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Treefall gap characteristics within an Appalachian hardwood forest in West Virginia: Influences of topographic position and forest type

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**TREEFALL GAP CHARACTERISTICS WITHIN AN APPALACHIAN HARDWOOD
FOREST IN WEST VIRGINIA: INFLUENCES OF TOPOGRAPHIC POSITION AND
FOREST TYPE**

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**Thesis submitted to the Davis College of Agriculture, Forestry,
and Consumer Sciences at West Virginia University
in partial fulfillment of the requirements
for the degree of**

**Master of Science
in
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Gap Dynamics, West Virginia University Research Forest**

ABSTRACT

TREEFALL GAP CHARACTERISTICS WITHIN AN APPALACHIAN HARDWOOD FOREST IN WEST VIRGINIA: INFLUENCES OF TOPOGRAPHIC POSITION AND FOREST TYPE

JAMIE MARIE HIMES

We examined the attributes of canopy gaps on the 3,100 ha West Virginia University Research Forest (WVURF) near Morgantown, WV. The WVURF is a 70 -80 year- old, second-growth, Appalachian hardwood forest. The objectives of this study were: 1) to describe specific gap characteristics (size, age, and fraction) of the forest as a whole, and 2) to assess whether gap characteristics varied by slope position (cove, mid, ridge), aspect (NE, NW, SE, SW), and forest cover type (cove hardwood, mesic oak, xeric oak).

Transect lines were digitized using GIS in ArcMap and systematically placed throughout the forest to include a range of aspects and slope positions. Sixty-one transects were established, with a total length of 22,508 m. Line intersect sampling was used to select gaps. Eighty gaps were identified. The average gap size was 98.59 (± 134.17) m². The average expanded gap size was 287.64 (± 238.49) m². Gap age ranged from 2-29 years old with a mean age of 16.42 (± 6.3) years. Overall, 2.73 (± 2.48) % of the forest was composed of gaps. These figures are small compared to old growth forests in the region. WVURF is a young forest, therefore the gaps created are relatively small and scattered. We speculate the WVURF remains in the late stem exclusion to early understory re-initiation stage.

There were no differences in gap size by aspect or slope position. Cove hardwoods had larger gap sizes than mesic and xeric oak. Expanded gaps were also largest in cove hardwoods and on northwest and southeast aspects. There were no differences in gap age based on slope position, aspect, or forest type. Gap fraction did not differ by slope position, but gap fraction was greatest on southeast slopes and in cove hardwoods.

Regeneration within gaps included a variety of species including oaks (*Quercus sp.*), black cherry (*Prunus serotina*), black birch (*Betula lenta*), maple (*Acer sp.*), and understory shrubs. Oak regeneration importance values did not vary by aspect or forest type, but were significantly higher in coves and mid- slopes than on ridges. Almost two- thirds of gap-makers, trees whose death created the gap, were oaks.

Understanding the disturbance dynamics, especially the canopy gap dynamics, of second growth forests is important in the development of ecosystem management policies. The framework advanced by this study could aid land managers in implementing informed management policies and practices that more closely resemble the natural disturbances that are occurring in the WVURF.

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INTRODUCTION

The dynamic nature of a forest ecosystem, its past, present, and future, has been an important area of research for many silviculturists (Runkle 1992). Natural disturbances are a source of environmental heterogeneity and patch effects, which occur on a wide variety of spatial and temporal scales (Valverde and Silvertown 1997, Clinton and Baker 2000). Ecologists are placing increasing emphasis on the role of disturbance as an organizing factor in natural ecosystems and structuring communities (Phillips and Shure 1990, McClure and Lee 1992).

Canopy disturbances that alter light availability (as well as climate, soils and other factors) affect species composition and structure for an area (Oliver 1980, Collins and Pickett 1982, Keller and Hix 1999, Rentch et al. 2003, Hart and Grissino-Grissino-Mayer 2009). In forests of the northeastern United States where catastrophic stand destroying disturbances are rare, stand dynamics are controlled by the creation of gaps due to single or multiple overstory tree mortality. Treefall gaps formed as a result of small scale disturbances allow for seedling recruitment and growth in forests (Almquist et al. 2000). Patterns of canopy tree mortality shape forest stand structure and dynamics through influencing forest regeneration, species composition, growth rates, density, age structure, and tree regeneration and replacement (Woods 2004, Weiskittel and Hix 2002).

The West Virginia University Research Forest has a variety of slope positions (cove, mid, ridge), aspects (NE, NW, SE, SW), and forests types (cove hardwoods, xeric oak, mesic oak). Mountain environments, where there are steep topographical and elevational gradients, support forests with perhaps the greatest potential for the gap regime to vary in space (Battles et al. 1995). The purpose of this study is to assess gap characteristics (size, age, fraction, and

regeneration). It is hypothesized that there will be statistically significant differences in these characteristics by slope position, aspect, and forest type.

CHAPTER 1

LITERATURE REVIEW

History of West Virginia University Research Forest

The prehistory of Monongalia County covers 16,000 years of occupation by a large number of different peoples, each group having its own distinctive artifacts and settlement patterns (Core 1974). The Indians and predecessors hunted in these forests for over twelve thousands of years with permanent settlements surrounding the Pittsburgh area. In the 18th century white colonists were settling Virginia while in the mountains of western Virginia (now West Virginia), the Six Nations of the Iroquois were fighting the Shawnee and their allies for access to land. In 1744, England purchased the land extending from the Allegheny Mountains to the Ohio River from the Six Nations, but not from the Shawnee who also had claim to the region. The Shawnee fought for their rightful claim to the land and settlers were not completely safe until 1794, when the Indians finally surrendered their land and moved west (Wiley 1883, Moreland 1940, Deike 1978, Rodd 1994).

European settlers first came into the area of the West Virginia University Research Forest (WVURF) around 1753. One of the first settlers was Frederick Ice, who began a settlement in 1759 on the Cheat River, where Lakeview and Ice's Ferry Bridge is today (Figure 1). Between 1759-1763 settlers colonized the land, navigating along Indian trails that followed streams and ridges (Wiley 1883, Moreland 1940, Deike 1978, Rodd 1994).

Since the time of European settlement the forests have been exploited. The Industrial Revolution affected the timber industry to a remarkable degree and helped to initiate the rapid denuding of the forests (Deike 1978). The first documented major disturbance upon the forests of the WVURF started in the late 1700's and was directly related to the manufacturing of

Figure 1: Ice's Ferry in the 1800's.

whiskey. All barrels to contain the whiskey were made out of white oak. White oak was preferred because; a) white oak vessel members are plugged by tyloses which inhibit pathogen movement in inactive wood, and b) the tyloses make the wood leak resistant (Rost et al. 2006). In addition to the depletion of white oaks for the use of whiskey barrels, around 1779 charcoal production began. Four furnaces utilized the forest resources that the area had to offer. The first furnace, known as the Davis or Pleasant Furnace, was built in 1798. Wood Grove and Henry Clay (Figure 2) were both built prior to 1840 while the Anna furnace was built in 1845 (Wiley 1883, Moreland 1940, Carvell 1973, Core 1974, Rodd 1994).

Forests were cut and wood burned to produce charcoal for the iron industry. The charcoal used in the furnaces came from smoldering trees. Charcoal works better than raw wood because it can burn hotter. Wood was cut into cords (3.6 m³), and stacked in a circular pit about 9- 14 m in diameter. The wood was then arranged in a dome that was 1.5- 2.5 m high. Most pits burned about eight cords at a time. The mound was covered with clay, leaving a single, small opening on the top of the mound, which was used to control the amount of air flow into the chamber (Figure 3). The wood would take three to ten days to smolder before it would produce charcoal and be suitable for a furnace. The main time for the wood cutting took place in the late fall, winter, and early spring. However, most of the charcoal was produced from May to October (Moreland 1940, Carvell 1973, Deike 1978, Dedek 1989, Paskoff 1989, Williams 1989, Rodd 1994). There were no recordings of wildfires following cuts; however, these heavy cuttings were almost certainly followed by fire (Carvell 1973).

The yield of charcoal varied by the quality and type of the wood. Most wood used to make charcoal was not of optimum quality. Hardwoods gave the best charcoal per cord because

Figure 2: Henry Clay Furnace (1834- 1839)

Figure 3: Charcoal mound made from cut lumber.

they are heavy and have a tight grain and low water content. On average, a cord of wood would produce about 20-40 bushels of charcoal. On average, 61 ha of wood were cut to produce 907180 kg of pig iron (Williams 1989). Yearly, a charcoal furnace could consume as much as 101 ha of forest (Carvell 1973, Rodd 1994).

Iron is mined from the ground as iron ore containing the pure iron bound to other minerals (impurities). In order to obtain useable iron, the iron ore must be heated to a very high temperature, which separates the impurities from the pure iron. After processing through the charcoal furnace some iron was sold locally, but most was floated down the Cheat and Monongahela Rivers to Pittsburgh and Greensboro, Pa. The Cheat Mountain iron industry gradually declined after 1848 and suspended operations in 1868. The last of these furnaces, Anna, ceased operation in 1868 (Moreland 1940, Deike 1978, Dedek 1989, Paskoff 1989, Williams 1989, Rodd 1994). This era had many implications on the forest system and stand composition. The forests would have been cut in circles around furnaces using a coppice cut. Fires weren't recorded but seemed inevitable. At the end of the charcoal era the forests were uneven aged and in rough shape.

After the closing of the iron industry in 1868, the WVURF was purchased by the Smyth and Chess families out of Pittsburgh. During the period of 1868 – 1911 the property lay idle and the forests were slowly allowed to regenerate. The Smyth and Chess brothers sold various cutting rights to any interested person and did light selective cuttings for specific tree species to make cross ties, and shingles (Carvell 1973, Deike 1978, Rodd 1994).

In 1911 the Smyth and Chess families sold 4430 ha to the Kendall Lumber Company. At the time, a major problem and expense of the timber industry was the transportation of resources,

particularly lumber. After trees were cut and bucked into logs of reasonable length, the logs needed to be moved to a sawmill (Deike 1978). Timber was moved out of the woods using small Shay and Climax steam engines (Figure 4). The Shay is a geared locomotive. The steam engine power is increased and its speed is produced by a gear drive. The locomotive runs on 4-wheel “trucks” like those on a railroad freight car, and it has no large driving wheels like those on ordinary locomotives. Anywhere a railroad car could go, a Shay could go, too. Sharp curves and bumpy rails posed few problems. Better yet, the wheels were small and with the gear drive the engine could climb very steep grades. The track could be built around or over almost anything, without expensive grading. Temporary tracks were laid, often following old tramways built for the iron industry. Kendall established a mill on Morgan Run in Darnell Hollow and a mill near the Henry Clay furnace (Figure 5). Small portable mills were also located throughout the forest (Carvell 1973, Deike 1978, Rodd 1994).

The Kendall Company cut extensively, leaving behind only small, scattered trees. Their band mill consumed 40,000 board feet a day. In 1929 the Summit Lumber Company leased and undertook the logging of this tract, completing the operation in the late 1930’s. During this period the entire acreage of the WVURF was cut except for small areas. These locations were spared because Kendall and Summit Lumber Company went bankrupt about this time (Carvell 1973, Rodd 1994).

Wildfires followed these heavy cuttings due to the sparks from the railroad engines and heavy slash left behind. Denudated areas burned almost annually and no part of the forest escaped. Such heavy burnings left a permanent mark on the forest composition. For example, many of the oaks we see today sprouted prolifically following these fires (Carvell 1973, Rodd 1994).

Figure 4: Shay locomotive

Figure 5: The remains of a lumber mill in the West Virginia University Research Forest

Following the purchase of the WVURF by the state in 1936, the Civilian Conservation Corps (CCC) worked to improve the damaged forest and put an end to the wildfires. The land was named Coopers Rock State Forest. The CCC members were young men 18-25 who worked in a Depression-era federal jobs program doing conservation work. The army ran the camp, but every morning the men were turned over to the U.S. Forest Service. They built recreation facilities roads, thinned dense timber stands, collected tree seeds, and planted trees. Corps' men were subject to call at anytime to control forest fires on the State lands (Figure 6). The WVURF CCC was named CCC Camp Rhododendron and was located at the base of Chestnut Ridge near Fairchance Road (Figure 7). To complete its work projects, Camp Rhododendron continued to operate until the spring of 1942. By the spring most of the men had left for military service or other employment, and the camp was officially closed on March 31st (Carvell 1973, Deike 1978, Harr 1992, Rodd 1994).

“The presence of established oaks in the overstory of a stand is often attributed to past stand disturbance” (Johnson 2002).

The abundance of oak in the present forest is closely related to past disturbances and stand histories. In northern forests heavy cutting removed the overstory and following fire understories of red and chestnut oak was released. The forest trees are even aged. White Oaks are scarce on the URF, hypothesizing that this depletion is due to the intense use of white oak for whiskey barrel making. Hemlocks are nonexistent because they are highly fire sensitive and the amounts of fire following cuttings have completely removed all hemlocks. Red Maples, Sassafras, and Blackgum are prolific sprouters and became more abundant than yellow poplar following the heavy cuttings and wildfires. Red Maples, Scarlet Oaks, and Blackgum were considered trash trees, and were usually left behind during harvests, hence the reason these species are so prevalent on the WVURF. (Carvell 1973, Rodd 1994).

Figure 6: CCC work done in Coopers Rock State Forest.

Corpsmen by camp sign. The designation S-75 indicates that the camp was working on state property. (Glen McIntyre Collection in West Virginia and Regional History Collection at West Virginia University.)

Figure 7: Camp Rhododendron

Today, the WVURF is a 70-80 year old, even aged, mixed hardwood forest. Since the 1930s, a third of localized forest has been subjected to silviculture treatments and fire has not been reported (Carvell 1973, Rodd 1994, Fekedulegn et al. 2004, WVURF shapefiles). Several stand wide gypsy moth outbreaks occurred from 1989 to 1994 causing severe defoliation and mortality to oak species (Muzika et al. 2000).

Forest Stand Dynamics and Disturbance

The dynamic nature of a forest ecosystem, past, present, and future, has been an important area of research for ecologists and silviculturists (Runkle 1992). Forest succession and regeneration can be thought of as the sum of processes by which one canopy individual is replaced by another (Runkle 1981). The development of a forest ecosystem rarely achieves a steady state, but is interrupted by catastrophic exogenous disturbances at irregular and relatively short intervals (Bormann and Likens 1979). Natural disturbances are a source of environmental heterogeneity and patch effects, which occur on a wide variety of spatial and temporal scales (Valverde and Silvertown 1997, Clinton and Baker 2000). Ecologists are placing increasing emphasis on the role of disturbance as an organizing factor in natural ecosystems and structuring communities (Phillips and Shure 1990, McClure and Lee 1992).

The disturbance regime of a forest represents the sum total of stem and stand replacing events, and many studies have characterized individual stands and forest types by disturbance agents, severity, and return time (Oliver 1980, Collins and Pickett 1982, Keller and Hix 1999, Rentch et al. 2002, Rentch et al. 2003, Hart and Grissino-Grissino-Mayer 2009). A disturbance regime encompasses all types of disturbances (e.g., fire, windstorm, slip, avalanche) and their frequency, intensity, and spatial pattern (Ogden et al. 1991).

As Oliver and Larson (1996) state, “Natural disturbances in forests kill vegetation and release growing space.” They defined growing space as the sum of necessary resources; sunlight, water, nutrients, temperature, oxygen, and carbon-dioxide, available to the individual organisms present. Growth continues until one or more of these components becomes limited. This release of growing space, along with the type of disturbance, competition, shade tolerance, and mortality among sapling species, control the composition of the stand as a new forest canopy develops and redistributes the growing space among survivors and new individuals (Oliver 1980, Runkle 1981, Collins and Pickett 1982, Clinton 2003, Rentch et al. 2003, Gould et al. 2005). Gaps are simultaneously a source of mortality for some individuals and a source of establishment and growth for others, and the ongoing process of death and replacement has a profound effect on forest structure and composition (Rentch et al. 2002). The pattern of disturbance acts as an environmental sieve whereby species better adapted to the resulting conditions pass through the sieve and remain competitive. The less competitive species are consequently “filtered” out.

It is necessary to reaffirm the importance of small scale disturbance in forests where they are most likely to be the primary source of forest turnover. - Runkle 1981.

Natural maintenance of forest communities depends upon a dynamic balance between canopy tree death and replacement (Yetter and Runkle 1986). The pattern of these deaths (i.e., forest disturbance regime) varies for different forests from large scale, highly episodic mortality to small scale, more continuous mortality in which more trees die singly or in small groups (Yetter and Runkle 1986). Disturbances of varying size, intensity, and frequency of variously sized gaps in otherwise unbroken canopy play a major role in structuring plant communities by producing a mosaic of patches at different successional states across the landscape (Phillips and Shure 1990, Battles et al. 1995, Valverde and Silvertown 1997, Fraver and White 2005). Effects

of these disturbances are more commonly diffuse, causing the death of scattered trees and patches rather than turnover of entire stands (Lorimer and White 2003).

Gap Dynamics in Eastern Hardwood Forests

In forests of the northeastern United States where catastrophic stand destroying disturbances are rare, stand dynamics are controlled by the creation of gaps due to single or multiple overstory tree mortality. These gaps play a critical role in maintaining canopy tree species composition, increasing the radiation, and changing the levels of soil moisture and nutrients available to regeneration (Barden 1980, Barden 1981, Runkle 1982, Yetter and Runkle 1986, Runkle 1990, Runkle 1992, Keller and Hix 1999, Forrester and Runkle 2000, Almquist et al. 2000, Clinton and Baker 2000, Busing 2005, Hart and Grissino-Mayer 2009). These events create resource heterogeneity along light, temperature, humidity, and soil resource gradients (Keller and Hix 1999, Rentch et al. 2002). In time, individual trees or groups of trees fall down creating smaller patches for younger vegetation. Eventually the whole forest will be composed of patches of varying size and age (Bormann and Likens 1979). Patterns of canopy tree mortality shape forest stand structure and dynamics by influencing forest regeneration, species composition, growth rates, density, age structure, and tree regeneration and replacement (Weiskittel and Hix 2002, Woods 2004).

Most definitions of gaps restrict the gap to the area directly under the canopy opening within the forest where the canopy (leaf height of tallest stems) is noticeably lower than in adjacent areas in the forest canopy (Runkle 1992, Almquist et al. 2000, Hix et al. 2003). Gaps may range in area from the openings created by the death of a single branch to a larger scale

blowdown of a catastrophic disturbance, such as a storm, a fire, or an aggregated insect outbreak (Kubo et al. 1996).

Quantifying gap patterns are crucial to understanding stand dynamics. The fundamental attributes of canopy gaps are their size, mode of origin, and shape, as these have the most effect on forest characteristics (Weiskittel and Hix 2002). Useful comparisons among forests include: 1) rates at which gaps form, 2) the total area occupied by gaps of different ages, 3) the gap area distribution, 4) the speed and mechanisms of gap closure, 5) fraction of land area under gaps (gap fraction), and 6) the method by which the gap forms (Runkle 1992, Battles et al. 1996, Anderson and Leopold 2002).

In eastern hardwood forests, gap size can vary widely by forest type but average sizes and range of sizes are similar (Runkle 1989). In the mixed mesophytic forests from Tennessee to Pennsylvania, average gap size is about 280 m² with a majority of the gap sizes over 100 m² (Table 1). Estimated turnover time, also known as the natural rotation time, in the mixed mesophytic region is about 140 years, ranging from 50- 270 years (Runkle 1982) (Table 1). In most northern hardwood forests, gap size ranges from a few m² to 500 m² except following intense disturbances (blow down, hurricanes, and fires) (Canham et al. 1990, DiGregorio et al. 1999, Lorimer and White 2003, Rebertus and Meier 2001, Weiskittel and Hix 2002, Hix et al. 2003).

Most gap studies of the mixed mesophytic forest type have occurred in small, mesic, old-growth remnants (Table 1). Gap phase replacement may begin prior to attainment of the old growth stage, when stands are still in the understory re-initiation phase (Oliver and Larson 1996). Old growth stands may not fully represent the gap phase dynamics of the second growth stands

Table 1: Studies of gap dynamics in mixed mesophytic forests. Includes forest type, author, year, location, stage of development, average gap size (m²), gap size range (m²), gap fraction (%), estimated turnover time (years), average cause of gap, and if topographical studies were assessed. Key: Oliver and Larson (1996) Stages of Development- OG= Old Growth, SG= Second Growth

Forest Type	Author	Year	Location	Stage of Development	Average Canopy Gap Size (m ²)	Gap Size Range (m ²)	Gap Fraction (%)	Estimated Turn-over Time (years)	Average Cause of Gap	Topographic Effects Studied?
Mixed Mesophytic	Barden	1980	TN	OG	-	2-215	-	-	-	-
Mixed Mesophytic	Barden	1981	TN	OG	-	8-1320	-	-	Broken Low	-
Mixed Mesophytic	Barden	1983	TN	OG	105	77-160	-	-	-	-
Mixed Mesophytic	Busing	2005	TN	OG	-	-	9.5	52-130	Snag	-
Mixed Mesophytic	Clinton and Baker	2000	NC	-	1175	181-4043	-	-	-	-
Mixed Mesophytic	Greenberg and McNab	1998	NC	SG	-	200-1100	-	-	Uprooting	-
Mixed Mesophytic	Hart and Grissino-Mayer	2009	TN	SG	43	1.14-158	6	116	Uprooting	-
Mixed Mesophytic	Hix et al.	2003	OH	-	86.4	6.7-291.6	-	-	Tip-up	Yes
Mixed Mesophytic	Keller and Hix	1999	OH	SG	-	-	9.37	-	Tip-up	Yes
Mixed Mesophytic	Romme and Martin	1981	KY	OG	374	74-1235	7	269	Breakage	-
Mixed Mesophytic	Runkle	1981	NC, TN, OH, PA	OG	200	28-2009	-	-	-	-
Mixed Mesophytic	Runkle	1982	NC, TN, OH, PA, NY	OG	-	50-2009	3.2-24.4	50-200	-	-
Mixed Mesophytic	Runkle	1984	OH	OG	-	-	3.89	-	-	-
Mixed Mesophytic	Runkle	2000	NC, TN, OH, PA	OG	-	-	-	-	Snag	-
Mixed Mesophytic	Runkle and Yetter	1987	OH	OG	65	1-1490	10	-	-	-
Mixed Mesophytic	Stringer et al	1989	KY	SG	-	-	3	-	-	-
Mixed Mesophytic	Yetter and Runkle	1986	TN	OG	155	-	-	-	-	Yes
Mixed Oak	Clinton et al	1994	NC	-	227	60-630	-	-	Gypsy Moth	Yes
Virgin White Oak	Weiskittel and Hix	2002	OH	OG	386	112-1105	17.7	-	Tip-up/ Snag	-

that presently dominate the eastern deciduous forest (Keller and Hix 1999). Little direct evidence is currently available on how overall gap dynamics might differ among a broad range of developmental stages in temperate hardwood forests (Dahir and Lorimer 1996).

Gaps can be small for two reasons. First, they may be created by the death of a small canopy tree or by one branch. Second, they may be old, the remnants of larger openings almost closed by the lateral extension (branch) growth of canopy trees surrounding the gap (Whitmore 1989, Runkle 1992, Valverde and Silvertown 1997). Very small gaps in the forest canopy are likely to be filled by crown expansion (in-growth) from adjacent trees; otherwise gaps are filled by suppressed seedlings or saplings (Crow 1988).

Gaps usually form at rates of ~1% of total land surface area per year (Runkle and Yetter 1987). In mixed mesophytic forests, gap fraction varied from 3- 25% (Table 1). In general, gap fraction was larger in old growth forest than in second growth. Studies of forest gap dynamics have demonstrated that new gaps are more likely to occur adjacent to pre- existing gaps (Young and Hubbell 1991, Kubo et al. 1996). Trees in the gap border tend to have a higher rate of disturbance. Runkle (1984) re-censuses canopy gaps 4 years after his initial census and found that 11% of gaps had enlarged by blowdown of peripheral trees in the canopy and that 31% of gaps had enlarged because of the death of surrounding trees. These results suggest that repeat disturbance affecting the same location may be common (Runkle and Yetter 1987). As the fraction of gap sites increase, the average size of clusters of gap sites also increases. Eventually gaps merge with each other and form large gaps (Kubo et al. 1996).

Gap-makers are those that trees died and thus formed a gap (Runkle 1992). Tree mortality has important implications for succession because the individuals it removes may not

be replaced (Franklin et al. 1987). Origin types, such as snags, blowdowns, and disease, are stand and region specific because tree mortality is closely related to various environmental variables and to community characteristics (Hix et al. 2003). Gap mode of origin has been shown to influence gap microenvironment and size, which affect the distribution of species regenerating within that stand (Weiskittel and Hix 2002).

The amount of resources made available depends on the number and size of trees that die. Resources may be made available instantaneously (i.e., light) or very slowly (i.e., nutrients and energy contained within the boles) (Franklin et al. 1987). Wind is one of the most frequent causes of large and small scale disturbance affecting eastern forests and is an important process in the creation of micro-topographic variation (Orwig and Abrams 1995, Clinton and Baker 2000).

Small scale disturbance in forests, such as single tree deaths, influence the abundance and composition of regeneration (Rantis and Johnson 2002). In forest communities where large scale disturbances are rare, tree species will depend on small gaps for establishment to eventually reach the overstory canopy (Clinton 2003).

Vegetation can reoccupy gaps by a combination of lateral extension of the crown of plants surrounding the gap, growth of advance regeneration, and establishment and growth of seedlings/ sprouts (Battles and Fahey 2000). While small gaps may be filled by horizontal growth of the crowns of adjacent trees, larger gaps are filled primarily by the upward growth of small trees (McClure et al. 2000). Environmental variables vary significantly among individual gaps, even among those in the same forest stand, contributing to diversity in canopy recruitment species (Almquist et al. 2000). Gaps may actively influence forest dynamics by altering the

dispersal patterns, germination rates, recruitment rates, growth rates, and growth forms of tree species (Rankin and Tramer 2002).

Because of the variable capacity of tree species to tolerate shaded conditions, changes in canopy structure often lead to changes to the composition and level of competitiveness of trees in the understory (Frelich and Lorimer 1991). Changes in species composition may occur, as different shade intolerant and tolerant species are able to utilize gap resources, thereby “invading” the gap and temporarily increasing the species richness therein (Anderson and Leopold 2002). For example, recent studies of oak forests have suggested that replacement of oaks by more shade tolerant species (i.e., maple) is occurring on many sites (Taylor and Lorimer 2003).

Although individuals are recruited to larger size classes and higher vertical positions in these gaps, it may take multiple disturbance events for many sub canopy individuals to reach the main canopy level (Hart and Grissino-Mayer 2009). Saplings that do not reach the canopy during an initial period of release many eventually reach the canopy after 1-5 episodes of suppression before eventually growing into the canopy (Canham 1985, Runkle and Yetter 1987). Growth rates are higher and mortality lower for plants establishing before or soon after treefall (Runkle 1989). The vegetational composition of a gap at any given time should be a good predictor of its composition in the future (Runkle and Yetter 1987).

Eventually one or more individuals will dominate, closing the canopy opening and completing what has been termed the gap phase of the forest turnover cycle (Forrester and Runkle 2000). Runkle (1982) declared gaps closed when gap saplings prevent a ground observer

from readily observing the canopy opening. He estimated that this will usually occur when trees are 10-20 m high in a forest with a 30-35 m tall canopy.

Gap Dynamics and Topography

Within the eastern deciduous forest of North America natural disturbance regimes are strongly correlated with broad geographic patterns of climate, topography, and soils, all of which influence the vegetation of a region (Runkle 1990, Rentch et al. 2003, Lorimer and White 2003). Factors such as topography, elevation, slope percent, aspect, slope position, weather patterns, light, moisture, disease, pests, and physiological characteristics of common tree species can affect the size and frequency of canopy disturbances (Clinton et al. 1994, Keller and Hix 1999, Fekedulegn et al. 2004).

Little research has been conducted concerning the effects of topography on gap dynamics in eastern forests. In Ohio, Hix et al. (2003) found that gap area did not vary significantly among four aspect classes, although exposed south facing slopes had more large gaps than small. Keller and Hix (1999) found no significant differences in gap fraction between north- and south-facing slopes, suggesting that aspect may not play a major role in the gap dynamics of second-growth forests in Ohio. In North Carolina, Clinton et al. (1994) discovered that ridges had a significantly greater total density of gaps than mid or lower slopes.

CHAPTER 2

METHODOLOGY

Study Area

The area under investigation is the 3100 ha West Virginia University Research Forest (WVURF), which lies 13.04 km east of Morgantown, WV (UTM: NAD 83, Zone 17 N). The WVURF is located in Monongalia and Preston County and is a parcel of Coopers Rock State Forest (Figure 8).

The WVURF is typical of many Appalachian forests with long, steep and rocky slopes (Fekedulegn et al. 2004). The average elevation of the watershed is 224m above sea level (Tajchman and Wiant 1983). The topography of the area is fairly rugged and the average slope inclination is 25%. The average oak site index is 26.6 m at 50 years.

The bedrock for the area is upper connequenesing sandstone of the Pottsville series, which include conglomeratic sandstones, thin coals, fire clay, and shale which are highly resistant to erosion (USDA 1959). The soils are characterized as Dekalb soils on well- drained hill slopes and ridge tops, and deeper Ernest soils on concave slopes bordering streams (Fekedulegn et al. 2004). These are loamy- skeletal, moderately deep, and well- drained soils of low natural fertility (USDA 1959). Annual precipitation averages 129.4 cm. The average temperature is 9 degrees C. The frost free season averages 167 days (April 30 – October 10) (Rentch et al. 2002).

Field Methods

In the summer 2008, transect lines were digitized using GIS in ArcMap and were placed in areas of the WVURF (Figure 9) that avoided obvious large scale human caused disturbances, including silvicultural treatments, which had been applied to a fraction of the forest. Transect

Figure 8: Location of the West Virginia University Research Forest.

Figure 9: Transect location throughout the West Virginia University Research Forest. Gaps found along transects represented by the green dots. WVURF projects indicate timber harvest areas.

lines were delineated and strategically placed throughout the forest on ridges, mid- slopes, and coves. Cove transects were located within 50- 100 m of a stream (confirmed in the field visually).

A total of 61 transects were laid out for data collection, with a total length of 22,508 m, and a mean length of 369 m. Each transect had two points, a beginning and an end. These points were loaded into a GPS unit to instruct the field workers where they needed to work and what distances they had already gone.

Every 25- 50 m along a transect line, the composition of living trees was determined using the point- centered quarter method (Cottam and Curtis 1956). This method examines a sub- sample of the forest in order to determine species composition of the transect line. In each quarter, dbh and species of the nearest trees ≥ 25 cm dbh were measured.

The definition of a canopy gap was important for determining if an opening along a transect would be sampled. By definition, a gap is an opening in the canopy created by the death of at least one tree (Runkle 1992). Two types of gaps were defined. The canopy gap was the land surface area directly under the canopy opening. The expanded gap consisted of the canopy gap plus the adjacent area extending to the bases of canopy trees surrounding the canopy gap. The expanded gap is useful to analyze because it includes the area directly and indirectly affected by the canopy opening because sunlight rises and lowers at an angle. Gaps were considered closed or indistinguishable from the background overstory when the regeneration within the gaps was approximately 10- 20 m high (Runkle 1982).

In some forests small areas are free from trees for a very long period due to soil, bedrock, or other biological factors. These “gaps” may resemble canopy gaps in composition, structure,

and function of biota but not in their dynamics (Runkle 1992). Therefore, only gaps that were formed by the death of at least one canopy tree were considered.

A gap was considered for data collection if any part of the gap itself crossed the transect line. If the gap did not intersect the transect line it was not considered (Figure 10). The first measurement taken after establishing a gap was the GPS point (UTM). The second measurement taken was of the portion of the transect intersecting the gap in order to determine the fraction of total land in gaps (gap fraction). The number of meters along the transect in each canopy gap was recorded (Figure 11). The area (A) for each gap intersected by transects was estimated by fitting gap length (L) (largest distance from gap edge to gap edge) and width (W) (largest distance perpendicular to the length) to the formula for an ellipse; $A = \pi LW/4$. A maximum gap size threshold was set at 1000 m² (Barden 1981, Collins and Pickett 1982, Runkle 1992, Almquist et al. 2000).

The number and species of tree(s) creating the gap (gap-maker) was also noted (Figure 12). The origin of each gap was classified into four groups: blow-down, snag, decay, or grape vine. Blow-down was any tree that had tipped over, but not necessarily including a stump pit and mound. A snag was any standing dead tree. Decay was due to heart rot that weakened the bowl. Finally, grape vine gaps were created by the vines pulling down trees and snapping off their trunks. In addition, aspect was recorded for each gap. Aspect was classified in four quadrants of 90° each (northeast 0-90°, southeast 91-180°, southwest 181- 270°, northwest 271-360°). Also, three, 1 m² plots were established at the beginning, middle, and end of each gap to assess gap regeneration. Any seedlings or sapling ≤ 10 m in height were recorded for its species and height (to the nearest 0.25m).

Figure 10: Method used for selecting gaps. Any gap that intersects the transect (A, B) was included in the analysis, while C was not. A. highlights in blue the canopy gap (CG), B. highlights in green the expanded canopy gap (ECG).

Figure 11: Canopy gap caused by the death of one or more trees. Transect is the line in red, blue represents the distance of the transect in gaps, and length and width of the canopy gap are in orange.

Figure 12: Examples of gap-makers (top left- snag, top right and middle left- grape vines, middle right and middle left- blow-down, and bottom right- decay).

To determine the age of the gap two trees near each gap were cored. These trees needed to have appeared to have received resources that the gap “released”. Trees with obvious bole defects were not cored. Tree cores were extracted at breast height and transferred to the laboratory in straws. Cores were air dried, mounted, and sanded with three levels of sand paper. Annual growth rings were measured with a Leica binocular microscope and Velmex measuring stage to the nearest 0.001mm. Data output were recorded using J2X software. The notebook file created from the J2X software was converted into an Excel file for analysis.

Data Analysis

To describe species composition along each transect for trees ≥ 25 cm dbh, calculations were made using equations 1, 2, and 3 to determine relative density, relative basal area, and relative frequency.

$$\text{Equation 1} \quad \text{Relative Density} = \frac{\text{individuals of species A}}{\text{total individuals of all species}} \times 100$$

$$\text{Equation 2} \quad \text{Relative Basal Area} = \frac{\text{total basal area of species A}}{\text{total basal area of all species}} \times 100$$

$$\text{Equation 3} \quad \text{Relative Frequency} = \frac{\text{frequency value for species A}}{\text{total frequency value for all species}} \times 100$$

$$\text{Where: Frequency} = \frac{\text{number of points at which species A occurs}}{\text{total number of points sampled}} \times 100$$

Importance values (IV) were derived from the sum of the relative density, relative basal area, and relative frequency/ 3. Forest cover types were determined from the species IVs. Cove hardwoods contained a majority (>50%) of the IVs in yellow-poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), and red maple (*Acer rubrum*). Mesic Oak included >50% of IVs

in northern red oak (*Quercus rubra*), yellow poplar, and red maple. Xeric oak included >50% of IVs in northern red oak, scarlet oak (*Quercus coccinea*), and chestnut oak (*Quercus prinus*).

The gap fraction is the sum of all forest area under gaps at one time, expressed at a percentage of the total area. Gap fraction was determined by dividing the transect distance in gaps by the total transect distance following Runkle (1985, 1992).

For the regeneration in each gap, species IVs were calculated by averaging the values of the three regeneration plots within that gap. I computed two measurements by species: relative density and relative height (equations 4 and 5). Importance values were determined by summing relative density and relative height / 2.

$$\text{Equation 4} \quad \text{Relative Density} = \frac{\text{number of individual of species A}}{\text{total individuals of all species}} \times 100$$

$$\text{Equation 5} \quad \text{Relative Density} = \frac{\text{sum of height of species A}}{\text{total sum height of all species}} \times 100$$

Disturbance would be expected to cause abrupt and sustained increases in growth of trees “released” by the death of nearby overstory trees and also increased growth of some of the adjacent surviving trees in the upper crown classes. The number of trees responding to the release would depend on the severity of the disturbance (Lorimer 1980, Fraver and White 2005). I used equation 6 to calculate percent growth change of cores extracted from released trees.

$$\text{Equation 6} \quad \text{Percent Growth Change (\%GC)} = [(M2-M1)/M1] \times 100$$

Percent Growth Change = percent growth change between preceding and subsequent 10 year means, M1= preceding 10 year mean (inclusive of the disturbance year), and M2= subsequent 10 year mean.

Three levels of crown release were recognized and modified by Nowacki and Abrams, based on more lenient criteria set up by Lorimer and Frelich (1989). 1) Major releases were defined as events where $\%GC \geq 100$ (complete overhead releases of smaller overtopped samplings and pole sized trees). 2) Moderate releases were classified as those with a $\%GC$ of 50-99%. 3) Minor releases caused by increased side light to a tree already in the over story, or a neighbors death in the self thinning process were classified as those with $\%GC$ 25-49% (Rentch et al. 2003).

The maximum percentage growth response associated with a given disturbance was found to be directly tied to the year of probable canopy perturbation (Nowacki and Abrams 1997). A precise correlation does not always exist between peak $\%GC$ as calculated. Differences in individual tree genetics and physiological condition before the disturbance and peak disturbance event were initially assigned a 3 year window (Rentch et al. 2003). However, Nowacki and Abrams proposed a one year lag interval to allow for the tree to respond to the disturbance (Rentch et al. 2003). Therefore a single year was assigned soon after (Rentch et al. 2003). If two releases occurred, the most recent (younger) release date was used.

Oscillations in temperature during the growing season (temperature, precipitation) exerted a significant influence on annual tree ring variation; however it was significantly less pronounced than non climatic events such as crown release and canopy disturbance (Lorimer 1980, Rentch et al. 2003).

Analysis of Variance (ANOVA) was performed using SAS (Statistical Analysis Software) to compare gap area, gap age, gap fraction, and regeneration IVs with slope position, aspect, and forest type. A square root transformation (appropriate when there is a Poisson

distribution) was applied to the data from gap area and expanded gap area. Arc-sin square root transformation was applied to gap fraction and regeneration IVs. This transformation is used when there is a proportional distribution and non continuous data. No transformation was applied to gap age. The multiple comparison procedure for gap area, fraction, and regeneration was Duncan's new multiple- range test. Gap age was analyzed by Student- Newman- Keuls' procedure. Statistical significance for all tests were accepted at $\alpha \leq 0.05$ (Dowdy et al. 2004).

CHAPTER 3

RESULTS

Forest Composition

The predominant species in this forest are red maple, yellow poplar, black cherry, white oak (*Quercus alba*), northern red oak, scarlet oak, chestnut oak, and black birch (*Betula lenta*) (Table 2). Xeric oak and mesic oak forest types contained almost equal numbers of transects with 28 and 24 and captured 8930.86 m of transects (40.66%) and 10507.48 m of transects (45.95%), respectively. Cove hardwoods comprised the least amount of transects with only 8, securing 2604.27 m of transect (13.40%).

Gap Size

Eighty gaps were identified along 61 transects (Table 3). Southwest aspects comprised the most gaps (45%) followed by southeast (22.5%), northwest (18.75%), and northeast (13.75%). Mid- slope positions dominated by containing 52.5% of gaps, followed by cove with 28.75% of gaps, and ridge with 18.75% of gaps. Xeric oak and mesic oak forest types contained almost equal numbers of gaps with 46.25% and 37.5%, respectively. Cove hardwoods possessed the least amount of gaps with only 16.25%.

The average canopy gap size was 98.59 m² (± 134.17). The minimum gap size found in the WVURF was 5.75 m², while the largest gap size was 962.88 m² (Table 3). Figure 13 shows the canopy gap area distribution of gap size classes. The distribution is skewed to the left with most gaps smaller than 100 m².

Mean gap size did not vary by aspect or slope position. However, gaps were significantly larger ($P = 0.0145$) in cove hardwoods than in the mesic oak and xeric oak forest types. Gaps in cove hardwoods averaged 192.76 m² (± 70.03) in size, while mean gap size in mesic and xeric oaks was 90.38 (± 25.39) and 72.16 (± 8.23), respectively (Table 3). There were no significant interactions between forest type, aspect, and topographic position.

Table 2: Species importance values by forest type on the West Virginia University Research Forest.

<u>Forest Cover Type</u>	<u>Cove Hardwood</u>	<u>Mesic Oak</u>	<u>Xeric Oak</u>	<u>Total</u>
Number of Transects	9	24	28	61
White Oak	0.76	4.88	5.67	4.63
Northern Red Oak	11.14	33.14	27.26	27.19
Chestnut Oak	5.59	7.43	24.34	14.92
Other Oak _a	5.42	4.20	11.69	7.55
Black Cherry	4.73	7.22	0.68	3.85
Yellow Poplar	47.90	17.47	6.06	16.72
Maple _b	12.79	15.37	13.07	14.08
Black Birch	3.80	3.63	2.14	2.97
Other _c	7.87	6.67	9.10	8.09

a) includes black oak (*Quercus velutina*) and scarlet oak,

b) mostly red maple with small amounts of sugar maple (*Acer saccharum*),

c) includes all the other species: american beech (*Fagus grandifolia*), american basswood (*Tilia americana*), black gum (*Nyssa sylvatica*), black locust (*Robinia pseudoacacia*), cucumber tree (*Magnolia acuminata*), pignut hickory (*Carya glabra*), sourwood (*Oxydendrum arboreum*), white ash (*Fraxinus americana*), and yellow birch (*Betula alleghaniensis*)

Table 3: Gap size (m²) characteristics varying by aspect, slope position, and forest type on the West Virginia University Research Forest. ANOVA (Proc GLM) was used to determine any differences, while Duncan's test was used to identify what means are different. Means denoted by different letters differ significantly in their square root transformations at the 0.05 probability level.

<u>Aspect</u>	<u>P- Value</u> 0.2361	<u>Number of Gaps</u>	<u>Mean (m²)</u>	<u>Std Error</u>	<u>Minimum</u>	<u>Maximum</u>
NE		11	99.51 _a	27.31	6.29	302.49
NW		15	148.13 _a	61.79	9.04	962.88
SE		18	112.97 _a	40.77	27.06	779.61
SW		36	70.48 _a	8.82	5.75	247.50
<u>Slope Position</u>	0.1889					
Cove		23	121.54 _a	33.52	6.29	779.61
Mid		42	100.41 _a	23.29	5.75	962.88
Ridge		15	58.30 _a	9.81	9.04	150.27
<u>Forest Type</u>	0.0145					
Cove Hardwood		13	192.76 _b	70.03	6.29	962.88
Mesic Oak		30	90.38 _a	25.39	9.04	779.61
Xeric Oak		37	72.16 _a	8.23	5.75	247.50
Total		80	98.59	134.17	9.03	617.52

Figure 13: Distribution of gap size classes on the West Virginia University Research Forest.

The average expanded gap size was 287.64 m² ($\pm$ 238.49). The minimum expanded gap size found in the WVURF was 43.31 m², while the largest gap size was 1820.07 m² (Table 4). Mean expanded gap size did not vary by slope position. Gaps on northwest slopes were significantly larger ($P= 0.0188$) than southwest slopes. Expanded gaps on northwest aspects averaged 422.09 m² ($\pm$ 120.38) in size, while expanded gap size on southeast, northeast, and southwest aspects averaged 320.84 m² ($\pm$ 69.70), 289.68 m² ($\pm$ 59.51), and 214.39 m² ($\pm$ 17.34), respectively (Table 4). Expanded gaps were significantly larger ($P= 0.0001$) in cove hardwoods than in the mesic oak and xeric oak forest types. Expanded gaps in cove hardwoods averaged 537.08 m² ($\pm$ 128.94) in size, while mean gap size in mesic and xeric oaks was 256.11 m² ($\pm$ 45.76) and 225.56 m² ($\pm$ 17.02), respectively (Table 4). There were no significant interactions between aspect, slope position, and forest type.

Gap Age

Although 80 gaps were identified, only 57 were available for gap age analysis due to limitations when using radial growth analysis to determine age. Gap age ranged from 2-29 years old with a mean age of 16.42 years ($\pm$ 6.3) (Table 5). Figure 14 shows the distribution of gap age classes. Mean gap age did not vary significantly by aspect, slope position, or forest type. The gap formation rate per year was determined by dividing the percent of land in gaps by the average age yielding 0.165%. The approximate time for the forest to completely turnover is 604.4 years. This was calculated by taking the gap formation rate to the -1 power. Turnover time will change over time and through stages of development.

Table 4: Expanded gap size (m²) characteristics varying by aspect, slope position, and forest type on the West Virginia University Research Forest. ANOVA (Proc GLM) was used to determine any differences, while Duncan's test was used to identify what means are different. Means denoted by different letters differ significantly in their square root transformations at the 0.05 probability level.

<u>Aspect</u>	<u>P- Value</u> 0.0188	<u>Number of Gaps</u>	<u>Mean (m²)</u>	<u>Std Error</u>	<u>Minimum</u>	<u>Maximum</u>
NE		11	289.68 _{ab}	59.51	58.34	635.24
NW		15	422.09 _a	120.38	43.31	1820.07
SE		18	320.84 _{ab}	69.70	135.34	1419.17
SW		36	214.39 _b	17.34	87.65	490.28
<u>Slope Position</u>	0.2578					
Cove		23	317.04 _a	59.32	58.34	1419.17
Mid		42	300.82 _a	46.84	43.31	1820.07
Ridge		15	205.64 _a	21.41	106.86	331.47
<u>Forest Type</u>	0.0001					
Cove Hardwood		13	537.08 _b	128.94	58.34	1820.07
Mesic Oak		30	256.11 _a	45.76	43.31	1419.17
Xeric Oak		37	225.56 _a	17.02	87.65	490.28
Total		80	287.64	238.49	72.25	1166.50

Table 5: Gap age (years) varying by aspect, slope position, and forest type on the West Virginia University Research Forest. ANOVA (Proc GLM) was used to determine any differences, while SNK's test was used to identify what means are different. Means denoted by different letters differ significantly at the 0.05 probability level.

<u>Aspect</u>	<u>P- Value</u> 0.1366	<u>Number of Gaps</u>	<u>Mean (years)</u>	<u>Std Error</u>	<u>Minimum</u>	<u>Maximum</u>
NE		9	13.67 _a	1.72	11	26
NW		10	15.70 _a	1.64	11	27
SE		12	13.83 _a	1.07	10	21
SW		26	18.85 _a	1.53	2	29
<u>Slope Position</u>	0.6012					
Cove		20	17.35 _a	1.52	8	29
Mid		30	16.23 _a	1.23	2	29
Ridge		7	14.57 _a	2.11	11	26
<u>Forest Type</u>	0.1507					
Cove Hardwood		10	12.30 _a	1.51	2	19
Mesic Oak		24	17.33 _a	1.47	8	29
Xeric Oak		23	17.26 _a	1.27	10	29
Total		57	16.42	6.30	7.50	26.40

Figure 14: Distribution of gap age classes on the West Virginia University Research Forest. Gap age <10 years are under estimated due to use of radial growth averaging technique to estimate gap age.

Gap Fraction

The average gap fraction along 61 transects in the WVURF was 2.73 % (± 2.48 %). The range of gap fraction for each transect was 0% (no gaps) - 13.06%. Mean gap fraction did not vary by slope position. Gap fraction on southeast aspects was significantly larger ($P = 0.0021$) than southwest and northeast slopes. Gaps on southeast aspects averaged 5.32 % (± 2.07), while mean gap fraction in northwest, southwest, and northeast was 4.34 % (± 1.23), 2.36 % (± 0.45), and 1.88 % (± 0.76), respectively (Table 6). Gappinness were significantly larger ($P = 0.0062$) in cove hardwoods than in the mesic oak and xeric oak forest types. Gaps in cove hardwoods averaged 5.29 % (± 1.62), while mean gap fraction in mesic and xeric oaks was 2.19 % (± 0.58) and 2.47 % (± 0.45), respectively (Table 6). There were no significant interactions between forest type, aspect, and slope position.

Gap Regeneration

Figure 15 shows gap importance values of gap regeneration. While oak is the most abundant species group regenerating in gaps, there is a mixture of species, including black cherry, maple, black birch, and understory shrubs such as spice bush (*Lindera benzoin*). Oak regeneration IVs did not vary by aspect or forest type. However, gaps had significantly larger oak IVs ($P = 0.0293$) in coves and mid- slopes than in ridge slope positions. Gaps in ridges averaged oak IVs of 10.17 (± 19.46), while mean gap oak IV's in coves and mid- slopes was 30.40 (± 32.86) and 27.63 (± 33.42), respectively (Table 7). There were no significant interactions between forest type, aspect, and slope position.

Table 6: Gap fraction varying by aspect, slope position, and forest type on the West Virginia University Research Forest. ANOVA (Proc GLM) was used to determine any differences, while Duncan's test was used to identify what means are different. Means denoted by different letters differ significantly in their arc-sin square root transformations at the 0.05 probability level.

<u>Aspect</u>	<u>P- Value</u> 0.0021	<u>Number of</u> <u>Transects</u>	<u>Mean (%)</u>	<u>Std Error</u>	<u>Minimum</u>	<u>Maximum</u>
NE		15	1.88 _c	0.76	0.00	9.02
NW		9	4.34 _{ab}	1.23	0.44	13.06
SE		4	5.32 _a	2.07	2.77	11.44
SW		32	2.36 _{bc}	0.45	0.00	8.91
<u>Slope Position</u>	0.8681					
Cove		15	2.45 _a	0.91	0.00	11.44
Mid		32	3.10 _a	0.56	0.00	13.06
Ridge		13	2.17 _a	0.58	0.00	6.72
<u>Forest Type</u>	0.0062					
Cove Hardwood		8	5.29 _b	1.62	0.00	13.06
Mesic Oak		24	2.19 _a	0.58	0.00	11.44
Xeric Oak		28	2.47 _a	0.45	0.00	8.91
Total		61	2.73	2.48	0.32	10.71

Figure 15: Species importance values for regeneration within gaps on the West Virginia University Research Forest.

Table 7: Oak regeneration importance values varying by aspect, slope position, and forest type on the West Virginia University Research Forest. ANOVA (Proc GLM) was used to determine any differences, while Duncan's test was used to identify what means are different. Means denoted by different letter differ significantly in their arc-sin square root transformations at the 0.05 probability level.

<u>Aspect</u>	<u>P- Value</u>	<u>Number of Gaps</u>	<u>IV OF OAK REGEN</u>	
			<u>Mean</u>	<u>Std Error</u>
NE	0.2432	11	6.28 _a	13.89
NW		15	11.81 _a	28.24
SE		18	17.83 _a	23.77
SW		36	40.13 _a	34.13
<u>Slope Position</u>	0.0293			
Cove		23	30.40 _a	32.86
Mid		42	27.63 _a	33.42
Ridge		15	10.17 _b	19.46
<u>Forest Type</u>	0.1016			
Cove Hardwood		13	11.85 _a	22.59
Mesic Oak		30	14.15 _a	24.32
Xeric Oak		37	38.74 _a	34.58
Total		80	25.15	26.73

Gap-makers

The average number of gap-makers per gap was 2.46 (± 2.42). However, the most frequent (median) number of gap-makers was one. The average gap-maker dbh was 36.19 cm, while the average gap-maker basal area per gap was 0.31 (± 0.27) m². Gap size was highly correlated with the number of gap-makers ($r = 0.81$) and the total basal area of gap-makers ($r = 0.86$). The majority (62%) of gap-makers were oak species (Figure 16). The origin of each gap in the WVURF was snags (50%) followed by blow-downs (44%). Decay created 5% of gaps and grape vines were responsible for creating gaps 1% of the time.

Figure 16: Species composition of gap-makers on the West Virginia University Research Forest.

CHAPTER 4

DISCUSSION

Gap characteristic values in undisturbed parts of the WVURF are consistent with values in other eastern hardwoods where single tree disturbances are dominant. Average gap area in the WVURF was 98.59 m². This value is relatively low in comparison to other forest gap studies (Table 1). Similarly, the average gap fraction was 2.73 %, which is on the low end of values reported from other mixed mesophytic forest (Table 1).

Gap disturbances may not only fluctuate through time, but may also vary with the stage of stand development (Dahir and Lorimer 1996). In eastern hardwood forests, canopy gaps are generally smaller in young stands than in old. As stands age and the average tree crown size increases, and the spacing between large individuals is greater than in younger forests. In addition, mortality is increasingly the result of senescence of large and old trees in older stands, which would be expected to create large gaps. Thus, when a canopy tree is lost from an old growth stand, the size of the canopy gap created should be larger than a comparable disturbance during earlier stages of forest development, and loss of these larger trees would result in more pronounced increases in resource levels. (Clebsch and Busing 1989, Dahir and Lorimer 1996, Tyrell and Crow 1994, Busing 1995, Runkle 1998, Beckage et al. 2000, Hix et al. 2003, Hart and Grissino-Mayer 2009).

Because the WVURF is a relatively young forest (70- 80 years old), it is reasonable that both gap size and gap fraction are on average smaller than in older forests. Field observations indicate the WVURF is in or nearing the understory re-initiation stage of forest development of (Oliver and Larson's 1996). During this stage of development the next generation of trees become established by germination of stored seed and subsequent release of new seedling by significant disturbance. Very little recruitment occurs in understory ruination stage except establishment of shade tolerant species. Single tree gaps do not allow recruitment of shade

intolerant species into upper crown classes. Although canopy gaps in secondary forests are generally smaller in size, they may still act as a mechanism for canopy tree replacement and forest development (Clebsch and Busing 1989,, Wilder et al. 1999, Taylor and Lorimer 2003, Cole and Lorimer 2005).

On the WVURF it is important to keep in mind that large wind events such as tornadoes occur but are relatively rare. High velocity, very localized, and short duration windstorms associated with thunderstorms account for 40-70% of severe weather events. These winds tend to create gaps during the growing season when trees are full leaf out, soils are near saturation, and foliage is heavy with recent rain. Disturbance agents such as heavy snow, ice storms, lightning, insect, and disease infestations also injure or kill trees and produce gaps (Rentch et al. 2003). It is an interesting note that figure 14 shows the increase in mortality in the years of 1987- 1997 which directly correlated to years of heavy gypsy moth infestation (Muzika et al. 2000). It is speculated because of the immense amounts of snags and direct correlation to age of gaps, gypsy moth was the agent of death for a majority of the trees in the WVURF.

Our results indicated that mean gap size did not vary by aspect or slope position. However, both gap size and expanded gap size were significantly larger in cove hardwoods than in the mesic oak and xeric oak forest types. Gap fraction was also greatest in cove hardwoods. This suggests that some characteristics of the cove hardwood forest type contributed to relatively large canopy gaps and an overall gappier structure.

Because cove hardwoods were dominated by yellow poplar, and fifty percent of yellow poplar had been blown over, I speculate that cove hardwoods have larger gap areas due to larger trees in looser soils that would be more prone to tipping and windthrow. In addition, yellow

poplar has the potential to be a less healthy tree (lower site index) at 70- 80 years old than northern red oak. It is believed that yellow poplar has a lower site index on the WVURF due to the fact that a majority of the sites that contain yellow poplar are not suited for optimum growth of yellow poplar. The tree species is growing off-site and most likely won't reach its maximum age. Therefore, yellow poplar is a less healthy tree at 70- 80 years old than northern red oak, and is reaching physiological maturity. Because of the species differences, gap difference will occur, and in this case larger and more frequent gaps in the areas that contain yellow poplar.

Plant community composition may be dependent upon both the frequency of gap creation and the mode of gap phase regeneration (Schnitzer et al. 2000). Over time there is a fundamental compatibility between a species presence and the prevailing disturbance regime. Plant species are found where their life history strategies are compatible with the existing disturbance regime (Rentch et al. 2003). However, without long term observations it is difficult to assess the role of treefall gaps over time (Goldblum 1997). Repeating sampling methods over time or revisiting the 60 gaps found in this study could provide insight into the role of gaps as the WVURF matures.

Treefall gaps may be hot spots of recruitment, seed production, and seed dispersal that serve to maintain the presence of a species in the understory (Goldblum 1997). All species require a minimum gap size to regenerate. Shade intolerant species usually require openings of at least 400 m² for successful regeneration, while oak regeneration is usually more abundant in multiple tree gaps (Runkle 1982, Clinton et al. 1994, Weiskittel and Hix 2002). The environmental heterogeneity provided by multiple canopy opening sizes could promote a high density of tree seedlings and saplings, and the regeneration of highly desirable and relatively shade intolerant species such as oak, which require large openings (Holladay et al. 2005). An

estimated 2.5% of the land area was in gaps $>400\text{m}^2$, while 60% of the land was in multiple tree gaps. This observed gap size distribution seems adequate to allow both shade intolerant species and mid tolerant oaks to persist in this forest.

Gaps contained all three classes of tolerance levels. Webster and Lorimer (2004) showed intermediate shade tolerant species require gaps of at least 100 m^2 , and prefer gaps $>250\text{ m}^2$. Looking at table 3, we see that cove and mid slopes support the gap sizes needed to support recruitment of oaks. This concept of minimum gap size is confirmed when looking at table 7. Oak IVs show a significant difference between coves/ mid slopes and ridges. The gaps on ridges in this stage of development just aren't big enough for recruitment of oak species.

Red maple occurred across a broad topographic gradient, from mesic sites to xeric sites, and on all aspects and slope positions. The understories of many mesic and dry mesic mature oak forests are presently becoming dominated by later successional species and contain only a small oak component (Gould et al. 2005). Effective fire suppression efforts in the eastern United States are thought to have allowed red maple to expand into upland sites where it had previously been excluded by frequent fires. In the absence of fire, red maple has the capacity to establish and survive in a wide range of habitats, from moist valleys to dry ridge tops. This ecological amplitude allows red maple to regenerate in stands where conditions previously favored other species (Gould et al. 2005). Maple has been noted to be expanding across the landscape; however, it was not the dominant species regenerating in gaps on the WVURF. Even though red maple was not the leading species when data was gathered, the maples will likely be the long term survivors in those gaps unless oak are released by a subsequent disturbance.

Management Implications Related to this Study

The study of “natural” (no human influence) forest disturbance is important not only because it determines forest structure, but also because disturbance may act as an important selective force on certain gap colonizing species. The frequency and magnitude of these natural disturbances are important considerations in shaping management policies of forest land (Lorimer 1980). Yet in many cases natural disturbance regimes, their consequences for forest structure, and their variability over the landscape mosaic are poorly understood.

Silviculture often focuses on allocating the available growing space in a forest to the highest quality individuals of preferred species. Most legitimate applications of silviculture focus on meeting management objectives involving regeneration of desired species which, in turn, requires creating conditions that favor those species. An alternative approach is for foresters to use modified silvicultural techniques that mimic natural patterns of disturbances, forest structure, and stand development (Kimball et al. 1995). Forest management policy on many public lands in North America and Europe has undergone a radical shift in recent years from an emphasis on sustainable timber yields on economic rotations to emphasis on overall ecosystem sustainability and the natural disturbance paradigm (Choi et al. 2001). Forest managers need additional information on stand development so that harvest prescriptions can be adjusted to meet long term management objectives. Natural gap dynamics can guide forest management to regenerate desired species. Follow up study of the 60 gaps found in the WVURF would disclose the dynamics over time.

Understanding the disturbance dynamics, especially the canopy gap dynamics of second growth forests is important in the development of ecosystem management policies (Keller and

Hix 1999). The framework advanced by this study could aid land managers in implementing informed management policies and practices that more closely resemble the natural disturbances that are occurring in undisturbed portions of the WVURF.

CHAPTER 5

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- National Deans List
- Ecology Scholarship from the Pymatuning Lab of Ecology, Univ. of Pittsburgh, Summer 2005
- Society of American Foresters (WVU and National chapters)
- WVU Chapter of Xi Sigma Pi, National Forestry Honor Society
- Davis College of Agriculture, Forestry & Consumer Science, 13th Annual Student Research Conference- Paper Presentation
- Paper Presentation accepted to the North American Forest Ecology Workshop, Utah State University, Logan, Utah- June 22-25, 2009

RELEVANT COURSE WORK

UNDERGRADUATE

PLANT ECOLOGY
FRESHWATER ECOLOGY
CELL BIOLOGY
GENETICS
ECOLOGICAL APPLICATIONS
COMM & ECOSYS DYNAMICS
GENERAL BOTANY
ORGANIC CHEM I & II
BIOCHEM I
GENERAL PHYSICS I & II

GRADUATE

STATISTICS I & II
SPATIAL ANALYST, RESOURCE MNGMNT (GIS)
APPLIED GIS TO NATURAL SCIENCE
ADVANCED FOREST ECOLOGY
FOREST STAND DYNAMICS
SILVICULTURE
LAB INSTRUCTOR FOR DENDROLOGY

MASTERS RESEARCH

Treefall Gap Characteristics within an Appalachian Hardwood Forest in West Virginia:
Influences of Topographic Position and Forest Type

SKILLS

✓ Microsoft Excel	✓ Tree Identification
✓ Microsoft Word	✓ ARCMAP (Geographic Information System)
✓ Microsoft PowerPoint	✓ SAS