Chapter 8. Predicting Forest Recovery Rates in Pennsylvania

In this chapter, we tie together the various influences on forest structure and diversity discussed earlier into a framework to be used as a basis for predicting forest recovery rates following the reduction of deer browsing. Prior estimation of recovery rates is part of the adaptive resource management process, which we see as key to managing deer from an ecosystem perspective.

Even with strong limitations on deer browsing pressure, forests cannot be expected to return to exactly the same conditions that existed prior to heavy deer browsing in the second-growth forests of the early twentieth century. The successional path of the forest has been changed by waves of introduced tree diseases, insect infestations, and invasive plants. Existing knowledge is sufficient to develop methods of reestablishing the tree component, there is limited knowledge in most of Pennsylvania[1] about exactly what kind of understory layer will return following the reduction of deer browsing pressure, even when actively fostered by restoration efforts. Nevertheless, the return of a diverse native forest understory and dramatic increases in the abundance of many currently rare tree, shrub, and herbaceous plant species can be expected, over varying time frames in different situations across the state. In this report, we call such a process structural recovery, with an important distinction between partial and full structural recovery.

Partial structural recovery consists of the restoration of quick-responding understory species such as blackberries and raspberries and the increase in abundance and height of other woody and herbaceous species that are preferred as food by deer. It can be reached relatively quickly in stands where deer browsing impacts have been low and of relatively short duration. It can be achieved somewhat more slowly, but still within 10 years, after deer density reduction in most overbrowsed stands if the canopy is open enough to allow substantial amounts of light to reach the forest floor. Full structural recovery, which includes the restoration of a suite of full-grown tree, shrub, and herbaceous species now absent from a stand, could take more than 50 years. Its speed depends on how long overbrowsing has taken place on a site and, to a lesser extent, on a site’s logging history, soil chemistry, length of the local growing season, presence of introduced invasive species, and other factors influencing propagule availability and growth rates of native plant species. Partial structural recovery denotes the reestablishment of robust shrub and herbaceous understory layers, even if they are composed of relatively few species. With full structural recovery, those layers are not only robust but include a large fraction of the native species that were once present in a given forest type and landscape position.

The challenge for the near term is to demonstrate that partial structural recovery is occurring following reduction of deer densities, so that concerned stakeholders and the general public can have confidence that natural processes are working as predicted. In regions where deer overbrowsing has been occurring for 50 years, it is not reasonable to expect full structural recovery across the region in less than 50 years, although patches within the region may recover fully in a shorter time.

In cases in which a landowner's objectives include periodic removal of wood for sale that requires the use of heavy machinery, then immigration of slow-dispersing forest floor herbaceous plants might regularly be cut off.[2] In such a situation, full structural recovery might not be possible but an intermediate level of structural recovery should be the goal.

Several major factors can influence structural recovery time in forest stands (Table 5). Based on knowledge of these factors and of the characteristics of individual plant species, it is possible to make some predictions about what course of events to expect after release from deer overbrowsing and in what time frame (outlined qualitatively as a flow chart in Figure 2). Quantitative versions of these predictions can be used to test the theoretical understanding on which any ecosystem management plan rests. In particular, they can be used as part of an A.R.M. protocol.

If a seed supply is present and sufficient light is reaching the forest floor, then some species (e.g., *Rubus* spp., seedlings of sweet birch, yellow birch, eastern hemlock, eastern white pine) can grow through a dense fern cover in as little as 5 years,[3] ultimately shading and reducing the ferns to their normal pattern of small, isolated individuals and patches. If light reaching the forest floor is low, then recovery must await the canopy opening up, either as a result of natural aging and mortality of trees, natural disturbance, or commercial logging. Clearcutting or heavy canopy thinning are likely to hasten partial recovery but delay full recovery by engendering dominance first by early-successional species and later by sapling and even-aged small adult trees, which sequentially suppress the growth of plant species characteristic of mature forest understories. If the propagule supply for a plant species is limited, as for many herbaceous plants, then immigration rates or the local availability of refugia may determine the length of time before that species increases to a large enough population to be self-sustaining in the long term. The presence of a dense hay-scented fern or New York fern cover induced by overbrowsing complicates the situation; the ferns may also prosper in conditions of good light, increasing their interference with reestablishment by other plants. A similar problem is associated with the presence of introduced invasive species.

Recovery time

It is possible to estimate the time to structural recovery by breaking the process into a number of steps. First, there is the time it takes for recovery to begin, which we call recovery start time. Recovery start time depends on how long it takes for natural or human processes to allow sufficient light to reach the forest floor to support the reestablishment of a diverse understory.

Table 5. Factors affecting forest recovery time following reduction of severe deer browsing

factor	effect	depends on, or varies with:
Amount of light reaching forest floor	Determines how fast plants can grow and produce seeds or other propagules, including species whose increased cover due to selective avoidance by densely populated deer interferes with reestablishment by other plant species.	Stand structure; stand age; forest type; recent disturbance history
Condition of seed supply in forest floor	Determines whether a species can recover prior to the immigration of new seeds.	Duration of deer overbrowsing; longevity of dormant seeds in soil
Availability of refugia	Speeds up the spread of plants that would otherwise require very long times to immigrate.	Presence of sites inaccessible to deer, e.g., boulder tops, steep slopes
Time since last removal of canopy trees	Recent removal speeds up partial structural recovery by increasing light and soil resources for seed production and growth, but slows full structural recovery after reduction of deer densities because succession after logging can suppress or eliminate some understory plants.	Logging history; history of major natural disturbance
Extent of hay-scented fern or New York fern cover	Interferes with the establishment and growth of many plants.	Duration of deer overbrowsing; presence of ferns at the start of deer overbrowsing and previous thinning of the canopy
Native forest species' growth rates	Some plants, e.g., forest herbs, especially those that rely on vegetative reproduction rather than seed, can grow so slowly that their inherent growth rate can be an important factor in the total time it will take to reach full recovery.	Species' reproductive modes

(Table continued on next page.)

factor	effect	depends on, or varies with:
Soil chemistry	Plant growth is slowed on sites with a low availability of N, Ca, Mg, or possibly K or P, or a high availability of Al or Mn.	Soil parent material (bedrock, glacial till, etc.) supplies (Ca, Mg, K, P); organic matter quality (N, P); pH (Al, Mn)
Soil moisture	Waterlogged soils or dry, sandy or rocky soils restrict recolonization to a subset of the available species and slow their growth.	Soil particle size distribution; topography; hydrology; growing-season droughts and unusually wet years (and their long-term patterns of occurrence)
Disease and insect pest outbreaks	Can change species composition and slow the recovery rate.	Immigration or importation of insects and pathogens; in some cases, prolonged drought or other stress

Once recovery starts, there are other sources of delay to consider. For instance, there is the time it may take for significant numbers of propagules to migrate into the stand if propagules have been lost or greatly depleted — termed propagule lag time.[4] Another delay arises from the time it takes newly released plants to penetrate and overwhelm the fern layer if a dense fern layer is present. We call this the fern-penetration lag time. Finally, there is the time it takes for a newly regenerated species to grow to maturity and compete with any deer-tolerant or deer-resistant species that may be dominating the stand — called the competition lag time.

Under this conceptual framework, the time to reach recovery in a particular stand is a function of the four terms. In many cases, the functional relationship would be a simple sum:

$$\begin{aligned}\textit{time to recovery} = \textit{recovery start time} + \textit{propagule lag time} + \\ \textit{fern penetration lag time} + \textit{competition lag time}\end{aligned} \qquad \text{Eq. 3}$$

In a particular stand, any one or all of these lag times could be zero. Some of them will be different for different species. Some will be different depending on whether or not partial or full recovery is under consideration.

Equation 3 does not account for deer densities that are below current levels but above sustainable levels. The effect of deer on structural recovery time could be parameterized as:

$$\textit{time to recovery} = T_{(deer = 0)} + D \times T_{slope1} + D^2 \times T_{slope2} \qquad \text{Eq. 4}$$

where $T_{(deer=0)}$ is the recovery time from Equation 3, D is deer density, and T_{slope1} and T_{slope2} are parameters to be determined from the literature or professional judgment.

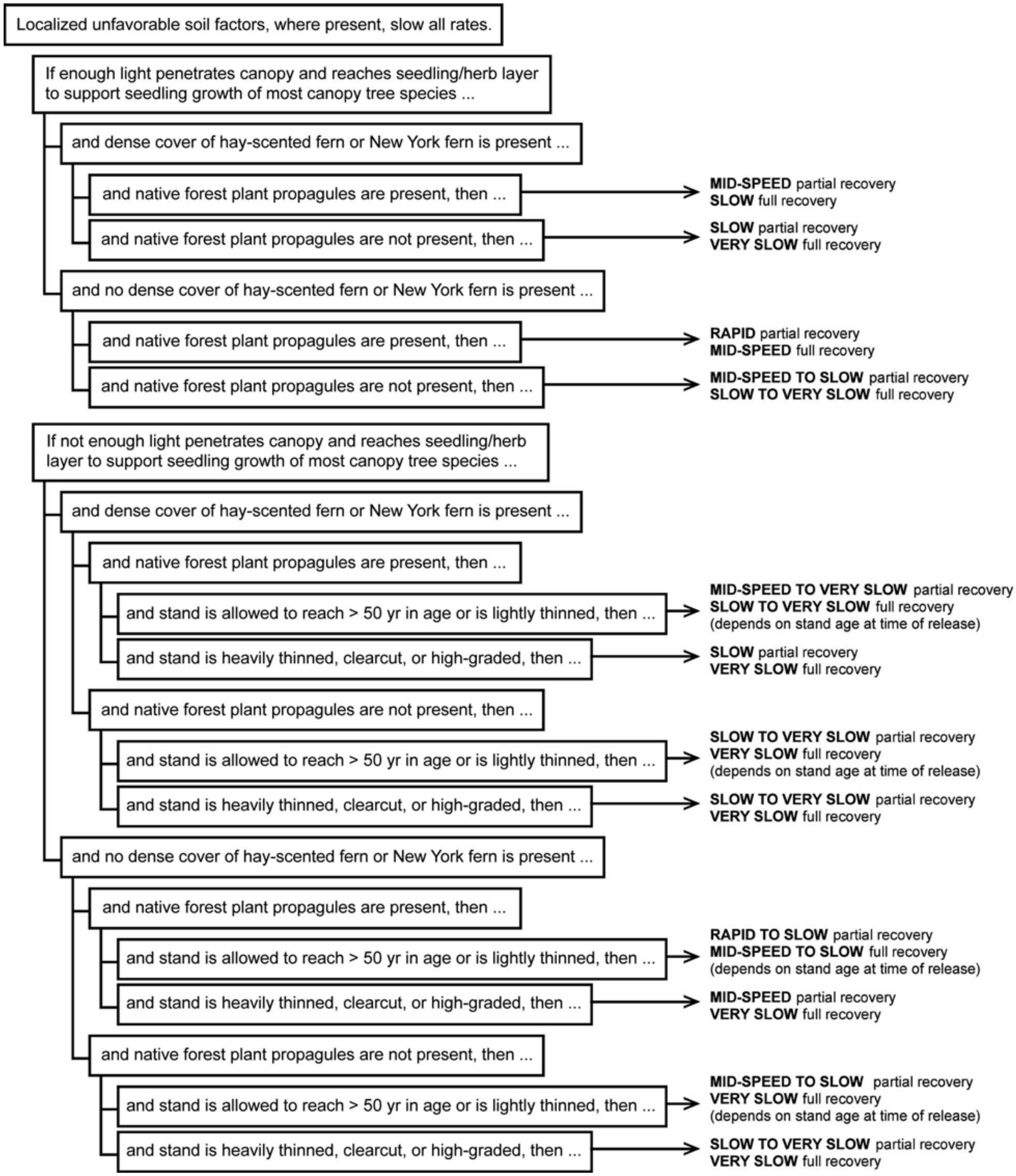


Figure 2. Relationships among major factors affecting rates of recovery of Pennsylvania forests after release from deer overbrowsing

Although this parameterized equation does not go to infinity, as it should, when *D* approaches current values of deer density, a very high value for recovery time, say 150 years, could be considered as tantamount to infinity for A.R.M. purposes.

Equations 3 and 4 provide the framework for a model that could be used as part of an A.R.M. protocol.[5] When a term in the equation for a particular class of species cannot be quantified based on past data, professional judgment needs to be called upon to determine a reasonable initial estimate. Coefficients needed for situations in which there exist no immediately applicable data from past field research could be devised by adjusting coefficients obtained from field data collected in the most similar situations available, using the modifying factors listed in Table 5 and professional judgment.

Under A.R.M., data from subsequent monitoring is used to refine the model coefficients. The only monitoring data that provide useful tests in the short term are from those species with relatively short recovery times or stands with favorable growth conditions such as adequate light at the forest floor. Monitoring of the earliest component of Equation 3, recovery start time, could also provide early tests of models in A.R.M. For example, structural recovery would be recorded as having started as soon as browsing-sensitive plants are found growing amid the fern layer above some threshold density based on data from overbrowsed stands of the same or a similar forest type. For slow-responding species, indicators of progress towards recovery, such as changes in average percent cover or the behavior of surrogates, might prove more useful. Change can be detected earliest by measuring herbaceous and understory plants that recover rapidly, such as *Rubus*, together with a surrogate for herbaceous vegetation in general. One such surrogate is the subset of tree species that can regenerate successfully only if browsing pressure is low enough to also permit recovery of shrub and herbaceous plant diversity (see Chapters 9 and 10 on the use of indicators). Use of this method is predicated on the assumption that seed sources remaining in the canopy are available to initiate fast recovery of this component of the woody flora.

Because each of the lag terms in Equation 3 can be different for individual stands and individual species, depending, for example, on the local availability of refugia and the past history of logging, a great variety of responses to reductions in deer browsing can be expected across the state and even among stands in close proximity to one another. Recovery will be heterogeneous in space and time and across species.

Recovery start time

The first site factor of importance is the amount of light reaching the forest floor. It is influenced by forest type, stand age since the last major, canopy-removing disturbance, stand structure, and the recent history of moderate disturbance. Forest type is important because different species of trees let different amounts of light reach the forest floor.[6] In older stands, mortality of old or injury-weakened trees opens up the canopy, allowing understory plants and tree seedlings to grow and reproduce. In stands thinned by commercial cutting, significant amounts of light reach the forest floor. Natural disturbances such as storms and fires also can open up or even occasionally remove the canopy. Selective browsing by deer on their preferred tree species produces a tight mid-story subcanopy that lets less light through. For example, in northern hardwoods, shade-tolerant striped maple and American beech, which are either less preferred by deer or are resilient to browsing, form a subcanopy layer that further attenuates the small amount of light penetrating the upper canopy. This greatly reduces light availability at the forest floor, effectively shutting down the regeneration of most species. Once a dense mid-story layer of American beech becomes established, it could take considerable time to reverse the pattern. With every year we delay dealing with overbrowsing, more forest acres are converted to this slow-to-recover regime.

Light availability at the forest floor is a crucial predictive factor. In shaded forest stands, recovery of both understory and overstory plants from long-term overbrowsing must await the day when either tree mortality, fire, windstorm, a pest outbreak, or loggers have opened up the canopy. In stands more than about 50 years old, which make up the majority of Pennsylvania forests, the canopy already has gaps that will facilitate recovery. In younger stands, say of age A, it will take around 50 minus A years for normal tree mortality to begin opening up the canopy. Processes other than aging can decrease that lag time. For instance, about 1.3% of the forest can be expected to be opened up by natural disturbance each year,[7] and about 2.5% of the forests in the state can be expected to be cut each year at varying levels of intensity.[8]

If a plant species remains in the understory in a suppressed form, then it will begin to recover as soon as light is available. If not, then additional delay will occur. Similarly, if a plant species persists in refuges protected from deer, such as large boulders or steep slopes, then it can begin to spread to the stand at large after release from overbrowsing as soon as light is available on the forest floor.

Propagule lag time

Condition of the seed supply (or more generally the propagule supply), is a major factor governing the rate of change for individual plant species.[9] For instance, if a tree species remains in the overstory, recovery of that species should be faster.

If a propagule supply is absent due to decades of heavy deer browsing and a lack of local refugia, then propagule lag time will depend on immigration rates. Species dispersed by birds, such as blackberries and raspberries, migrate the fastest. Immigration rates of herbaceous plants dispersed by means other than birds, for example, those dependant on ant or gravity dispersal,[10] are poorly known and may be dominated by unusual events in an area's history that speed up what would otherwise be a very slow process. Many forest herbs migrate slowly, often depending entirely or almost entirely on vegetative spread. Recolonization by such species is expected to be exceedingly slow. Clearly, propagule lag time varies greatly by species.

Some immigration may take place before the recovery start time. Thus, in certain situations immigration might delay recovery only slightly. For species with wind-dispersed seeds, immigration may be facilitated by some of the same events that open the canopy to light, such as storms and high winds. Other canopy-opening events, such as logging, will not carry propagules into an area unless loggers and foresters bring them in deliberately.

Fern penetration lag time

Dense forest-floor cover by hay-scented fern and New York fern often is associated with severe overbrowsing in combination with canopy thinning,[11] and may occur only in the presence of these two factors together.[12] Rhizomatous fern dominance of the forest understory is quite prevalent in some areas of Pennsylvania. Dense cover of these two fern species was found to affect 48% of the stands in a survey taken in the heavily browsed Allegheny National Forest.[13] In the northeastern counties of Pennsylvania, fern dominance was found on approximately 33% of a large sample of non-industrial private lands.[14]

Dense cover of rhizomatous ferns in the forest understory hinders the emergence and establishment of other plant species[15] (see detailed discussion of this issue in Chapters 5 and 7). If deer overbrowsing followed by thinning has driven a forest stand into understory dominance by ferns, recovery times will be longer for nearly all native forest species, in at least some cases a great deal longer.[16]

Competition lag time

The time it takes for a species to reestablish a self-sustaining population depends on how effectively individuals of that species can garner essential resources and preempt them from other plants, given the specific habitat's levels of supply. The lag due to competition depends partly on soil conditions, roughly equivalent to the forestry concept of "site quality." Plants compete less and grow faster in stands with high nutrient availability and adequate (but not excessive) moisture. Other factors being equal, deep, loamy soils[17] high in calcium and magnesium derived from carbonate-containing bedrock (limestone, dolomite, marble) support faster growth than other types of soil for many plant species.

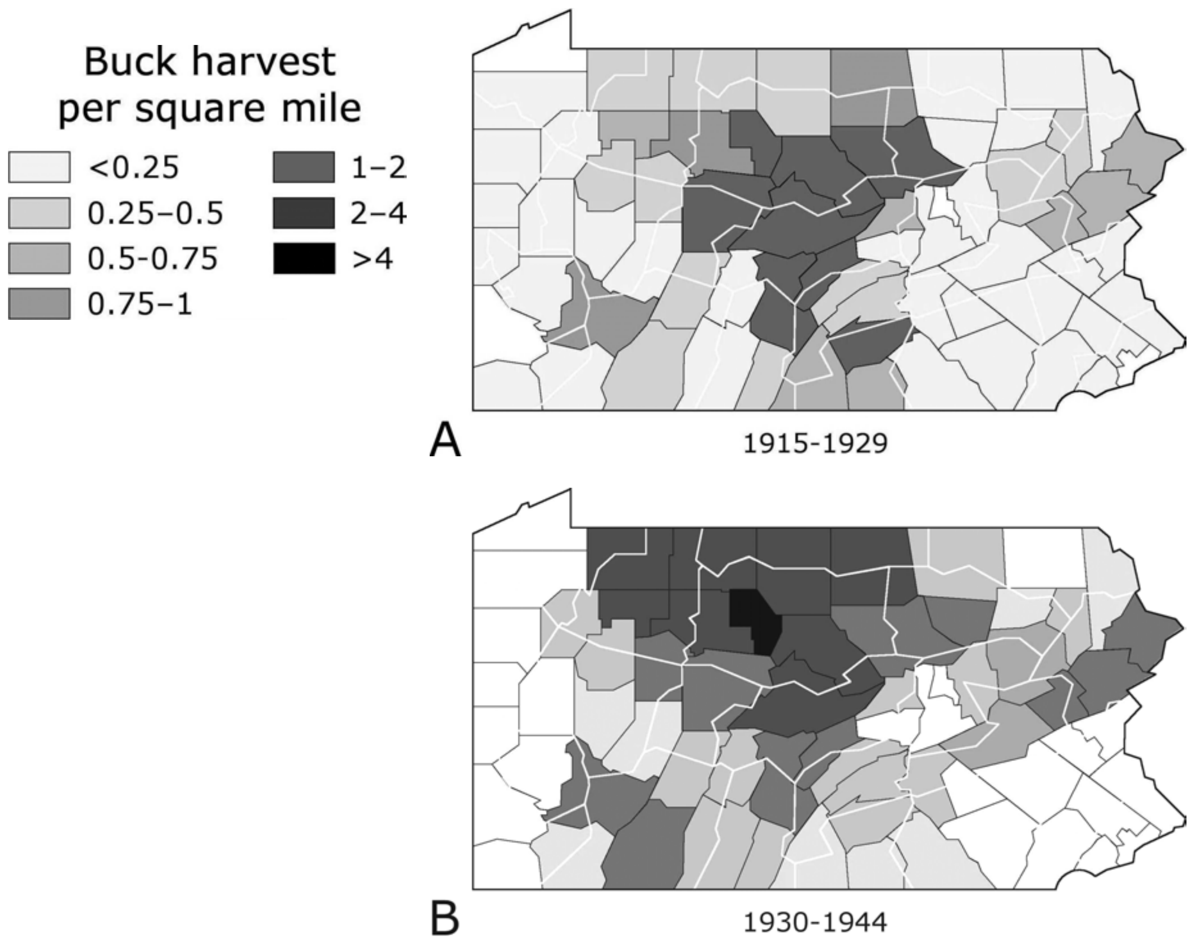
Where moderate light levels are present, such as in thinned stands, *Rubus* and a few other plants (including sweet birch, yellow birch, eastern hemlock, and eastern white pine) can grow through the fern layer, eventually casting enough shade to thin or eliminate it. Later still, when the new tree and shrub growth becomes large enough to begin self-thinning or when the canopy is again thinned by disturbance, enough light can reach the forest floor to support the establishment and growth of species that were not able to grow through the fern layer. Although tree seedlings of some tree species may quickly overtop the ferns, it will still take many more years for the trees to grow tall enough to take their place in the forest canopy.

Variation in climate affects recovery rates, even in an area with as narrow a range in latitude and elevation as Pennsylvania. The frost-free period in parts of Pennsylvania's Piedmont and Atlantic Coastal Plain is more than 30% longer than in McKean County; the length of the growing season varies between these extremes elsewhere in the state,[18] depending on elevation and on distance and direction to Lake Erie and the Atlantic Ocean. A roughly parallel geographic pattern of expected daily radiation (a combination of solar angle and the amount of time when the sun is not behind clouds) most likely magnifies the effect of different growing seasons on plant growth rates, but it may be counterbalanced to some degree by a reverse pattern of annual moisture deficit.[19] The net effect of regional climate on recovery times is likely to favor the fastest recovery rates, if all else were equal, in the southeastern and extreme southwestern counties and produce the slowest recovery rates in the north-central counties.

Average time to recovery

Even though there will be considerable variation in recovery time from stand to stand, we can make some estimates of average time to partial recovery based on the following assumptions: (1) stand age is distributed evenly within size-class categories for which the U.S. Forest Service collects aggregate data,[20] (2) the rate of canopy openings caused by natural disturbance is 1.3% per year, (3) the rate of cutting is 1.25% per year for long-rotation stands (more than 75 years between cuts) and 3% for all others, (4) propagules of some species are still present or immigrate quickly through bird dispersal, and (5) it takes 5 years for fast-growing species like shrubs in the genus *Rubus* to overtop the fern layer, if a fern layer is present. With these assumptions, about 1.6-million acres of timber lands in long rotation and older than 50 years could show partial recovery within 5 years, that is, restoration of a basic understory (e.g., one composed mostly of *Rubus*).[21] For species that require wind dispersal for migration of propagules to replace the local supply destroyed by decades of deer browsing, recovery on long-rotation stands will take longer; the average time for recovery might range from 5 to 80 years, depending on proximity to areas with source propagules.[22] In similar situations, ant- and gravity-dispersed species and those that reproduce vegetatively may take a century or longer to recover without replanting by humans.[23]

Insufficient data are available to estimate partial recovery times for non-industrial private lands that have been partially harvested, either with diameter-limit cuts or thinning. Presumably, the recovery times will be longer than for stands in long rotation because of stronger "legacy effects" from long-term deer overbrowsing (i.e., interfering cover of unpalatable or browsing-resistant species, mainly striped maple, American beech, hay-scented fern, or New York fern). The recovery prospects for stands that have undergone both intense deer browsing and more than two diameter-limit cuts appears particularly bleak.[24] The longer Pennsylvanians wait to reduce deer densities on non-industrial private lands, the more stands will pass into a state that is highly



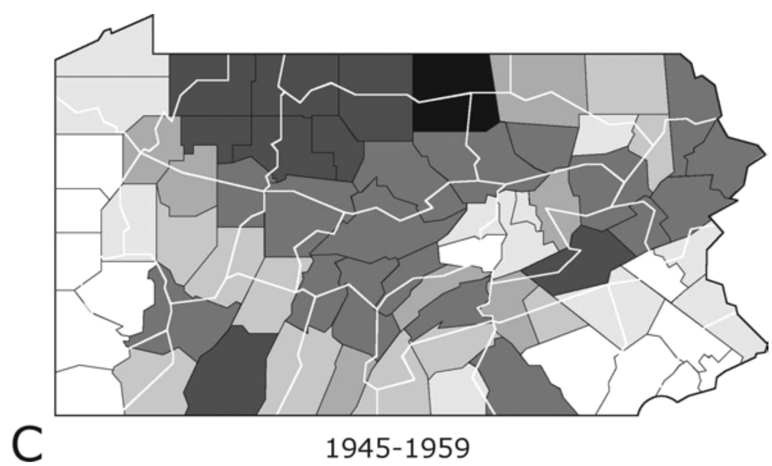


Figure 3. Average yearly buck harvest by county, 1915-1998.[25] Boundaries of the Pennsylvania Game Commission's wildlife management units (W.M.U.s) are shown in white (see Figure 4A).

resistant to recovery, brought about by intense deer pressure and, in many cases, a third diameter-limit cut.

Predicting average times to full structural recovery is a much more difficult exercise than trying to predict times to partial recovery. On non-industrial private lands, the recovery time could exceed the average time between harvests, which may be as low as 27.[26] Consequently, the long-term degree of forest recovery on non-industrial private lands after reduction of deer overbrowsing may have more to do with the quality of future cutting practices than any other factor we have discussed. On lands where trees are not harvested, we assume that full structural recovery will take, on average, at least 50 to 100 years.

D 1960-1974

E 1975-1989

F 1990-1998

Geographical distribution of partial recovery times

It is important to bear in mind that the above figures are intended as ranges and averages. Partial recovery times will vary among forest stands from zero to many decades. Under certain conditions, some changes following release from deer overbrowsing will occur relatively quickly. For instance, where overbrowsing began recently and fern dominance and loss of seed supply are negligible, as in many of the southern-tier counties in Pennsylvania, partial structural recovery should be very rapid in stands where a significant amount of light reaches the forest floor.

Of the four key site factors affecting recovery rates we have identified, three are strongly influenced by deer overbrowsing, namely the amount of light reaching the forest floor, the condition of the seed supply, and the extent to which rhizomatous ferns have taken over. Consequently, the duration of severe deer browsing (see Figure 3, page 122) can serve as an overarching predictor of recovery rate. In parts of the state where deer overbrowsing has gone on for many decades, especially the northern counties, forest recovery is expected to be relatively slow, all other factors being equal. The opposite is expected to be true in the southern counties. Another regional influence is forest type; oak stands, characteristic of most of the southern two-thirds of the state (Figure 4B), tend to let more light reach the forest floor than do northern hardwood and beech-maple forests.[27] Regional variation in the length of the growing season and in expected daily solar radiation roughly parallels the distribution of oak dominance and may reinforce the geographical patterns of both duration of overbrowsing and light transmission through the forest canopy. In addition, nearly all of the areas underlain by carbonate rock, where soils are richest in available calcium and magnesium (and best buffered against acidification by air pollution), are scattered across the southern two-thirds of the state.[28]

The Allegheny High Plateaus region (W.M.U.s 2F, 2G, 3A, and 3B on Figure 4A) has the strongest legacy effects of prolonged high deer densities (Figure 4D, 4E, and 4F). Heavy cover of rhizomatous ferns (Figure 4D) is an important legacy effect but its distribution tells only part of the story. Heavy fern cover typically does not occur where striped maple and American beech saplings already are established and producing dense shade, a frequent occurrence across the northern hardwoods region in the northern one-third of Pennsylvania. Density of shrub cover (Figure 4E) and diversity of shrub species (Figure 4F) may be more reliable than fern cover for comparing the magnitude of legacy effects among different forest types in the state.

Where deer densities are greater than 24 per square mile (Figure 4C), there are assumed to be negative effects on tree regeneration and the higher the deer density, the more severe the effects on regeneration. However, even deer densities below 10 per square mile are likely to limit the full recovery of forest understories.[29] The current very high deer densities (averaging over 40 per square mile) in parts of western Pennsylvania are in the eastern broadleaf–west silvicultural region where the highest regeneration rates are found (Table 3, page 40). This area has the best chance of quick recovery, but only if deer densities are reduced soon. Despite estimates of low overall average deer density in extreme southeastern Pennsylvania (Figure 4C, page 126), dense urban and suburban development and highly fragmented forests there mean that some areas have no deer and small pockets have some of the highest deer numbers found anywhere. Located in the eastern broadleaf–east silvicultural region (Table 3), this part of the state has some of the least-severe legacy effects and should recover quickly after deer density reduction even though regeneration rates are not as high there as in western Pennsylvania.

The good news, in terms of recovery rates, is that there are large areas of forested land in Pennsylvania that should begin to recover relatively quickly after reduction of deer densities (in the lighter-colored areas in Figures 4D through 4F, page 127). The bad news is that the longer we wait to take action on deer, the more this potentially fast-recovering acreage will shrink. Also, there are large areas in the forests of Pennsylvania that will not recover until sufficient time has elapsed for self-thinning, commercial thinning, or natural disturbance to occur. In areas where rhizomatous ferns have become abnormally abundant due to many years of deer overbrowsing combined with tree thinning, it will take even longer for full structural recovery. As a result, there has been interest in exploring ways of speeding up recovery, with the focus so far being on the overstory layer and those trees that have commercial value to the wood products industry.

Speeding up recovery

Historically, measures to speed up recovery following reduction or elimination of deer overbrowsing have been carried out by the wood products industry, targeting the regeneration of commercially valuable tree species following canopy removal by logging. The first and most crucial step has been to reduce deer browsing. Deer browsing pressure has been reduced by cutting large enough tracts to saturate the existing deer population with forage, which grows rapidly after elimination of all overstory shade. With sheer numbers of tree seedlings overwhelming even a dense deer population's food needs, some have the chance to grow to heights beyond the reach of deer. By the time the canopy closes and the amount of alternate forage (shrubs and herbaceous plants) declines, the trees are saplings with leaves above the browse line, able to survive the presence of deer even in high numbers. Although such a technique can work for trees, it will not work for understory plants whose maximum height is near or below the height a deer can reach. Consequently, saturation cutting is not among the methods available to reduce deer browsing pressure when the goal is ecosystem recovery.

Another method of reducing deer browsing pressure other than harvesting the deer themselves is the use of fencing. Successful fencing leads to heterogeneous population densities of deer but at a smaller scale than selective hunting by region. Typically, areas fenced for commercial tree regeneration enclose 10 to 40 acres on state forest lands and the Allegheny National Forest or up to 100 acres on land managed by large wood-products companies, and are maintained for 5 to 10 years before being removed or relocated. Whether fencing is cheaper than hunting or alternative deer removal techniques is an economic question that is not explored in this study. However, if fences were to be repaired indefinitely, as is required to maintain an understory layer, the cost of fencing would be far higher than where the goal is solely to reestablish tree seedlings.

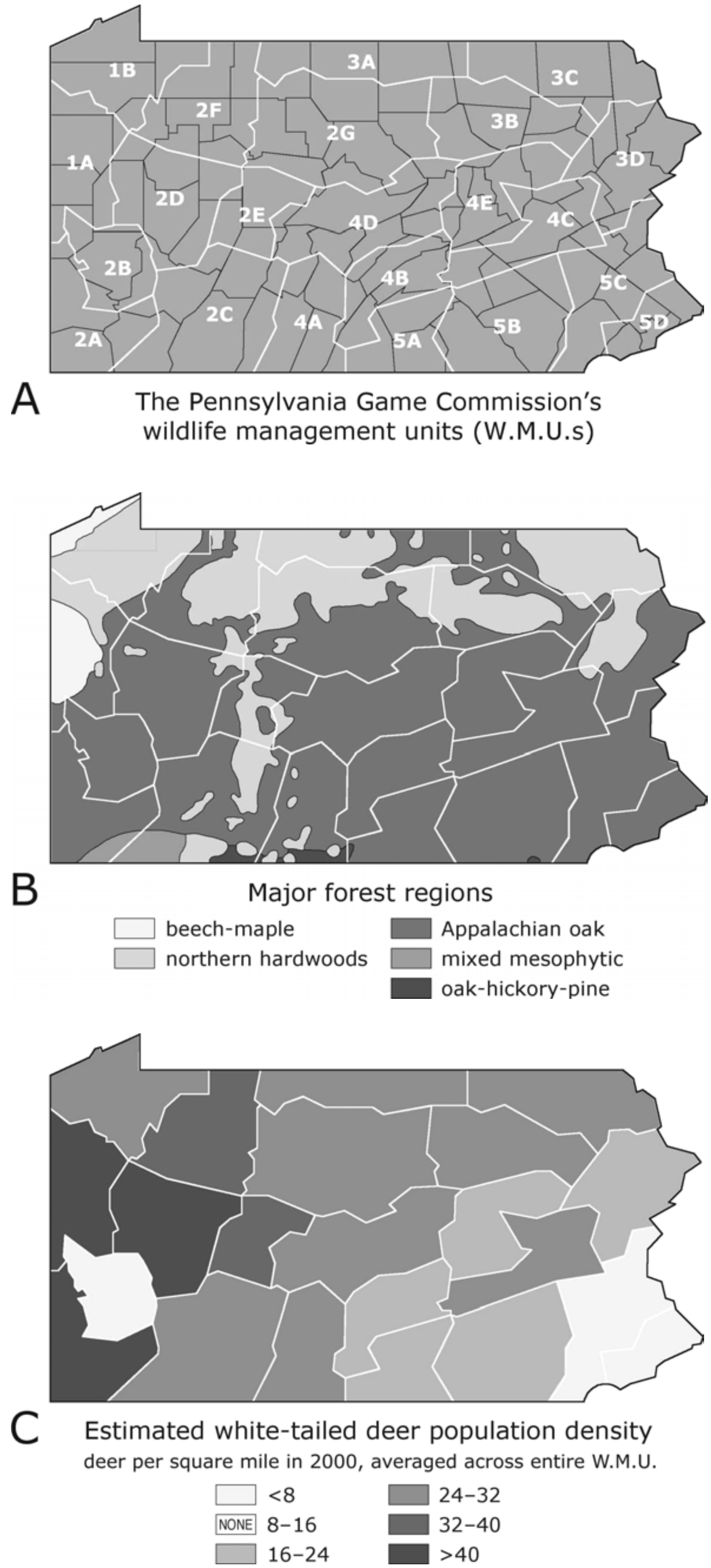
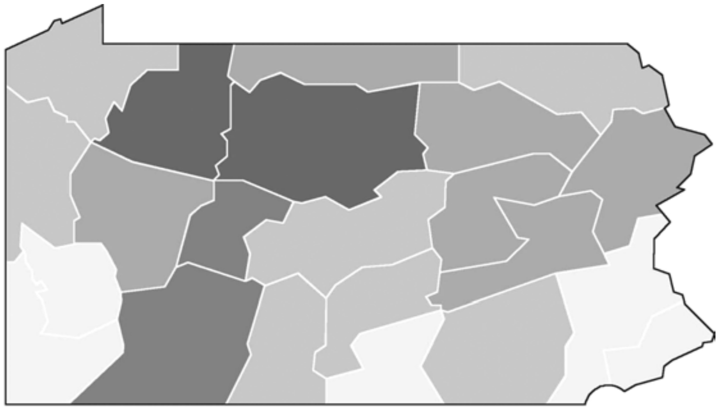
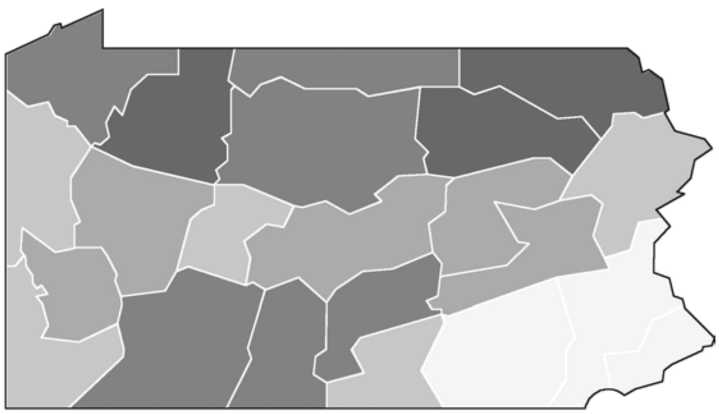


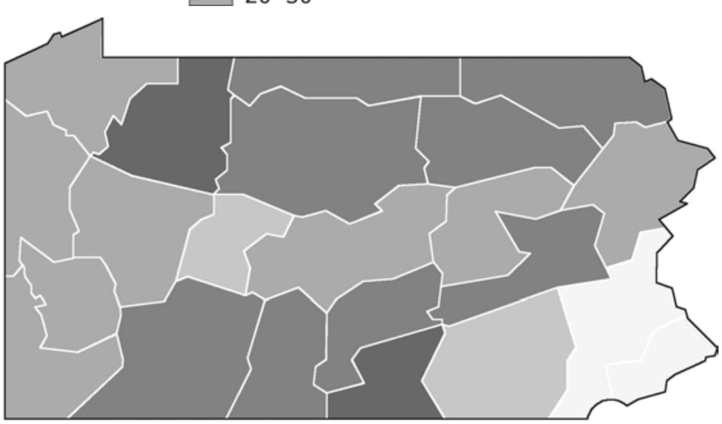
Figure 4. Indicators of factors influencing rates of forest recovery following deer population reduction, by wildlife management unit.[30] Large-scale trends only are depicted; site-specific factors on a local scale can affect individual stands dramatically and in many cases will override the regional trends.



D Frequency of forest plots with >30% fern cover
as percentage of total plots
0
1–10
10–20
20–30
>30



E Frequency of forest plots with <20% shrub cover
as percentage of total plots
<10
10–20
20–30
30–40
>40



F Average shrub species richness in F.I.A. plots
>4.0
3.4–4.0
2.7–3.3
2.0–2.6
<1.9

Once deer browsing pressure has been reduced, herbicide is often used in silviculture to remove ferns from fern-dominated forest understories, thereby eliminating the fern-penetration lag time. Measures to remove fern cover with herbicides[31] have been taken on a routine basis by some foresters and landowners since the 1980s.[32] For instance, in the mid-1990s, 4,000 to 5,000 acres per year were sprayed in Pennsylvania to remove ferns and interfering, browsing-tolerant hardwood understories. Virtually all of this practice takes place on public lands and some tracts owned by large wood-products companies. There is little intervention to speed the reduction of understory fern dominance following tree harvesting on private, non-industrial lands. Given the millions of acres in Pennsylvania that have been affected by deer populations, these efforts would need to be vastly expanded following reduction of deer populations if recovery were ever to be accelerated on a large scale. The potential impacts of such a large-scale application of herbicides would also need to be thoroughly explored.[33]

Leaving some trees standing as seed sources also speeds up recovery of tree species. A goal for residual tree cover of 10 square feet of basal area per acre has been recommended for regenerating trees for future harvest.[34] Options for speeding up the recovery of shrubs and herbaceous species through forest management policies need to be explored. In theory, the costs of restoring a diverse understory layer and reversing understory dominance by ferns could be reduced by involving loggers and foresters in dispersing native understory plant seeds. At present, there is no material incentive for landowners, loggers, and foresters to absorb restoration costs. If recourse were to be made to regulations or subsidies, then research should be undertaken to find the best ways of reducing costs. Scientific research is fundamental to speeding recovery and reducing its cost. There is a variety of potential experiments that would increase our understanding of recovery rates for various species following the reduction of deer browsing.[35]

Findings on predicting forest recovery

(1) The length of time that a forest has been subjected to overbrowsing and the extent to which a dense layer of unpalatable vegetation has developed are major variables that will influence the recovery time.

(2) Recovery of forest structure and species diversity will be heterogeneous in space and time and across species. Large areas should begin partial recovery relatively soon after reduction of deer densities; other forest stands will not undergo even partial recovery until sufficient time has elapsed for self-thinning or natural disturbance to occur (unless commercial thinning is undertaken) or for immigration of seeds. Full structural recovery will take decades to a century or more.

(3) A major challenge for the near term is to find rapid and effective measures for detecting partial structural recovery following reduction of deer browsing pressure, so that concerned stakeholders and the general public can have the confidence and patience that will be required to sustain support for continued deer management through the slow process of full structural recovery.

Recommendations on predicting forest recovery

(1) Do not delay action to reduce deer overbrowsing.

(2) Recognize that full forest recovery is a long process, but that partial recovery will be quick in some areas.

(3) Support research on, and development of, indicators of recovery progress.

(4) Focus initial monitoring efforts in those areas where rapid partial recovery is expected to occur.

Endnotes

[1] But see Horsley et al. (2003), which reports the results of 10 years of change with logging and controlled deer densities of 10, 20, 38 and 64 deer per square mile on the Allegheny Plateau in northwestern and north-central Pennsylvania.

[2] Meier et al. 1995

[3] Horsley and Marquis 1983

[4] Some immigration may take place during the recovery start time.

[5] A study nearing completion in the Adirondacks at Huntington Forest shows that absolute densities of deer are not good predictors of impacts of deer on vegetation (Dr. William F. Porter, Professor of Wildlife Ecology, Department of Environmental and Forest Biology, State University of New York, personal communication, 2003). Rather, deer density relative to food supply (absolute density divided by the proportion of forested area in regeneration) appears to be a better statistical predictor. Furthermore, the relationship between deer density and vegetation recovery may not be linear but instead may resemble the curve in Figure 1 of this report (Chapter 5). This work, when completed, may serve as the basis for a better model than Equation 4.

[6] Canham et al. 1994

[7] Lorimer 1977, 1980; Runkle 1982; Frelich and Lorimer 1991

[8] Assuming 400,000 acres are cut each year on private lands (Dr. James C. Finley, Professor of Forest Resources, School of Forest Resources, Pennsylvania State University, personal communication, 2002) and 17,000 per year on state lands (Mark W. Deibler, Chief, Silviculture Section, Bureau of Forestry, Pennsylvania Department of Conservation and Natural Resources, personal communication, 2002)

[9] Matlack 1994; Peterson and Pickett 1995

[10] Meier et al. 1995; Kot et al. 1996

[11] de la Cretaz and Kelty 1999; Horsley et al. 2003

[12] Although the primary disturbance associated with the spread of rhizomatous ferns is the thinning of timber stands, any large disturbance that opens up the canopy (e.g., ice storm, severe windstorm) can also increase the density of a fern understory. However, they are minor in terms of the area affected compared with silvicultural thinning.

[13] Allegheny National Forest 1995

[14] Fredericksen et al. 1998

[15] Horsley 1977, 1993a, 1993b; Horsley and Marquis 1983; George and Bazzaz 1999a, 1999b

[16] Augustine et al. 1998; Stromayer and Warren 1997

[17] Loams are soils that are intermediate in texture, neither predominantly fine- or coarse-textured. They contain moderate amounts of all three size classes of soil particles — sand, silt, and clay.

[18] Cuff et al. 1989

[19] Cuff et al. 1989

[20] The U.S. Forest Service gives for the year 2002 the following proportion of timber by size class: 58% (9.3 million acres), 30% (4.9 million acres), and 11% (1.8 million acres) for sawtimber, poletimber, and saplings, respectively (U.S. Forest Service 2003: Table 3. Area of timberland by forest-type group and stand-size class, Pennsylvania, 2002). For estimation purposes, we take the age of saplings to range from 0 to 20 years; the age of poletimber stands to range from 20 to 65 years, and the age of sawtimber stands to be greater than 65 years.

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[21] These are poletimber stands older than 50 years, which we take to be $\frac{15}{45}$ of the total poletimber stand acreage in Pennsylvania (4.9 million acres) on the assumption that the age distribution of poletimber stands is flat between 20 and 65 years. ($\frac{15}{45} \times 4.9$ million acres = 1.63 million acres. See previous endnote for origin of acreage numbers and assumptions about age distributions in timber classes.) In the absence of high deer pressure, these stands could begin to recover immediately in the absence of a fern layer and at 5 years with a fern layer, under our assumptions.

[22] At one extreme a stand could be relatively close to lands with propagule supplies, so that wind dispersal would not be limiting. In such a case, partial recovery could begin within 5 years. At the other extreme, it might be necessary to wait for a wind disturbance event. In the latter case, we need both a wind disturbance event, with an assumed probability of 1.3% per year and a stand that has passed the 50-year age mark located near enough upwind to contribute wind-dispersed seeds. A numerical integration produces a 79-year average time for this to occur, which is not much longer than the result of a hand calculation computed by neglecting the time for all of the stands to pass the 50-year age mark.

[23] Roberts and Gilliam 2003; Neufield and Young 2003; slow migration and growth rates have been documented for many forest floor herbaceous species (e.g., see Sobey and Barkhouse 1977; Bierzychudek 1982).

[24] After a third diameter-limit cut, the economic potential of most stands has been exhausted. For a very long time the understory will have little prospect of being exposed to sunlight by further logging or by any natural disturbance other than fire. Furthermore, the propagule supply will be gone. Consequently, there is little likelihood of canopy replacement by a new crop of merchantable tree species. Only fire, which is relatively rare, is a likely source of renewal, although the lack of a propagule supply would make even postfire recovery a very slow process.

[25] Data depicted on Figure 3 maps were provided by Dr. Duane R. Diefenbach and Justin Vreeland, Cooperative Fish and Wildlife Research Unit, Pennsylvania State University.

[26] Estimating the average time between harvests on Pennsylvania's non-industrial private lands from available data is a challenge. We base our estimate on the U.S. Forest Service's Forest Inventory and Analysis (F.I.A.) statistics for 1989 (U.S. Forest Service 1993). To get the number of acres cut per year, we make two estimates using different sets of data. First, we rely on an F.I.A. estimate that 30% of the Pennsylvania timber base of 15.9 million acres was cut to some degree from 1978 through 1989 (Dr. William H. McWilliams, U.S. Forest Service, Forest Inventory and Analysis, personal communication, 2004). Dividing 30% by 11 years yields an estimate of 2.72%, or 430,000 acres, per year. If these cuts were spread uniformly over the 15.9 million acres, the average time between cuts would be 37 years, which we round to 40. However, the average turnaround time on non-industrial private lands is lower, because considerable timberland in Pennsylvania is in long rotation (in excess of 75 years between cuts). In fact, based on the acreage in sapling and poletimber size classes (8.2 million acres), it appears that about half of all timberlands were in long rotation in 1989. Assuming that 50% of the land is in 75-year rotation or longer (using an average of 80 years), the average time between cuts on the remaining land must be 27 years, if the 40-year estimate of the average for the entire timber base is accepted. Our second estimate is derived by using production statistics in board-feet per year to obtain the average number of acres cut per year, by dividing the number of board feet removed per year by the average number of board feet removed per acre (Dr. James C. Finley, School of Forest Resources, Pennsylvania State University, personal communication, 2004). Using 1989

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F.I.A. data (U.S. Forest Service 1993), we estimate total timberland harvested during the year at 220,000 acres. Assuming, again, that 50% of the timber land base is in an 80-year rotation, we find from this second method of estimation that the average time between cuts on the remaining land will be the same as on the long rotation, 80 years. Given the disparity in the estimates (27 vs. 80 years), the only conclusion we can draw from the available data is that the average time between cuts on non-industrial private land *may* be as low as 27 years.

[27] Dr. Patrick H. Brose, Research Silviculturist, Northeastern Research Station, U.S. Forest Service, Irvine, Pennsylvania, personal communication, 2004

[28] Cuff et al. 1989

[29] deCalesta and Stout 1997

[30] Sources: Figure 4B, Küchler 1964; Figure 4C, data provided by Dr. Marrett D. Grund and Chris Rosenberry, Pennsylvania Game Commission; Figures 4D through 4F, data provided by Dr. William H. McWilliams, Forest Inventory and Analysis, U.S. Forest Service

[31] At $122 per acre treated with herbicide, fully treating a million acres would be very expensive. For comparison, the annual budget of the Pennsylvania Game Commission is ~ $60 million. The cost of herbicides is not usually economically justifiable in non-industrial private forestry, so it is not reasonable to expect private landowners to cover these costs routinely.

[32] There presently are three Pennsylvania contractors who spray herbicide. The Allegheny National Forest, Pennsylvania Bureau of Forestry, and Pennsylvania Game Commission conduct fencing and herbicide operations themselves or use contracting firms. Development of the herbicide guidelines using glyphosate (Accord) and sulfometuron methyl (Oust) that now are in wide use in Pennsylvania began in 1976; use of these prescriptions increased dramatically in the 1980s and 1990s.

[33] Research has been underway for 9 years by the U.S. Forest Service Northeastern Research Station in northwestern Pennsylvania to assess the effects on understory structure and diversity of large-scale herbicide application to accelerate tree regeneration after deer density reduction and canopy removal. Publication of the results is awaiting completion of the first 10 years of data collection.

[34] Horsley et al. 1994

[35] Robinson and Handel 2000