Adequacy of Natural Hardwood Regeneration on Forestlands in Northeastern Pennsylvania

Todd S. Fredericksen, *National Audubon Society (current affiliation: Tropical Research and Development Inc.), Proyecto Bolfor, Santa Cruz, Bolivia;* **Brad Ross,** *National Audubon Society, 204 Ferguson Building, The Pennsylvania State University, University Park, PA 16802;* **Wayne Hoffman,** *National Audubon Society, 115 Indian Mound Trail, Tavernier, FL 33070;* **Mike Lester,** *The Procter & Gamble Company, P.O. Box 32, Mehoopany, PA 18629-0032;* **Jan Beyea,** *Consulting in the Public Interest, 53 Clinton St., Lambertville, NJ 08530;* **Michael L. Morrison,** *Department of Biological Sciences, California State University, Sacramento, CA 95819;* and **Bradley N. Johnson,** *The Procter & Gamble Company, 6100 Center Hill Avenue, Cincinnati, OH 45224.*

ABSTRACT: *The density of established and newly germinated commercial tree regeneration was assessed on 33 stands in northeastern Pennsylvania representing both northern hardwood and oak-hickory forest types. The purpose of the study was to determine the amount of regeneration on stands with differing amounts of residual basal area after harvest. Most stands were on nonindustrial private lands that had been harvested between 2–8 yr ago. The density of new germinants decreased while the density of seedling and sapling regeneration greater than 3 ft tall increased with increasing basal area removal. This result suggests that recruitment of taller seedlings and saplings improves with increasing intensity of harvests. Evidence of browsing by white-tailed deer* (Odocoileus virginianus *Zimmermann) was observed on nearly all species and was 50% or higher for seven species. High fern cover was most evident in heavily browsed areas. Neither slash cover nor height of slash was related to the density of any of the regeneration classes. This suggests that slash may not always afford adequate protection from deer. As in other parts of the state, a relative scarcity of sapling regeneration and high browsing incidence on many commercially valuable species indicates that problems with deer and competing species, like fern, need to be addressed in order to achieve sustainable forest management in northeastern Pennsylvania. North. J. Appl. For. 15(3):130–134.*

Nonindustrial private forestlands (NIPFs) comprise the majority of commercial forestlands in most northeastern states. In Pennsylvania, 75% of commercial forestlands are categorized as NIPF, representing nearly one-half million tracts of land with an average size of only 37.5 ac (Widmann 1995). While industry and government forestlands are often managed by professional foresters, only 20% of harvests on Pennsylvania NIPF lands are guided by foresters or other natural resource professionals, and only 6% of these lands have a written management plan (Birch and Stelter 1993).

NOTE: Todd S. Fredericksen is the corresponding author, and he can be contacted at Tropical Research and Development Inc., Proyecto Bolfor, Santa Cruz, Bolivia, Mailing Address: Top Bol 5053, PO Box 52-0777, Miami, FL 33152-0777—Phone: 591-3-480766; Fax: 591-3-480854; E-mail: nelltodd@bibosi.scz.entelnet.bo. The authors wish to thank the following institutions and organizations for their support of this study: The School of Forest Resources at the Pennsylvania State University, The Heinz Endowment, The Bureau of Forestry of the Pennsylvania Department of Conservation and Natural Resources, The Pennsylvania Game Commission, and The Nature Conservancy of Pennsylvania. In addition we are grateful for the logistical and field support from Alys Campaigne, Nell Fredericksen, Cynthia Jones, Eric Ross, and Chris Snyder.

Sustainability of forest harvesting requires successful regeneration of trees from seedlings and sprouts. Throughout much of the northeastern United States, and in Pennsylvania particularly, regeneration success has been negatively affected by a combination of intensive browsing of seedlings and saplings by white-tailed deer (*Odocoileus virginianus* Zimmerman) and intense competition for resources from fern species (Marquis and Brenneman 1981, Horsley and Marquis 1983, Tilghman 1989, DeCalesta 1994, Kittredge and Ashton 1995). Preferential browsing appears to favor the formation of dense stands of fern that can reproduce both by spores and rhizomes, such as hay-scented fern (*Dennstaedtia punctilobula* Michx.) and New York fern (*Thelypteris noveboracensis* L.) (Horsley and Marquis 1983). Dense fern stands further inhibit the establishment of other herbaceous and woody plant species through competition for resources such as light (Horsley 1993). Assuring regeneration success on forestlands in the northeastern United States will require adapting forest management to prevent or ameliorate browsing by deer and competition from fern.

By increasing light to the forest floor, intensive harvesting is likely to change the composition of understory regeneration from shade-tolerant to shade-intolerant species. Increased light to the forest floor resulting from forest harvesting may also increase regeneration of tree and shrub species (Behrend and Patric 1969, Kelty and Nyland 1981, Niese and Strong 1992), perhaps in sufficient quantity and with more rapid growth rates that allow enough regeneration to escape browsing by white-tailed deer. Logging slash, in the form of felled cull trees and unutilized tree tops may also protect advance regeneration from deer (Grisez 1960, Tilghman 1989).

We assessed tree regeneration on 33 recently harvested forest stands in northeastern Pennsylvania, 27 of which were nonindustrial private forestlands. Six other stands were located on State Gamelands or State Forestlands. Stands had received various intensities of harvest from near complete removal of the overstory to only light harvests or no cutting.

Table 1. Summary of stand characteristics for 33 forest study stands in northeastern Pennsylvania.

Site	Basal area[1]	Forest type[2]	Harvest type	Date cut	Ownership
1	2	NH	Clearcut	1992	NIPF
2	97	NH	Selective	1992	NIPF
3	78	NH	Selective	1991	NIPF
4	77	OH	Selective	1992	State
5	123	OH	None	Uncut	State
6	81	NH	Selective	1992	NIPF
7	28	OH	Selective	1993	NIPF
8	19	NH	Selective	1994	NIPF
9	151	NH	None	Uncut	NIPF
10	3	OH	Clearcut	1990	State
11	150	NH	TSI	1990	NIPF
12	47	OH	Selective	1993	NIPF
13	74	NH	Selective	1988	NIPF
14	96	NH	Selective	1993	NIPF
15	113	NH	Selective	1990	NIPF
16	16	OH	Selective	1993	State
17	100	NH	Selective	1989	NIPF
18	101	NH	Selective	1994	NIPF
19	89	NH	Selective	1992	NIPF
20	47	OH	Selective	1993	NIPF
21	29	OH	Selective	1993	NIPF
22	78	NH	Selective	1993	NIPF
23	81	NH	Selective	1994	NIPF
24	70	NH	Selective	1991	NIPF
25	22	NH	Dm-limit	1993	NIPF
26	71	OH	Selective	1994	NIPF
27	80	OH	Selective	1989	NIPF
28	115	NH	Selective	1991	NIPF
29	169	NH	None	Uncut	NIPF
30	113	OH	None	Uncut	State
31	99	OH	None	Uncut	State
32	25	NH	Dm-limit	1988	NIPF
33	162	NH	None	Uncut	NIPF

[1] Live Basal Area (ft^2/ac).
[2] NH = northern hardwood, OH = oak-hickory.

Methods

Study Sites

Study stands were located in five counties (Monroe, Pike, Susquehanna, Wayne, and Wyoming) in northeastern Pennsylvania (centered around N41°25′, W75°25′). This area lies within the glaciated low plateau and glaciated Pocono Plateau sections of the Allegheny Plateau Physiographic province. Elevations range from 340–2700 ft. Rainfall average is 44 in./yr. Soils are derived from sandstone and siltstone.

Thirty-three stands were selected to represent the two major forest types in northeastern PA, oak-hickory (11) and northern hardwoods (22), and a range of residual overstory cover. Sampled stands covered a range of nearly zero forest overstory tree cover to near complete forest overstory cover associated with mature forest and little or no recent harvesting (Table 1). Most stands were harvested within the past 8 yr using some type of selection cutting, the most common type of harvesting on forestlands in the northeastern United States. However, two stands had been essentially clearcut (2 and 6 yr ago), and six stands had no harvesting at least within the past 70 yr.

Study sites represented a wide spectrum of the NIPF lands in northeastern Pennsylvania incorporating a large amount of topographic variation, harvesting methods, and land uses. Timber harvesting, hunting, dog training, wildlife observation, nature protection, and cattle grazing were among the management objectives for the forest stands in this study. The study is thus a retrospective analysis of regeneration on stands associated with different amounts of residual basal area resulting from differing harvesting intensities and management objectives.

Measurements

Measurements of regeneration were made on saplings and seedlings in July and August, 1996. Fifteen plots were randomly located in each stand using a systematic sampling design. The number of plots was determined from sample size calculations based on variance measurements obtained during a pilot study of 15 stands during 1995. The number and size of seedlings, saplings, and shrubs was measured using 95 ft^2 plots, while the number of new germinants and the percent cover of herbaceous plants was measured using 10.6 ft^2 plots. Regeneration size classes included new germinants (young seedlings with two or fewer leaves), and woody seedling and sapling regeneration in classes <3 ft, 3–6 ft, and >6 ft (hereafter referred to as *established regeneration*). Only saplings up to 4 in. in diameter at dbh were counted. Evidence of deer browsing was recorded for each seedling or sapling stem. The height of slash and the percentage of slash, fern, and *Rubus* spp. (blackberry and raspberry) and *Vaccinium* spp. (blueberry) cover on each plot was also ocularly estimated. Stand basal area was sampled using a 10 BAF prism cruise of all trees greater than 4 in. dbh incorporating 20 points located along transects throughout the stand using a systematic sampling design so that sampling occurred in all parts of the stand.

Treatment of Data and Statistical Analysis

Analysis of new germinant and established regeneration was restricted to commercially valuable tree species in northeastern Pennsylvania. No significant differences were detected in the data between the regeneration of commercially valuable species valued only for pulpwood and those valued for pulpwood and sawtimber. Therefore results reported here group all commercially valuable species together regardless of product value. The experimental unit for statistical analyses was the stand, except when slash variables were related to regeneration. Because cover and height of slash could be related to regeneration density at each sampling plot instead of the stand level, correlations were conducted between slash variables and regeneration success at the individual plot level. Correlation analysis was conducted to examine linear relationships between the amount of regeneration and the residual basal area, slash variables, and selected herbaceous, semiwoody, and shrub cover. Regressions were also performed with stand age used as a covariate to examine possible impacts of this effect on regeneration. Transformations were performed in cases of nonlinear relationships before conducting linear correlation or regression.

Results and Discussion

Density of established regeneration was negatively correlated with residual basal area for seedling and sapling size classes larger than 3 ft tall (Table 2). However, new germinant regeneration increased, and seedling regeneration less than 3 ft tall did not vary with the amount of residual basal area (Table 2). Stand age was a significant covariate ($P = 0.01$) only for seedling regeneration less than 3 ft tall, where the number of seedlings decreased with stand age. Correlations conducted with residual basal area and regeneration for individual forest type did not yield any significant differences in results from those obtained with the forest types grouped together.

New germinant density was significantly and negatively correlated with *Vaccinium* cover, but density of seedling regeneration 3–6 ft tall was positively correlated with *Vaccinium* (Table 2). Fern abundance was weakly and negatively correlated with the abundance of seedling regeneration less than 3 ft tall. No significant correlation was detected between the density of new germinant or established regeneration with the percentage cover of *Rubus* (Table 2). Height and cover of slash were not related to the density of any regeneration size class (Table 2).

New germinants may not be readily visible to deer. In addition, regeneration taller than 6 ft is mostly beyond the reach of deer. For these reasons, analysis of browsing data excluded new germinants and saplings greater than 6 ft tall. Browsing evidence within the seedling size classes of regeneration was observed on nearly all species of trees (Table 3). There were seven species with 50% or more stems showing evidence of browsing. Browsing incidence was greatest on American beech (*Fagus grandifolia* Ehrh.), quaking aspen (*Populus tremuloides* Michx.), black oak (*Quercus velutina* Lam.), tulip-poplar (*Liriodendron tulipifera* L.), and yellow birch (*Betula alleghaniensis* Britton). Browsing incidence was not significantly correlated with residual basal area ($r = 0.13$, $r = 0.49$), but was significantly and positively correlated with percent fern cover within stands ($r = 0.41$, $P = 0.01$).

Table 2. Correlation of new germinant and woody seedling and sapling regeneration to residual basal area, height of logging slash, percentage cover of logging slash, fern, *Rubus*, and *Vaccinium*. r = Pearson's correlation coefficient, and P = probability of a type I error. Relationships are considered statistically significant at $P < 0.10$ level.

	New germinants	Seedlings (< 3 ft tall)	Seedlings (3–6 ft tall)	Saplings (>6 ft tall)
Residual basal area	$r = 0.36$	$r = -0.24$	$r = -0.53$	$r = -0.47$
	$P = 0.04$	$P = 0.17$	$P = 0.002$	$P = 0.005$
Height of slash	$r = -0.02$	$r = -0.06$	$r = -0.06$	$r = -0.04$
	$P = 0.72$	$P = 0.32$	$P = 0.51$	$P = 0.75$
Slash cover	$r = 0.01$	$r = -0.02$	$r = -0.06$	$r = -0.02$
	$P = 0.79$	$P = 0.69$	$P = 0.50$	$P = 0.55$
Fern cover	$r = 0.22$	$r = -0.30$	$r = -0.26$	$r = -0.05$
	$P = 0.21$	$P = 0.09$	$P = 0.14$	$P = 0.80$
Rubus cover	$r = 0.005$	$r = -0.15$	$r = -0.02$	$r = -0.07$
	$P = 0.98$	$P = 0.40$	$P = 0.90$	$P = 0.69$
Vaccinium cover	$r = -0.41$	$r = 0.28$	$r = 0.32$	$r = 0.17$
	$P = 0.02$	$P = 0.11$	$P = 0.07$	$P = 0.33$

Table 3. Average mean density (# stems/ac) of new germinants, established regeneration <6 ft tall and established regeneration >6 ft tall for commercially valuable tree species over all study stands. Percentage of individual stems browsed within the range of deer (established regeneration <6 ft tall) is presented also.

	Density			
Species	New germinants	< 6 ft tall	> 6 ft tall	% browsed
American basswood	16.7	1.9	0.0	0.0
American beech	183.3	464.9	53.7	74.1
Big-tooth aspen	33.3	29.6	86.1	15.4
Black birch	1,574.4	913.0	275.0	46.6
Black cherry	5,989.3	115.8	77.8	22.4
Black gum	16.7	5.6	0.0	33.3
Black oak	108.3	203.7	8.3	60.8
Chestnut oak	399.8	451.0	13.9	42.7
Eastern hemlock	416.5	11.1	7.4	26.8
Mockernut hickory	8.3	7.4	5.6	8.7
Northern red oak	208.3	165.8	8.3	30.0
Paper birch	16.7	1.9	1.9	50.0
Pignut hickory	91.6	45.4	4.6	32.4
Quaking aspen	0.0	41.7	11.1	64.6
Red maple	9,038.1	524.1	122.2	29.6
Sassafras	91.6	60.2	1.9	21.9
Slippery elm	0.0	2.0	0.0	0.0
Sugar maple	1,474.4	48.2	34.3	9.9
Tulip poplar	58.3	4.6	0.0	60.0
White ash	3,681.9	293.5	34.3	15.8
White oak	66.6	164.8	6.5	54.3
White pine	0.0	5.6	1.9	12.5
Yellow birch	366.5	29.6	0.0	59.6

Despite greater recruitment of new germinants with increasing residual basal area, the density of seedling and sapling regeneration of commercially valuable tree species increased with decreasing residual basal area. Low light levels may favor germination and first-year survival, while high light may favor long-term survival and escape from deer. As other studies have indicated (Behrend and Patric 1969, Kelty and Nyland 1981, Niese and Strong 1992), increasing light to the forest floor through intensive harvesting may facilitate recruitment into larger size classes of regeneration. Especially in areas with high deer densities, added light from canopy openings may accelerate the growth of some seedlings enough to grow out of the reach of deer.

The abundance of alternative browse in open areas associated with more intensive harvesting also may alleviate browsing pressure on regeneration (Marquis et al. 1992). As was true with advanced regeneration, preferred alternative deer foods, particularly *Rubus*, increased in the study area with decreasing residual basal area. However, *Rubus* cover was not significantly correlated with the density of woody regeneration, perhaps because *Rubus* may compete with woody regeneration for resources. Although stands in this study with decreasing residual basal area were positively correlated with advanced regeneration and *Rubus*, stands with dense understories of *Rubus* often had little evidence of regeneration. Most of these stands with high amounts of *Rubus* cover had been used recently for cattle grazing, which may help explain both the increased cover of *Rubus* (more efficient seed dispersal through cattle) and decreased tree regeneration due to cattle browsing. Thus the impact of overstory removal and cattle browsing may be confounded in this study.

In contrast to established tree regeneration, new germinants had a greater density with increasing residual basal area. New germinants are often inconspicuous among the other forest floor vegetation and may not be vulnerable to browsing by deer until they emerge from the other vegetation. The relatively higher moisture conditions of less intensively cut stands compared to stands with high basal area removal also may provide more favorable conditions for germination. This hypothesis may be supported by the higher number of newly germinated seedlings in moister northern hardwood stands, compared to drier oak-hickory stands.

Red maple (*Acer rubrum* L.), white ash (*Fraxinus americana* L.), and black cherry (*Prunus serotina* Ehrh.) had the greatest average density of new germinant seedlings on the study areas. Regeneration appeared to mirror overstory cover type, with oak regeneration abundant on oak-hickory stands and northern hardwood regeneration dominant under northern hardwood stands. The number of stems decreased with increasing size class for these species. This result might be expected as, due to competition, only a fraction of new germinants are likely to survive and become established. However, the number of established stems of black birch (*Betula lenta* L.), American beech, and oak (*Quercus*) species was greater than the number of new germinants. The lack of new germinant beech and oak seedlings may be attributable to the lack of recent good mast years. Also, it is likely that established regeneration from these species may have originated from sprouts as well as new seedlings.

Nearly all species of trees showed signs of browsing on seedlings. The presence of browsing damage may not necessarily indicate the degree of preference or palatability of stems to deer, since deer also may eliminate seedlings of preferred species leading to underestimation of browsing pressure on those species. For example, despite its reported high palatability to deer, a high percentage of browsing damage was not detected on eastern hemlock (*Tsuga canadensis* Carr.), because hemlock seedlings and saplings were largely absent from the study areas. Given this caveat however, it appears that American beech was a species with heavy browsing pressure, with nearly 75% of all sapling stems showing some evidence of browsing. Other species displaying browsing percentages greater than 50% included yellow birch, tulip-poplar, quaking aspen, black oak, and white oak (*Quercus alba* L.). Black cherry, white ash, and sugar maple (*Acer saccharum* Marsh.) all had less than 25% of stems browsed.

Despite the apparent high pressure on American beech, deer do not appear to be selecting against its abundance in the stand. This may partially be explained by the fact that American beech aggressively regenerates by stump sprouting and root suckers. In addition, the intensity of deer browsing on any one seedling did not appear to be high, despite the high percentage of all seedlings showing evidence of browsing. Deer may sample beech seedlings and find them relatively unpalatable, subsequently moving on until they find a more palatable stem.

Percent browsing was positively correlated with fern cover, despite no significant correlation between established regeneration density and fern cover. Fern abundance was greatest on lightly harvested northern hardwood stands, perhaps because the more shaded conditions associated with light compared to heavy harvesting of this moister forest type encouraged transport and germination of spores. Fern abundance has been linked to soil moisture in stands in Pennsylvania (Groninger and McCormick 1992). Hay-scented fern was the most abundant understory plant species on one-third of the study areas and was among the top three most abundant species on two-thirds of the study sites. Four stands had fern covering more than 50% of the forest floor and nine stands had fern cover greater than 25%. Heavy fern abundance, particularly hay-scented fern and New York fern, are often indicators of high deer browsing pressure (Horsley and Marquis 1983) since deer do not prefer to eat fern. Instead, deer browse heavily on most woody stems that become conspicuous as they rise above the fern layer. Fern also competes effectively for light with smaller tree seedlings and may lead to reduced regeneration success (Horsley 1993).

Unlike other studies (Grisez 1960, Tilghman 1989), logging slash in our study stands did not appear to afford adequate protection to tree regeneration from browsing, despite the fairly high quantity of logging slash left on some of these recently harvested sites. Slash piles may not provide adequate protection unless they are large (contiguous) enough to serve as an impenetrable barrier to deer, which may be unlikely in stands which are selectively harvested. Deer may also be able to gain access to regeneration in the midst of slash during winter if snow is heavy and deep enough to compact slash and allow access to seedlings. Although this was not a controlled study on the viability of slash protection for seedlings, these results indicate that leaving slash, in itself, may not always provide enough protection from deer to allow for adequate regeneration.

Summary and Applications

Most stands in this study could be characterized by abundant evidence of deer browsing, high amounts of fern cover, and relatively scarce regeneration for many commercially valuable species. The most successful species included black birch, red maple, and American beech; species with some commercial value, but not the most commercially valuable species. More intensive harvesting increased the density of established regeneration, but probably not enough to adequately stock the stand in most cases. Slash did not appear to deter browsing by deer enough to provide adequate regeneration. The results of this study support similar studies conducted in other parts of the state (Marquis and Brenneman 1981, Horsley and Marquis 1983, Tilghman 1989, DeCalesta 1994, McWilliams et al. 1995) in that any strategy to incorporate sustainable management on many stands in Pennsylvania will first need to overcome regeneration problems caused by deer and fern.

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