GAP CHARACTERISTICS OF SOUTHEASTERN OHIO SECOND-GROWTH FORESTS

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ABSTRACT.—Transect sampling was used to assess the features of 30 gaps encountered in upland oak stands on the Wayne National Forest. Tip-ups caused the most canopy gaps (52 percent), two-thirds of which were small (< 100 m^2). Only on south-facing slopes were more large gaps found than small gaps. Gaps in the youngest age class (1 to 9 years) were significantly larger than older gaps. Twenty-seven percent of the gaps were shaped like an ellipse. Sugar maple was the dominant tree species successfully regenerating in both small and large gaps. These results indicate that gap dynamics will likely result in a species composition shift from oaks to mesic species in the future.

Most second-growth forest stands of the mixed mesophytic forest region (Braun 1950) regenerated under different disturbance regimes than the remaining old-growth stands (Runkle 1996). Both types of stands experience gap dynamics, yet few studies have focused on naturally occurring gaps in second-growth forests of the Central Hardwood region (e.g., Clinton and others 1993, Wilder and others 1999). A gap is defined by Runkle (1992) as "an area within the forest where the canopy (leaf height of tallest stems) is noticeably lower than in adjacent areas." More studies are also needed that examine gap dynamics on steeply sloping terrain, since these are most often the areas that have been continually forested due to their relative inaccessibility for agriculture (Clinton and others 1994).

Gaps occur in forests for a variety of reasons, e.g., wind damage, individual-tree mortality due to old age. The cause of a gap (or origin type) influences forest microenvironment (i.e., light intensity and available moisture) that in turn affects stand structure, including the composition and distribution of plant species (Putz and others 1983, Battles and others 1996). Origin types are expected to be stand- and region-specific because tree mortality is closely related to various environmental variables and to community characteristics.

The size and shape distributions of gaps are important because they determine both the amount of space and the types of forest floor microsites available for regeneration. Cho and Boerner (1991) found that in moderately well-drained to poorly drained Ohio old-growth forests, most gaps were < 100 m^2. Runkle (1982) also found mostly small (50 to 100 m^2) gaps in old-growth mesic forests in the eastern United States. Gaps on relatively dry, south slopes may be expected to be larger in area (≥ 100 m^2) because vegetation will grow more slowly and canopy openings will not fill as quickly as occurs on mesic slopes (Anderson 1954). Finally, many gap studies estimate area by assuming an elliptical shape for all gaps (Runkle 1982, Lorimer and Frelich 1989, Cho and Boerner 1991). This model can be tested against other calculation methods.

This study focuses on the characteristics of gaps on steep slopes in second-growth upland Central Hardwood forest stands. The major objectives were:

1) to determine the most common types of gap origins,
2) to assess the sizes (areas) and shapes of gaps, and
3) to describe the regeneration of tree species occurring in canopy gaps.

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STUDY AREA

The location for this study was southeastern Ohio, specifically the Marietta Unit of the Wayne National Forest. All areas studied were located in Washington County, which is bordered on the south by the Ohio River. Sampling was limited to forest stands in upper- and mid-slope positions. A prominent feature of the study area is the steep topography. The slope percent was measured on each sample area, and ranged from 25 to 88 percent (mean gradient was 45 percent). The soils of these forest ecosystems are mapped as one of two fine, mesic series: Upshur Hapludalfs (silty clay loam and clay) or Gilpin Hapludults (silt loam) (Lessig and others 1977).

The study area is within the mixed mesophytic forest region (Braun 1950), although the most common overstory trees are upland oaks (Griffith and others 1993). The forest stands investigated in this study had been disturbed one or more times since settlement in the late 18th Century (Gordon 1969). The most frequent types of disturbance have been partial harvesting, grazing, and oil and gas extraction. Suppression of most fires has occurred for at least the past 5 decades. The study area has not yet been invaded by the gypsy moth, and a moderate or higher level of mortality, due to oak decline or other causes, was not observed. Mesophytic species (e.g., sugar maple (*Acer saccharum* Marsh.)) often dominate the understory structural layer of stands in the region. Several studies have indicated that given the expected disturbance regime, these species will likely become a major component of the overstory in many local stands in the future (e.g., Downs and Abrams 1991, Drury 1996).

METHODS

Thirteen line transects were installed in portions of the second-growth forest stands described in the previous section. Starting points were randomly determined in the field, and the total length of transect sampled was approximately 4,000 m. Each transect roughly followed the contour and was oriented parallel to the ridge line. Using Runkle's (1992) line intersect sampling method, we recorded the position along each transect when the line intersected the boundary of a canopy gap. A tree was considered capable of creating or making a gap if it was ≥25 cm in diameter at breast height (DBH). Gap makers were identified (species or genus) whenever possible. Regeneration in gaps was assessed by determining which sapling or small tree would likely fill the gap (Helfrich 1998), i.e., the individual with the greatest potential to reach the canopy in the space left by the gap maker(s). Nomenclature follows Little (1979).

The type of origin for each gap was classified into one of the following five categories: tip-up, basal shear, snag, crown-crash, or geologic. A tip-up occurs when a tree falls and is uprooted, lifting a portion of the soil profile up with its root disk and producing pit- and mound-topography (Peterson and Campbell 1993). When the majority of the canopy opening is concentrated where the top of the tree fell rather than near its original bole position, the gap is considered a crown-crash origin type. The crown-crash origin type is normally associated with a tip-up; however, a much different microenvironment is created (i.e., a large amount of coarse woody debris). Basal shear is a fallen tree that has broken off at or slightly above the base of its bole. A snag is a standing dead tree. Some gaps were caused by a geologic event, i.e., slope movement. The null hypothesis that an equal number of observations would be found in each of the five origin type categories was tested using Chi-square analysis, following the procedure described by Brown and Downhower (1988).

Canopy gap areas were measured in the field according to Runkle's (1992) sampling protocol by locating and measuring two perpendicular lines in each gap: one along the longest line visible and one perpendicular to it at the widest section of the gap. Canopy gap area was calculated using three different methods. First, assuming gaps are ellipsoidal in shape, gap areas (m^2) were determined using the following equation: (π*[length*width]/4).

Second, in the field, the perpendicular lines measured in each gap were transferred to graph paper. From these scaled lines, oriented sketches of each canopy gap were drawn. Canopy gap area was estimated by counting the graph paper squares enclosed in each gap drawing and multiplying that number by the representative area of each square (0.9 x 0.9 m).

The third technique used to estimate canopy gap area consisted of fitting the most representative geometric shape(s) (e.g., a parabola in combination with half of an ellipse) over each gap sketch and counting the squares within the shape(s) area. Using one-way analyses of variance (ANOVAs), no significant differences were found among the three canopy gap area calculation techniques for either the sample of small gaps (< 100 m^2) or of large gaps (≥ 100 m^2) encountered in this study (small: $F_{2,59} = 0.77$, $P = 0.469$; large: $F_{2,30} = 1.47$, $P = 0.247$). Given the above, the values of canopy gap area used in the analyses were determined by averaging the results from the three area calculation methods.

Gap areas were analyzed using non-parametric Kruskal-Wallis tests (Minitab, Inc., Version 11.0). The Kruskal-Wallis test was used, given the large variances of the populations, to compare canopy gap areas among: four aspect categories (north, east, south, and west), three origin categories (tip-up, basal shear, and other), and three age classes (1 to 9 yrs, 10 to 20 yrs, and 21+ yrs).

Gap age was defined as the number of winters a gap has existed (Runkle 1979). To determine gap ages, we measured the radial growth response in overstory trees adjacent to canopy openings. Radial increment cores were taken from two mature trees on the canopy gap border for each gap sampled. The cores were extracted at 1.37 m above the ground. By examining each core and recording the annual radial increments, we detected major releases from competition (approximately 70 to 90 percent growth increase sustained for approximately 10 to 15 years since the previous 15 years (Lorimer and Frelich 1989). The estimated age for each gap was determined by the most recent major release.

RESULTS

Origin of Gaps

The 30 gaps encountered in this study originated following a variety of events (fig. 1). Each gap was formed following the demise of one or more canopy trees, i.e., more than one tree contributed to gap formation in 36.7 percent of the observations. The number of observations in four of the five origin type categories varied significantly from the expected (equal) number ($x^2_{4,46} = 32.7$, $P < 0.0001$). Tip-ups occurred more often than expected (52.2 percent of the total observations) and crown-crash, snag and geologic origins occurred less often than expected (each of these three categories contained 8.7 percent). Basal shear occurred as frequently as expected (21.7 percent of the total observations).

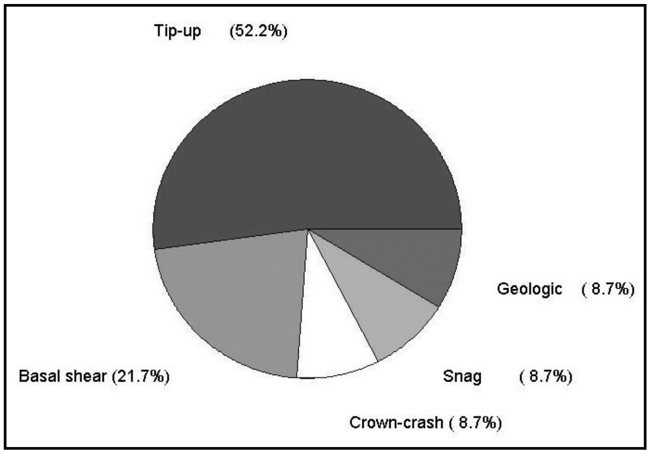

Figure 1.–*Percentages of five origin types for the 30 gaps encountered in second-growth forests of southeastern Ohio.*

Size of Gaps

Small canopy gaps (< 100 m^2) comprised 66.7 percent of the sample and ranged in area from 6.7 to 82.2 m^2. Large canopy gaps (≥ 100 m^2) ranged in area from 101.9 to 291.6 m^2. Overall, the mean canopy gap area was 86.4 m^2 (sd = 58.3 m^2).

Tip-ups tended to create the largest canopy gap areas (table 1); however, there was no significant difference at the 5 percent level in mean canopy gap area among origin types ($H_{2,29} = 5.61$, $P = 0.061$). Mean canopy gap areas also did not significantly differ among slope aspects ($H_{3,28} = 4.65$, $P = 0.200$). Only on the exposed, south-facing slopes were more large gaps found than small gaps (fig. 2).

Gap area was significantly different ($H_{2,27} = 6.77$, $P = 0.034$) among the three age classes, as expected (table 1). Gaps aged 1 to 9 years were

Table 1.—*Means and standard deviations (SDs) of canopy gap areas (m^2) by origin, gap age, and aspect*

	ORIGIN			GAP AGE			ASPECT			
	Tip-up	Basal shear	Other	1-9 years	10-20 years	21+ years	North	East	South	West
Mean	135.9	42.6	49.7	163.2	37.5	95.6	47.0	72.0	137.4	46.7
SD	99.5	21.0	28.6	118.2	16.9	82.0	34.1	39.1	107.1	31.8

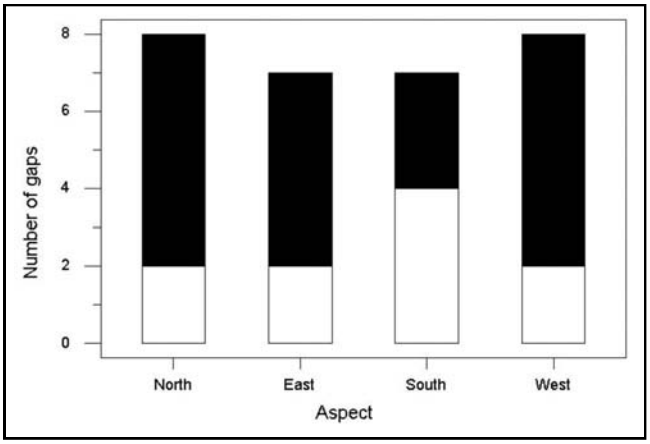

Figure 2.–*The numbers of small (shaded portion of each bar) and of large (≥ 100* m² *) gaps found on each of the four slope aspect classes.*

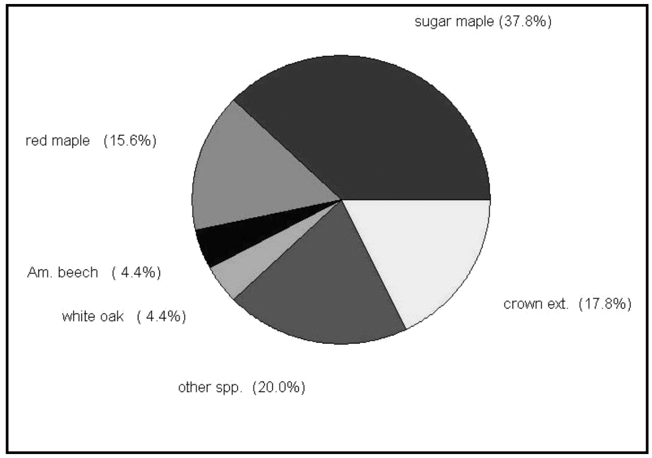

Figure 4.–*Percentages of each species or of lateral crown extension filling the 30 gaps.*

Figure 3.–*The number of gaps in each of three age classes.*

larger than the other age classes in mean canopy gap area. Gaps aged 10 to 20 years were the smallest. Most gaps (63.3 percent) were ≤ 20-years-old (fig. 3).

Shape of Gaps

Most gaps were not shaped like a single ellipse, however, 26.7 percent were judged to most closely resemble single ellipses. The shapes of 43.3 percent of the total gaps were observed to contain an entire or partial ellipse, along with another geometric figure, e.g., circle. Half of the gaps were described as having more than one type of shape.

Gap Maker Trees

Oaks comprised the majority of gap makers in this study. Twenty-five of the 39 gap maker trees were identified: 36.0 percent were northern red oaks (*Quercus rubra* L.), 20.0 percent were chestnut oaks (*Q. prinus* L.), 12.0 percent were white oaks (*Q. alba* L.), 8.0 percent were hickories (*Carya* spp. Nutt.), 8.0 percent were maples (*Acer* spp. L.), and 8.0 percent were American basswoods (*Tilia americana* L.). The remainder of the gap maker trees were yellow-poplars (*Liriodendron tulipifera* L.) and elms (*Ulmus* spp. L.). Each of these last two species made up 4.0 percent of the gap maker trees.

Regeneration in the Gaps

Sugar maple saplings and small trees were the most common mode by which gaps were filling (fig.4). Red maple (*Acer rubrum* L.) was the second most common species; 15.6 percent of the gap fillers were this species. In 17.8 percent of the gaps, lateral crown extension was the dominant process of gap closure. Other species that had expressed dominance in 4.4 percent or less of the gaps were American beech (*Fagus grandifolia* Ehrh.) and white oak.

The regeneration in both small and large gaps was primarily sugar and red maple (table 2). In large gaps, these two tree species were filling 76.0 percent of the canopy openings. American beech was the dominant species in 10.0 percent of the small gaps, but none of the large gaps. Species dominating 6.0 percent of the large gaps, but none of the small gaps, were slippery elm (*Ulmus rubra* Muhl.), Ohio buckeye (*Aesculus glabra* Willd.), and hackberry (*Celtis occidentalis* L.).

DISCUSSION

Wind damage is associated with tip-ups (Peterson and Pickett 1991) and tip-ups are associated with large gaps (Whitmore 1975). In this study, the majority of the gaps were created by tip-ups; however, most of the gaps were small in area. The relatively high frequency of

Table 2.—*The percentages of each tree species filling both small and large gaps*

	Small Gaps	Large Gaps
Acer saccharum	45	57
A. rubrum	20	19
Aesculus glabra	0	6
Carya tomentosa	5	0
Celtis occidentalis	0	6
Fagus grandifolia	10	0
Liriodendron tulipifera	5	0
Quercus alba	5	6
Q. prinus	5	0
Q. rubra	5	0
Ulmus rubra	0	6

tip-ups encountered compared with the frequency of tip-ups reported in other studies (e.g., Krasny and Whitmore 1991) may be due to differences in the stands' species compositions. Oaks comprised the majority of the gap makers in this study, and, because of their wood properties, trees of this genus may be more susceptible to windthrow than those of other tree species.

In a study by Putz and others (1983) of a Panama tropical rainforest, tree species with short, stocky boles and dense, strong wood (similar to oaks in second-growth forests) uprooted relatively more often than species not generally possessing those characteristics. Additionally, Putz and others (1983) found that frequency of origin type did not significantly differ with changes in degree of slope, so species composition likewise may have had more influence on the high frequency of tip-ups in this study than did the steepness of the topography.

In contrast, Runkle (1982) found the origin of most gaps in eastern mesic old-growth forests was basal shears, and only 19 percent of origins were tip-ups. Oaks were not the dominant species in the stands studied by Runkle (1982). Similarly, Whitmore (1975) found that basal shear in tropical rainforests created smaller gaps than tip-ups. The above trends are intuitive; tip-ups involve an entire tree falling at once, while basal shear involves only some portion of the tree falling and snags gradually deteriorate over time (Krasny and Whitmore 1991).

Most gaps (67 percent) were small (< 100 m^2). Small gaps were also numerous in a study of a second-growth cove forest in the Great Smoky Mountains (Clebsch and Busing 1989). Part of the reason for the abundance of small gaps and lack of large gaps is the absence of major disturbances that cause large gaps in southeastern Ohio (Goebel and Hix 1996). The lack of large gaps can also be attributed to the second-growth forest structure—basal area is not concentrated in a few large trees capable of creating larger gaps like in the tropics where canopy height is also relatively higher (Whitmore 1975, McCarthy and others 1987). Among the four aspect classes, only on exposed, south-facing slopes were more large gaps found than small gaps. The prevailing winds along with the soil water limitations of south-facing aspects may cause gaps to fill slowly, with the result being the presence of relatively more large gaps on these slopes.

As a gap ages, lateral crown extension of the surrounding trees fills it and the size of the gap becomes smaller (Runkle and Yetter 1987). Therefore, it was expected that the older gaps would be smaller than the younger gaps. Gaps 1-9 years old were the largest, but the 10-20 year age class had the smallest areas instead of the oldest age class (≥ 21 years). One reason for this may be that gap colonization occurs "nonrandomly" like origin (Whitmore 1975), and the rate of colonization is fastest between 10-20 years after a gap is created. Most gaps in Runkle's (1982) study were less than 15 years old, while the majority of the gaps we encountered were less than 20 years of age.

Different methods of gap area calculation have been compared within and among various studies (e.g., Runkle 1985, Battles and others 1996). Results have indicated that gap area may be overestimated by assuming an elliptical shape (Battles and others 1996). The majority of gaps we encountered were not single ellipses, and half of the gaps consisted of multiple shapes. In this study, assuming elliptical shapes for all gaps did not significantly overestimate area when compared with our two graphical approaches to gap area estimation. If a quick gap area calculation is desired, an ellipse is the most obvious choice as a model.

The species composition of the gap maker trees closely reflects the composition of forest stands of the study area. Fifty-six percent of the living trees in second-growth forests of Washington County, Ohio, are oaks and hickories (Keller and Hix 1999). In comparison, 76 percent of the identified gap makers were the same species. The regeneration successfully established in both small and large gaps indicates a shift in species composition is very likely to occur in the future.

Although 18 percent of the gaps were closing due to lateral crown expansion, sugar maple and red maple were filling 53 percent of the gaps.

Tree species richness was greater in small gaps than in large gaps (eight versus six regeneration species). Only white oak was found to be successful in both small and large gaps. The conclusions of others (e.g., Drury 1996, Runkle 1996) concerning the successional trajectory over time of similar stands in the region are supported by this study: as canopy gaps naturally occur, oaks will be replaced by mesic species such as sugar maple.

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