

AFTER 25 YEARS, WHAT DOES THE PENNSYLVANIA REGENERATION STUDY TELL US ABOUT OAK/HICKORY FORESTS UNDER STRESS?

William H. McWilliams, James A. Westfall, Patrick H. Brose, Shawn L. Lehman, Randall S. Morin, Todd E. Ristau, Alejandro A. Royo, and Susan L. Stout¹

Abstract.—The Pennsylvania Regeneration Study was initiated in 1989 because of concerns about a long history of stress on oak/hickory (*Quercus/Carya*) forests from herbivory and other factors. The study, which addresses the need for landscape-level information about regeneration quality and abundance, comprises a suite of regeneration indicator measurements installed on a subset of Forest Inventory and Analysis monitoring plots. The State's oak/hickory forests have been under increasing stress because aging stands that originate from large-scale disturbances from more than 100 years ago are inundated by herbivory of preferred plants and invasion of native and nonnative invasive plants. Maintaining oaks in young stands is difficult because of herbivory, invasive plants, climate change, lack of fire, and other factors. This paper summarizes the Pennsylvania Regeneration Study results, offering a look at likely challenges faced by managers and policy makers, as well as by inventory specialists who design forest inventories for stressed forests.

INTRODUCTION

Pennsylvania is well known for its oak/hickory (*Quercus/Carya*) forest, which accounts for more than half the State's forest land, or 9.1 million acres. Oaks deliver more income from timber products than any other genus and are by far the most important source of mast for wildlife. A lack of major disturbances such as wildfire has led to conditions in which a dearth of available light limits the establishment of young oak seedlings. Competing vegetation is a critical factor for oak seedling establishment during the stand initiation phase because of competition for light and growing space (Jackson and Finley 2011). Concurrent with the lack of disturbance, white-tailed deer (*Odocoileus virginianus*) have emerged as the keystone herbivore that drives understory composition and structure (Horsley et al. 2003, Waller and Alverson 1997). Dey (2014) paraphrases these conditions as “not enough light and too many deer.” This paper has two goals: (1) to describe how the results of a landscape-level study of regeneration address the need for inventorying and monitoring the condition and health of forest regeneration; and (2) to discuss lessons learned about monitoring, management, and policy that are pertinent to the oak/hickory forests of Pennsylvania and other regions.

¹ Research Foresters (WHM, JAW, and RSM), U.S. Forest Service, Northern Research Station, 11 Campus Boulevard, Suite 200, Newtown Square, PA 19073; Research Foresters (PHB and SLS) and Research Ecologists (TER and AAR), U.S. Forest Service, Northern Research Station; Inventory and Monitoring Chief (SLL), Pennsylvania Bureau of Forestry. WHM is corresponding author: to contact, call 610-557-4050 or email at wmcwilliams@fs.fed.us.

Pennsylvania Regeneration Study

In preparation for the Northern Research Station, Forest Inventory and Analysis (NRS-FIA) 1989 inventory of Pennsylvania's forest land, the Pennsylvania Bureau of Forestry convened a summit of environmental organizations to assist in guiding research toward issues that are pertinent to oak/hickory forests. It became clear that the overriding issue was the impact that deer were having on advance regeneration, and the perception was that favorable regeneration was lacking over large areas. As a result, a set of regeneration measurement protocols based on the silvicultural findings published by Marquis (1994) were implemented on all NRS-FIA plots measured during the leaf-on season. This marked the beginning of the Pennsylvania Regeneration Study (PRS).

By 1995, the NRS-FIA findings demonstrated that more than half the samples in stands that had adequate light for regeneration did not have adequate stocking of tree seedlings or saplings, a condition described as "impoverished" (McWilliams et al. 1995). In 2000, the NRS-FIA program changed from periodic inventories that were conducted about every 10 years to an annual approach in which some sample plots are measured each year. A pilot study was conducted to adapt the regeneration measurements from the periodic inventory to the new national plot design (McWilliams et al. 2001). In 2001, the new plot design was adopted as a standard feature of the inventory (McWilliams et al. 2015). Lessons learned from the PRS eventually led to the implementation of these regeneration indicator measurements across all 24 states served by the NRS-FIA beginning in 2012.

METHODS

Sample Design

The national FIA program's three-phase inventory and monitoring system was the source of field sample data for the study region (Bechtold and Patterson 2005). In Phase 1, classified remote sensing imagery was used to prestratify sample plots, allowing stratified estimation to reduce uncertainty (variance) for estimates of population totals. Phase 2 consisted of field samples at an intensity of roughly one plot per 6,000 acres. The sample of adult trees and other forest vegetation comprised a cluster of four 24-foot fixed-radius subplots. Each subplot contained a 6.8-foot radius microplot offset from the subplot center to tally saplings and seedlings. The standard Phase 2 inventory provided data and information at the plot, subplot, microplot, and tree levels using a mapped design that considers different site conditions to reduce bias and improve classification. The Phase 3 sample consisted of a suite of forest health indicators that were measured during the leaf-on summer season on a subset of plots. The PRS is a component of the Phase 3 sample with a sample size that fluctuates from year to year because it is a subset of the total number of forested Phase 2 annual inventory plots. It usually, though, consists of about 400 samples.

Primary Regeneration Indicator Measurements

Browse Impact

A browse impact code was used to indicate the pressure that herbivores are exerting on tree seedlings and other understory flora for the area surrounding the sample plot. Browse is defined as "the consumption of tender shoots, twigs, and leaves of trees and shrubs used by animals for food." This approach is distinguished from other browse studies that assess the amount of material removed from specific plants (Latham et al. 2005). The reason for assessing overall impact is that it is difficult to identify browse if no seedlings or other vegetation are present to

be browsed (Latham et al. 2009). If the site has no understory vegetation, it can still be difficult to estimate browse impact. The following five codes were used:

1. Very low: plot is inside a well-maintained enclosure.
2. Low: no browsing is observed or vigorous seedlings are present (no enclosure is present).
3. Medium: browsing evidence is observed but uncommon; seedlings are common.
4. High: browsing evidence is common.
5. Very high: browsing evidence is omnipresent or a severe browse line exists.

Tree Seedling Counts

Seedling height is an important factor for estimating survival likelihood for naturally and artificially established seedlings, especially in areas with competing vegetation and herbivory (Brose et al. 2008, Sander 1972). Tree seedling counts are needed to generate estimates of the number of seedlings per unit area for populations of interest and to evaluate the adequacy of advance regeneration. Tree seedlings were counted on forested microplot conditions by species, source, and height class. All seedlings that have survived for 1 year and are at least 2 inches tall were included. In the case of large-seeded species, such as oak, hickory, and walnut (*Juglans* spp.), the level of establishment was determined by evaluating root collar diameter (RCD). An RCD of at least 0.25 inch defined a stem that is established. Seedlings with an RCD of at least 0.75 inch and a diameter at breast height smaller than 1 inch were coded as competitive. Large-seeded species at least 3 feet tall were also included as competitive.

Spatial Analysis

To create continuous maps of browse impact, indicator kriging (Isaaks and Srivastava 1989) within Esri's ArcMap 10.2.2 geostatistical analyst package (Esri, Inc., Redlands, CA) was used to create an interpolated surface from the sample data. Indicator kriging, a geostatistical technique that models autocorrelations between observations as a function of distance, yielded a visualization of the probability of exceeding the low browse impact class.

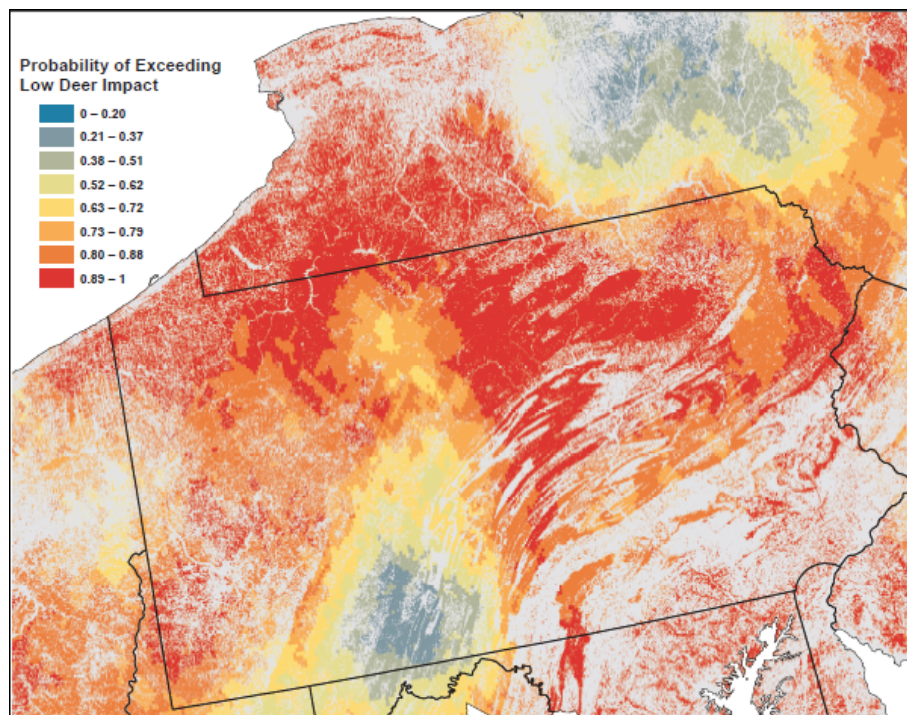


Figure 1.—Map showing the probability of exceeding low ungulate browse impact, throughout Pennsylvania, 2014.

RESULTS

PRS data and results have been used for a variety of assessments since the study began. We describe four representative case studies to highlight applications so far. Topics covered are herbivory impacts, overstory and understory composition and structure, regeneration adequacy, and habitat trends.

Herbivory Impacts

Sources of information that show the spatial distribution of herbivory impact are almost completely lacking. Sources have used population-based approaches that have proven difficult to develop and maintain over time. Some of the major challenges are estimating deer density, developing useful models of population based on stand conditions, and tracking deer movement. In addition, the lack of empirical data means that estimates of sampling error are not available.

Results from the PRS estimate the percentage of samples by impact level as 19 percent very low/low, 60 percent medium, and 21 percent high/very high. A geographic visualization was constructed to represent variations in occurrence based on the probability of exceeding low impact, which is the level where regeneration management options should be considered (Fig. 1). Areas of Pennsylvania with higher probability are apparent in the northwestern, northeastern, and southeastern regions. Areas with lower probabilities are in the mountains of the south-central region.

Overstory and Understory Composition and Structure

Pennsylvania's oak/hickory forests are maturing and will need to be able to regenerate and retain competitive tree seedlings and saplings in the stand-initiation phase of development. The relationship between overstory and understory tree composition and structure gives us a

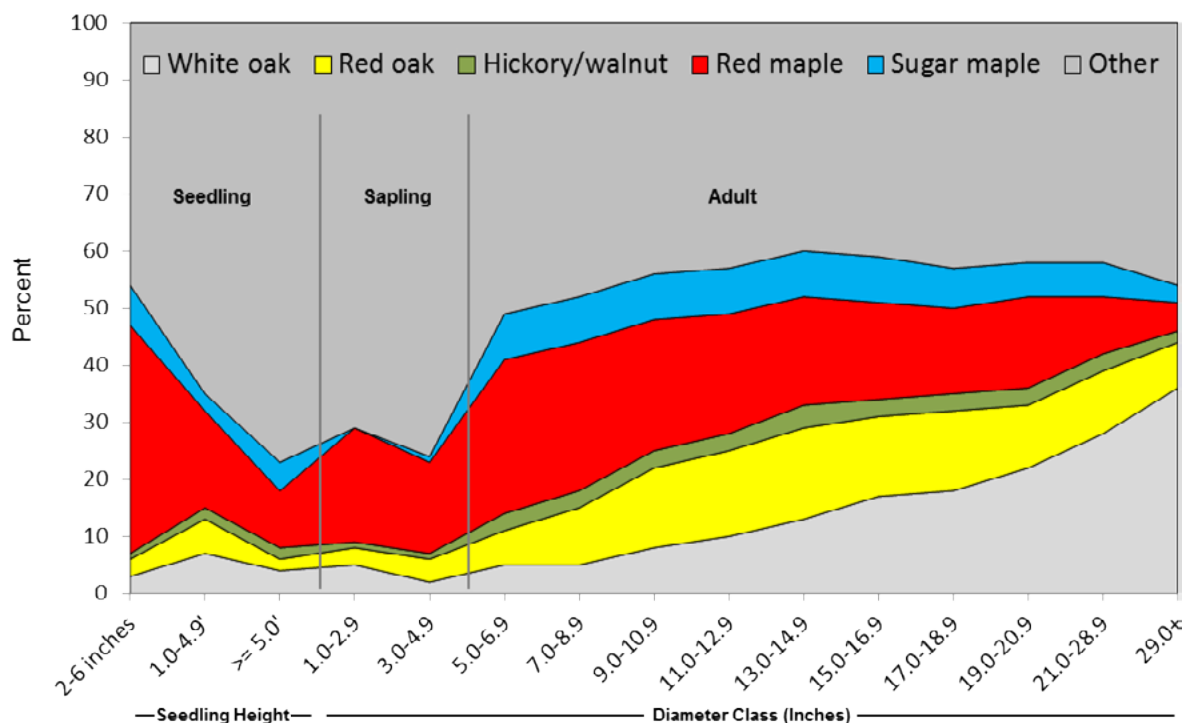


Figure 2.—Proportion of the number of seedlings, saplings, and dominant/codominant growing-stock trees (Adult) on forest land for select species or species group by size. Seedling estimates are for 2012–2014. Sapling and tree estimates are for 2010–2014. Black walnut is included in hickory species.

basis for understanding future forest conditions. Adding PRS seedling height results to stand profiles for larger trees extends the region of inference for regeneration to newly established and older seedlings (Fig. 2). Relative differences between the percentage of stems for seedlings and saplings versus adults yield information about prospective winners and losers in landscape-level stand development that in turn imply likely shifts in future composition and structure. The most prominent seedling and sapling winner that has the potential to reach high canopy was red maple (*Acer rubrum*). Other possible winners not shown are American beech (*Fagus grandifolia*) and birch (*Betula* spp.). High-canopy taxa that are under-represented as seedlings and saplings are white oak (*Q. alba*), red oak (*Q. rubra*), hickory/walnut (*Carya/Juglans*), and sugar maple (*A. saccharum*). Some of the more common understory and midcanopy taxa are serviceberry (*Amelanchier* spp.), striped maple (*A. pensylvanicum*), sassafras (*Sassafras albidum*), blackgum (*Nyssa silvatica*), hawthorn (*Crataegus* spp.), and eastern hophornbeam (*Ostrya virginiana*).

Regeneration Adequacy

Regeneration adequacy metrics developed for Pennsylvania’s forest-type groups were used to compare the number of seedlings in the FIA sample by height class to published regeneration guidelines (McWilliams et al. 2015). Before applying these metrics, we screened samples for favorable light conditions for seedling establishment and development by limiting the sample to plots from 40 percent to 75 percent stocked with all-live trees based on the findings of Marquis (1994). The samples were deemed adequate if the regeneration sample exceeded the regeneration guidelines.

Oak/hickory samples with fewer than 70 percent of the microplots adequately stocked with regeneration represent conditions that may need some form of treatment to increase oak stocking. The current results show that more than 60 percent of the samples had fewer than 70

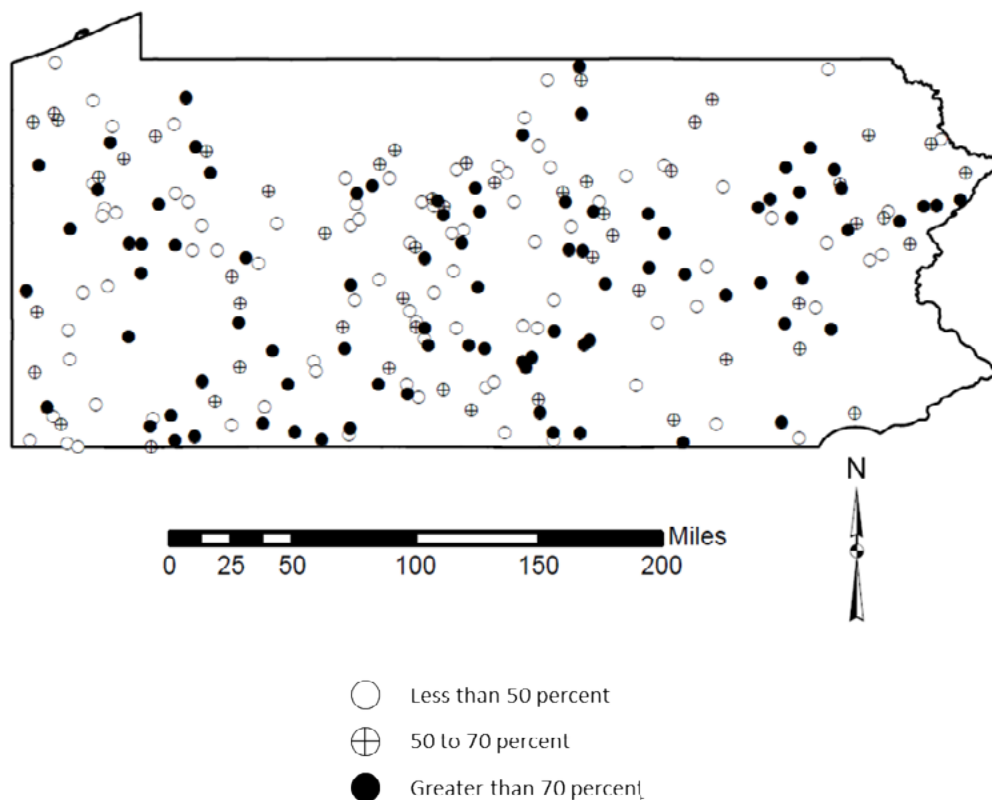


Figure 3.—Distribution of samples on forest land (in the mixed oak forest-type group with live tree stocking levels of 40 to 75 percent) by percentage of microplots with adequate advance regeneration of canopy replacement species, Pennsylvania, 2009–2013.

percent of the microplots with adequate advance regeneration. The geographic findings do not indicate a particular pattern (Fig. 3). The metrics used here include species other than oak that have the potential to achieve high canopy. This means that some of the samples with adequate stocking of advance regeneration may not have restocked with oaks, but rather with other species (e.g., red maple regeneration that commonly occurs under an oak canopy).

Habitat Trends

Balancing the need for healthy regeneration and wildlife habitat in new forests requires careful monitoring. The last case study covers the use of PRS data as part of a large-scale wildlife management planning process. The Pennsylvania Game Commission uses PRS information to help evaluate deer habitat health for determining the number of deer to harvest for Pennsylvania's wildlife management units (WMUs) shown in Fig. 4 (Rosenberry et al. 2009). A pivotal question for long-term planning has been: Are habitat conditions improving over time?

The PRS approach described in the previous section has been used to estimate the percentage of samples classified as oak/hickory with adequate stocking of species that can achieve a high canopy position. For contrast, this case study also evaluates composition for commercially desirable species. The basic difference is that the commercially desirable species list excludes beech and birch that are considered high canopy species.

Estimates of the percentage of samples classified as adequate over time for two WMUs in the oak/hickory region that have a history of high browse pressure illustrate habitat trends. WMU 2G is in the north-central region and has shown statistically significant improvement for high

canopy species since 2005 (Fig. 4). In 2005, 36 percent of the 2G samples were adequately stocked with regeneration of high canopy species compared to 41 percent in 2013. Commercial species showed a significant decrease from 35 percent to 30 percent since 2005. WMU 4D lies to the south of 2G and is characterized by a higher concentration of oak/hickory compared to maple/beech/birch (*Acer/Betula/Fagus*), which is more common in WMU 2G. The trends show improvement for both high canopy and commercial species between 2005 and 2013. This case study uses a subset of the overall sample population yielding higher sampling errors that can limit the number of inferences that can be drawn. This means that when error rates are high, improvements in regeneration may remain undetected (Westfall and McWilliams 2012).

DISCUSSION

Twenty-five years of experience in monitoring tree regeneration in Pennsylvania offers guidance through lessons learned about monitoring, management, and policy. The tenet that all forest management activity has reciprocal impacts on wildlife habitat and other ecosystem services underlies forest management planning in Pennsylvania. This means that inventory specialists, managers, and policy makers must adjust goals and objectives to implement practices and prescriptions that balance the need for regeneration with healthy habitat for deer and other wildlife. Implications for broad-scale forest management of oak/hickory forests under stress begin with understory development before and after a stand-initiating disturbance. Currently only 4 percent of Pennsylvania's oak/hickory forest is classified as 20 years or younger. This dearth of young stands is a product of traditional use of partial harvests and passive management on private forest land. Regenerating oak/hickory forests requires both the development of competitive oak advance regeneration before harvest and near-complete overstory removal to allow for light. For most private oak/hickory forest in need of replacement, neither strategy is common. Private owners control 7 of every 10 acres of Pennsylvania's oak/hickory forest.

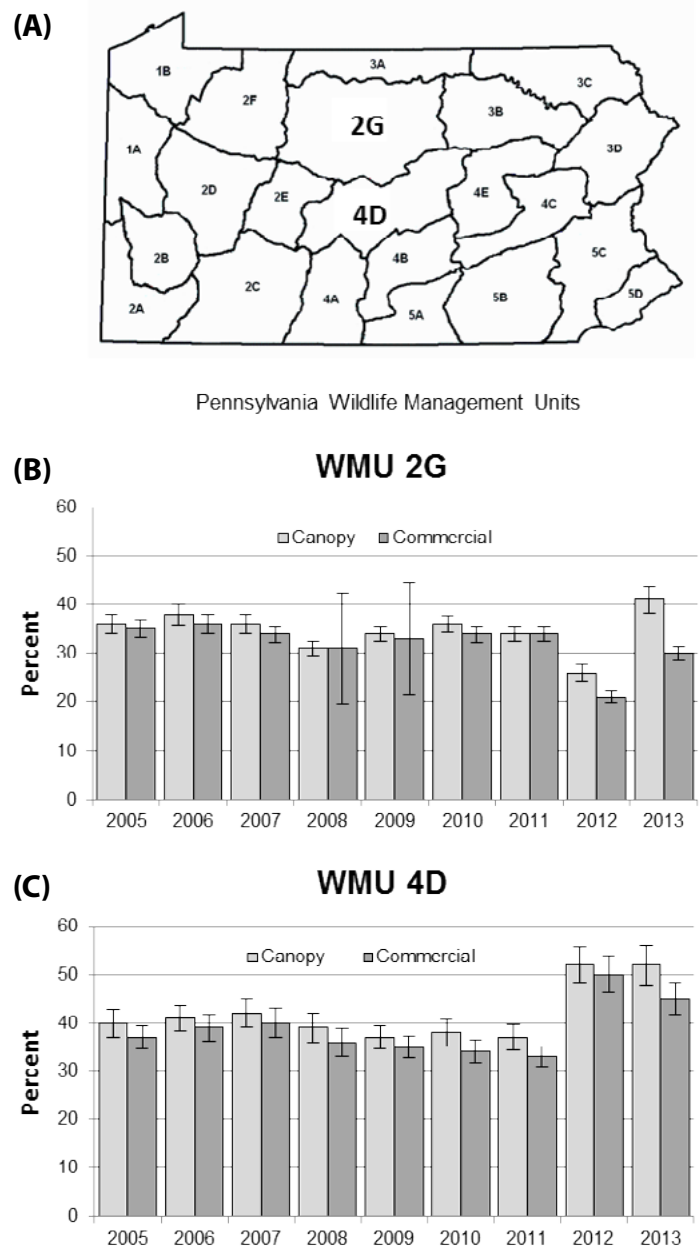


Figure 4.—Pennsylvania WMU boundaries (A) and percentage of samples adequately stocked with advance tree seedling and sapling regeneration for canopy replacement species for WMU 2G (B), and WMU 4D (C), 2005–2013. Sampling error bars are shown for the 68-percent confidence level.

Monitoring

Some basic techniques for regeneration inventory and monitoring have been delivered and vetted in the literature (McWilliams et al. 2015):

- The PRS sample facilitates useful statistical inference for baseline and trend analysis of herbivory levels and seedling attributes.
- Regeneration indicator data support a wide range of regeneration evaluation metrics to address taxa-level research questions.
- Preliminary work assessing regeneration adequacy for oak/hickory of the mid-Atlantic region shows promise for modifying the approach for use in other areas of the NRS region.
- Including regeneration status in FIA reports fills a critical gap in understanding the formation and development of young forests under stress from multiple interacting stressors.
- The regeneration indicator database satisfies the need for publicly available information about tree seedlings and herbivory impacts for subcontinental-scale studies.
- Incorporating regeneration indicator data will improve the interaction of ecological process models and other models with seedling recruitment modules.

Management

Another tenet is that regeneration potential is set during the understory reinitiation and stand initiation phases of early stand development (Dey 2014, Oliver and Larson 1996). Management options for oak/hickory forests under stress from herbivory and other factors will require a mix of silvicultural prescriptions. Managers will need to consider current methods and keep abreast of new research to make fully informed decisions. Most of the lessons learned for managing forests under stress are not new, but in Pennsylvania the full suite of stressors and their complex interactions must be considered. Some prominent examples follow:

- Prescriptions that establish, recruit, and retain competitive oak seedlings from the mature stand before harvest through the stem exclusion phase after harvest will need to pay particular attention to contemporary drivers and stressors (e.g., invasive plants and climate change).
- Herbivory by white-tailed deer needs to be considered before harvest in oak/hickory stands scheduled for stand initiation in medium-pressure and high-pressure subregions.
- The most successful technique for regenerating oaks stands is the shelterwood system and related management prescriptions described by Brose et al. (2008).
- Fencing is often needed to reduce deer impacts and facilitate application of herbicides and other controls.
- Controlling composition and structure of understory vegetation in stands with entrenched legacy vegetation as described by Royo et al. (2010) typically requires prescriptions that are often too costly for private forest landowners.
- Developing adequate stocking of competitive oak and associate species requires vigilant stewardship through the sapling stage in many cases.
- Information evaluated so far indicates a slow restorative process for understories with sparse regeneration.

Policy

Pennsylvania policy makers, planners, and legislators have used PRS results for guiding forest and wildlife management projects (Frye 2006). Prominent activities that may also be relevant for other areas of the mid-Atlantic region are as follows:

- Inform the Pennsylvania Bureau of Forestry planning efforts for state-owned forest land and support strategies for state-level private forest stewardship.
- Inform other state agencies and nongovernmental organizations grappling with contemporary forest issues such as forest health.
- Inform the forestry community by supplying content for 5-year state forest resource reports, technical articles, annual bulletins, and other outlets.
- Help the Pennsylvania Game Commission continue to improve the methods for deriving habitat health estimates for deer and other wildlife.
- Develop and distribute guidance for budgetary decisions on allocating funds among forest research projects.

CONCLUSIONS

The connections between humans, wildlife, forest health, and forest regeneration are important for sound forest management and policy formulation. Cumulative effects of these and other factors make for complicated policy and management decisions. As pointed out by McShea and Healy (2002), plans for maintaining the oak component are needed to slow the potential loss of oak trees over the next 100 years.

Oak regeneration has become a major forest-policy issue, even though excellent guides are available for regenerating oak (Brose et al. 2008, Johnson et al. 2009, Steiner et al. 2008). The heart of the issue is that the conditions for regenerating oaks and associate species are not favorable, forcing very high costs for management activities such as fencing, herbicide application, and weeding, to control competing vegetation, available light, and deer, (Jackson and Finley 2011). The cost of investing in future forest benefits is challenging for the diverse mix of private forest landowners who control most of the oak/hickory forest.

The PRS has confirmed that deer and the widespread application of partial harvest are drivers and barriers to young oak/hickory forest formation across Pennsylvania. Over the 25-year history of this study, the balance between regeneration and available browse has shifted in a positive direction, primarily because of reductions in the deer herd. A rough measure for the balance or imbalance may be the percent of forest by broad browse impact level. About 20 percent of the forest is estimated to have very low/low impact, or a positive balance. An estimate of 60 percent for medium impact means that large areas of oak/hickory forest will need management that considers browse impact along with local conditions. The estimate for high/very high impact is roughly 20 percent, which implies conditions that are out of balance. The PRS adds utility for monitoring, managing, and developing policy strategies for improving the health and resiliency of Pennsylvania's oak/hickory forest.

LITERATURE CITED

- Bechtold, W.A.; Patterson, P.L., eds. 2005. **The enhanced forest inventory and analysis program—national sampling design and estimation procedures**. Gen. Tech. Rep. SRS-80. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 85 p.
- Brose, P.H.; Gottschalk, K.W.; Horsley, S.P.; Knopp, P.D.; Kochendorfer, J.N. [et al.]. 2008. **Prescribing regeneration treatments for mixed-oak forests of the mid-Atlantic region**. Gen. Tech. Rep. NRS-33. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 100 p.
- Dey, D.C. 2014. **Sustaining oak forests in eastern North America: regeneration and recruitment, the pillars of sustainability**. *Forest Science*. 60(5): 926-942.
- Frye, R. 2006. **Deer wars: science, tradition, and the battle over managing white-tails in Pennsylvania**. University Park, PA: Penn State University Press. 328 p.
- Horsley, S.B.; Stout, S.L.; DeCalesta, D.S. 2003. **White-tailed deer impact on vegetation dynamics of a northern hardwood forest**. *Ecological Applications*. 13(1): 98-118.
- Isaaks, E.H.; Srivastava, R.M. 1989. **An introduction to applied geostatistics**. Oxford, UK: Oxford University Press. 561 p.
- Jackson, D.R.; Finley, J.C. 2011. **Herbicides and forest management, controlling unwanted trees, brush, and other competing vegetation**. University Park, PA: The Pennsylvania State University. 20 p. <http://pubs.cas.psu.edu/freepubs/pdfs/UH174.pdf> (accessed January 2016.)
- Johnson, P.S.; Shifley, S.R.; Rogers, R. 2009. **The ecology and silviculture of oaks**. New York, NY: CABI Publishing. 560 p.
- Latham, R.E.; Beyea, J.; Benner, M.; Dunn, C.A.; Fajvan, M.A. [et al.]. 2005. **Managing white-tailed deer in forest habitat from an ecosystem perspective: Pennsylvania case study**. Report by the Deer Management Forum for Audubon Pennsylvania and Pennsylvania Habitat Alliance, Harrisburg, PA. 40 p.
- Latham, R.E.; Horsley, S.B.; Hones, B.C.; McWilliams, W.H.; Nielson, C.K., et al. 2009. **Monitoring deer effects on forest ecosystems in Pennsylvania state forests**. Research peer review and recommendations for the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry. 49 p.
- Marquis, D.A., ed. 1994. **Quantitative silviculture for hardwood forests of the Alleghenies**. Gen. Tech. Rep. NE-183. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 143 p.
- McShea, W.J.; Healy, W.M. 2002. **Oak forest ecosystems: ecology and management for wildlife**. Baltimore, MD: The Johns Hopkins University Press. 432 p.
- McWilliams, W.H.; King, S.; Scott, C.T. 2001. **Assessing regeneration adequacy in Pennsylvania's forests: a pilot study**. In: Reams, G.A.; McRoberts, R.E.; Van Deusen, P.C., eds. *Proceedings of the second annual Forest Inventory and Analysis symposium; 2000 October 17-18; Salt Lake City, UT*. Gen. Tech. Rep. SRS-47. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 119-122.

- McWilliams, W.H.; Stout, S.L.; Bowersox, T.W.; McCormick, L.H. 1995. **Adequacy of advance tree-seedling regeneration in Pennsylvania forests.** Northern Journal of Applied Forestry. 12(4): 187-191.
- McWilliams, W.H.; Westfall, J.A.; Brose, P.H.; Dey, D.C.; Hatfield, M. [et al.]. 2015. **A regeneration indicator for forest inventory and analysis: history, sampling, estimation, analytics, and potential use in the midwest and northeast USA.** Gen. Tech. Rep. NRS-48. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 74 p.
- Oliver, C.D.; Larson, B.C. 1996. **Forest stand dynamics.** New York, NY: John Wiley & Sons. 537 p.
- Rosenberry, C.S.; Fleegle, J.T.; Wallingford, B.D. 2009. **Management and biology of white-tailed deer in Pennsylvania, 2009-2018.** Harrisburg, PA: Pennsylvania Game Commission. 123 p. Available at file:///C:/Users/wmcwilliams/Downloads/2009-2018%20PGC%20DEER%20MGMT%20PLAN%20-%20FINAL%20VERSION%20(4).pdf (accessed January 2016).
- Royo, A.A.; Stout, S.L.; deCalesta, D.S.; Pearson, T.G. 2010. **Restoring forest herb communities through landscape-level deer herd reductions: is recovery limited by legacy effects?** Biological Conservation. 143(11): 2425-2434.
- Sander, I.L. 1972. **Size of oak advance regeneration: key to growth following harvest cutting.** Res. Pap. NC-79. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 6 p.
- Steiner, K.C.; Finley, J.C.; Gould, P.J.; Fei, S.; McDill, M. 2008. **Oak regeneration guidelines for the central Appalachians.** Northern Journal of Applied Forestry. 25(1): 5-16.
- Waller, D.M.; Alverson, W.S. 1997. **The white-tailed deer: a keystone herbivore.** Wildlife Society Bulletin. 25(2): 217-266.
- Westfall, J.A.; McWilliams, W.H. 2012. **Detecting change in advance tree regeneration using forest inventory data: the implications of type II error.** Environmental Monitoring Assessment. 184: 5601-5611.

The content of this paper reflects the views of the author(s), who are responsible for the facts and accuracy of the information presented herein.