearcut ca. 1930s	Heavy partial cut 1938; Single-tree selection since 1954
Year(s) of study establishment	1994-1995	2003
Stand age structure at establishement	Even-aged forest (approx. 60-years-old at study establishment)	Uneven-aged (4+ age classes)
Legacy-tree retention with group opening	No	Yes
Tree d.b.h. (cm) harvested	>2.5	>10
Data collected (years post-harvest)	23–24	15–18
Group opening radius (m) (no. of replicates)	0 ([reference, uncut], 12) 3 (11) 5 (11) 10 (11) 20 (12) 23 (12)	0 ([reference, single-tree selection], 20) 11 (16) 16.6 (17) 22 (16)

RESULTS AND DISCUSSION

We first investigated regeneration layer density in openings at both experiments one to two decades after harvest. In general, seedling and sapling densities were higher in openings than references at both experiments (Table 2; Knapp et al. 2019a, 2021). At DCGS, sapling density was largely at acceptable levels for sustainability, except in large openings (i.e., 46 m diameter) where 23 years after harvest regeneration density was low and > 40 percent of our sample plots (i.e., 1.83 m radius) were considered regeneration failures (without trees taller than 1.37 m; Knapp et al. 2021). At YBLP—where legacy trees were retained—opening size did not affect rates of within-opening regeneration failures 15 years after harvest; frequency of regeneration failures was similar to DCGS. Regeneration failures were not related to resource and microclimate gradients within openings at either experiment (VanderMolen et al. 2021). Rather, using data from DCGS, regeneration densities at year 23 after harvest were best predicted by the observed densities at year 2 after harvest (Knapp et al. 2021). Earlier research at DCGS documented thick *Rubus* spp. cover in large openings (Kern et al. 2013). At YBLP, previous research showed *Rubus* patches resisted reinvasion by trees for over a decade (Widen et al. 2018). The research at both experiments demonstrated the importance of advance regeneration at the time of harvest when additional treatments are not planned (e.g., scarification, artificial regeneration).

We next investigated the composition and diversity of regeneration when present at both experiments one to two decades after harvest. Richness and evenness were not different across opening sizes at either experiment (Table 2; Knapp et al. 2019a, 2021). Species richness was low (i.e., 1 to 3 species) at DCGS 23 years after harvest (Knapp et al. 2021). Species richness was

Table 2.—Summary of results from two long-term group selection experiments (See Table 1 descriptions)

	Reference	Smaller Opening Sizes	Larger Opening Sizes	(Citation)
Density, all regeneration				(Knapp et al. 2019a, 2021)
DCGS, 23 years after harvest	Low	Acceptable	Some failures	
YBLP, 15 years after harvest	Low	Acceptable	Some failures	
Diversity, all regeneration				(Knapp et al. 2019a, 2021)
DCGS, 23 years after harvest	Low	Low	Low	
YBLP, 15 years after harvest	Low	Moderate-Low	Moderate-Low	
Composition, all regeneration				(Knapp et al. 2019a, 2021)
DCGS, 23 years after harvest	Sugar maple	Mix of sugar maple, ironwood, white ash	Mix of sugar maple, ironwood, white ash	
YBLP, 15 years after harvest	Sugar maple	Sugar maple with some red maple	Sugar maple with mix of red maple, yellow birch	
Composition, gap-capturing saplings				(Knapp et al. 2019b)
DCGS, 23 years after harvest	Sugar maple (overstory)	Mix of sugar maple, ironwood, white ash	Mix of sugar maple, ironwood, white ash	
YBLP, 15 years after harvest	Sugar maple with mix of eastern hemlock and yellow birch (overstory)	Sugar maple with mix of red maple, black cherry, ironwood	Sugar maple with mix of red maple, black cherry	

moderately low (3 to 5 species) across opening sizes at YBLP 15 years after harvest. However, at YBLP openings had slightly more species (i.e., 1+ species) and diversity (i.e., Shannon's Diversity Index and evenness) of regenerated seedlings compared to references 15 years after harvest. YBLP also showed some compositional differences that were not detected at DCGS; YBLP openings with legacy-tree retention were commonly composed of red maple (*Acer rubrum* L.) and yellow birch in addition to dominant sugar maple (*Acer saccharum* Marsh.). Moreover, red maple regeneration was frequently >1 m tall, while yellow birch regeneration was rarely over 2 m tall 15 years after harvest (Knapp et al. 2019a). Companion studies of deer exclosures at the DCGS and near the YBLP indicate ungulate browsing is likely influencing composition in openings at both experiments (Kern et al. 2012, VanderMolen and Webster 2021). For example, 18 years after harvest, browse sensitive species >1 m tall were frequent inside but rare outside exclosures existing on the same land base as the YBLP (VanderMolen and Webster 2021). The research at both experiments demonstrated varying opening size alone had minimal effects on regeneration diversity and composition. Legacy-tree retention was correlated with compositional shifts; however, deer browsing is likely a major filter for regenerating tree composition as saplings ascend toward the canopy.

Given the results stated above, we lastly investigated only the saplings with the best potential to attain a canopy position—the tallest saplings within an opening (hereafter "gap-capturing saplings"). Only one or a few saplings are needed to eventually fill a small canopy gap and the composition of these tall saplings may not reflect the general trends we observed in the assessments of the full regeneration layer. Gap-capturing sapling composition did not match the surrounding canopy dominated by sugar maple at either experiment, and opening size had limited effects on sapling diversity (Table 2; Knapp et al. 2019b). At DCGS, 23 years after harvest, we found—regardless of opening size—that gap-capturing sapling composition was dominated by sugar maple, ironwood (*Ostrya virginiana* [Mill.] K. Koch) and white ash (*Fraxinus americana* L.), which was similar to the advance regeneration composition remaining at year two post-harvest. Because of the lethal effects of anticipated emerald ash borer (*Agrilus planipennis*) on ash trees and the subtree growth form of ironwood to fill lower canopy positions, future canopy composition is not expected to change significantly over the next several cutting cycles. At YBLP, openings were dominated by sugar maple 15 years after harvest but opening size moderately affected composition. Large openings had more shade mid-tolerant red maple (*A. rubrum* L.) and intolerant black cherry (*Prunus serotina* Ehrh.). Large opening composition was different from the surrounding canopy, which had more eastern hemlock (*Tsuga canadensis* [L.] Carrière) than regeneration layers. This compositional deviation between gap-capturing saplings and surrounding canopy trees may alter canopy composition over several cutting cycles (Knapp et al. 2019b). Yellow birch was not a significant part of opening composition, despite yellow birch left as legacy trees and localized seed sources in all YBLP openings. Yellow birch regeneration was significantly aggregated across spatial scales and tended to occur at higher abundance in the shade of the legacy tree and along the southern edges of openings (Poznanovic et al. 2014). YBLP openings were not scarified after harvest, therefore, lack of suitable substrate may have limited yellow birch establishment (Caspersen and Saprunoff 2005, Willis et al. 2016).

The varying outcomes between these experiments may be due to available seed sources, legacy-tree effects, browsing intensities, stage of stand development, and management histories that differed between the sites (Table 1; Knapp et al. 2019b). More broadly, contemporary ecosystems such as these are experiencing significant challenges to resilience due to an array of legacy, ongoing, and novel factors (Webster et al. 2018). Continued study and evaluation of silvicultural tools across a range of site conditions and time frames is essential.

CONCLUSIONS

Theory predicts that group selection openings should promote increased recruitment of shade-intolerant and midtolerant species in temperate hardwoods, but our experimental results suggest that opening creation alone only modestly affected diversity and more broadly resulted in regeneration failures in large openings. Legacy-tree retention in gaps was associated with some opening-size effects, including more light-demanding species in gap-capturing saplings and slight increases in regeneration diversity in general with increasing opening size. The moderating effects of the retained tree cover may facilitate species coexistence, but more research is needed. Our results also suggest that outcomes following group selection are highly context dependent, and that factors unrelated to opening size such as management history and browsing intensity may profoundly influence results even decades after harvest. Careful placement of openings and postharvest treatments such as planting and/or browse protection might be necessary for group selection to be successful in contemporary hardwood forests in the western Great Lakes region.

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