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Stand dynamics of an old-growth hemlock-hardwood forest in West Virginia

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STAND DYNAMICS OF AN OLD-GROWTH HEMLOCK- HARDWOOD FOREST IN WEST VIRGINIA

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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
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**Master of Science
in
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Approved by

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ABSTRACT

STAND DYNAMICS OF AN OLD-GROWTH HEMLOCK-HARDWOOD FOREST IN WEST VIRGINIA

Nathan R. Beane

Cathedral State Park (CSP) is a 54-ha, old-growth, hemlock-hardwood forest located in the central Appalachian Mountains of West Virginia. Trees larger than 100 cm diameter at breast height (dbh) and 35 m tall are common. Hemlock woolly adelgid (HWA) (*Adelges tsugae* Annand) is an exotic insect that currently threatens eastern hemlock (*Tsuga canadensis* (L.) Carr.) throughout its native range, and was found in CSP in 2002. In 2006, field plots established in 2000 were remeasured to assess adelgid-induced changes to forest structure and species composition. The herbaceous plant community was also measured during the 2006 growing season to describe how the ground flora has changed since it was originally surveyed in 1965. In addition, snag density, snag basal area, and the volume of downed dead wood in CSP were compared to 25 similar old-growth hemlock-hardwood stands in the eastern United States. From 2000 to 2006 relatively little change occurred in woody vegetation in CSP. However, more than 10% of overstory hemlocks measured were identified with HWA, with plot infestations ranging from 0-93%. Currently, no hemlock mortality can be attributed to HWA, but many trees already show symptoms of infestation. The ground flora has remained relatively unchanged since it was originally sampled, with the most common species in 1965 still prevalent in 2006. Snag basal area was similar ($p=0.86$) to 25 comparable old-growth hemlock-hardwood stands, although less than half the snag density ($p<0.001$) was found in CSP. CSP also had more than twice the volume of logs ≥ 20 cm mid-point diameter compared to other old-growth hemlock-hardwood stands. This study serves as a reference of forest structure and species composition in CSP prior to HWA-induced mortality.

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INTRODUCTION

Cathedral State Park (CSP) is a 54-ha, old-growth, hemlock-hardwood forest located in the central Appalachian Mountains of West Virginia. CSP is dominated by eastern hemlock (*Tsuga canadensis* L. Carr), with some trees believed to be 400 years old or more (Venable, date unknown). Trees larger than 100 cm diameter at breast height (dbh) and 35 m tall are not uncommon. CSP is a stunning reminder of the virgin hemlock forests that once flourished in the Appalachian region (Patterson 1988). Hill (1965) described the uniqueness of this old-growth forest:

A few steps into the shady green twilight of this virgin forest preserve and the visitor feels as though he were in another world..., a timeless, changeless world, ancient beyond calculation. Cool shaded paths lure the curious to explore deeper into the woods to find themselves in the living presence of these kings of the mountains.

Old-growth forests in the northeast United States contribute <1% of the total forested area (Davis 1996). An even smaller fraction of forests in West Virginia are old-growth. Areas like CSP should not only be preserved, but studied and researched because of their rarity and ecological importance.

The onset of an exotic pest, hemlock woolly adelgid (HWA) (*Adelges tsugae* Annand), currently threatens the fate of hemlocks and the unique habitat they provide. In the eastern U.S., both eastern hemlock and Carolina hemlock (*Tsuga caroliniana* Engelm.) are very susceptible to HWA, with all size and age classes at risk. Since the mid 1980s, HWA has spread at a rate of 20 to 30 km per year (McClure et al. 2001). West Virginia lies within the native range of eastern hemlock and is rapidly being

infested by HWA. As of 2006, HWA has been found in 28 counties (51% of state), with HWA discovered in CSP in 2002 (USDA-Forest Service 2007).

In 2000, the United States Forest Service established permanent vegetation plots in CSP to record stand conditions prior to the arrival of HWA. In 2006, these plots were re-measured to assess the impact of HWA to overstory, understory, and regeneration vegetation layers. In addition, herbaceous samples were collected throughout the 2006 growing season and compared to an original flora survey of CSP performed in 1965. Finally, the volume of downed dead wood in CSP was quantified and compared to other old-growth hemlock forests in the eastern United States.

LITERATURE REVIEW

History of Cathedral State Park

Cathedral State Park (CSP) is dissected by U.S. Highway 50, formerly known as the Northwestern Turnpike, which played a vital role in the preservation of the forest. The turnpike was originally constructed in 1830 to connect eastern and western Virginia, and was an important conduit for Western migration. Small towns and inns soon followed to accommodate travelers, with the small town of Aurora becoming established in 1833 (Callahan 1913). The turnpike became a busy thoroughfare of travel and traffic, with reports of droves of turkey, cattle, and sheep driven to distant markets, including Baltimore, MD, Washington D.C., and Winchester, VA (Patterson 1988). It was heavily used by stagecoaches, teams and wagons (including Conestoga's— a popular freight vehicle in the Appalachians prior to the railroad), horseback riders, and pedestrians until 1845. At that time, the nearby Baltimore and Ohio (B&O) Railroad was completed, making available a cheaper and faster means of traveling to western lands (Callahan 1913, Patterson 1988). A person could travel on the B&O Railroad from Green Spring to Parkersburg, a distance of 210 miles, for \$10 (Callahan 1913).

The Brookside Hotel, standing where the current CSP office is located on Highway 50, was constructed by Judge Vail of Harper's Ferry in 1884 and was located west of the Red Horse Tavern. The tavern, also known as Ye Old Stone House, was once an active stagecoach terminal and resting area for travelers (Wills 1949). The area surrounding the Brookside Hotel covered nearly 97 ha (including CSP) and was known locally as Brookside. In 1891, Judge Vail sold Brookside to a Mr. Middleton, who

defaulted on the mortgage held by Preston Wright (Wills 1949, Patterson 1988). Mr. Wright took over ownership of Brookside in 1893, selling the land (but not the hotel) in 1894 to an early guest of the hotel, Lee McBride (Wills 1949, Kenneth Carvell, Morgantown, WV, personal communication).

Mr. McBride was a successful businessman and president of a large wholesale firm (Root & McBride) in Cleveland, OH. He and his wife fell in love with the beauty of Brookside and the cool summer climate available during a time without air-conditioning. In 1896, the couple built a home opposite the hotel known as “Gaymont”, purchasing the Brookside Hotel in 1900 (Wills 1949). The McBrides transformed the hotel into one of the finest summer resorts in northern West Virginia, adding a lake for boating and fishing, a casino, a double bowling alley, croquet grounds, and tennis courts (Patterson 1988). They also purchased fine saddle horses, some from Washington D.C., and enlarged the Brookside stables (Wills 1949). Mr. and Mrs. Kirkpatrick were hired by the McBrides to manage and operate the resort and Brookside Woods, with Mr. Kirkpatrick dying in less than a year. Management of the resort fell to his widow, who successfully managed the Brookside Hotel until 1918 (Patterson 1988).

The Brookside Woods was a major attraction to visitors of the Brookside Hotel and no harvesting was allowed to take place (Wills 1949). During the logging era in West Virginia (1879-1912), most old-growth forests were cut. Clarkson (1964) reported that by 1920 most of the original virgin forest in West Virginia had been harvested, apart from a few isolated areas of small acreage. Several harvests did occur on property surrounding Brookside and resulted in the establishment of tram-road networks

throughout the area by logging companies. During this period, a law stated that if a railroad company could secretly grade a right-of-way at least halfway through private property without intervention from the landowner, the railroad could complete the line. In 1898, Preston Lumber and Coal Co. attempted to complete a right-of-way through the Brookside Woods. In only one night, with the use of 50 horses and 140 workmen, a right-of-way was graded more than halfway through the Brookside Woods. This enraged Mr. McBride, and he strongly refused to sell any timber to the company (Patterson 1988).

Lee McBride died in 1909, with Mrs. McBride selling the resort to Brandon Haas in 1922. Mr. Haas remained a close friend of Mrs. McBride until her death in 1925. The resort closed in 1924, with ownership of the Brookside Woods belonging to Mr. Haas. In 1942, through the efforts of A.B. Knight, Honorable A.G. Martin, and T.D. Gray, director of the West Virginia Conservation Commission, Mr. Haas sold 48 ha of the Brookside Woods to the state (Wills 1949, Quick and Barnett 1949). He sold the land for \$13,000, a price much lower than the value of the timber alone. Mr. Haas only agreed to sell the land with the stipulations that it never be cut by axe or saw and that it would be given the necessary protection to preserve it. He had a deep passion for the Brookside Woods and remained the caretaker of the forest until 1956 (Hill 1965, Patterson 1988). Four small additional neighboring tracts were acquired by CSP in 1950, 1960, and 1978, bringing the total acreage of the park to 54 ha (Patterson 1988).

Today, CSP represents the finest example of an old-growth hemlock-hardwood forest in West Virginia, and has received several commendations. In 1966, CSP was entered into the National Registry of Natural History Landmarks because of its

uniqueness. In 1983, the Society of American Foresters recognized CSP in its National Natural Areas Program as an outstanding example of a vegetative community in a near-natural condition (Patterson 1988). Because of Mr. Haas' determination to keep CSP "just as God had made it", visitors today can enjoy the park as the early explorers did (Hill 1965).

Previous Studies in CSP

Three published studies have been established in CSP since its creation. In the first study, Bieri and Anliot (1965) identified several distinct forest communities, with two primary communities described: hemlock-fern and hemlock-rhododendron. The hemlock-fern community was hemlock-dominated, well drained, and had a closed canopy. Accompanying species included black cherry (*Prunus serotina* Ehrh.), American beech (*Fagus grandifolia* Ehrh.), yellow birch (*Betula alleghaniensis* Britt.), and ash (*Fraxinus* spp.). The hemlock-rhododendron community was also hemlock-dominated but with a less dense canopy and accompanied by a dense shrub layer of great laurel (*Rhododendron maximum* L.). Associated species included sweet birch (*Betula lenta* L.), red maple (*Acer rubrum* L.), black cherry, northern red oak (*Quercus rubra* L.), and pitch pine (*Pinus rigida* P. Mill.). This community occurred near streams and other areas of poor drainage.

Three smaller communities were also identified: hemlock-duff; red maple-black cherry-yellow birch; and a hemlock-fern/hemlock-rhododendron ecotone. The hemlock-duff community occurred where the highest density of canopy trees existed. Within this community the herbaceous layer was almost absent, with rare occurrences of Canada

mayflower (*Maianthemum canadense* Desf.), and partridgeberry (*Mitchella repens* L.). The maple-cherry-birch community had very poor drainage with reports of skunk cabbage (*Symplocarpus foetidus* (L.) Salisb. ex Nutt.) growing well in late summer. The herbaceous layer of this community consisted primarily of cinnamon fern (*Osmunda cinnamomea* L.) and northern long sedge (*Carex folliculata* L.). In the hemlock-fern/hemlock-rhododendron ecotone, an intermediate rather than two-layered structure existed. This community possessed a shrub layer of rhododendron and mountain holly (*Ilex montana* Torr. & Gray ex Gray), but lacked the obvious two-layer structure of the hemlock-fern and hemlock-rhododendron communities. This ecotone was also characterized by hemlocks of all ages, with abundant black cherry, eastern hemlock, and red maple seedlings (Bieri and Anliot 1965).

In the second study, Maguire and Foreman (1983) examined the associations between tree seedling density and herbaceous cover. Ninety-four percent of all seedlings were black cherry (60%), eastern hemlock (20%), and red maple (14%). Overall, there was a negative relationship between total tree seedlings and herbaceous cover. For example, within patches of eastern hay-scented fern (*Dennstaedtia punctilobula* (Michx.) T. Moore), the frequency of red maple, birch, black cherry, and eastern hemlock were significantly lower. Patches of shining clubmoss (*Huperzia lucidula* (Michx.) Trevisan; previously *Lycopodium lucidulum*) had lower densities of red maple, eastern hemlock, and total tree seedlings. Within patches of partridgeberry, however, significantly higher seedling densities occurred for red maple and eastern hemlock.

In the third study, Maguire (1985), using the same methodology as Maguire and Forman (1983), identified interspecific associations and correlations between tree seedling establishment and herbaceous cover. Five herbaceous species made up 91% of the total herbaceous cover: spinulose shield fern (*Dryopteris carthusiana* (Vill.) H.P. Fuchs; previously *Dryopteris spinulosa*) (42%), eastern hay-scented fern (28%), mountain woodsorrel (*Oxalis montana* Raf.) (10%), partridgeberry (6%), and shining clubmoss (5%). Interspecific associations identified were: partridgeberry x hemlock, partridgeberry x maple, hay-scented fern x clubmoss, clubmoss x serviceberry, and woodsorrel x cherry.

Studies in Other Old-Growth Hemlock-Hardwood Forests

Oosting and Billings (1939) described the forest structure in an old-growth hemlock stand in North Carolina. Hemlock made up 50-70% of the dominant trees, with associated species of sweet birch, American chestnut (*Castanea dentata* (Marsh.) Borkh.), tuliptree (*Liriodendron tulipifera* L.), red maple, and northern red oak. The understory and regeneration were composed primarily of hemlock and sweet birch, with scanty reproduction of American chestnut due to chestnut blight. Two understory communities were also identified: rhododendron (i.e., great laurel) and deerberry (*Vaccinium stamineum* L.; previously *Polycodium stamineum* (L.) Greene). The rhododendron community, because of heavy shade, seemingly inhibited other flora from developing. Only two flowering species, covering 12% of the ground surface, were identified: partridgeberry and beetleweed (*Galax urceolata* (Poir.) Brummitt; previously

Galax aphylla). In contrast, the deerberry community contained 16 species of flowering plants and ferns, covering 57% of the ground surface.

Old-growth hemlock-hardwood forests are characterized by structural complexity. An important component of this structure includes dead trees. Standing dead trees (snags) and downed dead wood (DDW) are collectively termed coarse woody debris (CWD). CWD is an important structural and functional element in forest ecosystems (McCarthy and Bailey 1994). CWD increases biodiversity and offers favorable germination and establishment sites for epiphytic bryophytes and lichens, fungi, and many vascular plants (Harmon et al. 1986, McGee et al. 1999). A variety of animals, including amphibians, mammals, reptiles, and arthropods, use CWD as travel corridors, perches, foraging areas, and safety from predation (McCarthy and Bailey 1994, McGee et al. 1999). CWD is also important for nutrient cycling and nitrogen fixation in terrestrial and aquatic ecosystems (Harmon et al. 1986, Ganjegunte et al. 2004). Although low in nutrient concentration, CWD is slow to decompose and offers a continuing source of energy and nutrients (Harmon et al. 1986).

Amounts of CWD (i.e., snags plus DDW) typically increase with stand age, with old-growth stands providing valuable information for management of younger stands with reduced or limited amounts of CWD (Tyrrell and Crow 1994a). Tyrrell and Crow (1994a, 1994b) examined the structural characteristics of 25 old-growth, hemlock-hardwood stands in northern Wisconsin and northern Michigan. All stands were 175-years-old or more, with over 50% hemlock basal area. Higher amounts of CWD occurred in older hemlock stands. Their results showed a decline in live tree density with

increasing stand age, with a lower limit of approximately 100 trees per ha occurring in stands approaching 300-years-old or more. Hemlock snag density decreased slightly with age; however, hemlock snag basal area and volume increased. As stand age increased, hemlock constituted a greater percentage of DDW, closely approaching the percentage of hemlock live tree basal area (Tyrrell and Crow 1994b)

Weckel et al. (2006) examined the structural and compositional changes of an old-growth hemlock forest in New York from 1965 to 2004. They identified several damaging agents that potentially affect hemlock forests. These agents were increased browsing from white-tailed deer (*Odocoileus virginianus* Zimmerman), and the introduction of two exotic pests: hemlock woolly adelgid (*Adelges tsugae* Annand) and elongate hemlock scale (*Fiorinia externa* Ferris). The overstory tree composition was similar in 1965 and 2004, with hemlock dominant during both periods. However, the understory and regeneration communities exhibited declines in species richness. From 1965 to 2004, sapling richness dropped from 15 to 3 species while seedling richness fell from 18 to 6 species, indicating a community shift. Hemlock and white ash (*Fraxinus americana* L.), the most abundant sapling and seedling species in 1964, were absent in 2004. American beech was the only species to increase in sapling and seedling abundance. These findings were explained by the overabundant deer populations which prevented successful establishment of hemlock. Hemlock seedlings and saplings are a preferred deer browse, particularly during winter months when food availability is scarce.

Loucks and Nighswander (1999) found that hemlock stands having low white-tailed deer populations (less than 3-4 deer per square kilometer) were able to develop all-

aged structures across broad geographic regions. In such areas, hemlock seedling success was higher on logs and stumps. These nutrient-rich establishment sites exist above the smothering litter layer on the forest floor. The authors concluded that for successful management of old-growth hemlock, younger stands must be maintained in age classes that are able to replace older trees should a cataclysmic event take place (i.e., fire, wind storms, and some types of insect infestation).

Hemlock Woolly Adelgid

The hemlock woolly adelgid (HWA) is an insect native to Asia that was first discovered in the eastern U.S. in Richmond, VA in 1951. Eastern and Carolina hemlock (*Tsuga caroliniana* Engelm.) are vulnerable. Other *Tsuga* species occurring in the western U.S. [western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.)] and Asia are not at risk because of native predators that suppress HWA populations. HWA spread slowly during the 1950s-1970s in the eastern United States, but since the mid 1980s has spread at a rapid rate of 20 to 30 km per year (Ward et al. 2004).

HWA measures less than 1.5 mm in length. Adelgids are unique in that they estivate (i.e., are dormant) from June to October and are most active during winter months. Hemlock woolly adelgids are dark-red to black and are covered with a woolly wax filament for all life stages, except when newly hatched (Ward et al. 2004).

The life cycle of HWA in the eastern U.S. consists of two parthenogenetic generations per year: sistens and progrediens. The sistens generation is a wingless generation that hatches in late spring. The nymphs, also referred to as crawlers,

immediately enter a period of dormancy. The progrediens are comprised of both winged (sexuparae) and wingless offspring. When mature, the sexuparae fly off in search of suitable spruce species (*Picea* spp.) in which to lay their eggs. Suitable spruce species for the sexuparae are not native to North America, leading to death and no reproduction for this population (Ward et al. 2004).

Hemlock trees are most susceptible to attack during the sistens generation, because twice as many eggs can be produced. A single female may lay up to 300 eggs during the sistens generation, allowing populations to increase and spread rapidly (McClure 2001). This is due to availability of nutrients stored in the needles and twigs of hemlocks during winter months and low levels of predation from natural enemies that are inactive. Dispersal of HWA is primarily by wind, mammals, and birds. HWA feeding causes needle desiccation and ultimately needle drop. Heavily infested trees show symptoms in a few months, with dieback of major limbs occurring in two years, and death usually within four years (Ward et al. 2004).

HWA was first detected in West Virginia during an initial survey in 1992, but was not found in CSP until 2002. Biological and chemical control efforts have been made to reduce damage within the park. Five release treatments of ladybird beetles from Japan have occurred in CSP since 2002. The ladybird beetle has had little impact on HWA in the park (Karen Kish, Forest Entomologist, West Virginia Department of Agriculture, Charlestown, WV, personal communication). However, the toothed-neck fungus beetle (*Laricobius nigrinus* Fender), a predatory beetle from British Columbia, may offer new hopes for slowing the spread of HWA. A complex of natural enemies, rather than a

single mode of control, will likely be needed to reduce HWA populations below damaging levels (Ward et al. 2004).

Chemical controls have also been tested in CSP using the insecticide Imidacloprid (Merit®, Imicide®, Pointer®) (Karen Kish, Forest Entomologist, West Virginia Department of Agriculture, Charleston, WV, personal communication). This treatment has been limited to high priority trees (e.g., trees alongside trails) because of the expense and intensive labor required. Imidacloprid works as a systemic and can be applied as a soil treatment, foliar application, or trunk injection, with soil treatments providing the longest duration of control (Silcox 2002). Although chemical treatments are promising, the process is not economically feasible to prevent infestations on a stand level.

Orwig and Foster (1998) examined the effects of HWA infestations in southern New England. Eight stands in south-central Connecticut were examined with overstory hemlock importance ranging from 49-88%. Damage to hemlock varied among stands, with overstory mortality ranging from near zero to greater than 95 percent. Hemlocks of all sizes and canopy classes were infested, with overtopped and intermediate canopy trees suffering higher mortality rates. All surviving hemlocks, with the exception of trees in one uninfested stand, suffered at least 25% foliage loss, with varying amounts of chlorotic foliage present.

Orwig and Foster (1998) also found significantly higher light levels reaching the forest floor in severely to moderately damaged stands. Two stands exhibited significantly higher seedling densities. Sweet birch seedlings represented 76% of all seedlings, with other species including red maple, black cherry, and several oak species.

The introduction of invasive and exotic plant species, including Japanese barberry (*Berberis thunbergii* DC.), tree-of-heaven (*Ailanthus altissima* (P. Mill.) Swingle), and Japanese stilt grass (*Microstegium vimineum* (Trin.) A. Camus), occurred in several stands damaged by HWA.

Eastern hemlocks are at risk of elimination on a stand level from HWA if effective controls are not discovered. HWA attacks all size classes of hemlock and has the potential to eliminate the species from a site within a few years. As a late-successional and opportunistic species, hemlocks maintain dominance in old-growth stands by occupying canopy gaps created by the mortality of individual or small cohorts of trees (Lorimer 1996). In stands with HWA infestation, larger canopy gaps will likely be created, allowing faster-growing, shade intolerant species to dominate these areas.

METHODOLOGY

Study Area

Cathedral State Park is located in Preston County, West Virginia (39°19.5'N, 79°32.5'W), and is 1.5 km east of Aurora near the Maryland/West Virginia border (Figure 1). Preston County lies within the Allegheny Mountain section of the Appalachian Plateau. The Allegheny Mountain section is located on the northeastern margin of the high plateau and rises 300 m above the Ridge and Valley Province. The topography of this region no longer resembles a plateau because of the mild folding along anticlines and synclines. Linear ridges now exist, and were formed by rising mountains and deeply cut ridges formed by streams (Patton et al. 1959, Rauscher 2004).

Preston County has daily January minimum and maximum temperatures of -9° C and 2° C, respectively, and 13° C and 29° C for July (Core 1966, Baldwin 1973). The county has a mean freeze-free period of 140 days, extending from May 15 to October 1, with an average relative humidity of 80% throughout the year. Mean annual precipitation is 137 cm with an average annual snowfall of 203 cm (Baldwin 1973).

Although situated in a mountainous region, CSP has a gentle northeastern slope. The elevation ranges from 750 to 800 m above sea level, as is shown in Figure 2. Rhine Creek meanders through CSP and is a tributary of the Youghiogeny River. The soils within the study area are Dekalb loam and Ernest stony silt loam. Dekalb soils are well- to excessively-drained uplands soils that are shallow to moderately deep. They are derived from acid sandstone and have slopes of 3 to 20 percent. Ernest soils are found on

Figure 1. Location map of Cathedral State Park.

Figure 2. Topographic map of Cathedral State Park and surrounding area.

lower slopes and adjacent to streams. These soils are characterized as deep and moderately well-drained and are derived from acid sandstone and shale (Patton et al. 1959).

Field Methods

2000 INVENTORY

The U.S. Forest Service Northern Research Station established thirteen, 0.4 ha circular plots (radius=35.89 m) in 2000. Their objective was to sample the forest structure in CSP prior to HWA infestation. Plot centers were marked with steel rebar, and were positioned on parallel transects using a N33E bearing (Figure 3). All plots were established north of Highway 50 in the area best representing the old-growth hemlock-hardwood forest type in CSP.

Within each 0.4 ha plot, all living and dead trees ≥ 12.7 cm dbh were recorded by species, dbh, and crown class (dominant, codominant, intermediate, suppressed). Total heights were measured for approximately 10% of the living trees. Nested within each overstory plot were four understory plots and eight regeneration plots. Understory plots were 0.004 ha circular plots (radius= 3.59 m) and located 15.24 m in each cardinal direction from plot center. Living trees ≥ 2.54 cm dbh and < 12.7 cm dbh were tallied by species, dbh, total height, crown class, and origin (seedling, stump sprout, root sprout). The regeneration plots were 0.0004 ha circular plots (radius= 1.13 m) and located 15.24 m and 30.48 m in each cardinal direction from plot center. Seedlings < 2.54 cm dbh were tallied by species, origin, and height class (< 15.24 cm; 15.24-30.48 cm; 30.49-91.44 cm;

Figure 3. Plot layout within Cathedral State Park.

91.45-152 cm; and ≥ 152 cm tall). Figure 4 shows a plot diagram for the understory and regeneration plots within each overstory plot.

2006 INVENTORY

In summer 2006, each permanent plot established in 2000 was located and flagged. The coordinates of each plot location were confirmed using a global positioning system (GPS). The inventory in 2006 followed the methodology used in 2000. In addition, any HWA presence on overstory hemlock trees ≥ 12.7 cm dbh was recorded. A species list of all woody vegetation sampled in 2000 and 2006 is presented in Appendix I. Nomenclature follows United States Department of Agriculture, Natural Resources Conservation Service, PLANTS Database (USDA-NRCS 2007).

In summer 2006, we also examined two elements of forest structure not inventoried in 2000: herbaceous vegetation and downed dead wood (DDW). Within each overstory plot, eight 1m² herbaceous plots were established (Figure 5). Each regeneration plot center marked the top-left corner of the herbaceous plot when facing north. An herbaceous plant is defined here as a plant with no persistent woody tissue occurring above ground. Two non-herbaceous plants were also included in the herbaceous plots: blackberry (*Rubus* spp.) and greenbrier (*Smilax* spp.). These species were included because of their similar growth form and competitive relationship within the herbaceous community. All herbaceous plots were visited every fourth week, with three sampling periods occurring from May-July 2006. Within each plot, herbaceous plants were identified by species, when possible, and percent cover estimated. A list of all herbaceous plants sampled in 2006 is presented in Appendix II. Nomenclature

Figure 4. Understory (0.004 ha) and regeneration (0.0004 ha) plot layout within each overstory plot at Cathedral State Park.

Figure 5. Herbaceous plot (1m²) layout within each overstory plot at Cathedral State Park.

follows United States Department of Agriculture, Natural Resources Conservation Service, PLANTS Database (USDA-NRCS 2007).

To quantify the characteristics of DDW, a 0.04 ha circular plot was established within each overstory plot (Figure 6). DDW is defined here as downed dead wood ≥ 10 cm at the mid-point diameter and at least 1 m in length. All DDW was tallied as hardwood or softwood, with diameter and log length recorded (Bragg 2004). At each log midpoint, diameter measurements were collected on two sides using tree calipers. Log length was measured end-to-end, and was measured for the dominant stem portion whenever a fork was encountered. The decay class of each downed log was also recorded on a scale of 1 (least decayed) to 5 (most decayed) (Thomas 1979) (Table 1). Using average diameter and log length, volume was calculated using Huber's formula (Avery and Burkhart 2002):

$$V = (B_{1/2})L \quad \text{(Equation 1)}$$

Where, $B_{1/2}$ = cross-sectional area at log midpoint
L = log length

Data Analysis

Changes in density, relative density, basal area, and relative basal area were examined for overstory and understory vegetation. Within the regeneration layer, density and relative density were examined by height class. A Shapiro-Wilk test was conducted to test for normality. A paired t-test was used for species normally distributed, while species not normally distributed were analyzed using a non-parametric, signed rank test.

Figure 6. Downed dead wood plot (0.04 ha) layout within each overstory plot at Cathedral State Park.

Table 1. Decay class descriptions for downed dead wood in Cathedral State Park.¹

DDW Characteristics	Decay Class 1	Decay Class 2	Decay Class 3	Decay Class 4	Decay Class 5
Bark	Intact	Intact	Trace	Absent	Absent
Twigs <3 cm	Present	Absent	Absent	Absent	Absent
Texture	Intact	Intact to partially soft	Hard, large pieces	Small, soft blocky pieces	Soft and powdery
Shape	Round	Round	Round	Round to oval	Oval
Color of wood	Original color	Original color	Original color to faded	Light brown to reddish brown	Red brown to gray brown
Portion of tree on ground	Tree elevated on support points	Tree elevated on support points but sagging slightly	Tree is sagging near ground	All of tree on ground	All of tree on ground
Invading roots	None	None	In sapwood	In heartwood	In heartwood

¹Adapted from Thomas (1979).

In the herbaceous samples, average frequency and percent cover for all three sampling periods were used. The eight herbaceous subplots within a given overstory plot were then averaged by species. Finally, the average of all thirteen overstory plots was used to create an average frequency and average relative percent cover for each herbaceous species. Importance values were then determined by species, using average relative frequency and average relative percent cover (i.e., $(\text{relative frequency} + \text{relative cover}) / 2$). To obtain relative percent cover, average percent cover was used. For example, the average of a 5-10% percent cover class would be 7.5.

The volume of DDW as well as the density and basal area of snags in CSP were compared to other old-growth hemlock-hardwood forests. Comparable stands were selected using the following criteria: 1) identified as an eastern old-growth forest, 2) described within the conifer-northern hardwood forest cover type, 3) hemlock dominated ($\geq 40\%$ hemlock basal area), and 4) information concerning DDW and snags (i.e., CWD) was available. Twenty-five old-growth stands were selected from northern Wisconsin and Michigan (Tyrrell and Crow 1994a, Tyrrell and Crow 1994b, Tyrrell et al. 1998). A Shapiro-Wilk test was conducted for selected stands and CSP to test for normality. Datasets not normally distributed were analyzed using a non-parametric, signed rank test, whereas those normally distributed were analyzed using a two-sample t-test. Plot means in CSP were compared to stand means from the 25 selected stands. This testing schematic was used because individual plot data were unavailable for selected stands (Tyrrell and Crow 1994a, Tyrrell and Crow 1994b, Tyrrell et al. 1998). All statistical

analyses were performed using SAS (2004), with statistical significance for all tests accepted at $\alpha \leq 0.05$.

RESULTS

Overstory Trees ≥ 12.7 cm dbh

Fifteen species comprised the overstory vegetation in 2000 and 2006 (Table 2). Four species made up 89 and 88% of total tree density in 2000 and 2006, respectively: eastern hemlock (59 and 61%), red maple (13 and 11%), sweet birch (11 and 10%), and black cherry (6 and 6%). All other species occupied less than 4% relative density. Total tree and hemlock density did not significantly change from 2000 to 2006. Total trees per hectare (tph) increased from 305.84 to 306.80, while hemlock increased from 180.01 to 186.47 tph.

Total overstory basal area was significantly lower ($p=0.03$) in 2006, decreasing from 43.26 to 41.44 m²/ha (Table 2). Hemlock decreased from 25.20 to 24.46 m²/ha, but this was not a significant change. Four species made up 86 and 85% of total basal area in 2000 and 2006, respectively: eastern hemlock (58 and 59%), red maple (12 and 11%), black cherry (9 and 9%), and white oak (*Quercus alba* L.) (7 and 6%).

Overstory volume (m³/ha) significantly decreased ($p=0.02$) from 2000 to 2006, falling from 332.24 to 316.81 m³/ha (Table 3). There was no evidence of a statistical change in hemlock volume ($p=0.2$), although the average volume decreased from 190.53 to 183.99 m³/ha. Six species accounted for 97 and 94% of total volume in 2000 and 2006: hemlock (57 and 58%), red maple (12 and 11%), black cherry (9 and 9%), white oak (7 and 6%), northern red oak (6 and 5%), and sweet birch (6 and 5%).

Diameter distributions in CSP for 2000 and 2006 resembled a reverse-J shape characteristic of uneven-aged forests (Figure 7). The majority of larger-sized trees were

Table 2. Density, relative density, basal area, and relative basal area of overstory trees ≥ 12.7 cm dbh at Cathedral State Park in 2000 and 2006.

Species	Density (trees/ha)			Relative Density			Basal Area (m ² /ha)			Relative Basal Area		
	2000	2006	p-value	2000	2006	p-value	2000	2006	p-value	2000	2006	p-value
<i>Acer pensylvanicum</i>	0.38	0.95	0.50	<1%	<1%	0.25	0.01	0.02	0.50	<1%	0%	0.25
<i>Acer rubrum</i>	38.40	33.26	0.06	13%	11%	0.08	5.03	4.57	0.11	12%	11%	0.24
<i>Amelanchier arborea</i>	0.76	0.95	1.00	<1%	<1%	0.13	0.02	0.03	1.00	<1%	<1%	0.63
<i>Betula alleghaniensis</i>	6.65	9.12	0.13	2%	3%	0.04	0.58	0.87	0.05	1%	2%	0.02
<i>Betula lenta</i>	32.69	30.22	0.27	11%	10%	0.64	2.66	2.23	0.22	6%	5%	0.22
<i>Fagus grandifolia</i>	6.08	7.03	0.38	2%	2%	0.13	0.73	0.75	0.20	2%	2%	0.02
<i>Fraxinus americana</i>	0.19	0.00	1.00	<1%	0%	0.50	0.01	0.00	1.00	<1%	0%	0.50
<i>Hamamelis virginiana</i>	0.19	0.19	.	<1%	<1%	0.50	<0.01	<0.01	1.00	<1%	<1%	0.50
<i>Liriodendron tulipifera</i>	0.19	0.19	.	<1%	<1%	0.50	0.01	0.01	1.00	<1%	<1%	0.50
<i>Magnolia acuminata</i>	0.57	0.57	.	<1%	<1%	0.63	0.04	0.04	0.25	<1%	<1%	0.13
<i>Nyssa sylvatica</i>	0.00	0.19	1.00	0%	<1%	0.50	0.00	0.03	1.00	0%	<1%	0.50
<i>Picea rubens</i>	0.38	0.38	.	<1%	<1%	0.50	0.06	0.06	0.50	<1%	<1%	0.25
<i>Prunus serotina</i>	18.82	18.25	0.39	6%	6%	0.19	3.79	3.70	0.59	9%	9%	0.27
<i>Quercus alba</i>	13.50	12.55	0.13	4%	4%	0.01	2.83	2.53	0.43	7%	6%	0.32
<i>Quercus rubra</i>	7.03	6.46	0.75	2%	2%	0.46	2.29	2.14	0.70	5%	5%	0.73
<i>Tsuga canadensis</i>	180.01	186.47	0.18	59%	61%	0.25	25.20	24.46	0.20	58%	59%	0.54
Total	305.84	306.80	0.84	-	-	-	43.26	41.44	0.03	-	-	-

Table 3. Volume of overstory trees ≥ 12.7 cm dbh at Cathedral State Park in 2000 and 2006.

Species	Volume (m ³ /ha)			Relative Volume (m ³ /ha)		
	2000	2006	p-value	2000	2006	p-value
<i>Acer pensylvanicum</i>	0.03	0.07	0.50	<1%	<1%	0.50
<i>Acer rubrum</i>	39.39	35.70	0.06	12%	11%	0.34
<i>Amelanchier arborea</i>	0.12	0.15	1.00	<1%	<1%	0.88
<i>Betula alleghaniensis</i>	4.43	6.68	0.06	1%	2%	0.08
<i>Betula lenta</i>	19.87	16.28	0.13	6%	5%	0.19
<i>Fagus grandifolia</i>	5.75	5.69	0.44	2%	2%	0.20
<i>Fraxinus americana</i>	0.06	0.00	1.00	<1%	0%	1.00
<i>Hamamelis virginiana</i>	0.00	0.00	.	0%	0%	.
<i>Liriodendron tulipifera</i>	0.03	0.06	1.00	<1%	<1%	1.00
<i>Magnolia acuminata</i>	0.28	0.28	.	<1%	<1%	0.25
<i>Nyssa sylvatica</i>	0.00	0.31	1.00	0%	<1%	1.00
<i>Picea rubens</i>	0.45	0.50	1.00	<1%	<1%	1.00
<i>Prunus serotina</i>	29.95	29.57	0.27	9%	9%	0.27
<i>Quercus alba</i>	22.80	20.17	0.16	7%	6%	0.28
<i>Quercus rubra</i>	18.55	17.36	0.79	6%	5%	0.46
<i>Tsuga canadensis</i>	190.53	183.99	0.15	57%	58%	0.68
Total	332.24	316.81	0.02	-	-	-

Figure 7. Diameter distributions for overstory trees ≥ 12.7 cm dbh in 2000 (A) and 2006 (B) at Cathedral State Park.

hemlock, with more non-hemlock occurring in smaller diameter classes. Hemlock made up 75 and 77% of trees ≥ 75 cm in 2000 and 2006, but only 58 and 59% of trees < 75 cm. Large-sized trees were not uncommon in CSP. In 2006, 8% of overstory trees were ≥ 75 cm dbh, with 28% of all tree heights over 30 m tall. The largest hemlock was 150 cm dbh and 43 m tall. Other large trees included a black cherry and American beech measuring 44 m tall, a northern red oak with a 91 cm dbh, and a black cherry with a 110 cm dbh.

Understory Trees ≥ 2.54 and < 12.7 cm dbh

Twelve species were found in the understory in 2000 and 2006 (Table 4). Six species made up 92 and 95% of relative density in 2000 and 2006, respectively: eastern hemlock (51 and 35%), great laurel (18 and 33%), black cherry (8 and 11%), sweet birch (7 and 6%), American witchhazel (*Hamamelis virginiana* L.) (5 and 7%), and red maple (3 and 3%). Striped maple (*Acer pensylvanicum* L.), present in 2000, was not sampled in 2006. Total understory tree density did not change between the two sampling periods, but there were fewer hemlock ($p=0.03$) in 2006. In 2000 and 2006, five species occupied 92% of basal area: hemlock (72 and 64%), great laurel (5 and 11%), black cherry (5 and 8%), sweet birch (6 and 6%), and American witchhazel (4 and 3%). There was no change in total understory basal area from 2000 to 2006, nor was there a significant change in hemlock basal area.

Table 4. Density, relative density, basal area, and relative basal area of understory trees ≥ 2.54 and < 12.7 cm dbh at Cathedral State Park in 2000 and 2006.

Species	Density (trees/ha)			Relative Density			Basal Area (m ² /ha)			Relative Basal Area		
	2000	2006	p-value	2000	2006	p-value	2000	2006	p-value	2000	2006	p-value
<i>Acer pensylvanicum</i>	4.75	0.00	1.00	<1%	0%	1.00	0.04	0.00	1.00	2%	0%	1.00
<i>Acer rubrum</i>	23.76	23.76	1.00	3%	3%	1.00	0.04	0.05	0.75	2%	2%	0.75
<i>Amelanchier arborea</i>	14.26	19.01	1.00	2%	2%	1.00	0.02	0.03	0.50	1%	2%	1.00
<i>Betula alleghaniensis</i>	14.26	9.50	1.00	2%	1%	0.50	0.04	0.04	1.00	2%	2%	0.50
<i>Betula lenta</i>	52.27	47.52	1.00	7%	6%	0.89	0.13	0.12	0.82	6%	6%	0.83
<i>Fagus grandifolia</i>	9.50	9.50	.	1%	1%	1.00	0.01	0.01	0.50	<1%	<1%	0.50
<i>Hamamelis virginiana</i>	33.26	52.27	0.50	5%	7%	0.84	0.08	0.05	1.00	4%	3%	1.00
<i>Ilex montana</i>	9.50	4.75	1.00	1%	<1%	0.50	0.02	0.01	0.50	1%	<1%	0.50
<i>Prunus serotina</i>	61.78	85.54	0.75	8%	11%	0.19	0.10	0.15	0.56	5%	8%	0.16
<i>Quercus rubra</i>	4.75	0.00	1.00	<1%	0%	1.00	0.01	0.00	1.00	<1%	0%	1.00
<i>Rhododendron maximum</i>	133.06	266.12	0.13	18%	33%	0.30	0.11	0.21	0.11	5%	11%	0.11
<i>Tsuga canadensis</i>	375.42	280.37	0.03	51%	35%	0.10	1.59	1.23	0.09	72%	64%	0.06
Total	736.57	798.35	0.52	-	-	-	2.21	1.90	0.12	-	-	-

Tree Regeneration <2.54 cm dbh

Among all five height classes, 22 species or species groups were identified in the regeneration layer, including an unknown sampled in 2000. Regeneration totals were significantly different for height classes 1 (<15.24 cm) and 3 (30.48-91.44 cm) from 2000 to 2006. Height class 1 increased ($p < 0.01$), while height class 3 decreased ($p = 0.01$) (Table 5).

Differences in species composition among height classes were also examined. In 2000 and 2006, great laurel was abundant in all height classes. It was especially noticeable among stems ≥ 30.49 cm tall. Smaller regeneration (height class 1 and 2) was predominantly black cherry, red maple, birch (*Betula* sp.), great laurel, and hemlock. No red maple was sampled ≥ 91.45 cm tall. There were more hemlock seedlings <15.24 cm tall in 2006 than in 2000 ($p = 0.05$).

Herbaceous Vegetation

Fifty-six herbaceous species, within 29 families, were sampled throughout the 2006 growing season. While some herbaceous plots lacked any herbaceous cover, other plots contained as many as 16 herb species. Woodfern (*Dryopteris* sp.), partridgeberry, and Canada mayflower were the most common herbs encountered, representing the top three species for relative cover, relative frequency, and importance value (Table 6). These three herbs alone accounted for more than 50% of the importance values. Jack in the pulpit (*Arisaema* sp.) ranked among the top five for frequency and importance value; however, it was not among the top five for percent cover. Eastern hayscented fern ranked

Table 5. Density (seedlings/ha) of tree regeneration <2.54 cm dbh by height class at Cathedral State Park in 2000 and 2006.

Species	Height Class 1 < 15.24 cm			Height Class 2 15.24 - 30.48 cm			Height Class 3 30.49 – 91.44 cm			Height Class 4 91.45 – 152 cm			Height Class 5 ≥ 152 cm		
	2000	2006	p-value	2000	2006	p-value	2000	2006	p-value	2000	2006	p-value	2000	2006	p-value
<i>Acer pensylvanicum</i>	190.08	166.32	1.00	190.08	71.28	0.50	332.65	23.76	0.75	71.28	0.00	1.00	0.00	0.00	.
<i>Acer rubrum</i>	20671.60	29439.22	0.17	570.25	736.57	0.92	95.04	71.28	1.00	0.00	0.00	.	23.76	0.00	1.00
<i>Amelanchier arborea</i>	498.97	23.76	0.05	308.89	0.00	0.03	0.00	0.00	.	0.00	0.00	.	0.00	0.00	.
<i>Betula</i> spp.	2732.45	7769.67	0.01	1188.02	2494.85	0.13	2209.72	380.17	0.06	23.76	47.52	1.00	71.28	0.00	0.50
<i>Carya</i> spp.	0.00	0.00	.	0.00	23.76	1.00	0.00	0.00	.	0.00	0.00	.	0.00	0.00	.
<i>Cornus alternifolia</i>	0.00	0.00	.	0.00	23.76	1.00	0.00	47.52	1.00	0.00	0.00	.	0.00	0.00	.
<i>Crataegus</i> spp.	0.00	190.08	0.50	118.80	23.76	1.00	0.00	23.76	1.00	23.76	0.00	1.00	0.00	23.76	1.00
<i>Fagus grandifolia</i>	0.00	118.80	1.00	142.56	95.04	1.00	261.37	237.60	1.00	0.00	47.52	0.50	0.00	0.00	.
<i>Hamamelis virginiana</i>	356.41	594.01	0.28	71.28	23.76	0.50	142.56	47.52	1.00	0.00	0.00	.	71.28	47.52	1.00
<i>Ilex montana</i>	902.90	950.42	0.79	546.49	213.84	0.06	451.45	95.04	0.03	0.00	0.00	.	0.00	0.00	.
<i>Kalmia latifolia</i>	0.00	0.00	.	23.76	0.00	1.00	0.00	0.00	.	0.00	0.00	.	23.76	0.00	1.00
<i>Liriodendron tulipifera</i>	23.76	0.00	1.00	0.00	0.00	.	0.00	0.00	.	0.00	0.00	.	0.00	0.00	.
<i>Nyssa sylvatica</i>	0.00	47.52	1.00	0.00	0.00	.	0.00	0.00	.	0.00	0.00	.	0.00	0.00	.
<i>Picea rubens</i>	0.00	23.76	1.00	23.76	0.00	1.00	0.00	0.00	.	0.00	0.00	.	0.00	0.00	.
<i>Prunus pensylvanica</i>	0.00	0.00	.	23.76	0.00	1.00	0.00	0.00	.	0.00	0.00	.	0.00	0.00	.
<i>Prunus serotina</i>	14137.48	31435.09	<0.01	1164.26	855.38	0.51	617.77	166.32	0.03	0.00	0.00	.	0.00	0.00	.
<i>Quercus rubra</i>	0.00	285.13	0.03	0.00	0.00	.	0.00	0.00	.	0.00	0.00	.	0.00	0.00	.
<i>Rhododendron maximum</i>	3350.23	4324.40	0.98	3112.62	902.90	0.09	4039.28	261.37	0.03	2304.77	190.08	0.06	1900.84	1164.26	0.19
<i>Sambucus nigra</i>	95.04	23.76	0.50	23.76	23.76	1.00	0.00	0.00	.	0.00	0.00	.	0.00	0.00	.
<i>Tsuga canadensis</i>	3136.38	7128.14	0.05	308.89	498.97	0.19	23.76	237.60	0.13	47.52	47.52	1.00	0.00	95.04	1.00
<i>Viburnum</i> spp.	0.00	47.52	1.00	0.00	23.76	.	0.00	23.76	.	0.00	0.00	.	0.00	0.00	.
Unknown	427.69	0.00	0.25	71.28	0.00	0.33	71.28	0.00	1.00	0.00	0.00	.	0.00	0.00	.
Total	46,522.99	82,567.61	<0.01	7,888.47	6,011.40	0.34	8,244.88	1,615.71	0.01	2,471.09	332.65	0.09	2,090.92	1,330.59	0.24

Table 6. Relative frequency (%), relative cover (%), and importance values (%) for herbaceous species in Cathedral State Park.

Species	Relative Frequency	Relative Cover	Importance Value
<i>Ageratina altissima</i>	0.13	0.12	0.12
<i>Alliaria petiolata</i>	0.27	0.00	0.13
<i>Arisaema</i> spp.	7.58	3.11	5.35
<i>Bellis perennis</i>	0.13	0.01	0.07
<i>Bidens</i> spp.	0.27	0.04	0.15
<i>Brachyelytrum erectum</i>	1.15	1.67	1.41
<i>Carex folliculata</i>	0.13	0.02	0.07
<i>Carex</i> spp.	0.68	0.51	0.60
<i>Chelone glabra</i>	0.76	0.11	0.44
<i>Circaea alpina</i>	2.02	0.35	1.18
<i>Claytonia carolinia</i>	0.12	0.00	0.06
<i>Danthonia compressa</i>	1.17	1.31	1.24
<i>Dennstaedtia punctiloba</i>	3.87	5.54	4.70
<i>Dryopteris</i> spp.	18.78	41.80	30.29
<i>Eupatorium perfoliatum</i>	0.13	0.02	0.07
<i>Eupatorium purpureum</i>	0.13	0.07	0.10
<i>Eurybia divaricata</i>	0.13	0.00	0.06
<i>Galium</i> spp.	0.71	0.08	0.40
<i>Glyceria striata</i>	0.27	0.09	0.18
<i>Huperzia lucidula</i>	2.53	2.08	2.30
<i>Hydrocotyle americana</i>	1.15	0.64	0.90
<i>Hypericum punctatum</i>	0.13	0.02	0.07
<i>Impatiens capensis</i>	1.81	1.47	1.64
<i>Iris pseudacorus</i>	0.64	0.41	0.53
<i>Laportea canadensis</i>	0.63	0.08	0.35
<i>Lycopodium digitatum</i>	0.74	0.63	0.69
<i>Lycopus uniflorus</i>	0.53	0.05	0.29
<i>Maianthemum candense</i>	10.87	9.66	10.27
<i>Medeola virginiana</i>	0.98	0.47	0.73
<i>Mitchella repens</i>	13.44	10.00	11.72
<i>Monotropa uniflora</i>	0.35	0.02	0.19
<i>Myosotis scorpioides</i>	0.64	0.51	0.57
<i>Osmunda cinnamomea</i>	0.62	1.91	1.27
<i>Oxalis</i> spp.	7.79	2.73	5.26
<i>Phlox paniculata</i>	0.25	0.32	0.28
<i>Pilea pumila</i>	0.25	0.28	0.27
<i>Poa</i> spp.	0.13	0.02	0.07
<i>Podophyllum peltatum</i>	0.25	0.01	0.13
<i>Polygonatum pubescens</i>	0.84	0.10	0.47
<i>Polygonum</i> spp.	0.94	0.30	0.62
<i>Ranunculus hispidus</i>	0.50	0.11	0.31
<i>Rubus</i> spp.	2.55	3.90	3.23
<i>Rumex obtusifolius</i>	0.63	1.08	0.86
<i>Sanicula odorata</i>	0.25	0.04	0.14

Table 6. continued.

<i>Scutellaria lateriflora</i>	0.27	0.04	0.15
<i>Smilax</i> spp.	0.56	0.15	0.35
<i>Symphyotrichum prenanthoides</i>	0.50	0.96	0.73
<i>Symplocarpus foetidus</i>	0.96	1.20	1.08
<i>Taraxacum officinale</i>	0.13	0.05	0.09
<i>Thalictrum pubescens</i>	0.13	0.04	0.08
<i>Thelypteris noveboracensis</i>	1.17	0.80	0.98
<i>Trillium undulatum</i>	0.99	0.08	0.53
Unknown Compositae	0.25	0.11	0.18
Unknown Gramineae	1.60	1.46	1.53
Unknown	1.06	0.27	0.66
<i>Viola</i> spp.	4.56	3.16	3.86

among the top three for percent cover, but did not rank within the top five for frequency or importance value.

Downed Dead Wood and Snags

In 2006, total density and volume of downed dead wood (DDW) in CSP was 682.40 logs/ha and 142.05 m³/ha. Hemlock made up 84% and 88% of total density and volume, respectively. Using mid-point diameter, 83% of all DDW was ≥ 20 cm. Hemlock comprised 89% of logs ≥ 20 cm.

Decay classes for DDW were examined on a scale of 1 (least decayed) to 5 (most decayed) (Thomas 1979). Figure 8 compares hardwoods and softwoods (i.e., non-hemlock and hemlock) by decay class. Decay class 1 was the only class in which non-hemlock dominated. The non-hemlock occurring in decay class 2 closely matched relative hemlock logs/ha, with decay classes 3-5 dominated by hemlock.

Snag density and snag basal area significantly decreased from 2000 to 2006. Snags/ha decreased ($p < 0.01$) from 57.03 to 35.26, while snag basal area decreased ($p = 0.02$) from 8.27 to 5.75 m²/ha. In 2006, hemlock accounted for 57% of snag density and 61% of snag basal area, while in 2000, hemlock accounted for 42% snag density and 41% snag basal area.

DDW and snags are integral components of old-growth forests (Tyrrell and Crow 1994a, Oliver and Larson 1996). Comparisons of DDW and snags in CSP were made with other old-growth hemlock-hardwood stands in northern Wisconsin and northern Michigan (Tyrrell and Crow 1994a, Tyrrell and Crow 1994b, Tyrrell et al. 1998). CSP had more than twice the log volume ($p < 0.01$) of DDW logs ≥ 20 cm mid-point diameter. Comparisons of snag basal area (≥ 12.7 cm dbh in CSP and ≥ 10 cm dbh from comparable

Figure 8. Downed dead wood logs per hectare by species group and decay class in Cathedral State Park.

stands) were similar ($p=0.86$). However, less than half the snag density ($p<0.001$) was found in CSP compared to other stands (Tyrrell and Crow 1994a, Tyrrell and Crow 1994b, Tyrrell et al. 1998). The lower density but comparable basal area, as well as the abundant volume of DDW, indicates that large-sized snags and DDW occur in CSP relative to the other stands evaluated.

Hemlock Woolly Adelgid Assessment

Of the 982 hemlocks measured in 2006, 12% were identified with HWA. HWA was found in six of 13 overstory plots with the following percentages of hemlock infestation: plot 3 (13%), plot 4 (93%), plot 5 (92%), plot 6 (4%), plot 8 (9%), and plot 9 (20%) (Figure 9). The relative density of hemlock within the HWA-infested plots (60%) was similar to uninfested overstory plots (61%); however, the HWA-infested plots had a relative hemlock basal area of 70%, compared to 51% for uninfested plots.

Crown classes were also used to determine overstory hemlock (≥ 12.7 cm) targeted by HWA. Figure 10 illustrates HWA-infested hemlock by diameter and crown class. The majority (81%) of HWA-infested trees were within the dominant and co-dominant canopy classes. Plots 4 and 5 were the most heavily infested, with more than 90% of hemlock with HWA.

Figure 9. Overstory plots in Cathedral State Park with hemlock woolly adelgid presence.

Figure 10. Hemlocks infested with hemlock woolly adelgid by dbh and crown class in Cathedral State Park.

DISCUSSION

The overstory and understory structure in CSP changed relatively little from 2000 to 2006. There was no change in overstory hemlock density, basal area, and volume, or in understory hemlock basal area. Also, snag density and basal area were lower in 2006 than in 2000, indicating no recent increase in tree mortality.

The herbaceous vegetation in 2006 was similar to that reported over 40 years ago by Bieri and Anliot (1965). The major herbaceous species in 1965 and 2006 were: wood fern, partridgeberry, Canada mayflower, woodsorrel (*Oxalis* sp.), Jack in the pulpit, violet (*Viola* sp.), eastern hayscented fern, blackberry (*Rubus* sp.), shining clubmoss, and small enchanter's nightshade (*Circaea alpina* L.). Herbaceous differences over time include more Canada mayflower found in 2006, and more Indian cucumber (*Medeola virginiana* L.) reported in 1965.

The two primary communities described by Bieri and Anliot (1965), hemlock-fern and hemlock-rhododendron, are still prominent within CSP. The hemlock-fern community is easily identified by its two-layered structure and a dense herbaceous layer of eastern hayscented fern and wood fern. Field observations suggest the dense fern layer and closed-canopy have prevented successful establishment of advance regeneration. Bieri and Anliot (1965) described this community to be "late-successional" in reference to the overstory vegetation, and it appears so in 2006. The hemlock-rhododendron community still occurs primarily in areas of poor drainage, especially adjacent to Rhine Creek. This community has a two-layered structure of hemlock and great laurel, with sweet birch and scattered northern red oak in the overstory. The most common seedlings

within this community are black cherry, birch, great laurel, and eastern hemlock. The majority of birch and hemlock seedlings appear to use DDW as sites for establishment (Bieri and Anliot 1965, Lorimer 1996, Loucks and Nighswander 1999).

The smaller communities described by Bieri and Anliot (1965) were also observed in 2006. The most common herbaceous plants in the hemlock-fern/hemlock-rhododendron ecotone were wood fern, partridgeberry, Jack in the pulpit, Canada mayflower, and Indian cucumber. The hemlock duff community is a unique area in which the herbaceous and regeneration layers not well developed, although rare occurrences of partridgeberry, wood fern, and Canada mayflower were identified. Bieri and Anliot (1965) speculated these characteristics were due to the “very dense canopy” of overstory trees. The maple-cherry-birch community still exists in extremely poorly-drained areas of the stand. In 2006, many of the overstory hardwoods within this community were dead, and hemlock appears to be slowly occupying these areas.

To date, no hemlock mortality in CSP can be directly attributed to HWA. However, the future of this hemlock-dominated stand is bleak. HWA infestation varies within CSP, with some plots having no HWA, while in other plots over 90% of hemlocks were infested. Other hemlock-dominated stands in the northeast have shown devastating results following HWA infestation. Orwig and Foster (1998) examined seven stands with HWA in southern New England, with two stands suffering more than 95% mortality in overstory hemlock density.

Unless more efficient means of adelgid control on a stand-level are found, the death of the great hemlocks in CSP will likely occur in the next few years (McClure

2001). Mortality will probably occur to overstory hemlock which already show initial symptoms of HWA infestation, including chlorotic foliage and needle and branch dieback. In CSP, the most damaged hemlocks occur in the north-west corner of the park. This area is dominated by larger, overstory hemlock, with a sparse understory, and a dense herbaceous layer consisting primarily of eastern hay-scented fern. This portion of CSP was defined by Bieri and Anliot (1965) as a hemlock-fern community. Although a closed-canopy area, the trees are spaced widely and have full, vigorous crowns. It appears this area is being targeted by HWA because of the healthy (i.e., more nutritious) foliage available from canopies receiving full sunlight, and the ease of adelgid dispersal (i.e., wind, tree-to-tree) among tall, overstory hemlocks.

Forest succession at CSP following HWA is unlikely to mimic the current species composition that now exists. Hemlock is extremely shade-tolerant (Godman and Lancaster 1990), and may not be able to compete successfully if large canopy gaps are created from groups of trees dying. Large canopy gaps will increase available sunlight to the forest floor, causing understory and herbaceous vegetation to flourish. Shade-intolerant and intermediate tree species should dominate in the future, since all sizes and age-classes of hemlock are susceptible to HWA. Tree species most likely to advance to the overstory in CSP are sweet birch and black cherry. Orwig and Foster (1998) and Eschtruth et al. (2006) reported the prolific establishment of sweet birch seedlings in HWA-infested stands, especially in those with a higher percentage of hemlock mortality. Nevertheless, whatever species become dominant, the stability documented for the past 40 years will likely be dramatically altered.

With large canopy gaps created, great laurel should remain important in the areas where it already thrives. This will create a major hindrance to future advance tree regeneration. The increased likelihood of invasive plant species will also be a management concern following hemlock mortality (Orwig and Foster 1998). Species such as tree-of-heaven (*Ailanthus altissima* (P. Mill.) Swingle) and Japanese stilt grass (*Microstegium vimineum* (Trin.) A. Camus) may pose a major threat to regeneration of native tree species.

In the next few decades, the structural characteristics of CSP following hemlock mortality will likely change. The level of change will depend on several factors including: fluctuations in seasonal HWA populations, success of stand-level control methods, browsing pressure by white-tailed deer, and the percentage of overstory occupied by hardwood species (Orwig and Foster 1998). If successful control methods are discovered, the chance for hemlock recovery is possible, given that a seed source is still present. In contrast, if the forest structure becomes dominated by shade-intolerant hardwood species following HWA-induced mortality, the transformation of this stand back to a hemlock-dominated forest will take decades or centuries, or may never occur.

Areas like CSP serve as a living history of what forest composition and structure were like prior to the extensive logging that occurred throughout much of the Appalachian region. This study documents the initial effects of HWA in CSP. The abundance of large snags and DDW demonstrate the uniqueness of this old-growth forest remnant. Understanding the dynamics of old-growth forests like CSP provide a pathway to the management of younger stands that lack many of these old-growth characteristics.

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APPENDIX I: WOODY VEGETATION SAMPLED IN 2006 AT CATHEDRAL STATE PARK.

Aceraceae

Acer pensylvanicum L.

striped maple

Acer rubrum L.

red maple

Aquifoliaceae

Ilex montana Torr. & Gray ex Gray

mountain holly

Betulaceae

Betula alleghaniensis Britt.

yellow birch

Betula lenta L.

sweet birch

Caprifoliaceae

Sambucus nigra L. ssp. *canadensis* (L.) R. Bolli

common elderberry

Viburnum spp. L.

arrowwood

Cornaceae

Cornus alternifolia L. f.

alternateteaf dogwood

Nyssa sylvatica Marsh.

blackgum

Ericaceae

Rhododendron maximum L.

great laurel

Fagaceae

Fagus grandifolia Ehrh.

American beech

Quercus alba L.

white oak

Quercus rubra L.

northern red oak

Hamamelidaceae

Hamamelis virginiana L.

American witchhazel

Juglandaceae

Carya spp. Nutt.

hickory

Magnoliaceae

Liriodendron tulipifera L.

tuliptree

Magnolia acuminata (L.) L.

cucumber-tree

Oleaceae

Fraxinus americana L.

white ash

Pinaceae

Picea rubens Sarg.

red spruce

Tsuga canadensis (L.) Carr

eastern hemlock

Rosaceae

Amelanchier arborea (Michx. f.) Fern.

var. *austromontana* (Ashe) Ahles

downy serviceberry

Crataegus spp. L.

hawthorn

Prunus serotina Ehrh.

black cherry

APPENDIX II: HERBACEOUS VEGETATION SAMPLED IN 2006 AT CATHEDRAL STATE PARK

Araceae	
<i>Arisaema</i> spp. Mart.	Jack in the pulpit
<i>Symplocarpus foetidus</i> (L.) Salisb. ex Nutt.	skunk cabbage
Balsaminaceae	
<i>Impatiens capensis</i> Meerb.	jewelweed
Berberidaceae	
<i>Podophyllum peltatum</i> L.	mayapple
Boraginaceae	
<i>Myosotis scorpioides</i> L.	true forget-me-not
Compositae	
<i>Eurybia divaricata</i> (L.) Nesom	white wood aster
<i>Symphyotrichum prenanthoides</i> (Muhl. ex Willd.) Nesom	crookedstem aster
<i>Bellis perennis</i> L.	lawndaisy
<i>Bidens</i> spp. L.	beggarticks
<i>Eupatorium perfoliatum</i> L.	common boneset
<i>Eupatorium purpureum</i> L.	sweetscented joeypyeweed
<i>Ageratina altissima</i> (L.) King & H.E. Robins var. <i>altissima</i>	white snakeroot
<i>Taraxacum officinale</i> G.H. Weber ex Wiggers	common dandelion
Unknown Compositae	
Cruciferae	
<i>Alliaria petiolata</i> (Bieb.) Cavara & Grande	garlic mustard
Cyperaceae	
<i>Carex</i> spp.	sedge
<i>Carex folliculata</i> L.	northern long sedge
Gramineae	
<i>Brachyelytrum erectum</i> (Schreb. ex Spreng.) Beauv.	bearded shorthusk
<i>Danthonia compressa</i> Austin	flattened oatgrass
<i>Glyceria striata</i> (Lam.) A.S. Hitchc.	fowl mannagrass
<i>Poa</i> spp.	bluegrass
Unknown Gramineae	

Guttiferae		
	<i>Hypericum punctatum</i> Lam.	spotted St. Johnswort
Iridaceae		
	<i>Iris pseudacorus</i> L.	pale yellow iris
Labiatae		
	<i>Lycopus uniflorus</i> Michx.	northern bugleweed
Labiatae		
	<i>Scutellaria lateriflora</i> L.	blue skullcap
Liliaceae		
	<i>Maianthemum canadense</i> Desf.	Canada mayflower
	<i>Medeola virginiana</i> L.	Indian cucumber
	<i>Polygonatum pubescens</i> (Willd.) Pursh	hairy Solomon's seal
	<i>Smilax</i> spp. L.	greenbrier
	<i>Trillium undulatum</i> Willd.	painted trillium
Lycopodiaceae		
	<i>Lycopodium digitatum</i> Dill. ex A. Braun	fan clubmoss
	<i>Huperzia lucidula</i> (Michx.) Trevisan	shining clubmoss
Monotropaceae		
	<i>Monotropa uniflora</i> L.	Indian pipe
Onagraceae		
	<i>Circaea alpina</i> L.	small enchanter's nightshade
Osmundaceae		
	<i>Osmunda cinnamomea</i> L.	cinnamon fern
Oxalidaceae		
	<i>Oxalis</i> spp. L.	woodsorrel
Polemoniaceae		
	<i>Phlox paniculata</i> L.	fall phlox
Polygonaceae		
	<i>Polygonum</i> spp. L.	knotweed
	<i>Rumex obtusifolius</i> L.	bitter dock

Polypodiaceae

Dennstaedtia punctiloba (Michx.) T. Moore

Dryopteris spp. Adans.

Thelypteris noveboracensis (L.) Nieuwl.

eastern hayscented fern

wood fern

New York fern

Portulacaceae

Claytonia carolinia Michx.

Carolina springbeauty

Ranunculaceae

Ranunculus hispidus Michx.

Thalictrum pubescens Pursh

bristly buttercup

king of the meadow

Rosaceae

Rubus spp. L.

Galium spp. L.

Mitchella repens L.

blackberry

bedstraw

partridgeberry

Schophulariaceae

Chelone glabra L.

white turtlehead

Umbelliferae

Hydrocotyle americana L.

Sanicula odorata (Raf.) K.M. Pryer

& L.R. Phillippe

American marshpennywort

clustered blacksnakeroot

Unknown

Unknown herb

Urticaceae

Laportea canadensis (L.) Weddell

Pilea pumila (L.) Gray

Canadian woodnettle

Canadian clearweed

Violaceae

Viola spp. L.

violet