FOREST REGENERATION IN NEW YORK STATE

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EXECUTIVE SUMMARY

Forests depend on adequate regeneration of tree species to be healthy and sustainable. Regeneration can be limited by many factors including deer browse, competition from other species, and poor soil conditions. This study of regeneration in New York, using data and methods from the U. S. Forest Service, found that regeneration was adequate in 68% of plots for canopy species and 43% of plots for timber species. Canopy regeneration was poorest in the southeast portion of the state, including Long Island, the southern Hudson Valley, and southern Catskills. Regeneration in the Adirondacks was dominated by low-value timber species such as American beech and balsam fir. These results suggest that limited regeneration is a problem for forests in many areas and is of particular economic concern for timber species in over half of the state. In order to maintain our forests in the face of increasing threats including climate change, energy development, invasive species, and air pollution, we should improve our understanding of the causes of limited regeneration. A partnership of public and private entities is needed to improve the accuracy and detail of data collected on forest health and incorporate this new information into resource management decisions. Specifically, we recommend intensification of USDA Forest Inventory and Analysis (FIA) data plots, the gathering of additional regeneration data on FIA plots, better incorporation of forest health measures when setting deer management objectives, and broader monitoring of atmospheric deposition impacts on forest regeneration.

This mixed hardwood forest in Seneca Falls, NYdisplays a lack of small trees in the understory.
(Photo: Tom Rawinski)

INTRODUCTION

New York's forests are a valuable economic and ecological resource, supporting industry and recreation, protecting water quality, and providing habitat for rare plants and wildlife. The forest manufacturing industry in New York State (NYS) contributed $6.9 billion dollars to the economy in 2005 (4.5% of manufacturing sales) and forest-based recreation and tourism generated revenues of $1.9 billion, providing employment for 14,600 with a $300 million payroll (NEFA 2007). The largest contribution to recreation revenues was from fall-foliage and wildlife viewing, both of which rely on healthy, diverse forests. Likewise, sustainable timber management goals can only be achieved through the regeneration of high quality commercial tree species.

The long-term health and economic viability of New York's forest ecosystems is dependent on sufficient tree regeneration. The presence of young trees in the forest understory is necessary to sustain forest canopy development after timber harvest or natural disturbances such as windstorms, insect outbreaks, or individual tree mortality that creates forest canopy gaps. The density of regeneration is expected to vary spatially due to forest type and physical site conditions (Liang and Seagle 2002, Ward et al. 2006) and temporally due to changes in seed production (Boerner and Brinkman 1996). Biological factors such as insects, disease, herbivory, and competing vegetation will also influence regeneration (Ward et al. 2006). Studies on regeneration requirements have been generally limited to models of forest dynamics, and little empirical information is available on the abundance of regeneration required for healthy forests to support wildlife and maintain ecological services. However, regeneration stocking guidelines to meet silvicultural objectives have been developed for eastern forests (Marquis et al. 1992).

The lack of adequate forest regeneration in some areas of the northeast is an issue recognized by both foresters and ecologists (Rawinski 2008). Two major challenges to forest regeneration in New York are deer herbivory and competition from aggressive, often allelopathic, understory plant species. The impacts of deer herbivory on regeneration in New York forests have been documented from the Adirondack (Sage et al. 2003) to the Allegany (Tilghman 1989) forests. Sustained overbrowse by deer is known to reduce forest regeneration and diversity, shift species composition, and have cascading effects on plant and wildlife communities (Cote et al. 2004), particularly wildflowers (*e.g.* Augustine and Frelich 1998, Fletcher et al. 2001, Rooney 2001, Rooney and Gross 2003) and forest bird species (*e.g.* DeCalesta 1994, Hino 2006, McShea and Rappole 2000). Additionally, selective herbivory, disease or altered disturbance regimes may cause certain plant species (both native and introduced) to form dense understory canopies that can suppress regeneration (Sage et al. 2003, Royo and Carson 2006). These stresses are occurring on a landscape that is also subject to nutrient and acid deposition that alters soil chemistry and decreases survival of key species (Lovett and Mitchell 2004, Zaccherio and Finzi 2007). Regeneration may also be reduced by the presence of exotic earthworms that deplete the forest floor (Hale et al. 2006). In addition, climate change is projected to dramatically alter species distributions and ecosystem functions, particularly in the northern forests of the Adirondacks (Jenkins 2010). The combined impacts of these multiple stresses have the potential to severely limit the capacity of New York's forests to replace themselves.

The purpose of this study is to assess the status of forest regeneration across New York State using data from the USDA Forest Inventory and Analysis (FIA) program. While there have been small-scale case of studies forest regeneration throughout the state, we are unaware of any consistent statewide assessment. Pennsylvania initiated a landscape-scale regeneration study (PRS) in 2001 to better address the issue after numerous studies documented regeneration failure. This study, which draws upon the PRS and FIA, provides an initial picture of forest regeneration status across New York, identifies areas of potential regeneration concern for further assessment and action, and recommends intensifying FIA data points to better refine the accuracy and utility of this dataset.

METHODS

FIELD SITE DESCRIPTION

The forests of New York cover approximately 60% of the state, occurring in small fragmented patches as well as a number of large contiguous blocks thousands of acres in size. Clusters of these forest blocks occur in areas designated as state forest preserve in the Adirondack and Catskill Mountains. Additional significant forested areas include the Allegany State Park, Tug Hill Plateau, Taconic Mountains, and Hudson Highlands.

The state contains portions of seven terrestrial ecoregions[1] (Figure 1) that contain a variety of forest types. According to the US Forest Service forest type classification, the majority of forests across the state (except in the North Atlantic Coast) are maple-beech-birch. Oak-hickory forests are also abundant in the NAC, GL, HAP, LNE-NP ecoregions. Additional forest types that occur at lower abundance throughout the state are white/red/jack pine, elm-ash-cottonwood, and aspen-birch. Spruce-fir forests occur in the northern portion of the state, representing a minor component of the two northern-most ecoregions. The NAC ecoregion on Long Island is dominated by oak-pine and pitch pine forests, which are otherwise uncommon in the rest of the state.

FIA FIELD METHODS

The US Forest Service FIA program (http://fia.fs.fed.us/) collects forest condition data annually on a rotating set of plots located on a 6000-acre grid. Each plot consists of four 24-ft radius subplots and nested 6.8-ft radius (1/300th acre) microplots. Of the many variables collected in the FIA protocol, seedling and sapling data are the most useful for regeneration assessments. Within microplots, all seedlings (< 1 inch in diameter and >= 6 inches tall for conifers or > 1 ft tall for hardwoods) are tallied by species; diameter, species and, optionally, height are recorded for saplings (1-5 inches dbh). For surveys prior to 2004, seedling tallies were capped at six stems per species, so seedling densities may be underestimated for these plots (USDA 2007).

SAMPLE DESIGN

We used the FIADB-Lite database tool (Miles 2008) to access all published FIA data available for New York. Sample plots were queried from the 2002-2006 annual inventories in order to cover one full cycle of statewide surveys. Since the variables we examined are not expected to change rapidly under natural conditions, it was considered valid to pool multiple survey years into one dataset. A query using the criteria described in Table 1 was used to select 1647 independent plots in the analysis. The highest density of plots occurred in the most heavily forested areas (*e.g.* Adirondacks, Catskills) as compared to areas dominated by non-forest land cover (*e.g.* Long Island, Great Lakes) (Figure 1).

We estimate that approximately 10% of species records have underreported seedling densities due to the survey tally cap. The affected plots were retained in the final dataset based on their even spatial

[1] North Atlantic Coast (NAC), Lower New England/Northern Piedmont (LNE-NP), High Allegheny Plateau (HAP), Western Allegheny Plateau (WAP), Great Lakes (GL), Northern Appalachian-Boreal Forest (NA-BF), and St. Lawrence/Champlain Valley (SL-LC).

distribution, and the fact that excluding them did not significantly change the overall distribution of regeneration status classes.

Table 1. Plot selection criteria applied to FIA plots.

Field	Code	Description
Status code (Plot, Subplot, and Condition)	1	Accessible forest land present, at least 10% stocked, and not subject to non-forest use(s) that prevent normal tree regeneration and succession
All-live-tree Stocking	20%-100%	The sum of stocking values of all live trees is between 20% and 100%. This removes plots not able to achieve the full potential range of regeneration values due to under or over stocking
Stand Size Code	1 or 2	The predominant diameter class of live trees is greater than 5 inches
Disturbance Code	Not equal to 80	Removes plots with human-caused damage in the last 5 years affecting at least an acre
Stand Origin Code	0	Restricts the sample to stands of natural origin, not established by planting or artificial seeding

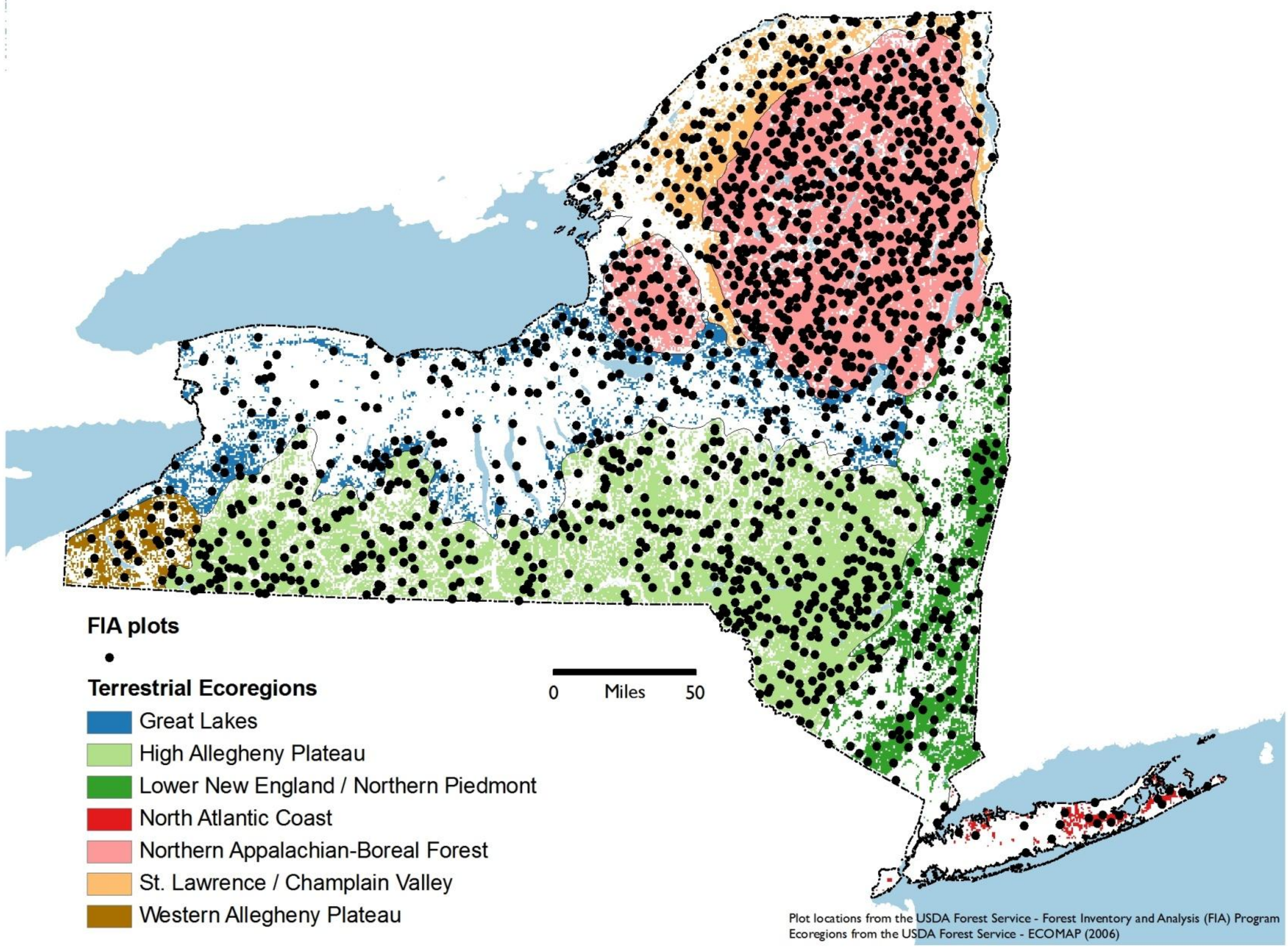

Figure 1. Forest Inventory and Analysis (FIA) plot locations with relation to forest cover and ecoregions in New York State.

Forest Regeneration Index

Based on the methods used for the PRS by McWilliams et al. (1995), we calculated a regeneration index based on seedling and sapling abundance. Live seedling and sapling counts were queried for each of two species groups – native canopy species and desirable timber species – that represent differing management goals for forestlands. Native canopy species included all tree species found on the selected plots, excluding non-native and understory trees. Desirable timber was a subset of the native canopy list that only included species representing at least 10% of the state timber harvest (based on NYS DEC's 2007 Timber Harvest and Consumption Report) or having a mean value of at least $100 per thousand board feet (based on NYS DEC 2008 and 2009 Stumpage Price Reports). The full list of 43 canopy species and 16 timber species can be found in Appendix A.

We modified the seedling and sapling weighting applied by McWilliams et al. (1995), since the standard FIA data does not include some data collected by the PRS (USDA 2001). The PRS included seedlings above 2 inches tall and height data for all stems. This enabled them to weight stems by height class, which we substituted with the equivalent diameter class (Table 2). The weighting factors were included in the calculation of a forest regeneration index (FRI) for each microplot:

$$\mathrm{FRI} = 20 * \mathrm{Ct}(\mathit{seedlings}) + 50 * \mathrm{Ct}(\mathit{saplings})$$

Where Ct(*x*) is the count of stems at each microplot. Since we did not have the data to split the seedlings into finer height classes, we applied the higher weighting of 20 to give all seedlings maximum weight in the index. Index values for the four microplots were summed to obtain a value for each independent FIA plot. These values were assigned to a category on a four-part scale rating the adequacy of regeneration and we calculated the percentage of plots falling in each category. We used the regeneration adequacy criteria for deer impact classes used in SILVAH[2] (Marquis et al. 1992) as the basis for minimum index thresholds, adjusted to scale proportionally with our use of both seedlings and saplings at all four microplots combined (Table 3). These ratings can be interpreted as the sufficiency of regeneration to tolerate varying levels of browse pressure and/or other stresses such as invasive plants. They also provide a guide to determine if management actions are warranted. While there is considerable variation in regeneration in studies of mature northern forests, and actual sufficiency of regeneration is often not reported, the range of seedling and sapling densities in the literature is generally consistent with our FRI categories (Bormann et al. 1970, Anderson and Loucks 1979, Tyrell and Crow 1994, Ziegler 2000).

[2] SILVAH is a U.S. Forest Service decision-support software tool used to generate silvicultural prescriptions for northern hardwood forests in the Allegheny Plateau (http://www.nrs.fs.fed.us/tools/silvah/).

Table 2. Seedling and sapling diameter classes for this study compared to height classes and weighting factors from McWilliams et al. (1995).

Diameter classes used for this study	Height classes McWilliams et al. (1995)	Weighting McWilliams et al. (1995)
Saplings (1-5 inches dbh) (all saplings with height data were > 5 ft tall)	> 5 ft	50
Seedlings (< 1 inch dbh)	3 ft – 5 ft	20
	1 ft – 3 ft	2
No data available	2 inches – 1 ft	1

Table 3. Description of forest regeneration categories derived from thresholds for deer browse impact classes from SILVAH (Marquis et al. 1992).

Category	Index Range	Equivalent stem density	Description	Level of Concern: Recommended Action
Poor	0-200	Not more than 769 seedlings or 307 saplings per acre	Regeneration inadequate under any level of browse pressure	Very High: Intervention likely required
Fair	201-400	770-1538 seedlings or 308-615 saplings per acre	Regeneration sufficient under low browse pressure	High: Intervention possibly needed, further evaluation required
Good	401-600	1539-2308 seedlings or 616-923 saplings per acre	Regeneration sufficient under moderate browse pressure	Medium: Continue monitoring using FIA
Very Good	>600	More than 2308 seedlings or 923 saplings per acre	Regeneration sufficient to tolerate high or severe browse pressure	Low: Continue monitoring using FIA

Mapping and Modeling

Each FRI value was mapped to the corresponding plot location in GIS. While we recognize that FIA plot coordinates are fuzzed and swapped for landowner privacy, we considered the introduced error to be acceptable for this statewide analysis, given that fuzzing is restricted to within 1 mile and only a portion of private plots are swapped with similar plots within the same county. We used the point data to model predicted value surfaces for both canopy and timber FRI with ordinary kriging using Geostatistical Analyst in ArcGIS 9.3.1. A full sector, 4-neighbor spherical neighborhood without anisotropy was used to retain local-scale variation. The models were selected to reduce mean predicted error and approach a value of one for root-mean-square standardized error (ESRI 2001). The final interpolated surface was masked by forest cover (NLCD 2001) to reflect forest patches 200 acres or greater in size.

RESULTS

ECOREGIONAL ANALYSIS

For the canopy species group, 68% of plots in New York were in the good or very good FRI categories (Figure 2a). The timber species group had a lower proportion of plots, 43%, in the good or very good FRI categories compared to the canopy species group (Figure 2b).

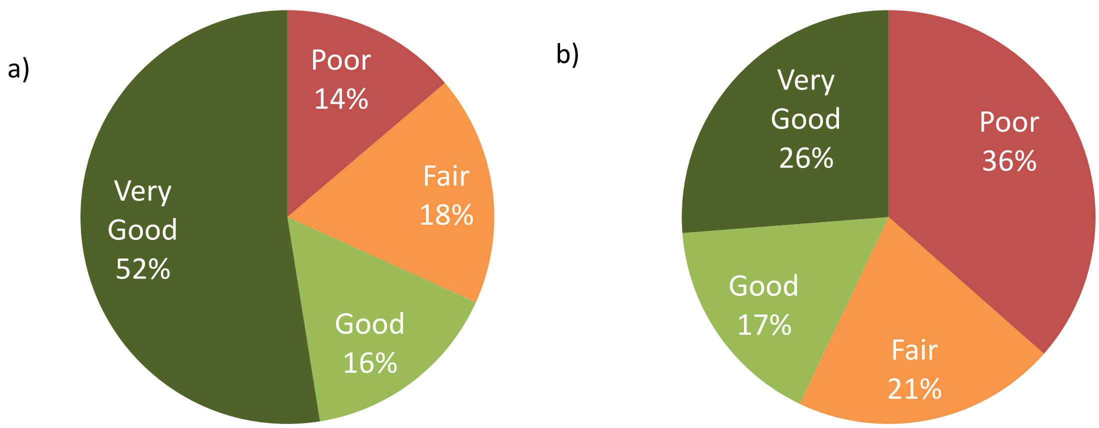

Figure 2. Percent of FIA plots within forest regeneration categories by species groups: a) canopy and b) timber.

The relative distribution of FRI categories varied significantly by ecoregion (Figure 3). The highest percentages of plots in the good and very good FRI categories for the canopy species group, 86% and 72% respectively, were found in the northerly NA-BF and SL-LC ecoregions. Timber species regeneration in these ecoregions was lower (approximately 51% in the good and very good FRI categories) but still greater than in any other ecoregion. The southern- and eastern-most NAC and LNE-NP ecoregions had the lowest percentages of plots in the very good category and the greatest percentages of plots in the poor category for both timber and canopy species. The condition of forest regeneration in the remaining central and western ecoregions (HAP, WAP, and GL) contained a relatively balanced mix of the four index categories.

Forest type was also a significant factor in the regeneration ratings (Figure 4), but this effect may be influenced by the spatial correspondence between forests types and ecoregions. A closer examination of the most common forest types (oak-hickory, maple-beech-birch, aspen-birch, pine, and spruce-fir) indicates that within individual ecoregions, the effect of forest type on FRI categories becomes non-significant. However, the effect of ecoregions was robust across forest types. While this does not mean that there is no effect of forest type on regeneration status, (for example, oak-hickory forests display a consistent but non-significant trend toward lower FRI scores than expected), a more targeted study would be needed to adequately investigate the combined effects of location, forest type, and other physical variables.

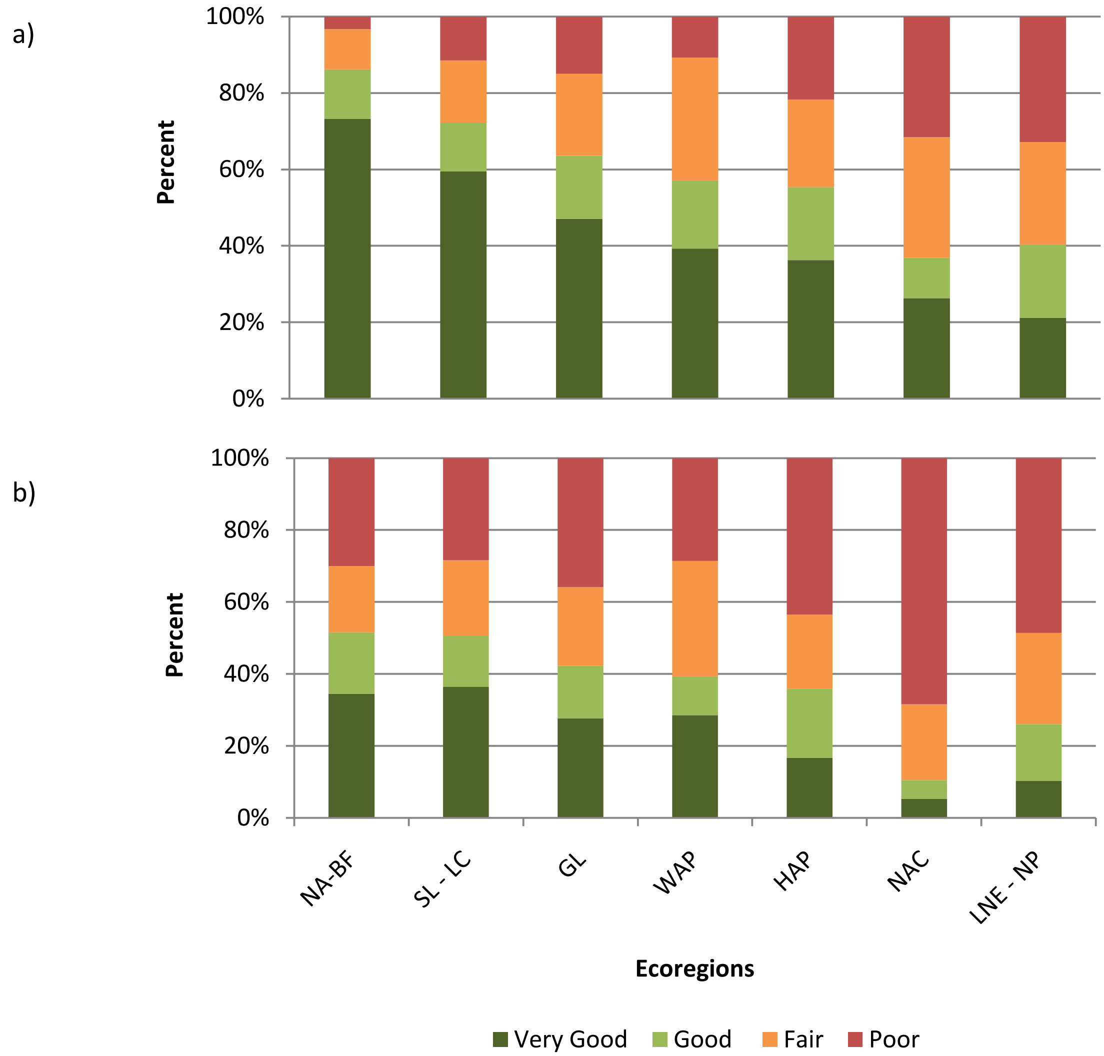

Figure 3. Percent of FIA plots in forest regeneration categories by ecoregion for a) canopy and b) timber species groups. NA-BF = Northern Appalachian-Boreal Forest, SL -LC = St. Lawrence/Champlain Valley, GL = Great Lakes, WAP = Western Allegheny Plateau, HAP = High Allegheny Plateau, NAC = North Atlantic Coast, and LNE – NP = Lower New England/Northern Piedmont.

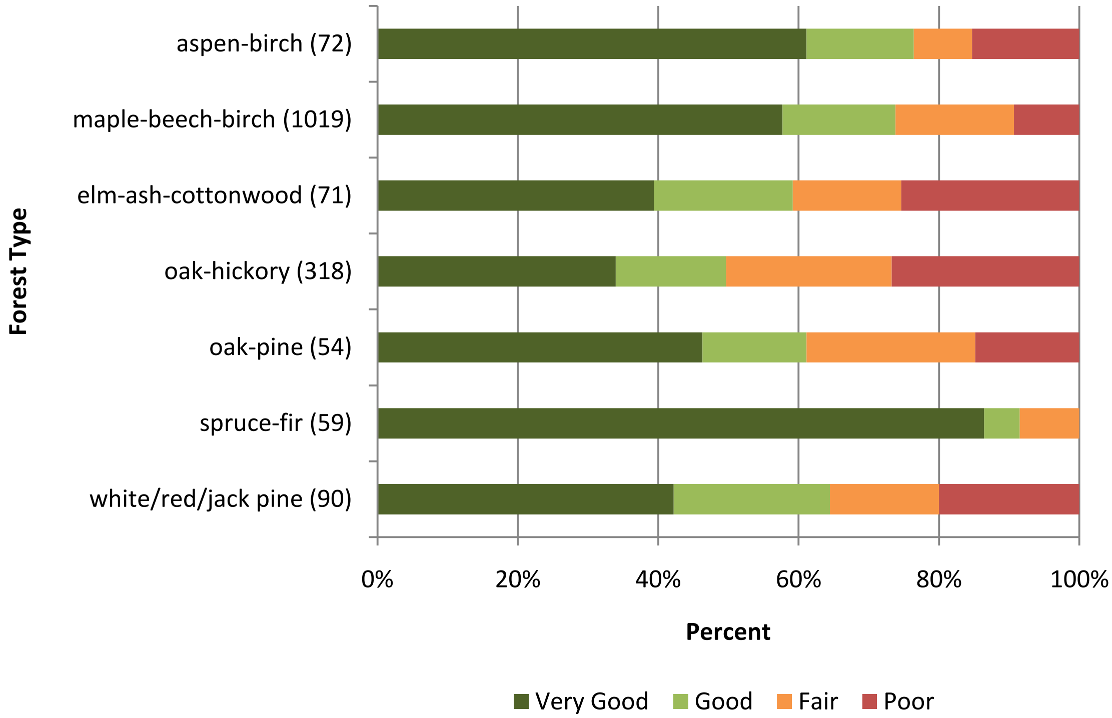

Figure 4. Percent of FIA plots in forest regeneration categories by forest type. The number of plots is shown after each forest type name; forest types with <10 plots statewide were excluded.

Spatial Modeling

The spatial patterns indicated by the ecoregional variation can be seen in more detail on the predicted surface maps (Figures 5 and 6). While there is significant small-scale variation in regeneration, there is a general north-south trend in the FRI for canopy species, with a greater probability of poor and fair values in western Long Island and the Hudson Valley, and generally very good values in the Adirondacks (Figure 4). The remaining parts of the state are a more complex pattern of intermixed classes, but with most areas in the middle range of fair or good. The priority forests in the western portion of the state range from poor to very good in the Catskill Mountains and fair to very good in the Allegany Forest.

Regeneration for timber species was generally lower than the canopy species group across the state, with most areas dropping at least one category (Figure 6). A larger area in the southeast portion of the state is poor, and much of western New York changes from good to fair when only timber species are included. The Adirondacks displays the largest difference between canopy and timber species, with most of the area that was very good for canopy species appearing as a mix of fair and good with patches of poor in the southern portion. While some decrease in FRI is expected when species are excluded, the degree of difference between canopy and timber species scores indicates how much of the existing regeneration is due to desirable timber species. In addition, the comparison of relative timber FRI scores among regions of the state is informative of spatial trends.

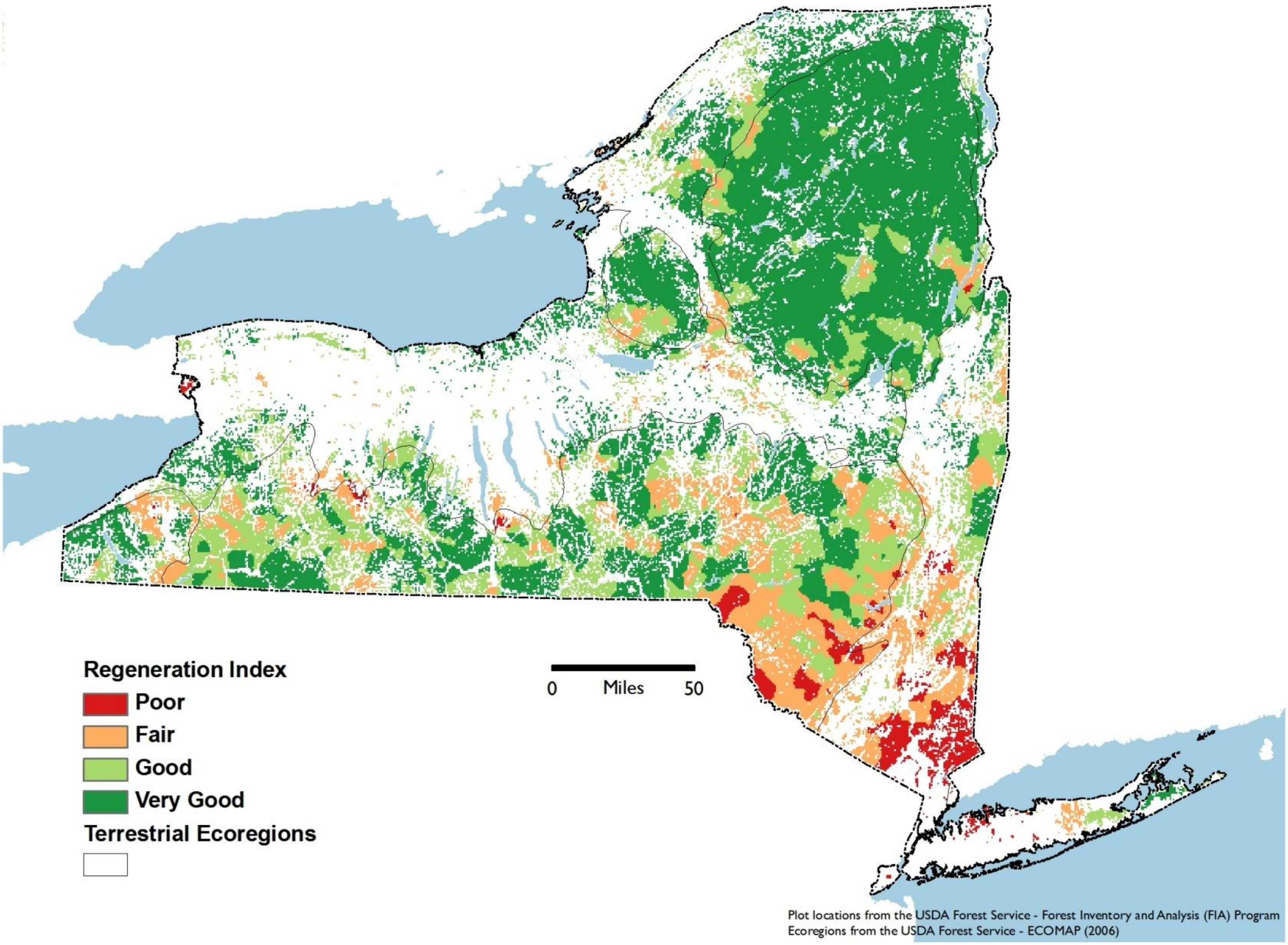

Figure 5. Predicted values for Regeneration Index of native canopy species in New York State.

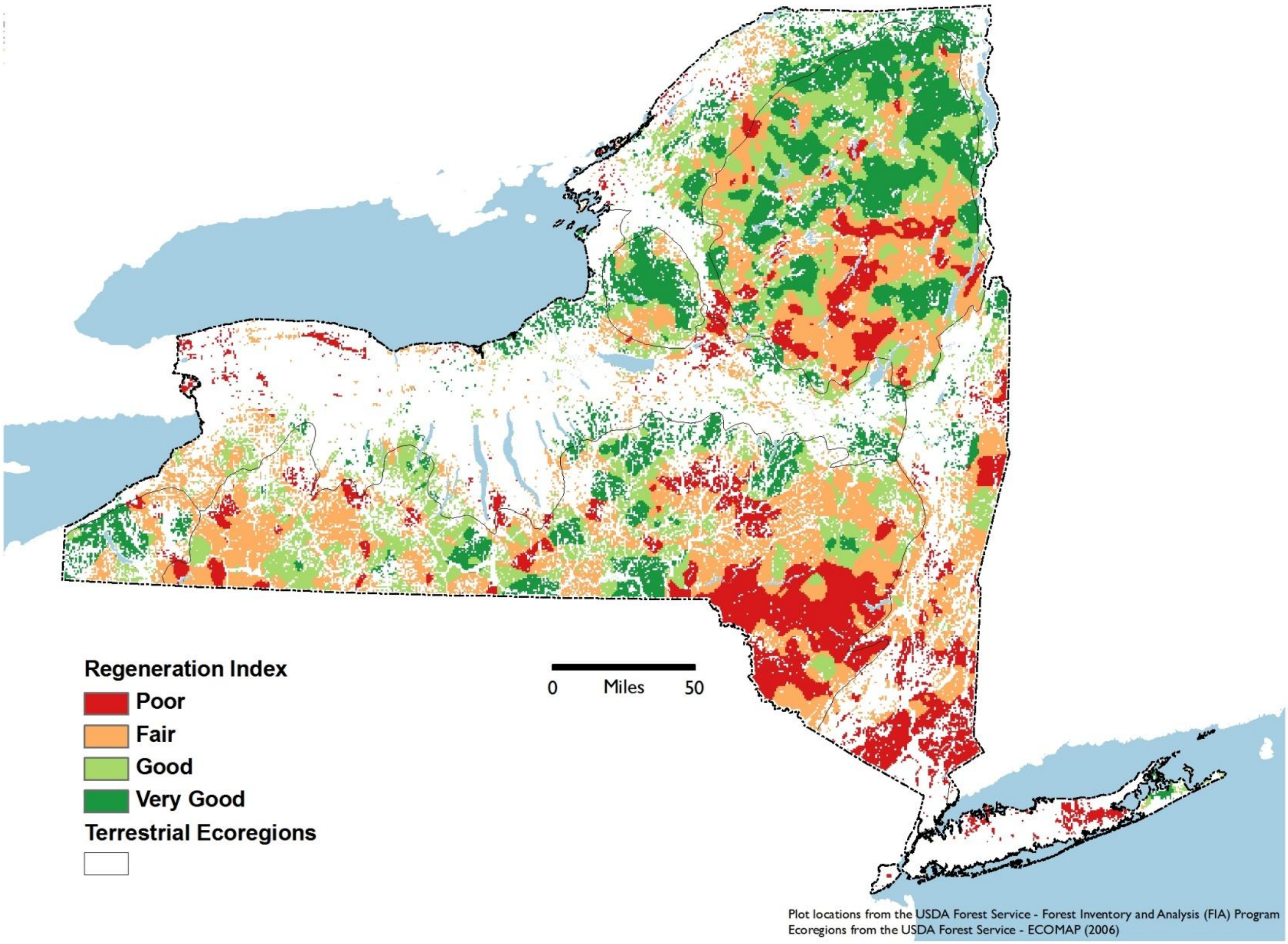

Figure 6. Predicted values for Regeneration Index of desirable timber species in New York State.

Composition of Regeneration

We do not expect the composition of forests to remain static over time, but it is instructive to examine which species are contributing most to the FRI scores. Nineteen tree species contributed at least 5% of the regeneration in at least one ecoregion (Table 4). Across all plots in New York, over half (58%) of the regeneration is due to four species: American beech, sugar maple, white ash, and red maple. American beech alone contributed nearly a quarter (23%) of the total forest regeneration, making it the largest component of forest regeneration in New York. The second largest contributor, sugar maple, was nearly half that of beech (14%). Following that, white ash, red maple, balsam fir, red spruce, and black cherry each made up > 5% of regeneration statewide.

The statewide dominance of American beech was driven by the heavily forested HAP and NA-BF ecoregions, with 29% of the regeneration in those ecoregions in beech. Sugar maple, white ash, and red maple were consistently found in all of the ecoregions except NAC. Balsam fir and red spruce occurred primarily in the NA-BF ecoregion. Black cherry was present in all ecoregions and was a particularly large component of regeneration in NAC. Overall, the composition of regeneration in NAC differed from that in other ecoregions, being dominated by pitch pine and oaks that were relatively absent from other ecoregions. LNE-NP and HAP were the only other ecoregions in NYS with >1% of regeneration in oaks.

Table 4. The percent contribution to forest regeneration of the most abundant[a] tree species in NYS ecoregions[b]. Desirable timber species are indicated by italics.

Species	GL	HAP	LNE – NP	NAC	NA-BF	SL – LC	WAP	Total
American beech	6.3	28.7	12.7	0.0	28.6	5.2	7.4	22.6
sugar maple	15.3	16.7	15.2	0.0	11.5	13.8	18.2	13.5
white ash	24.4	20.5	17.0	0.0	2.7	12.0	34.1	11.0
red maple	8.9	9.4	10.2	2.2	10.2	18.1	8.3	10.5
balsam fir	2.4	0.1	0.2	0.0	15.9	4.5	0.0	8.8
red spruce	0.1	0.4	1.5	0.0	12.5	0.5	0.0	6.6
black cherry	7.1	6.4	7.2	26.0	3.9	7.5	17.2	5.7
yellow birch	2.6	1.6	0.5	0.0	6.3	1.7	0.2	4.0
eastern hemlock	5.2	3.0	2.8	0.0	2.3	2.3	2.4	2.8
eastern white pine	1.2	1.9	5.8	0.9	1.3	2.4	0.0	1.7
green ash	9.5	0.5	1.0	0.0	0.1	2.7	1.6	1.6
American elm	3.5	0.8	4.3	0.0	0.3	4.7	1.6	1.4
sweet birch	0.2	2.4	6.8	0.0	0.3	0.7	0.0	1.1
northern white-cedar	1.2	0.0	0.0	0.0	0.3	5.4	0.0	0.8
silver maple	1.0	0.0	0.0	0.0	0.0	1.0	4.6	0.3
white oak	0.0	0.6	1.3	11.5	0.0	0.2	0.0	0.3
chestnut oak	0.0	0.5	2.1	4.6	0.0	0.0	0.0	0.2
scarlet oak	0.0	0.2	0.2	22.0	0.0	0.0	0.0	0.2
pitch pine	0.0	0.1	0.0	28.8	0.0	0.0	0.0	0.2
Number of samples	206	466	146	19	634	148	28	1647

a. Tree species making up > 5% of either the total FRI score or the score for any ecoregion were reported

b. NA-BF = Northern Appalachian-Boreal Forest, SL -LC = St. Lawrence-Champlain Valley, GL = Great Lakes, WAP = Western Allegheny Plateau, HAP = High Allegheny Plateau, NAC = North Atlantic Coast, and LNE – NP = Lower New England / Northern Piedmont.

Discussion

The results from this study indicate that there is evidence for concern over the status of forest regeneration in NYS. Regeneration is in the poorest condition in the southeast portion of state and in the best condition in the northern portion of the state. Overall, a majority (68%) of forest in NYS has adequate regeneration of canopy tree species. However, this means that nearly one-third (32%) of the state may not have sufficient regeneration to replace the forest canopy after a significant overstory disturbance. When considering only commercially desirable timber species, nearly half (43%) of NYS had insufficient regeneration.

The difference in the results for canopy and timber species is due to the fact that regeneration in the state is dominated by species that do not have high timber value. Of the 27 canopy tree species that were excluded from the timber species group, two species, beech and balsam fir, made up a substantial proportion of the overall regeneration in the state. The contribution of beech to forest regeneration is pronounced across a majority of NYS, while balsam fir was present in a high proportion in the NA-BF ecoregion. Since these two species combined made up nearly half (45%) of the total FRI score for the NA-BF ecoregion, their exclusion from the timber species group had a significant impact on the results for that region.

The results presented here are supported by other smaller-scale studies in the state. Poor regeneration of hardwood species (including oaks) has been documented at the Mashomack Preserve, the Central Pine Barrens, and several other sites on Long Island (pers. comm., Marilyn Jordan). Densities of seedlings <0.5 m (oaks, red maple, and sassafras) and cover of forbs increased at the Mashomack Preserve from 2000 to 2005 following an increase in deer hunting (pers. comm., Marilyn Jordan and Michael Scheibel, The Nature Conservancy). In the Hudson Valley, seedlings and saplings were shown to be significantly more abundant within deer exclosures and managed areas than in the surrounding forest (Levine et al. 2008). A 24-year study in an old eastern hemlock forest in the northern Catskills showed a drastic decline in seedlings and saplings (Runkle 2005). A recent survey of practicing foresters in the state reported a regeneration success rate of only 30%, with the greatest problems in the Lower Hudson, Capital District, and Great Lakes regions, mostly attributed to deer herbivory and secondarily to interfering vegetation (Connelly et al. 2010). Our study corroborates the observation of these foresters.

The status of forest regeneration in NYS is similar to findings from the PRS. In Pennsylvania, only half of the forestland is considered adequately stocked with canopy species and only one-third has adequate regeneration for commercially desirable timber species (McWilliams et al. 2004). This is consistent with our findings from the ecoregions along the PA-NY border. It may indicate a broader problem with forest regeneration across the northeast. A survey of regeneration at National Parks for the Vital Signs Program, which uses both a stocking index and a ratio of seedling richness, found that regeneration was limited at most parks within the Northeast Temperate Network, with the majority of plots falling outside an acceptable range of variation (Tierney et al. 2009, NPS 2009)

There are a number of factors that could be influencing forest regeneration in NYS. While this study does not specifically investigate these factors, a number of studies and reviews have shown that deer herbivory (Marquis 1981, Rooney 2001, Horsley et al. 2003, Rooney and Waller 2003, Russell et al. 2001, Sage et al. 2003, Rawinski 2008, Wiegmann and Waller 2006), competing vegetation (Horsley and Marquis 1983, Royo and Carson 2006), and acid deposition (Lovett and Mitchell 2004) can all suppress regeneration. Given the abundance of low FRI values in the southeast portion of NYS (southern Catskill Mountains, Eastern Alleghany Plateau, Hudson Valley, Taconic foothills, Hudson Highlands, and Long Island) it is likely that a combination of these factors is influencing regeneration in this landscape, possibly exacerbated by fragmentation. In addition, beech bark disease, which kills mature trees and stimulates root sprouting (Sage et al. 2003, Runkle 2007), has almost certainly contributed to the abundant beech regeneration statewide. The combination of beech bark disease and high deer herbivory are known to have led to a dominance of beech regeneration in some forest understories (Runkle 2007). While this abundant regeneration may be adaptive for beech, it is unknown how overall forest health and function will be affected by a dense understory of beech that cannot fully mature to canopy height.

Given the natural variation in regeneration across forest types and site conditions, and the lack of clear guidance in the scientific literature on sustainable levels of regeneration for different forests, our use of a universal rating scheme should be interpreted with caution. But by applying a single rating scheme across the state, we have provided an initial assessment of general regeneration patterns that reveals broad trends. Our results indicate that regeneration failure of canopy-forming species may be occurring in some areas of the state, providing an opportunity to further study the causes and perhaps prevent further decline. If the condition worsens, the long-term consequences could include loss of forest diversity, reduction in timber production, loss of revenue and jobs from forest-dependent businesses, alteration of wildlife habitat, and a decrease in the services provided by the state's forests, such as water quality protection and carbon sequestration. In particular, the generally inadequate regeneration of timber species in most of the state indicates potential current and future problems for the timber industry. These results raise concern about regeneration in the state and identify areas for further investigation.

In order to advance our understanding of this issue, NYS should maintain and expand the periodic collection of forest data to inform natural resource management. The modifications we made to the PRS regeneration metric would allow analysis of any area with standard FIA data. An audit of the PRS (Wildlife Management Institute 2010) raised concerns that there is insufficient precision in the regeneration data for use as the primary decision variable to guide deer management. We agree that caution must be used when inferring regeneration to direct management at the local scale; however, FIA is the best, most comprehensive dataset available to consistently and transparently assess forest regeneration and the plot density of FIA is sufficient for large-scale analyses. By using standard FIA Phase 2 plots and expanding the range of stocking classes, we were able to improve our sample size, but in order for FIA to be useful at the scale of NYS DEC's Wildlife Management Units, we suggest that strategic intensification of data collection will be needed. Standard FIA also does not include some variables that are used in the PRS (*e.g.* understory vegetation, deer impact assessments, or counts of seedlings < 1 ft.). Data on these variables, as well as soil chemistry, would be useful in identifying the causes of poor regeneration.

While there are limitations to our current knowledge, we have good reason to be concerned that inadequate regeneration is likely to be a problem for forests in many areas of the state, particularly for timber species and in the southeast region. If we wish to sustainably maintain forest cover, diversity, and function, we should take action now to improve our understanding of this important issue and incorporate new information into resource management decisions. Specifically, we recommend intensification of FIA data plots, the gathering of additional regeneration data on FIA plots, better incorporation of forest health measures when setting deer management objectives, and broader monitoring of atmospheric deposition impacts on forest regeneration.

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Appendix A

Native Canopy Species	
Scientific Name	**Common Name**
Abies balsamea	balsam fir
Acer saccharum	sugar maple
Acer rubrum	red maple
Acer saccharinum	silver maple
Betula alleghaniensis	yellow birch
Betula lenta	sweet birch
Betula papyrifera	paper birch
Carya cordiformis	bitternut hickory
Carya glabra	pignut hickory
Carya ovata	shagbark hickory
Carya alba	mockernut hickory
Fagus grandifolia	American beech
Fraxinus americana	white ash
Fraxinus nigra	black ash
Fraxinus pennsylvanica	green ash
Juglans nigra	black walnut
Larix laricina	tamarack (native)
Liriodendron tulipifera	yellow-poplar
Magnolia acuminata	cucumbertree
Nyssa sylvatica	blackgum
Picea glauca	white spruce
Picea mariana	black spruce
Picea rubens	red spruce
Pinus strobus	eastern white pine
Pinus resinosa	red pine
Pinus rigida	pitch pine
Populus grandidentata	bigtooth aspen

Populus tremuloides	quaking aspen
Prunus serotina	black cherry
Quercus rubra	northern red oak
Quercus alba	white oak
Quercus prinus	chestnut oak
Quercus bicolor	swamp white oak
Quercus coccinea	scarlet oak
Quercus ellipsoidalis	northern pin oak
Quercus macrocarpa	bur oak
Quercus palustris	pin oak
Quercus stellata	post oak
Quercus velutina	black oak
Thuja occidentalis	northern white-cedar
Tilia americana	American basswood
Tsuga canadensis	eastern hemlock
Ulmus americana	American elm

Desirable Timber Species

Scientific Name	Common Name
Acer saccharum	sugar maple
Acer rubrum	red maple
Betula alleghaniensis	yellow birch
Betula papyrifera	paper birch
Fraxinus americana	white ash
Juglans nigra	black walnut
Picea glauca	white spruce
Picea mariana	black spruce
Picea rubens	red spruce
Pinus strobus	eastern white pine
Prunus serotina	black cherry
Quercus rubra	northern red oak
Quercus alba	white oak
Quercus prinus	chestnut oak
Tsuga canadensis	eastern hemlock
Ulmus americana	American elm

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