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Growth and Productivity of a 45-year-old Norway Spruce Plantation on the Fernow Experimental Forest

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Abstract

In 1973, as part of research addressing the timing, volume, and source of streamflows, a 22.34 ha watershed on the Fernow Experimental Forest was planted with Norway spruce (*Picea abies*). This publication describes the growth and productivity of this unusual Norway spruce plantation over the intervening 45 years, including information on stand density, incursion of native hardwoods, and reaction to a major disturbance, Superstorm Sandy in 2012.

Key words: Norway spruce, stand dynamics, long-term research, watershed research

Cover photos
BACKGROUND: Norway spruce (*Picea abies*). Photo by Norbert Frank, University of West Hungary, Bugwood.org.
INSET: Watershed 6 on the Fernow Experimental Forest in 1982, showing planted Norway spruce. View is toward the northwest. Photo by USDA Forest Service.

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Introduction

Early watershed research in forests addressed questions related to the timing, volume, and source of streamflow from forested watersheds (Vose et al. 2012). To understand the effects of various forest management activities on water yield, scientists at the Fernow Experimental Forest (FEF) in West Virginia designed and implemented research to fully develop water budgets to understand alteration in timing and volume of flow (Patric and Reinhart 1971). Experimental treatments included clearcutting and applying herbicide to forested watersheds to create watersheds with little or no vegetation, representative of an extreme treatment. Part of this study involved a subsequent treatment of planting a monoculture of Norway spruce[1] to evaluate how conifer conversion would affect stream flow dynamics relative to a regenerating mixed hardwood stand.

In this paper, we report on the growth and stand development of the watershed planted to Norway spruce. This information will be useful in future assessments of the hydrologic effects of forest type conversion on water yield and nutrient cycling. In addition, understanding how this stand developed over time will be useful in evaluating the effects of afforestation and forest type change, and for land managers in developing management prescriptions for a changing climate.

Site Description and Methods

Watershed 6 (WS6) is a 22.34-ha, south-facing catchment located on the FEF (Figure 1). Prior to clearcutting in 1964-1969, the stand was mature, second-growth mixed hardwood, and the dominant tree species were white and chestnut oaks, with a basal area of 33.06 $m^2 ha^{-1}$ (Patrick and Reinhart 1971). Elevation ranges from 730 to 830 m (2400 to 2720 ft). Soils in the watershed were originally (1967) mapped exclusively as Calvin channery silt loam (loamy-skeletal, mixed, active mesic Typic Dystrudepts). In 2018, the watershed was remapped, resulting in about half of

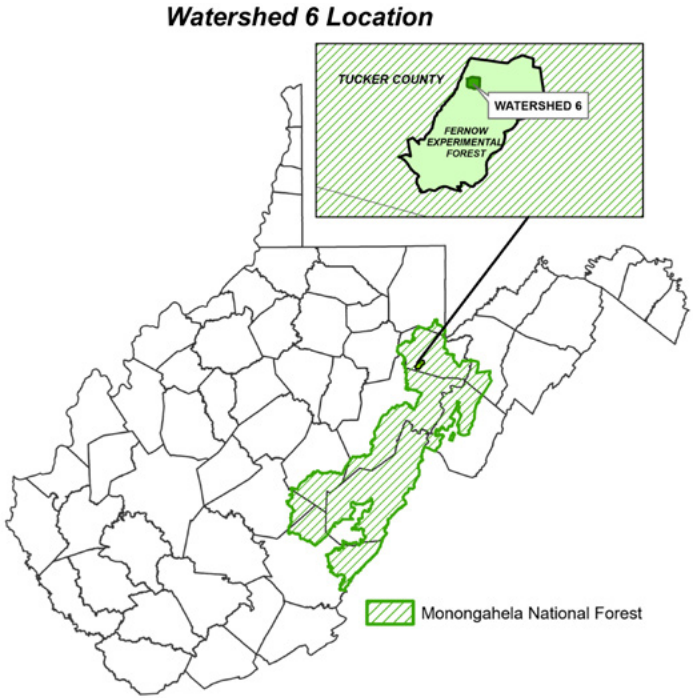

Figure 1.—Map showing location of Fernow Experimental Forest and Watershed 6.

[1] See appendix for scientific names of trees and other plants referenced in this report.

the area described as Cateache channery silt loam (fine loamy-mixed active, mesic Ultic Hapuldalfs), and most of the remainder as Calvin. This is a reflection of changes in understanding and descriptions of the soil series, rather than a major genetic change in the soil.[2]

A 120° V-notch weir was installed in November 1956 (weir coordinates 39.06612N 79.67698W) and the initial calibration period occurred between November 1956 and February 1964. Between March and October 1964, the lower half of the watershed was clearcut, which removed 51 percent of the original basal area, followed by the removal of pulpwood and all other standing vegetation greater than 1 inch in diameter. Between May 1965 and October 1969, the lower half was maintained barren with herbicides (Patric and Reinhart 1971). Between October 1967 and February 1968, the remaining upper half of the watershed was clearcut, removing 49 percent of the original stand basal area. From May 1968 to October 1969, the upper half was also maintained barren with herbicides.

Natural regeneration occurred from 1970 to 1973, mostly from seed sources from the surrounding forest. During March and April 1973, 2-0 Norway spruce seedlings were planted at a 3.05 m × 3.05 m (10 ft × 10 ft) spacing, resulting in 1077 trees ha^{-1}; however, notes in the study file suggest the trees were planted more closely than the original design.[3] Follow-up herbicide treatments in August 1975 (2,4,5-T at 2.24 kg ha^{-1} a.e. [acid equivalent]), and September 1980 (glyphosate at 1.68 kg ha^{-1} a.e.), were performed to release the Norway spruce trees from competing hardwood tree species, hay-scented fern, and blackberry (Wendel and Kochenderfer 1984).

The Norway spruce trees have been measured several times since 1973, with slightly different sampling methodology, as described in the study files. The first stocking survey was conducted in December 1975, using 134 plots (1.5-m radius) located on transects across the watershed. In 1980, 65 permanent plot centers were established at 1 chain intervals on three transects. At each plot center, the percentage of a milacre (0.0004 ha) covered by 5 percent or more of a species was estimated and recorded. The average vegetation height was estimated by averaging several height measurements of the major ground cover components on the plot. The diameter and species of all hardwood trees on a 0.04-ha plot were recorded around the same plot center. Finally, the height and crown class of all the spruce were recorded on the 0.04-ha plot. All of the Norway spruce trees on the plot were tagged with numbered tags for future reference. All plots were retallied at 1 and 2 years after spraying with glyphosate that same year.

In March 1983, 65 0.04-ha circular plots were assessed, using the same plot centers. Norway spruce trees were measured for diameter at breast height (d.b.h.; measured at 1.37 m above ground), height, and crown width. In 1987 and 1992, these same plots were resurveyed and 13 more plots from the previously unsampled part of the watershed were added to the transects. Norway spruce were again measured for d.b.h., height, and crown width. In 2003, larger plots (0.20 ha) were used around the same plot centers, and the diameter of Norway spruce trees were measured on 18 plots. In 2018, still larger plots (0.40 ha) were used around the same plot centers. On these 18 plots, the species, diameter, crown class, and status of all trees greater than 12.7 cm d.b.h. were recorded.

[2] Personal communication from Wendy Noll, Natural Resources Conservation Service, 2019.

[3] All study files and reports referenced herein are on file at the USDA Forest Service Timber and Watershed Laboratory, Parsons, WV.

Stand Development

The initial stocking survey in December 1975 revealed 1371 live trees ha^{-1}, providing evidence that the spruce were planted at a closer spacing than 3.05 m × 3.05 m. There were five small, understocked areas identified, which were then replanted in spring of 1976.

In 1980, 80 percent of plots had at least one living Norway spruce tree, and the average height of spruce on the stocked plots was 1.08 m (3.54 ft). At this time the average height of the competing vegetation was 1.20 m (3.95 ft), slightly taller than the average height of the spruce (Figure 2). The dominant competing species were blackberries, hay-scented fern, and golden rod[4] (Wendel and Kochenderfer 1984).

Most of the trees prior to spraying of glyphosate in 1980 ranged in size from 1.27 to 5.08 cm d.b.h. Red maple, sugar maple, and striped maple were found in multiple sprout clumps, whereas most of the others species were single or double stems sprouting from old root systems following the 2,4,5-T spraying (Wendel and Kochenderfer 1984). Norway spruce was the most abundant species on WS6 7 years following planting (and before treatment with glyphosate), followed by red maple, sugar maple, yellow-poplar, black locust, sweet birch, and black cherry (Table 1). Damage to Norway spruce was negligible from the glyphosate, and excellent control of the other hardwood tree species was obtained, with the exception of northern red oak and a few individual hickory (Table 1).

Figure 2.—Small Norway spruce seedling (center of photo) almost entirely overtopped by competing vegetation, including blackberry, hay-scented fern and goldenrod. Photo by USDA Forest Service.

[4] Establishment report 4300-FS-NE-1602-30, 1974, on file at the Timber and Watershed Laboratory, Parsons, WV.

Between 1980 and 1987, the Norway spruce trees nearly tripled in mean height, growing at a rate of 0.38 m y^{-1}. It was noted in the April 28, 1987, Progress Report that "The spread between average height was about 2.0 feet from the best site (SI 80 for red oak) to the poorest site (SI=60). Thus, there is a strong indication that site index is beginning to exert a strong influence on spruce height growth." It was also estimated that in 1983, spruce crown covered about 5 percent of the ground area, which increased to about 24 percent by 1987 (Table 2).

By 2003, the stand had developed to a closed canopy spruce forest with dense stand structure (Figure 3). The basal area was 23 m^2 ha^{-1}, and hardwood trees made up less than 4 percent of the total basal area (Kelly et al. 2011a). A litter layer characteristic of mature conifer stands (mor-type) had developed. The forest floor was characterized by a relatively thick horizon (approximately 2 to 8 cm) of nondecomposed needles above further decomposed organic material of spruce origin. There is evidence of development of an E (eluviated) horizon which suggests leaching and podsolization may be occurring. Aboveground biomass was estimated as 116,800 kg ha^{-1} (compared to 166,000 kg ha^{-1} for a nearby hardwood watershed of approximately the same age). Belowground biomass estimates were also less in the spruce (21,000 kg ha^{-1}) relative to the hardwood watershed (38,000 kg ha^{-1}; Kelly et al. 2011b).

In 2018, Norway spruce trees made up 75 percent of the live stems on WS6, with 10 percent red maple, 4.4 percent black cherry, and 3.9 percent yellow-poplar, although 16 hardwood tree species were recorded (Table 3). Norway spruce live basal area was 39.2 m^2 ha^{-1}, about 90 percent of the stand live basal area. Basal area of standing dead trees was 3.38 m^2 ha^{-1}, or about 7 percent of the total basal area, and was also mostly Norway spruce. There were 332 dead spruce trees ha^{-1} in 2018, almost all of them sapling size (2.54 to 12.7 cm d.b.h.) (data not shown).

Figure 3.—Aerial image of Watershed 6, Fernow Experimental Forest, April 2010. Photo by USDA Forest Service.

Table 1. Stem density (stems ha^{-1}), and percentage of stems dead 2 years after spraying with glyphosate in 1980, by species. Norway spruce were planted in 1973. For scientific names of trees, see appendix.

Species	Stem density *stems ha^{-1}*	Stems killed after 2 years *%*
Commercial tree species		
Norway spruce	1339	2
Red maple	1142	88
Sugar maple	269	56
Yellow-poplar	225	73
Black locust	183	92
Chestnut oak	183	73
Sweet birch	171	98
Black cherry	161	98
Sassafras	77	95
Red oak	62	50
Cucumbertree	54	79
White ash	42	100
Sourwood	35	100
Bigtoothed aspen	7	100
Hickory	5	0
Hemlock	5	0
American beech	5	100
Willow	5	100
Noncommercial tree species		
Striped maple	274	69
Serviceberry	72	100
American chestnut	5	100
Fire cherry	5	100
Shrubs		
Hercules club	220	97
Mapleleaf viburnum	213	57
Flame azalea	195	100
Elderberry	22	83
Huckleberry	20	100
Smooth sumac	5	100
Total stems	**4999**	

Table 2. Summary of Norway spruce growth data, 1983 and 1987. Note that in 1987, there were an additional 13 plots measured that were not included in 1983.

1983 n=356			1987 n=419		
Average d.b.h. (cm)	Average height (m)	Average crown width (m)	Average d.b.h. (cm)	Average height (m)	Average crown width (m)
0.74	1.34	0.707	3.74	3.10	1.52

Table 3. Watershed 6 stand composition, basal area, density, and average d.b.h., 2018.

Species	Basal area *m^2 ha^{-1}*	Density *trees ha^{-1}*	Average d.b.h. *cm*
Norway spruce	39.2	823.7	22.9
Yellow-poplar	1.3	42.6	18.5
Red maple	1.0	109.8	9.7
Black cherry	1.0	48.0	14.0
Cucumbertree	0.2	6.9	19.3
Black birch	0.2	17.8	10.9
Chestnut oak	0.2	6.9	14.7
No. red oak	0.2	8.2	14.0
Black locust	0.1	4.1	15.2
Sugar maple	0.0	5.5	9.7
Sourwood	0.0	2.7	11.2
Downy serviceberry	0.0	8.2	4.6
Striped maple	0.0	2.7	3.8
Hercules club	0.0	2.7	4.3
White oak	0.0	1.4	2.5
Scarlet oak	0.0	1.4	2.8
Black oak	0.0	1.4	2.5
Total	**43.3**	**1094.1**	

In general over the study period, Norway spruce stocking declined from 1371 trees ha^{-1} to 822 trees ha^{-1} (Figure 4), while the average diameter increased to 22.9 cm. Red maple and yellow-poplar have increased substantially since the 1980 glyphosate spraying, and other tree species are also increasingly becoming part of the stand.

Over the 45 years, the Norway spruce stand has gone from a very thick, dark stand with little light hitting the forest floor to a more open stand, through self-pruning of branches (Figure 5).

In October 2012, Superstorm Sandy dropped almost 3 feet of heavy wet snow on the FEF, with considerable tree damage across the area (Walters 2016). We evaluated stem damage on WS6, using seven damage classes, on eight randomly selected permanent growth plots. While the 67 percent of the stems surveyed did not sustain damage (Figure 6), almost a third of the trees did sustain some damage. From our surveys, 15 percent of the trees had snapped stems, 12 percent had broken branches, and 4 percent broken crowns. While the broken branches and broken crowns may not result in tree mortality, there could be important implications for growth and form of the trees.

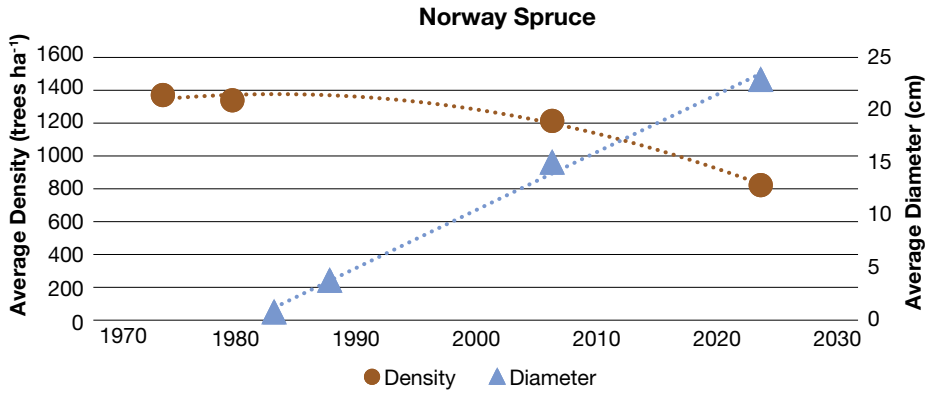

Figure 4—Average Norway spruce density (tree ha^{-1}) and diameter (d.b.h. in cm) on Watershed 6 over time.

Figure 5.—Norway spruce stand shown in 2003 (left) and 2018 (right), demonstrating the substantial self-pruning of branches which occurred between the two measurement dates. Note the proliferation of mushrooms in the photo on the left. Photo by USDA Forest Service.

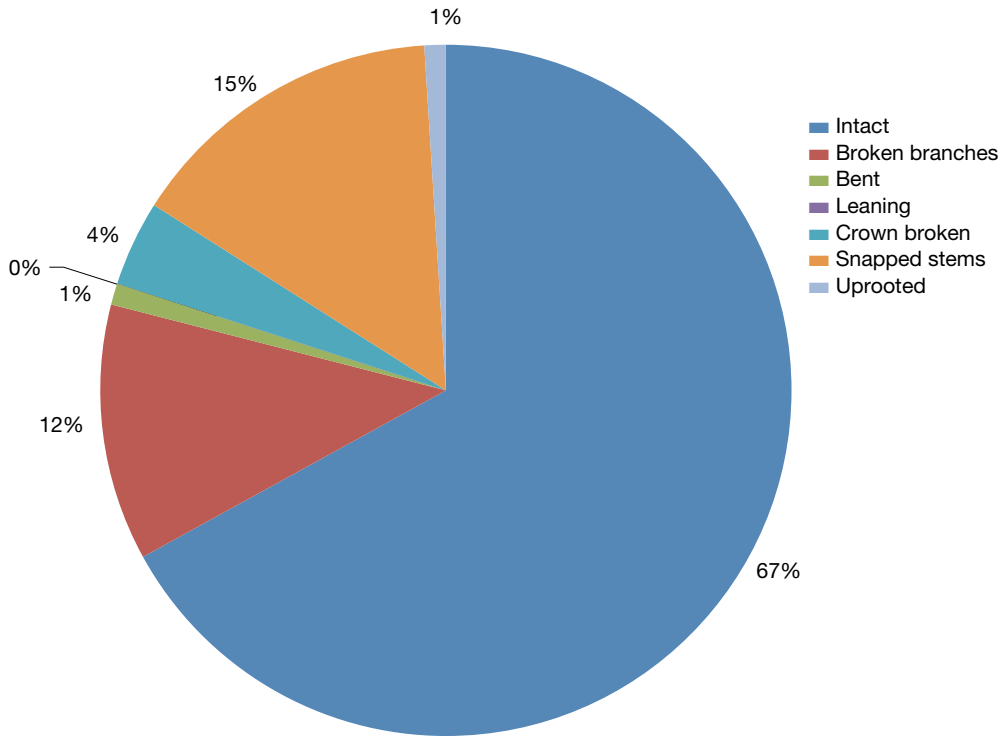

Figure 6.—Damage from Superstorm Sandy by category, expressed as percentage of stems (n=166 trees), on Watershed 6.

Conclusions

Herbicide interventions allowed the planted Norway spruce to fully occupy the site, resulting in substantial changes to streamflow/hydrology and nutrient cycling (Kelly et al. 2011b). In more recent years, the hardwood component of the stand is again increasing, and mortality of Norway spruce has increased. Damage from Superstorm Sandy has also impacted the stand, with the implications on stand development yet to be determined. We predict that without further intervention, the spruce will steadily decline in abundance and the hardwoods will at some point become co-dominant or equally important in influencing stand and ecosystem processes. Further analyses of the effects of the spruce plantation on ecosystem processes are ongoing, and will be published in the future.

Acknowledgments

Long-term experiments such as this represent an investment of money, time, property, and human endeavor. The authors acknowledge the far-sighted investigators who established the study, and the many dedicated staff who kept the experiment going and ensured quality data and meta-data during the decades.

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Appendix

Common and scientific names of plants found on Watershed 6, Fernow Experimental Forest, Parsons, WV.

Norway spruce	*Picea abies*
Sweet birch	*Betula lenta*
American beech	*Fagus grandifolia*
Cucumbertree	*Magnolia acuminata*
Black cherry	*Prunus serotina*
Sugar maple	*Acer saccharum*
Striped maple	*Acer pensylvanicum*
Red maple	*Acer rubrum*
White oak	*Quercus alba*
Chestnut oak	*Quercus montana*
Northern red oak	*Quercus rubra*
Scarlet oak	*Quercus coccinea*
Black oak	*Quercus velutina*
Yellow-poplar	*Liriodendron tulipifera*
Downy Serviceberry	*Amelanchier arborea*
Pin cherry	*Prunus pensylvanica*
Black locust	*Robinia pseudoacacia*
Sourwood	*Oxydendrum arboreum*
White ash	*Fraxinus americana*
Hickory	*Carya* spp.
Sassafras	*Sassafrs albidum*
Bigtooth aspen	*Populus grandidentata*
Hemlock	*Tsuga canadensis*
Willow	*Salix* spp.
American chestnut	*Castanea dentata*
Hercules club	*Aralia spinosa*
Mapleleaf viburnum	*Viburnum acerifolium*
Flame azalea	*Rhododendron calendulaceum*
Elderberry	*Sambucus* spp.
Huckleberry	*Gaylusaccia* spp.
Smooth sumac	*Rhus glabra*
Blackberry	*Rubus* spp.
Hay-scented fern	*Dennstaedtia punctilobula*
Golden rod	*Solidago* spp.

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