CANOPY GAP CHARACTERISTICS OF AN OLD-GROWTH AND AN ADJACENT SECOND-GROWTH BEECH-MAPLE STAND IN NORTH-CENTRAL OHIO

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Abstract.—The increased importance of integrating concepts of natural disturbance regimes into forest management, as well as the need to manage for complex forest structures, requires an understanding of how forest stands develop following natural disturbances. One of the primary natural disturbance types occurring in beech-maple ecosystems of the Central Hardwood Forest is canopy gaps. We characterized canopy gaps of an old-growth beech-maple stand in north-central Ohio and compared these characteristics with an adjacent mature second-growth stand. Using a line-intercept approach, we found that 9.3 percent of the forest area of the old-growth stand was in canopy gaps while 3.7 percent of the second-growth stand was in canopy gaps. Mean canopy gap size was not different between the old-growth and second-growth stands (145.6 m^2 and 126.8 m^2, respectively). Mean gap-maker size was larger in the old-growth stand than in the second-growth stand, and the species compositions of gapmakers were similar to the surrounding canopy trees. However, the modes of canopy gap formation were not different despite the differences in gapmaker species. Sugar maple and American beech are the dominant tree species regenerating in canopy gaps in both stands. Based on our results, forest managers may be able to emulate canopy gap dynamics in similar forest ecosystems using the selection method.

INTRODUCTION

Mature hardwood forests, including beech-maple (*Fagus* L.-*Acer* L.) ecosystems, were once extensive throughout the Central Hardwood Forest (National Council for Science and the Environment 2008). Much of the original forest has been converted to other land uses, primarily agriculture and urban development (Parker 1989). In an effort to restore and increase the complexity of altered forest ecosystems, a recent focus of forest ecologists and managers is to emulate natural disturbance regimes using innovative silvicultural practices (Franklin and others 2007). The few remaining old-growth stands are essential benchmarks, providing reference conditions for forest ecosystem restoration and management (Society for Ecological Restoration International Science and Policy Working Group 2004). Studying these stands will help us understand ecosystem processes of undisturbed forests, as well as learn how management practices may affect those processes and the ecological integrity of managed stands (National Council for Science and the Environment 2008). Using comparative studies of second- and old-growth stands is important when restoring the old-growth characteristics we may desire to develop in younger forests (Lorimer and Frelich 1994).

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One important forest ecosystem process needing more study is the canopy gap dynamics of old-growth stands. This process is important because canopy gaps directly affect the successional trajectory of a stand by influencing regeneration development, species composition, growth rates, and age structure (Lorimer 1989, Runkle 1992, Franklin and Van Pelt 2004). Specifically, the size, origin, and shape of gaps affect several stand characteristics (Runkle 1992). Individual-tree death causing canopy gaps has been found to be the primary disturbance type in beech-maple forests (Runkle 1982).

The objective of this study was to determine and contrast the canopy gap characteristics of adjacent old-growth and mature second-growth beech-maple stands in a north-central Ohio forest. This forest provides a unique opportunity to study the canopy gap characteristics of adjacent old-growth and mature second-growth beech-maple stands. Both stands have very similar environmental conditions, but they have had different disturbance histories.

STUDY AREA

This study was conducted at Crall Woods, a 37.4-ha forest in Ashland County, OH. The forest was designated a National Natural Landmark in 1974, one of 23 currently in Ohio (Ashland County Park District 2005). It is one of the few remaining old-growth forests in north-central Ohio. Two of its stands were compared in this study: a 4.0-ha mature second-growth stand and a 16.2-ha old-growth beech-maple stand.

Crall Woods is located in the Low Lime Drift Plain (Level IV Ecoregion) of the Erie/Ontario Drift Lake Plain. The Low Lime Drift Plain is characterized by gently undulating topography with scattered end moraines and kettles (Woods and others 1998). Annual precipitation in the region ranges from 900 to 1,030 mm, and annual average temperature ranges from 10 to 13 °C (McNab and Avers 1994). The predominant soil series of the area is Bennington silt loam, a somewhat poorly drained soil originating from glacial till (Aughanbaugh 1964). Embedded within Crall Woods are small vernal pools that have standing water for extended periods of the year.

The old-growth stand is dominated by sugar maple (*Acer saccharum* Marsh.), American beech (*Fagus grandifolia* Ehrh.), American basswood (*Tilia americana* L.), and yellow-poplar (*Liriodendron tulipifera* L.), and has essentially been undisturbed by humans for approximately 250 or more years (Pinheiro and others 2008). The second-growth stand contains many of the same species, as well as northern red oak (*Quercus rubra* L.) and various hickory (*Carya* Nutt.) species (Pinheiro and others 2008). Pinheiro and others (2008) determined that the second-growth stand is approximately 140 years old, and it is becoming more similar in species composition to the old-growth stand.

METHODS

DATA COLLECTION

We used a modified version of Runkle's (1992) methodology to sample the canopy gaps of both stands at Crall Woods. Four parallel line transects were permanently established approximately 50 m apart and inventoried during August 2008. The two stands share an east-west boundary; each transect ran north-south from the second-growth stand into the old-growth stand across this boundary. Since these transects were permanently located, we were able to sample them again during November 2009. The spacing between each pair of transects was chosen to assure that no canopy gap was intersected by more than one transect. Their placement was designed to avoid all stand edges by at least 50 m, and to sample the entirety of each stand. The transects ranged in length from 574-819 m, primarily because their ending points within the old-growth stand varied in relation to its southern boundary.

Along the length of each transect, the canopy was classified as either closed or a gap. Canopy gaps were areas where the canopy height was < 50 percent of that of the adjacent forest. When a canopy gap was intersected, these characteristics were noted: the number of gap makers (i.e., a single- or a multiple-tree gap), the species and diameter at 1.37 m above the ground (d.b.h.) of each gap maker (trees having a d.b.h. of at least 20.0 cm) (Runkle 1992). A single-tree gap was formed by the death of one gap maker, whereas a multiple-tree gap was created by the death of two or more gap-maker trees. In multiple-tree gaps the main gap maker was the tree with the largest d.b.h. For each gap, the mode of gap origin was determined as tip-up, basal shear, standing dead (snag), limb dead or broken, or due to wet soils (Weiskittel and Hix 2003). The longest axis (A major), along its perpendicular axis (A minor), were measured and used to estimate gap size (Runkle 1992).

Within each gap, the probable replacement tree(s) were determined. These trees were chosen because of their location, height, and health (Runkle 1992). Along with the species of each tree, its height was measured with the aid of a telescoping height pole or a clinometer.

DATA ANALYSES

For each stand, the proportion of land area in canopy gaps was calculated as the proportion of the total transect distance in gaps divided by the total length of transect lines (Runkle 1992). Gap size was determined by using the area formula for an ellipse: area = [3.14 × (A major × A minor)/4]. Eccentricity of gap shape was calculated by dividing A major by A minor; a circular shape occurs with a value of one and a value greater than one indicates an elliptical shape (Battles and others 1996).

Proportion of land area in canopy gaps, gap size, d.b.h. of gap-maker trees, and eccentricity of gap shape between the old-growth stand and the second-growth stands were analyzed using t-tests. Mode of gap origin by stand type data was analyzed using the Chi-square method of contingency analysis for categorical data. These analyses used only the 2008 data, and were accomplished using MINITAB® version 15 statistical software (Minitab Inc., State College, PA).

RESULTS

The old-growth stand had a significantly higher (P = 0.025) proportion of land area in canopy gaps than did the second-growth stand (9.3 percent vs. 3.7 percent, respectively). A total of 1,958 m of transect was sampled in the old-growth stand, and 17 gaps were encountered in 2008. In the second-growth stand, 728 m of transect was sampled and three gaps were encountered.

Only one additional canopy gap was found on the same transect lines in 2009. This single-tree gap occurred in the old-growth stand and had an area of 148 m^2.

Most (66.7 percent) of the gaps in the second-growth stand were small (<100.0 m^2), whereas half of the gaps in the old-growth stand were large (≥100.00 m^2) (Fig. 1). The mean canopy gap size in the old-growth stand was larger (145.6 ± 94.0 m^2), but it was not different (P = 0.793) from the mean size in the second-growth stand (126.8 ± 101.6 m^2) (Table 1).

All gaps had eccentricity values greater than one, indicating elliptical shapes. The mean eccentricity value for canopy gap shape was not significantly different (P = 0.103) between the two stands.

In the old-growth stand, multiple-tree gaps were 52.9 percent of the canopy gaps, whereas 66.7 percent of the canopy gaps in the second-growth were multiple-tree gaps. Tip-ups and snags were the dominant modes that originated gaps for both the old-growth and second-growth stands (Table 2). No difference in the observed vs. expected frequencies of mode of gap origin were detected between the two stands (P = 0.130).

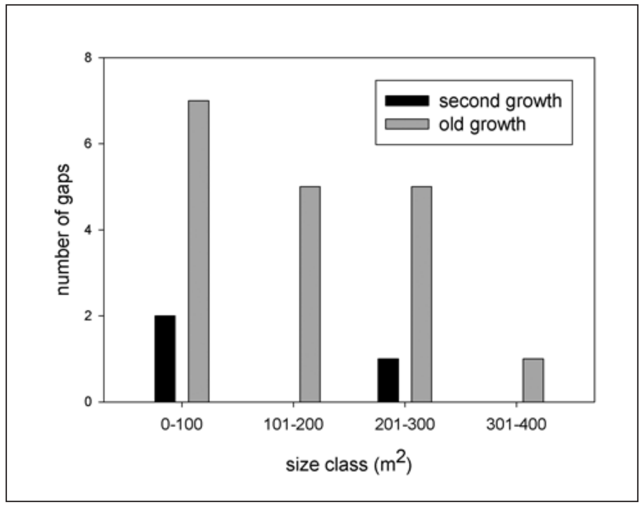

Figure 1.—Size distributions (m^2) of canopy gaps in old-growth and second-growth stands at Crall Woods.

Mean gap-maker size was larger (P = 0.081) in the old-growth stand (52.3 cm d.b.h.) than in the second-growth stand (45.8 cm d.b.h.) (Table 3). Sugar maple and American beech were the dominant gap-maker species in the old-growth stand, whereas northern red oak caused most of the gaps in the second-growth stand (Fig. 2).

Sugar maple will be the most common probable replacement tree species in canopy gaps in both the old-growth and second-growth stands. This species represented 83 percent and 54 percent, respectively, of the dominant stems in canopy gaps in the second-growth and old-growth stands. In the old-growth stand, American beech assumed this role in 32 percent of the canopy gaps.

Table 1.—Gap size characteristics (m^2) for the old-growth and second-growth stand gaps at Crall Woods.

	Old-growth	Second-growth
Mean ± standard deviation	145.6 ± 94.0	126.8 ± 101.6
Median	106.2	71.4
Maximum	302.0	244.0
Minimum	41.2	64.8

Table 2.—Number of gap makers by mode by which they originated canopy gaps for the old-growth and second-growth stands at Crall Woods.

	Old-growth	Second-growth
Tip-up	10	8
Basal shear	5	0
Standing dead (snag)	14	3
Limb dead or broken	2	0
Wet soil	2	0

Table 3.—Gap-maker size (cm d.b.h.) for old-growth and second-growth stands at Crall Woods.

	Old-growth	Second-growth
Mean ± standard deviation	53.4 ± 24.3	42.7 ± 13.3
Median	56.0	46.1
Maximum	113.9	67.2
Minimum	18	23.3

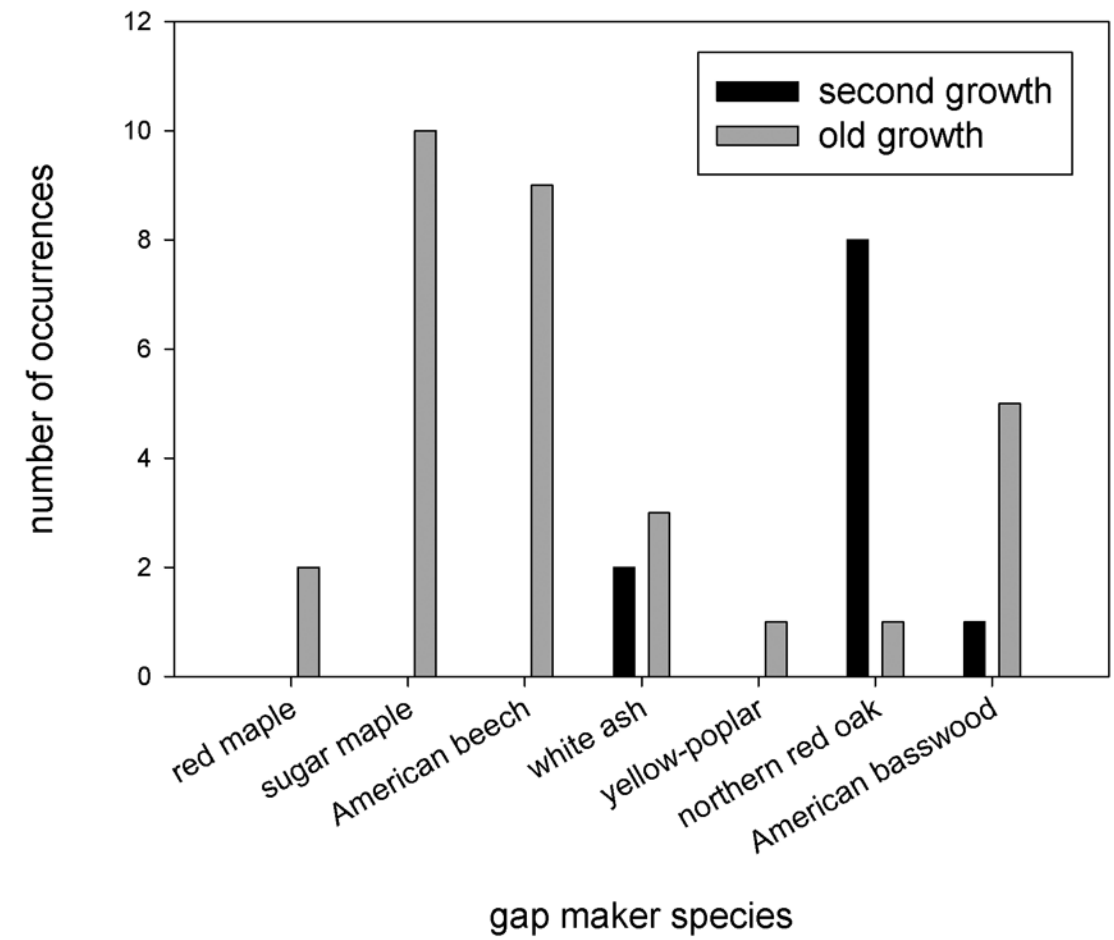

Figure 2.—Gap-maker species in the old-growth and second-growth stands at Crall Woods.

DISCUSSION

OLD-GROWTH STAND

The proportion of land area in canopy gaps in the old-growth stand was similar to those reported in other studies of old-growth Central Hardwood forests (Runkle 1982, Runkle 1990). Single- and multiple-tree canopy gap sizes in the old-growth stand at Crall Woods are typical of other old-growth beech-maple forests studied in Ohio (Runkle 1990, Forrester and Runkle 2000). However, the average gap size found in this study was smaller than the 280- to 375-m^2 range Lorimer (1989) found was typical of old-growth deciduous forests. Mean canopy gap size was also smaller than that for a nearby old-growth oak-beech-maple, wet-mesic stand in Johnson Woods in northeastern Ohio (Weiskittel and Hix 2003). Johnson Woods also had a larger gap fraction, possibly due to the deteriorating state of its very large, old (~400 years old) oaks (Weiskittel and Hix 2003). Gap shape for the old-growth stand at Crall Woods was more eccentric than in another study in an old-growth beech-maple stand in southwestern Ohio (Runkle 1990), where most gaps in Hueston Woods (65 percent) were approximately circular (Runkle 1990).

It is typical of old-growth forests for gaps to be created by snags and broken limbs resulting from single-tree deaths (Runkle 1982, Runkle 1990). Crall Woods follows this trend, since snags caused about half of the canopy gaps in the old-growth stand. This old-growth stand nonetheless differs from some other similar stands in the region since it has many tip-ups that have resulted in the formation of multiple-tree gaps. The above-mentioned study of Johnson Woods also found a high proportion of tip-ups (Weiskittel and Hix 2003). It is possible that the large crowns, somewhat poorly drained soils, and presence of surrounding agricultural land resulting in a 'hard' edge makes trees more susceptible to windthrow in the remaining old-growth stands of north-central Ohio.

The old-growth stand contained more canopy gaps than did the second-growth stand, but this finding was expected. Old-growth forests tend to have more canopy gaps than younger forests because such gaps have had more time to develop (Lorimer 1989).

SECOND-GROWTH STAND

Gap sizes between the two stands at Crall Woods were not different, possibly due to the similarity in size of the gap makers. Gap sizes in these stands, however, may have been overestimated. Battles and others (1996) found the more elongated the ellipse, the greater the overestimation. Gap shape was elliptical for all gaps in both the second-growth stand and the old-growth stand. The mean eccentricity value for all gaps was 2.5. When eccentricity values are 2 or less, the error is less than 10 percent (Battles and others 1996). Weiskittel and Hix (2003) also found most gaps were eccentric in shape.

The second-growth stand gaps were created primarily by tip-ups, which resulted in multiple-tree gaps. The high number of tip-ups resulting in single- and multiple-tree gaps in both the second- and old-growth stands is probably attributable to the somewhat poorly drained soils of Crall Woods, which cause the trees to be shallow-rooted and more susceptible to wind disturbance (Lorimer and Frelich 1994). In many forests, wind is a primary disturbance agent (Franklin and others 2007). The somewhat poorly drained soils and wind have interacted to create many of the canopy gaps in both stands in Crall Woods. These windthrown trees create pit and mound micro-topography, which affects species compositions and soil processes (Franklin and others 2007).

COMPOSITION OF CRALL WOODS

A recent study of Crall Woods was conducted to determine the current composition and structure of the old-growth and second-growth stands (Pinheiro and others 2008). This study found that the overstory of the old-growth stand is dominated by sugar maple, American beech, American basswood, and yellow-poplar (Pinheiro and others 2008). The overstory of the second-growth stand contains many of the same species, as well as northern red oak and various hickory species (Pinheiro and others 2008). Sugar maple and American beech were the most important gap-maker species in the old-growth stand, whereas northern red oak was the most important gap maker species in the second-growth stand. The significant differences in overstory species composition (Pinheiro 2008) help explain the differences in gap-maker species between the two stands. Despite the differences in overstory species, the understories of the two stands are both dominated by American beech and sugar maple (Pinheiro and others 2008). These two species were also identified as the most common probable replacement tree species in canopy gaps in both stands.

LIMITATIONS OF THE STUDY AND CONCLUSIONS

Our research results constitute a case study of the canopy gap characteristics of a very significant forest in north-central Ohio. Crall Woods presents an important opportunity to examine ecosystem processes of adjacent old-growth and mature second-growth stands, both possessing very similar environmental conditions (i.e., edaphic and physiographic properties). It should be noted that the somewhat poorly drained soil characteristic of Crall Woods may predispose trees to wind throw. Another limitation is the relatively small size of both stands, particularly the second-growth stand.

The information obtained from the study of the composition of Crall Woods, in conjunction with our results, suggests that the composition and structure of both stands are converging, largely in response to individual species' life-history traits and disturbances in the form of canopy gap formation. Despite the small size of Crall Woods, this forest ecosystem represents one of the best remaining examples of a relatively undisturbed old-growth forest in the region. Based upon our results and the conclusions of other studies (e.g., Runkle 1991), we suggest that forest managers may emulate canopy gap dynamics in similar beech-maple forest ecosystems of the Central Hardwood Forest using the selection regeneration method. We found that relatively small gaps occur naturally as trees die and (or) fall over. By harvesting small groups of mature trees (e.g., two to three) to both create new gaps and expand old gaps, managers may emulate the natural disturbance regime.

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