# Listening to Old Beech and Young Cherry Trees—Long-term Research in the Alleghenies

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## Introduction

Long-term research results have been a foundation of forestry practice on the Allegheny Plateau since the 1970s. This includes results from monitoring reference conditions in areas set aside for this purpose and from long-running manipulative studies, some dating back to the 1920s. The success of long-term research in this region reflects the commitment of a handful of individuals, the institutional support of the U.S. Forest Service, and the translation of the results into useable guidelines for forest management. For this paper, we will consider studies or monitoring programs that run for a decade or more to be long term. The values and benefits to be examined include humility, unexpected outcomes, environmental education resources, enhanced understanding of ecological interactions, quantification of trade-offs, and answers to unanticipated questions. We also discuss some of the key factors to sustaining a successful long-term research program in our region and emerging challenges to sustaining them in the future.

## Reference Condition Monitoring on the Allegheny Plateau

Reference condition monitoring occurs in areas that have been set aside to represent ecological systems without direct human intervention. In Pennsylvania, these include the Research Natural Area and National Scenic Area programs of the U.S. Forest Service (Table 1), the Wild Area and Natural Area programs of the Pennsylvania Department of Conservation and Natural Resources, and the bioreserve programs of the Nature Conservancy.

## Examples of Reference Condition Monitoring

On the Allegheny Plateau, the "reference condition" concept of long-term research is epitomized by monitoring in the Tionesta Scenic and Research Natural Areas (Cope and Hawkins 1934, Cope 1936, Bjorkbom and Larson 1977). Tionesta is a 4,000-acre tract on the U.S. Forest Service Allegheny National Forest, acquired in 1936. In 1940, half of the area was designated a Research Natural Area (RNA). Although the other half is designated a Scenic Area, the management approach to both halves emphasizes conservation of the unique ecosystem for scientific purposes (Allegheny National Forest 1986). This area is considered one of the best current representatives of the beech-hemlock forests that covered more than 16 million acres at the time of European settlement. Since being set aside as a RNA, it has provided critically important data about natural disturbance regimes at several scales. These include gap phase replacement, windstorms, the impact of white-tailed deer on forest communities, relationships between disturbance and forest soil carbon, and effects of exotic insects and diseases, specifically including the beech bark disease complex.

Runkle (1981, 1982, 2000) studied gap phase replacement in old-growth forests including Tionesta. His work showed that about 12 percent of Tionesta was within gaps and that the species composition of Tionesta was dominated by American beech (*Fagus grandifolia* Ehrh.) and Eastern hemlock (*Tsuga canadensis* (L.) Carr.). Only minor changes in species composition occurred in the areas surveyed between the mid-1970s and the early 1990s. However, Bjorkbom and Larson (1977), Peterson and Pickett (1991), and Ruffner and Abrams (2003) emphasize the role of medium- and large-scale wind disturbance. Within the Tionesta Scenic and RNA, there are three major tornado tracks (from 1808 and 1870 events reported in Bjorkbom and Larson 1977, and from 1985 reported in Peterson and Pickett 1991). Peterson and Pickett (1995) showed that recovery from the 1985 tornado in Tionesta differed from recovery in adjacent second-growth forest affected by the same tornado. In second-growth forest, where time since last disturbance was much shorter, species that persist for many decades in the seed bank, especially pin cherry (*Prunus pensylvanica* L.), were an important element of forest recovery. In Tionesta's tornado swath, however, pin cherry was a minor component, as it had been several hundred years since the prior disturbance. Thus, the seed bank there contained little viable pin cherry seed. Ruffner and Abrams (2003) supplemented traditional witness tree and gap measurements with dendroecology at several sites in Tionesta to detect medium intensity disturbances. They found that, especially on the plateau top, a return interval for medium intensity disturbances was between 210 and 620 years, shorter than that found by previous researchers.

Tionesta also provided important data about the role of soil in carbon sequestration and changes in forest soil carbon following disturbance. These topics have gained importance in the face of increasing efforts to manage anthropogenic contributions to global climate change (Hoover and others 2002). Soils were collected in four different zones of the Tionesta Scenic and Research Natural Areas, including the swaths of the 1808, 1872, and 1985 tornados and the zone of true old growth whose last stand-replacing disturbance predates records in the area. This chronosequence showed that soil carbon increased with time since disturbance. The level of soil carbon observed in soils from the old-growth zone suggests a maximum content of 35 metric tons per acre. This recent research in a site set aside more than 60 years ago shows that such areas can answer questions that were not anticipated at the time of site establishment.

Hearts Content, a 120-acre remnant old-growth forest, is another important reference condition site for long-term monitoring. Both Tionesta and Hearts Content have been important in providing documentation of the impacts of white-tailed deer overabundance, a critically important ecological concern (see, for example, Latham et al. 2005). Shortly after Tionesa became a RNA, Hough installed a series of 20 permanent photo points to show changes in the understory of the forest. In 1965, he published results, showing the near-disappearance of hobblebush (*Viburnum alnifolium*) because of deer browsing (Hough 1965). In Hearts Content, Lutz (1930, 1934) made a comprehensive study of the vegetation as this land was acquired by the U.S. Forest Service. In 1978, Whitney (1984) revisited Lutz' plots and determined that, probably because of deer overabundance, gap phase replacement of trees in Hearts Content had failed for the intervening 50 years. Rooney and Dress (1997) used techniques similar to those used by Lutz, but did not revisit the same plots. They determined that several species of herbaceous plants had disappeared from Hearts Content, including many that were highly preferred by deer. In 2000, Ristau (2001) and colleagues at the Forestry Sciences Laboratory in Warren, PA, again relocated Lutz' plots. They conducted a comprehensive vegetative survey, including, as Lutz and his colleagues had, a systematic search of the area between plots for rare specimens. They found that hobblebush, which occurred on 50 percent of the sample plots in 1928, was only found in the systematic search. Sixteen other species that had been found on plots in 1928 had become so rare by 2000 that they were found only in the systematic search. In addition, seven species that were found on plots in 1928 were not found at all in 2000, while 32 species not found in 1928, many early successional, were found in the 2000 search. Rhizomatous ferns (Dennsteadtia punctolobula and Thelypteris noveboracensis) increased in abundance from 3 to 21 percent.

Both Tionesta and Hearts Content are also good demonstration areas for the effects of other landscape scale anthropogenic changes, such as exotic insect and disease organisms and acid deposition. Research on sugar maple decline in the region showed incidentally that beech growth was unaffected across a range of soil pH from less than 4.0 through more than 6.0 (Long and others 1997). The persistence of old beech in both reference areas until the arrival of beech bark disease is consistent with this observation. Beech bark disease has entered both areas resulting in substantial mortality, altered understory light regimes, and interactions with white-tailed deer browsing. These are stories yet to be written, but already available for environmental education to those who visit Tionesta and Hearts Content.

## Lessons and Pitfalls of Reference Condition Monitoring

Long-term reference sites are invaluable for understanding forest ecosystems and for recognizing which changes are happening at the landscape scale and which are due to site-specific management. Their demonstration value is also high. The Tionesta, with its network of naturally disturbed areas and responses visibly affected by white-tailed deer, and Hearts Content, showing evidence of both deer overabundance and, more recently, recovery, have been important in helping people understand how deer impact has shaped the landscapes of Pennsylvania.

The remarkable resilience and grandeur of these reference forests humble us and serve as a living reminder of our stewardship responsibilities. Tionesta is at the heart of current discussions about future wilderness areas on the Allegheny National Forests (Friends of Allegheny Wilderness 2003), with a wide array of audiences uncertain about the adequacy of protections provided by RNA status.

There are, however, some pitfalls associated with the use of long-term preserves as reference areas. On the Allegheny Plateau, logging at the turn of the 19th century resulted in substantial changes in species composition (Whitney 1990). Comparisons between second-growth forests and the reference areas, representing first-growth forests, are thus increasingly problematic. There is a natural temptation to assume that differences between reference areas and managed areas are due to management, or, conversely, that these differences are due to the "old growth" status of the reference areas. When age is confounded by substantial differences in species composition, this can lead to erroneous conclusions. For example, eastern hemlock represents well over 20 percent of the trees in both Tionesta and Hearts Content (unpublished data on file at the Forestry Sciences Laboratory, Irvine, PA). But it represented only 7 percent of the trees found in a large expanse of second-growth forest sampled by the Allegheny National Forest in 1992 (Allegheny National Forest 1995). Are differences in bird communities between these reference areas and second-growth forest due to differences in species composition, or differences in management? This is not merely an academic question. Managers and the public are currently debating appropriate responses to the likely arrival of the hemlock woolly adelgid and the adoption of silvicultural strategies that might accelerate the development of old-growth characteristics in selected stands and landscape corridors.

## Long-term Manipulative Studies on the Allegheny Plateau

U.S. Forest Service Research has sustained a diverse array of medium- and long-term studies conducted across the Allegheny Plateau region over the last eight decades (Table 2). These include studies of white-tailed deer impact (Horsley and others 2003), forest liming (Long and others 1997), stand development (Marquis 1992), and silvicultural treatments (Church 1955, Marquis and Ernst 1991, Stout 1994, Nowak 1996, Ristau and Horsley 1999).

## Surprises from Long-term Studies

In 1985, U.S. Forest Service Research and the Pennsylvania Bureau of Forestry launched a split-split plot study of the impacts of forest liming, herbicide treatments to remove interfering plants, and fences to exclude white-tailed deer in Allegheny hardwood stands. The study areas included a substantial component of declining sugar maple in the overstory, with little advance regeneration (Auchmoody 1988). There were four replicates of each treatment. The liming treatment was ground application of 10 tons per acre of dolomitic limestone. Detailed measurements showed substantial changes in the pH of the limed soils, with changes reaching deeper and deeper into the soil over time. Yet for the first 5 years, there were no significant differences in overstory tree growth between limed and unlimed plots. This lack of early response had been reported before in the literature (Lea and others 1979 – two years of growth data; Leaf and Bickelhaupt 1975 – three years of growth data). However, starting in 1990 and persisting through the present, sugar maple basal area and diameter growth and flower and seed production responded to the liming treatment, and were significantly greater on limed than unlimed plots. Neither beech nor black cherry exhibited a growth response to liming for the period 1985-1993 (Long and others 1997). In this case, sustaining a study for 5 years brought results that were not expected when the study was installed.

A similar surprise emerged from the study of the impact of white-tailed deer on forest regeneration and other resources (Tilghman 1989, deCalesta 1994, Horsley and others 2003) conducted by the U.S. Forest Service and a coalition of partners. The Deer Enclosure Study had four replicates, widely dispersed across the Allegheny Plateau. At each study site, deer densities of 10, 20, 38, and 64 deer per square mile were simulated by enclosing female deer within fenced, managed forests. Seedlings for deer to browse were stimulated by clearcutting 10 percent and thinning 30 percent of the area of each enclosure.

In an earlier study Marquis (1981) assessed regeneration outcomes of regeneration cuttings that were divided evenly into a fenced, or zero deer per square mile, area and an unfenced area at ambient deer density of 40-60 deer per square mile. Adequate regeneration failed to develop in about 60 percent of the ambient deer density (unfenced) areas. In 87 percent of the areas where regeneration failures occurred outside the fences, regeneration was successful inside the fence. This previous work led us to expect that the clearcuts in the high deer density pens of the Deer Enclosure Study would fail to regenerate. At year 5, however, regeneration stocking of desirable species, dominated by black cherry, averaged about 80 percent in the highest deer density pens.

This surprise led scientists to the concept of deer impact (Marquis and others 1992, deCalesta and Stout 1997). This holds that the impact of deer on regeneration and other forest resources is a joint function of the density of deer and the amount of available forage within the landscape that they use. In the Allegheny Plateau region, managers used guidelines developed by U.S. Forest Service research to assess advance regeneration stocking

(Marquis and Bjorkbom 1982) to designate areas for regeneration cuttings. In managed landscapes, this created a vicious cycle: overabundant deer prevented development of advance regeneration, which led to decreased harvesting rates, which increased deer impact. At the time of the deer enclosure study, lack of advance regeneration was one reason that only 4 percent of the Allegheny National Forest was in the 0-10 year old, high-deer-forage-producing, age class. Only 13 percent of the area was recently thinned (personal communication, R.L. White, Silviculturist, Allegheny National Forest). This meant less forage in the landscape than the 10 percent clearcut, 30 percent thinned conditions inside the study enclosures, and explained why the same numbers of deer in the high deer density enclosure study areas had much less impact than we observed outside. Managers have used the deer impact concept to develop practices of concentrating harvests in space and time, to reduce the impact of deer during a regeneration phase.

## Other Benefits from Long-term Studies

In addition to providing occasional surprises, long-term studies can enhance sustainable forest management by giving long-term answers to contemporary questions, by enhancing our comprehensive understanding of the ecology and development of managed forests, and by developing resources, such as photography series, for environmental education.

## Long-term Research on the Kane Experimental Forest

When the Kane Experimental Forest (KEF) was established in 1932 (Smithbauer 1999), many of the forests on the Allegheny Plateau were just entering the stem exclusion phase of stand development after the turn of the century railroad logging era. The second study established on the KEF, by Ash Hough in 1936, was called the weeding study, although the practice that it examined would be termed cleaning today. At four replicate sites on the KEF, three different levels of cleaning were compared to control plots, in 13- or 18-year-old Allegheny hardwood stands. Church (1955) demonstrated that the heavy and silvicultural cleaning treatments resulted in significantly better crop tree growth.

This long-term study took on added importance in the late 20th century for two reasons. First, reduced deer impact in fenced stands and in areas with concentrated large forage-producing cuts across the Plateau resulted in the re-emergence of pin cherry (Prunus pensylvanica L.) as an important factor in some young stands. Ristau and Horsley (1999) used data from the weeding study to show that at age 70, stands with low early densities of pin cherry had substantially higher sawtimber volumes than stands with high early densities of pin cherry. Second, by the 1990s, many of the stands that originated during the railroad logging era were being regenerated, and managers were once again asking about appropriate management strategies for young stands. Church's results – and their confirmation by continued measurements in the 1936 weeding study – helped managers evaluate the cost-benefit tradeoffs of precommercial treatments.

Ben Roach and others installed a long-term thinning study on the KEF in 1971. Thirty-two 2-acre plots were set aside to study the effects of residual density and stand structure on growth of mixed hardwood stands after thinning. Each 2-acre treatment plot contained an interior 0.6-acre measurement plot in which each tree was numbered and remeasured every 5 years, along with eight 6-foot-radius understory sample plots, remeasured on a similar cycle. The study incorporated a synthesis of Roach's ideas about the interactions of species composition, stand density and stand structure (Marquis 1994b). Results have been used to develop tools for measuring relative density in mixed hardwood stands (Roach 1977, Stout and Nyland 1986), guidelines for both residual density (Nowak 1996) and structure (Marquis and Ernst 1991) after thinning, and for how these parameters vary with species composition (Nowak 1996). They have also been used to characterize understory responses to partial cutting (Yanai and others 1998), and in developing the growth model in the SILVAH decision support system (Marquis and Ernst 1992).

A third example of a long-term study on the KEF is the management strategies study installed by John Bjorkbom in the last 2 years of his career, from 1979-1981. The study plan outlines an 80-year study applied to a stand with at least two age classes at the time of installation. The growth and yields of five different silvicultural systems will be compared over the course of one full even-aged rotation. Even-age silviculture, two-age silviculture, economic selection, group selection, and single-tree selection were each applied to four replicate 4.9-acre plots. Responses to the varied regeneration treatments have been reported by Stout (1994). The second round of cutting treatments harvests will begin in 2006.

A final example of a long-term study on the KEF is a study that was replicated on many Forest Service Experimental Forests in the 1950s. It is reported here mostly as a cautionary tale. This study, called the Cutting Practice Level study, included 4 degrees of cutting. In our files, we have a typed progress report (unpublished progress report on file, Forestry Sciences Laboratory, Irvine, PA) that describes the treatments "High Order, Good, Fair, and Poor" in the typescript. A number of hand-written corrections to the report are on the page, along with Harold Huntzinger's initials and the date "12-58" in the corner. The handwritten notes cross out the value-laden treatment names and redescribe them (in order) as a "light partial cutting" on a 5-year cutting cycle, a "medium partial cut" on a 15-year cutting cycle, a "10-inch diameter limit cut with standards", and a "clear cutting," presumed associated with a 50-60-year cutting cycle. Culturally, forestry made a substantial shift during the 50s, from a strong preference for partial cuts to a strong preference for even-age silviculture, based on the better regeneration of high-value shade-intolerant species in even-age harvest treatments. Folklore in Forest Service research suggests that when this particular study was installed, signs were erected with the value-laden labels. As results accumulated, the signs on the treatments were literally and physically reversed across the range of the study. A better lesson is perhaps embodied in Harold Huntzinger's notes, suggesting that we stick to less value-laden language describing treatments.

## Long-term Research for Demonstration and Environmental Education

The first U.S. Forest Service study of forest management practices on the Allegheny Plateau was installed in conjunction with the first timber sale along Little Arnot Creek on the new (established in 1923) Allegheny National Forest in 1927. Although the study was not replicated, it included four different harvest treatments— three partial cuts and a silvicultural clearcut. Complete vegetative inventories of each treatment area were taken preharvest and existing trees and down woody debris were mapped. Permanent photo points were established in each treatment area. Detailed 5-year inventories were conducted on all four plots through the 1950s, and eventually, the partial cutting treatments were dropped from the study. However, the development of the clearcut continues to be measured and photographed through the present (Figure 1). This photographic record has been used widely to display the developmental pathway of forests after clearcutting, to help current users of the forest to understand its origins, and to teach about stand development in stratified mixed hardwoods. Note in these photographs the relative growth rates of black cherry, in the left foreground, red maple in the center background, and sugar maple in the right foreground.

## Thoughts about Sustaining Long-term Research

To our knowledge, formal studies in how to sustain long-term research have not occurred. However, the history of the Kane Experimental Forest and the Forest Service research unit associated with the KEF suggests that at least three factors have been important.

The first is a series of committed and dedicated individuals. Ashbel F. Hough was a Forest Service scientist with the Allegheny Forest Experiment Station who resided in the Philadelphia area, near Station Headquarters. He brought his entire family to KEF each summer to install and remeasure studies both on and off the Experimental Forest[1]. His personal commitment and vision resulted in studies that were both important enough, in the issues they addressed, and sufficiently well-designed to merit continuation. His passion for his work and for this forest region laid an extraordinary informational foundation for future work. He was still writing about Allegheny hardwood forests during the careers of Ben Roach and Dave Marquis, as each of them worked for a time in the Philadelphia regional headquarters. Marquis and Roach were both later assigned to the KEF, and both understood the importance of long-term research. They worked hard to relocate many of Hough's studies that had gone unmeasured for a period during the late 50s and early 60s, and to re-establish those studies.

Marquis and Roach hired several permanent forestry technicians. These people became committed to long-term research and to conserving the ecological understanding that could be derived from studies observed over decades. Virgil Flick, David Saf, Harry Steele, Ernie Wiltsie, Vonley Brown and Julie Smithbauer have provided the continuity and expertise to sustain studies even as the cast of scientists has changed. In some cases, their extraordinary field skills have been keys that allowed long-abandoned studies to be restarted. For example, a crew including Steele, Brown, Smithbauer, and Wiltsie worked with Ristau, using stem maps and field notes from Lutz' Hearts Content work, to relocate Lutz' plots and reopen the vegetation record at that site. The same crew worked with Hoover to relocate plots near the Tionesta RNA that had been installed and measured by Hough in the 1930s. Sustaining a permanent cadre of forestry technicians with a specific understanding of the requirements for research measurements, study plot installation, and long-term record-keeping is difficult when high proportions of operating budgets are based on funding for individual studies.

In addition to dedicated individual scientists and technicians, an institutional structure that focuses on research mission and problems rather than on individual careers has been critically important to sustaining long-term research at KEF. Forest Service research units assign existing studies to new scientists and technicians as long as these studies continue to enhance our understanding of forest growth, development, and management. Historically, maintenance of long-term research could also be enhanced by Forest Service supported funding to university partners for data analysis and superimposed measurements. As research programs become more and more focused on study-specific and competitive funding, this institutional support for long-term research is jeopardized. The National Science Foundation's Long-Term Ecological Research program is by definition confined to sites already selected. But competitive granting programs often focus on new ideas and rarely provide support for studies that last longer than 5 years. Over the past 25 years, the proportion of Forest Service research operational funding from these "soft" or competitive programs has increased steadily, placing long-term research in jeopardy.

**[1]Kane Experimental Forest Memories, Part 1 & 2. CD Recording of discussion with all four of Hough's sons and others held at the Kane Experimental Forest on the celebration of its 70th birthday, May 31, 2002. On file, Forestry Sciences Laboratory, Irvine, PA.**

Finally, long-term research on the KEF has been sustained because it is constantly being put into use. Marquis and Roach, with Pennsylvania State University Cooperative Extension colleague Roe S. "Sandy" Cochran, launched a silvicultural training program in 1978 to translate results from long- and short-term studies on the KEF and across the Allegheny Plateau into guidelines for sustainable forest management (Marquis and others 1992, Marquis 1994a). These sessions included hands-on training in the use of these guidelines, and they have been sustained through the present. At the time the first guidelines and training sessions were developed, regeneration problems from white-tailed deer overabundance were rampant. Training session guidelines provided measurable improvements in forest regeneration. The systematic approach to management prescriptions embodied in the training sessions later developed into the SILVAH computerized decision support tools (Marquis and Ernst 1992). When independent auditors for the Forest Stewardship Council began to assess management practices in Pennsylvania in the late 1990s, use of these guidelines was cited as evidence of sustainable practice.[2]

## Summary

Long-term research in Pennsylvania's Allegheny Plateau region is a foundation for sustainable forestry practices in the region. This research includes monitoring of forests in a reference condition and long-term measurement of research studies that have tested different alternatives for sustainable management. Lessons from long-term research have included surprises, such as a growth and health response to forest liming that was limited to a single woody species – sugar maple – and only emerged 6 years after treatment. Results have also taught us humility in the face of the resilience and magnificence of the region's forests. Support for a comprehensive portfolio of long-term research is based on some extraordinary scientists and technicians, on the institutional, mission-focused structure of Forest Service research, and on the utility of the results. Increased reliance on short-term competitive funding for Forest Service research units is a threat to this invaluable scientific asset and its many benefits to sustainable forestry in the Allegheny Plateau region.

**[2]Scientific Certification Systems. 1997. An evaluation of the Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry Districts 9, 10, 12, 13, 15, and 16 under the SCS forest conservation program. On file with PA DCNR Bureau of Forestry, Harrisburg, PA.**

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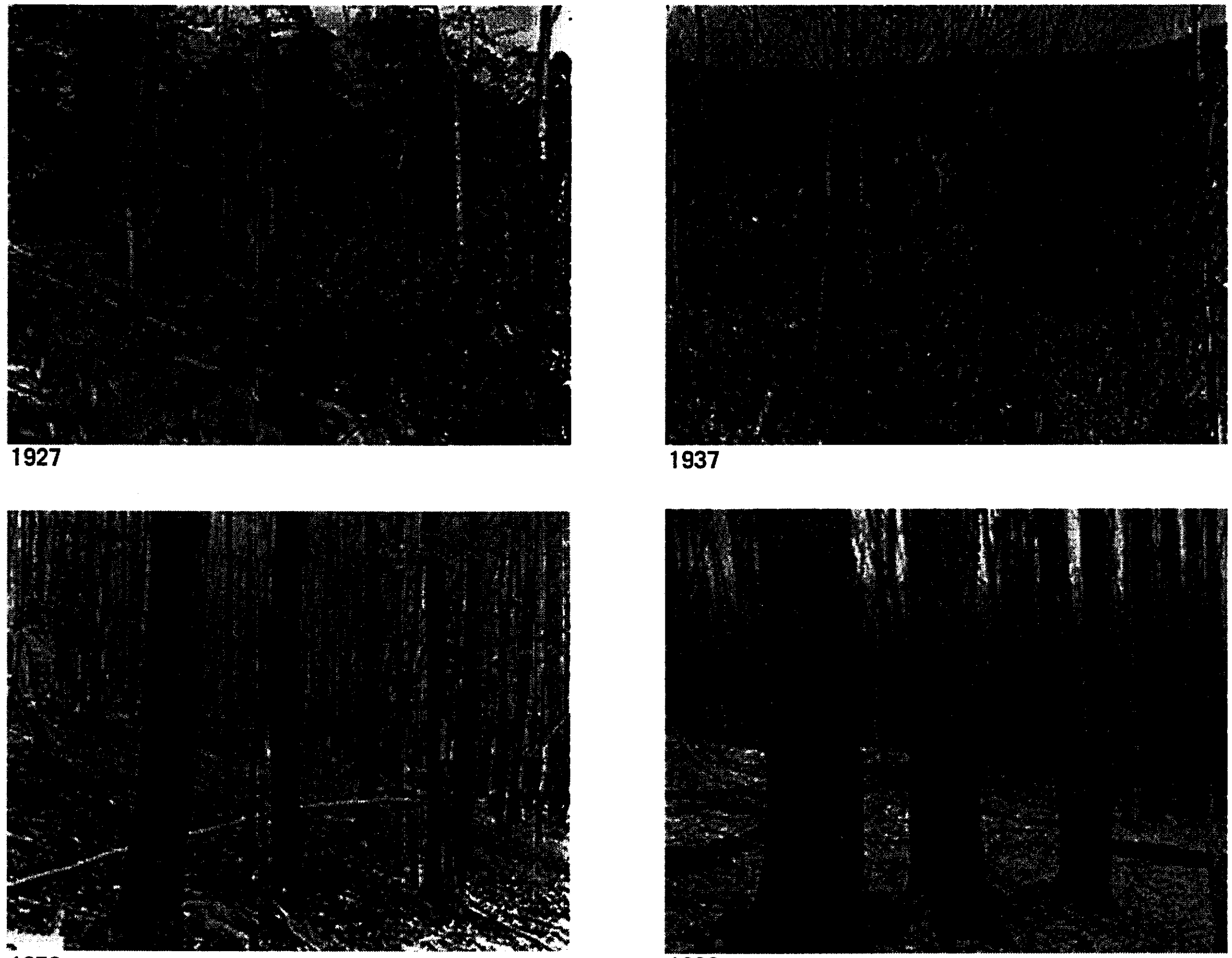

1927 1937

1958 1988

**Figure 1. Stand development after clearcutting in Allegheny hardwoods, based on permanent photographic record of the Little Arnot study, USDA Forest Service, Allegheny National Forest, Pennsylvania.**

**Table 1. Long-term research information table – reference condition research on U.S. Forest Service sites in northwestern Pennsylvania USA.**

| Research Site | Site Establishment | Forest Type | Study Establishment | Study Focus | Variables | Measurement Schedule |
|---|---|---|---|---|---|---|
| Tionesta Scenic and Research Natural Area | 1940 | Hemlock-Beech | | | | |
| | Bjorkbom, John C.; Larson, Ronald G. 1977. The Tionesta scenic and natural area. Upper Darby, PA: U.S. Dept. of Ag., For. Serv., Northeastern Forest Exp. Stn. Gen. Tech. Rep. NE-31. 24 p.<br>Cope, Theodora Morris. 1936. Observations on the vertebrate ecology of some Pennsylvania virgin forests. Ithaca, NY: Cornell University, Ph. D. Dissertation. 239 p.<br>Cope, Theodora M.; Hawkins, Arthur S. 1934. A preliminary survey of the flora and fauna of the East Tionesta virgin forest, Pennsylvania. Forest Leaves 24: 23-27. | | | | | |
| | | | 1942 | Understory change | Seedling species, numbers, sizes | 5-year: Photo record since 1942, detailed measurements since 1972 |
| | Hough, A.F. 1965. A twenty-year record of understory vegetation change in a virgin Pennsylvania forest. Ecology 46: 370-373. | | | | | |
| | | | 1970s | Gap formation and disturbance patterns | Gap size, gap regeneration, tree mortality | Periodic since 1970s |
| | Runkle, James R. 1981. Gap regeneration in some old-growth forests of the eastern United States. Ecology 62: 1041-1051.<br>Runkle, James R. 1982. Patterns of disturbance in some old-growth forests of eastern North America. Ecology 63:1533-1546.<br>Runkle, James R. 2000. Canopy tree turnover in old-growth mesic forests of eastern North America. Ecology 81: 554-567. | | | | | |
| | | | 1985 | Forest recovery after tornado | Seedling species, numbers, sizes | Annual since 1985 |
| | Peterson, C.J.; Pickett, S.T.A. 1991. Treefall and resprouting following catastrophic windthrow in an old-growth hemlock-hardwoods forest. Forest Ecology and Management 42: 205-217.<br>Peterson, C.J.; Pickett, S.T.A. 1995. Forest reorganization: a case study in an old-growth forests catastrophic blowdown. Ecology 76: 763-774. | | | | | |
| | | | 2000 | Soil carbon dynamics | Soil carbon content, concentration, and character | Twice since 2000 |
| | Hoover, C.M.; Magrini, K.A.; Evans, R.J. 2002. Soil carbon content and character in an old-growth forest in northwestern Pennsylvania: a case study introducing pyrolysis molecular beam mass spectrometry (py-MBMS). Environmental Pollution 116: S269-S275. | | | | | |

**Table 1. Long-term research information table – reference condition research on U.S. Forest Service sites in northwestern Pennsylvania USA.**

| Research Site | Site Establishment | Forest Type | Study Establishment | Study Focus | Variables | Measurement Schedule |
|---|---|---|---|---|---|---|
| Heart's Content National Scenic Area | 1926 | Hemlock-beech-white pine | 1928 | Vegetation change | Herbaceous plant presence/absence and abundance, tree and tree seedling counts by size class | 1928, 1958, 1998 |
| | Lutz, H.J. 1930. The vegetation of Heart's Content: A virgin forest in northwestern Pennsylvania. Ecology 11:1-29.<br>Lutz, H.J. 1934. Additions to the flora of Heart's Content, a virgin forest in northwestern Pennsylvania. Ecology 15: 295-297.<br>Whitney, G.G. 1984. Fifty years change in the arboreal vegetation of Heart's Content, an old-growth hemlock-white pine-northern hardwood stand. Ecology 65: 403-408.<br>Rooney, Thomas P.; Dress, William J. 1997. Species loss over sixty-six years in the ground-layer vegetation of Heart's Content, and old-growth forest in Pennsylvania, USA. Natural Areas Journal 17: 297-305.<br>Ristau, Todd E. 2001. Seventy-two years of change in the herbaceous vegetation layer of Heart's Content Scenic Area, Warren County, PA. In: Keeping all the parts: 86th annual meeting of the Ecological Society of America: abstract booklet. August 5-10, 2001, Madison, WI. Ecological Society of America, Washington, DC. | | | | | |

Table 2. Long-term research information table - manipulative research in northwestern Pennsylvania and adjacent regions.

| Research Site | Site Establishment | Forest Type | Study Establishment | Study Focus | Variables | Measurement Schedule |
|---|---|---|---|---|---|---|
| Kane Experimental Forest | 1932 | Allegheny hardwood – cherry maple | | | | |
| | Smithbauer, Julie. 1999. Kane Experimental Forest. Inf. Rep. NE-137. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 20 p. | | | | | |
| | | | 1936 | Weeding/Cleaning | Individual tree species, diameter, mortality | Five-year intervals with breaks since 1936; second rotation test to begin in 2005 |
| | Church, Thomas W., Jr. 1955. Weeding: An effective treatment for stimulating growth of northern hardwoods. Journal of Forestry 53: 717-719.<br>Ristau, Todd E.; Horsley, Stephen B. 1999. Pin cherry effects on Allegheny hardwood stand development. Canadian Journal of Forest Research 29: 73-84. | | | | | |
| | | | 1973 | Regeneration methods | Seedling counts by species on permanent plots | Annually through 1978, intermittently thereafter |
| | Bjorkbom, John C.; Walters, Russell S. 1986. Allegheny hardwood regeneration response to even-age harvesting methods. U.S. Dept. of Ag., Forest Service. Northeastern Research Station Res. Pap. NE-581. Broomall, PA: 13 pp | | | | | |
| | | | 1971 | Thinning effects on stand development and growth | Individual tree species and diameter, mortality, seedlings by species and height class on permanent plots, ground cover by ferns and other herbaceous plant groups | 5-year cycle from 1975 through present |
| | Roach, Benjamin A. 1977. A stocking guide for Allegheny hardwoods and its use in controlling intermediate cuttings. Res. Pap. NE-373. Upper Darby, PA: U.S. Department of Agriculture, Forest Service. Northeastern Forest Experiment Station. 30 p.<br>Stout, Susan L.; Nyland, Ralph D. 1986. Role of species composition in relative density measurement in Allegheny hardwoods. Canadian Journal of Forest Research. 16: 574-579.<br>Marquis, David A.; Ernst, Richard L. 1991. The effects of stand structure after thinning on the growth of an Allegheny hardwood stand. Forest Science. 37:1182-1200.<br>Nowak, Christopher A. 1996. Wood volume increment in thinned, 50- to 55-year-old, mixed-species Allegheny hardwoods. Canadian Journal of Forest Research. 26:819-835.<br>Yanai, Ruth; Twery, Mark J.; Stout, Susan L. 1998. Woody understory response to changes in overstory density: thinning in Allegheny hardwoods. Forest Ecology and Management. 102: 45-60. | | | | | |

| Research Site | Site Establishment | Forest Type | Study Establishment | Study Focus | Variables | Measurement Schedule |
|---|---|---|---|---|---|---|
| | | | 1979 | Silvicultural systems and stand development – Even-age, Two-age, Group Selection, Individual tree selection, economic selection | Overstory trees by species and diameter class, individual tree diameter growth, seedlings and selected herbaceous plant groups on permanent plots | 5-year cycle through 2080 |
| | Stout, Susan L. 1994. Silvicultural systems and stand dynamics in Allegheny hardwoods. New Haven, CT: Yale University. 169 p. D.F. dissertation. | | | | | |
| Long-term Manipulative Studies on Partner Lands | Various | Northern and Allegheny hardwoods, selected mixed oak stands | | | | |
| | | Allegheny hardwoods | 1979 | Impact of deer on forest regeneration | Seedling counts by species and size class, selected herbaceous plant group abundance on permanent plots | 1980, 1983, 1985, 1990, 1995 (subset) |
| | Tilghman, N.G. 1989. Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. Journal of Wildlife Managment. 53:524-532.<br>deCalesta, D.S. 1994. Effect of white-tailed deer on songbirds within managed forests in Pennsylvania. Journal of Wildlife Management. 58: 711-718.<br>deCalesta, David S.; Stout, Susan L. 1997. Relative deer density and sustainability: a conceptual framework for integrating deer management with ecosystem management. Wildlife Society Bulletin 25: 252-258.<br>Horsley, Stephen B.; Stout, Susan L.; deCalesta, David S. 2003. White-tailed deer impact on the vegetation dynamics of a northern hardwood forest. Ecological Applications 13: 98-118. | | | | | |
| | | Northern hardwoods | 1985 | Impact of liming on forest development and regeneration | Individual tree growth; flower and seed crops of sugar maple trees; seedling counts by species and size class, selected herbaceous plant group abundance on permanent plots; soil chemical analyses | 1985 through present; periods are different for different measurements |
| | Long, Robert P.; Horsley, Stephen B.; Lilja, Paul R. 1997. Impact of forest liming on growth and crown vigor of sugar maple and associated hardwoods. Canadian Journal of Forest Research 27: 1560-1573. | | | | | |