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A Regeneration Indicator for Forest Inventory and Analysis: History, Sampling, Estimation, Analytics, and Potential Use in the Midwest and Northeast United States

Forest Service

Northern Research Station

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Abstract

The density and composition of regeneration drives future forest character for forests in need of replacement. Forested ecosystems face numerous regeneration stressors including invasive plants, insects and diseases, herbivory, lack of management, and climate change. As stands that make up these systems age, it is imperative to track the viability of forest reproduction. The information required for understanding the complexity of forest dynamics during the stand establishment stage has been lacking in our Nation's forest inventory. This poses a particular problem for analysts working with the major deciduous forest systems of the Midwest and Northeast United States that require detailed information on advance reproduction. To address this need, the Forest Inventory and Analysis (FIA) program of the U.S. Forest Service, Northern Research Station (NRS) has added protocols for measuring all established tree seedlings and for assessing browse impact. This information is compiled using new NRS-FIA forest sampling and analytical methodologies—the regeneration indicator. The regeneration indicator is described along with examples and suggestions to guide research on the difficult question of whether the region's forests are able to regenerate in the face of numerous stressors.

Cover Photos

Top left: Eastern white pine seedlings. Photo by Steven Katovich, U.S. Forest Service, Bugwood.org.

Top right: Red spruce and balsam fir seedlings. Photo by William H. McWilliams, U.S. Forest Service.

Bottom left: Oak reproduction within a white-tailed deer exclosure. Photo by William H. McWilliams, U.S. Forest Service.

Bottom right: Sugar maple seedlings. Photo by William H. McWilliams, U.S. Forest Service.

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METRIC EQUIVALENTS

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters (cm)
Feet (ft)	0.305	Meters (m)
Acres (ac)	0.405	Hectares (ha)

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Research Problem and Objectives

Yellow-poplar reproduction following a fire. Photo by Rich Widmann, U.S. Forest Service.

Introduction

The U.S. Forest Service, Northern Research Station (NRS) conducts research for a 24-state region across the Midwest and Northeast United States (Fig. 1). Forest systems of the region face numerous regeneration stressors including invasive plants, insects and diseases, herbivory, lack of management, and climate change. As stands that make up these systems mature, it is imperative to know the viability of forest reproduction. Although artificial methods such as planting or seeding are an option in some stands, the region is dominated by forest systems that regenerate naturally. In most situations, establishing desirable reproduction is the key to successful systems of natural regeneration that replace existing stands with high canopy species that meet manager's objectives (Nyland 2002, Smith 1997, Wenger 1984). Information on how well forests are regenerating is critically important for understanding and projecting future forest character that ultimately determines sustainability of forest values.

To address the need for more detailed information on regeneration, the NRS Forest Inventory and Analysis (FIA) program has added new measurement protocols for data collected on a subset of NRS-FIA sample plots measured during the growing season. The new procedures measure all established trees less than 1 inch in diameter at breast height (d.b.h.) and include a browse assessment. This information improves NRS-FIA's ability to evaluate this important aspect of forest health and sustainability. The new procedures are referred to as the regeneration indicator.

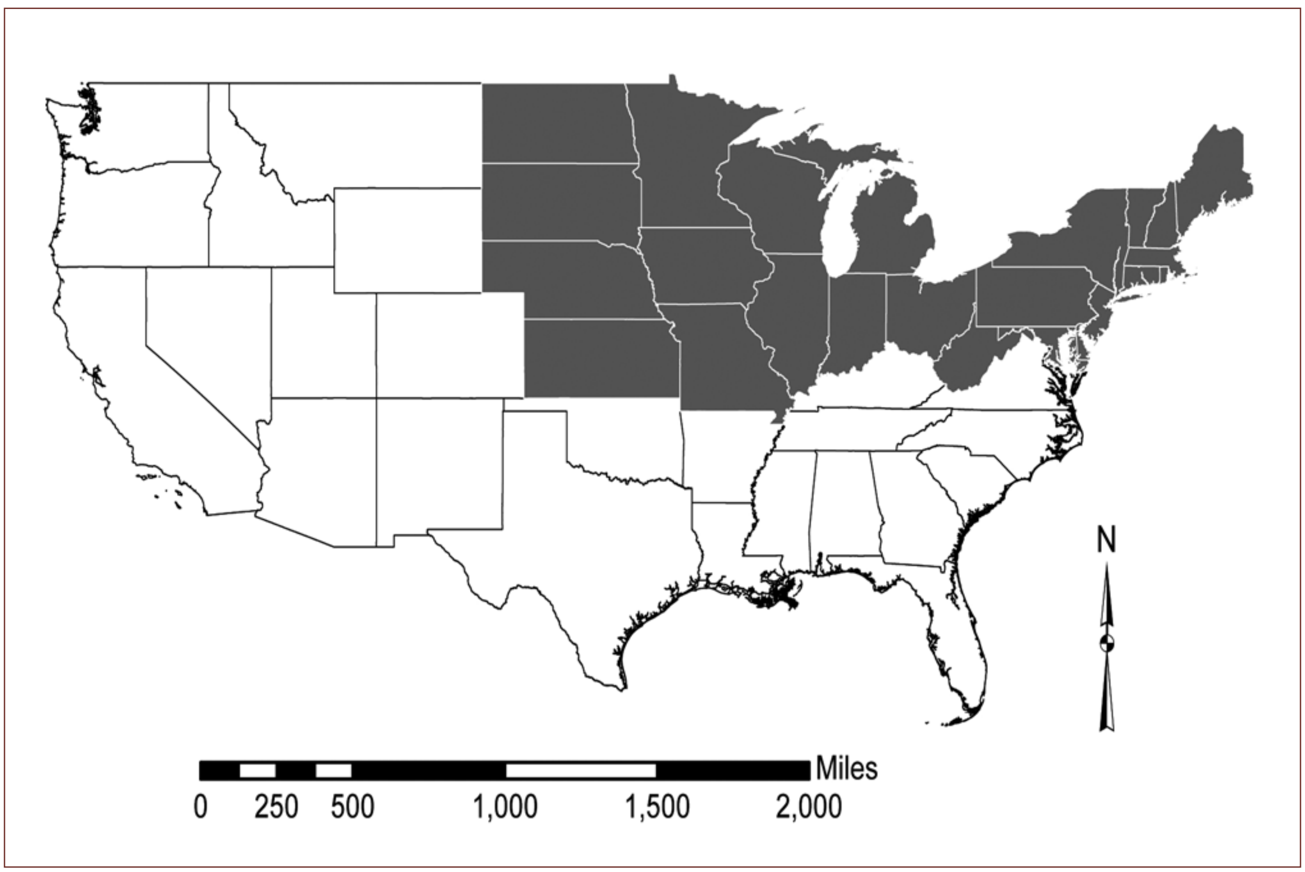

Figure 1.—Location of the Midwest and Northeast United States.

The main topic of this research is inventory and monitoring of regeneration for large forest landscapes. As used here, landscape refers to large sample domains designed for informing managers and policymakers on the quality of regeneration. Typical landscapes of interest are states, forest-type groups, wildlife management areas, and other geographic areas. The areas cover heterogeneous patches of habitat across a collection of land features. The landscape approach includes the capacity to evaluate broad ecological units, such as those developed by Cleland et al. (2007). Ecoregions are defined as groupings of landscape mosaics, typically defined in nested hierarchies that consider climate (moisture and solar radiation), landform, and vegetation (Bailey 1996). Other homogenous land characteristics, such as southwest facing mountainous slopes or low-lying flatlands, can also be analyzed. In this sense, the regeneration indicator provides a metric for evaluating groups of stands that make up landscape-level forest ecosystems.

Evaluation of landscape-level patterns requires some method to accommodate a mix of regeneration sources. The Midwest and Northeast span a broad array of forest types that regenerate either naturally, or in some cases artificially from planting or seeding. Natural regeneration originates from seed trees, seed stored in the soil, seed blown from adjacent stands, and stump or root sprouts (where stumps are defined as at least 2 inches in diameter) (Dey et al. 2012). This study includes all sources that produce seedlings or sprouts that occupy the FIA sample plot. The regeneration indicator considers only tree seedlings that are at least 2.0 inches tall, less than 1.0-inch d.b.h., and have been established for at least 1 year.

This report defines the research problem and includes a literature review, a brief history of the Pennsylvania Regeneration Study (PRS) that is a precursor of the approach used here, and an overview of Midwest and Northeast forest systems. This is followed by sampling and estimation techniques for large landscapes. A series of computational analytics for quantifying regeneration character are also provided along with examples to guide analyses using the new data.

Regeneration Research Problem Statement

The research need addressed in this report is the lack of measurements, metrics, and analytics necessary to quantify the tree seedling component for forests at policy-relevant scales for the Midwest and Northeast in order to address the reproductive capacity following natural or anthropogenic processes, such as wind storms or harvesting, that make forests eligible for regeneration. The overall goal is to inform forest management planning, policy, and modeling efforts by quantifying and assessing the abundance, composition, structure, and quality of forest regeneration. The intent is to apply a consistent, transparent, and seamless research method across large scales, such as ecological provinces.

Objectives

Specific objectives are:

1. Prepare baseline estimates of numbers of tree seedlings by species, length class, and other explanatory variables, such as forest-type group.
2. Implement metrics of regeneration adequacy using accepted regeneration stocking guidelines.
3. Estimate trends for numbers of seedlings, advance regeneration, and related analytics.
4. Explore geospatial relationships of estimates and metrics for use in geographic visualizations.
5. Investigate modeling methods for quantifying advance tree regeneration, and evaluate the utility of the models for providing input to forest-stand dynamics models.
6. Incorporate regeneration estimates into resource projections and assessments.

The data and methods described herein are intended to provide a platform for accomplishing these objectives. Objectives that require additional research are discussed in enough detail to guide future work. Examples in this report draw heavily on experience in Pennsylvania because sampling there has been ongoing since 1989, and the sample intensity is twice that of other states. Across all 24 states in the study region, the new protocols are now being used for the third year.

Background

Golden-winged warbler. Photo by Laura Erickson, Cornell University, used with permission.

Literature Review

Importance of Young Forests

The composition of early successional, young forest is critical for maintaining quality habitat for plant and animal species that depend on them (DeGraaf and Yamasaki 2003, Gilbert 2012, Greenberg et al. 2011, Lorimer and White 2003, Swanson et al. 2011). Declines in the area of young forest have been documented for North America (Hunter et al. 2001, Trani et al. 2001) and the northeastern United States (Brooks 2003). The FIA sapling-seedling stand-size class quantifies the area of young forest, with sapling-seedling stands defined as forest land with a plurality of stand stocking in trees with a d.b.h. less than 5.0 inches. Currently, these young forests occupy 29 million acres, or 16 percent of total forest land of the Midwest and Northeast (Miles 2014). The percentage of young forest is lower for mixed oak (9 percent) and northern hardwoods (10 percent), and is much lower in some states (4 percent in Massachusetts).

Shifley et al. (2014) list a lack of age class diversity, most notably the declining area of young early successional forest habitat, as one of five factors that will radically alter future forest conditions and management needs. The issue is important because a lack of advance tree reproduction threatens the sustainability of northern forest values (Loftis and McGee 1993, McWilliams et al. 1995). Shifley and Thompson (2011) demonstrate that practices that increase the rate of regeneration and establishment of young forests will increase landscape-scale structural diversity. It is important to achieve a more balanced distribution of forest land by conserving the area of late successional forest with the potential of becoming old growth forest because this stage of development is also rare in extent compared to middle to late successional forest.

Forest Ecology, Silvics, Management, and Regeneration Requirements

The breadth and depth of literature on the basic forest ecology, silvics, management, and regeneration requirements for forest types of the Midwest and Northeast reflects the challenge of adapting regeneration guidelines for use with FIA measurements. The history of research for these forest types is wide and precludes a full discussion so is only briefly mentioned here. A selected summary of pertinent literature is shown in Table 1. The references listed contain general information and details useful for understanding fundamental processes and dynamics of the region's forest systems. The literature also provides guidance on regeneration stocking requirements. In general, there are few publications on specific regeneration stocking requirements for established stands, but many silviculture and management guides are available and regeneration requirements are embedded in some of these guides. The references in the table include some older, foundational sources (e.g., Braun 1950, Frothingham 1915, Hough and Forbes 1943, Westveld 1949) and more contemporary work for general contextual background.

Management of mixed oak, northern hardwoods, and aspen/birch forest-type groups is described in numerous publications on regeneration requirements. (Scientific names for trees are listed in Appendix I.) The management of spruce/fir has also been well studied, but specific regeneration requirements for using with NRS-FIA data are needed. Information for management and regeneration for other forest types is largely lacking. In some cases, the regeneration guidelines are published for a specific forest type, such as black ash (Erdman and others 1987), but guidelines cannot always be generalized to other similar types. More information for the elm/ash/cottonwood and white/red/jack pine groups is needed to develop seedling stocking requirements for natural and planted stands.

Table 1.—Selected references for the major NRS-FIA forest-type groups

Forest-type group	General	Ecology and silvics	Management guidelines	Regeneration requirements
Mixed oak	Abrams 2003, Oliver 1978	Dey et al. 2010, Johnson et al. 2009, Hicks 1998	Brose et al. 2008, Sander 1977, Gingrich 1971	Sander 1972, Sander et al. 1976, Sander et al. 1984, Steiner et al. 2007
Northern hardwoods	Nyland 1998, Frothingham 1915	Hornbeck and Leak 1992, Leak et al. 1969, Hough and Forbes 1943	Leak et al. 2014, Marquis 1994, Tubbs 1977, Eyre 1953	Marquis and Bjorkbom 1982, Grisez and Peace 1973
Aspen/birch	Adams 1990, Alban et al. 1991, U.S. Forest Service 1969	Safford 1983, Steneker 1976	Perala 1977, Marquis et al. 1969	Doucet 1989, Perala and Alm 1990
Spruce/fir	Seymour and Hunter 1992, Eagar and Adams 1992	Frank and Bjorkbom 1973, Seymour 1992	Wilson et al. 1999	
Elm/ash/cottonwood	Shifley and Brown 1978	Burns and Honkala 1990	Larsen et al. 2010, Myers and Buchman 1984	
White/red/jack pine	Leak and Yamasaki 2013	Stine and Baughman 1992, Horton and Bedell 1960	Gilmore and Palik 2006, Lancaster and Leak 1978, Seymour and Smith 1987, Benzie 1977	
All groups	Nowacki and Abrams 2008, Braun 1950	Nyland 2002, Smith et al. 1997, Burns and Honkala 1990, Westveld 1949	Burns and Honkala 1990	Dey et al. 2012, Burns and Honkala 1990

Regeneration Stressors

The success or failure of regeneration in the stand initiation and understory re-initiation phases of stand development depends on intricate interactions of abiotic, biotic, and anthropogenic factors (Oliver and Larson 1996).

Important abiotic factors that affect forest regeneration needs for seedling establishment and development are:

- Soil chemistry (Cronan and Grigal 1995, Driscoll et al. 2001, Drohan and Sharpe 1997, Sharpe and Drohan 1999, Zaccherio and Finzi 2007)
- Available light (Latham et al. 2005)
- Local weather history including drought, wind, and ice events (Irland 2000)
- Climate change (Dukes et al. 2009, Glick et al. 2011, Iverson et al. 2008)

Notable biotic factors that affect forest regeneration are:

- Native and nonnative competing vegetation, including invasive species (Engleman and Nyland 2006, Kelty and Cretaz 2002, Knight et al. 2009, Royo et al. 2010b)
- Herbivory (Horsley et al. 2003, Royo et al. 2010a, Tremblay et al. 2007, White 2012)
- Native and nonnative insects and diseases (Latham et al. 2005)
- Available seed sources, seed production, and seed predation (Brose et al. 2008)

Anthropogenic stresses resulting from people interacting with forest ecosystems and obstructing the development of quality forest habitat include:

- Exclusion of fire (Brose et al. 2012, 2013)
- Lack of regeneration management actions (Marquis 1994)
- Poor cutting practices (Nyland 1998, 2002)
- Multiple owner objectives (Butler 2008)
- Lack of management planning (Butler 2008)
- High ungulate populations relative to agriculture food crops (Marquis and Brenneman 1981)
- Forest fragmentation, e.g., patch size and connectivity (Allen et al. 2013)

It is important to note that not all anthropogenic factors have a negative influence. Positive anthropogenic factors include tree planting, competing vegetation control, and other management treatments to encourage desirable reproduction and limit negative abiotic and biotic factors.

The mix of stressors and the scales at which they operate make it particularly difficult to understand management challenges and assess consequences. Research on cross-relationships and multiple interactions is in its infancy. For example, Dukes et al. (2009) found that several pests, diseases, and invasive species are likely to have more of an impact under projected climate change scenarios and that relationships depend on incompletely understood and unstable interactions.

Understory Vegetation and Herbivory

The pervasive nature of the herbivory factor bears further discussion. The reproductive capacity of a forest ecosystem depends on the stocking of tree reproduction and the composition, structure, and abundance of shrubs, vines, and herbaceous vegetation that occupy vital growing space as stands are being replaced (Jackson and Finley 2011). Herbivory is a process that removes palatable understory plants and leaves unpalatable plants; however, research has shown that high levels of herbivory can also cause a decline in unpalatable herbaceous plants (Heckel et al. 2010). The overall question of ecological impacts of white-tailed deer (*Odocoileus virginianus*) overabundance has been thoroughly described by Cote et al. (2004). Deer continue to be a persistent force controlling the amount and composition of tree regeneration in the Midwest and Northeast (Jenkins et al. 2014, Nuttle et al. 2014, Shelton et al. 2014).

The impact of herbivory on regeneration quality and abundance was recognized in the literature as early as 1930 (Frontz 1930) and later by Leopold et al. (1947). Much of the concern and research within the Midwest and Northeast has centered on white-tailed deer where studies have revealed the relationship between deer density and regeneration (Marquis 1974, Marquis and Brenneman 1981, Tilghman 1989). Kittredge and Ashton (1995), Abrams and Johnson (2012), Rooney and Waller (2003), and Sage et al. (2003) provide important edification of deer impacts. Latham et al. (2005) offer a detailed review based on experience in Pennsylvania and stress that quality forest regeneration and wildlife habitat are codependent. DiTommaso et al. (2014) found that impacts of deer herbivory in their study in New York were severe and immediate, resulting in significantly more bare soil, reduced plant biomass, reduced recruitment of woody species, and relatively fewer native species. Russell et al. (2001) provide a comprehensive review of deer effects for north-central and northeastern states. Jenkins et al. (2014) found that reducing deer density increased the cover of tree seedlings and recovery of degraded vegetation communities.

Research on vegetation specific to the understory has addressed the development of new and novel formations of species that result from overbrowsing combined with invasion by native and nonnative plants (Horsley et al. 2003; Kain et al. 2011; Royo and Carson 2006; Royo et al. 2010a, 2010b; Wiegmann and Waller 2006). Native and nonnative invasive plants and communities are discussed by Baumer and Runkle (2010), Engleman and Nyland (2006), Fei et al. (2010), Huebner et al. (2010), and Knight et al. (2009).

Regeneration Sampling

A technical session on regeneration surveys was convened as part of the 1983 Society of American Foresters national convention. The proceedings provided a wealth of information to consider when designing regeneration surveys. Stage and Ferguson (1984) and Stein (1984b) state that the purposes of regeneration surveys are to determine regeneration status, demonstrate conservation potential, evaluate effectiveness of the regeneration method, identify cultural needs, and project future forest yield. Stein (1984a) and Dennis (1984) cover fixed-plot and distance sampling methods, respectively. Kaltenberg (1984) and MaClean (1984) cover other sampling issues. Recent work by Ristau and Stout (2014) indicates that percentage of cover of seedlings is not a reliable surrogate for seedling counts.

Regeneration Assessments

Studies that utilize FIA seedling measurements to evaluate regenerative capacity are rare compared to work on other forest components, such as established trees in the main canopy. In the eastern United States, most of the work has been for pine forests in the South (McWilliams 1990, McWilliams and Birdsey 1984). Landscape-level regeneration results are available for Pennsylvania (McCaskill et al. 2013; McWilliams et al. 1995, 2007). General findings using traditional FIA variables are available in state resource reports including those for Virginia (Rose 2009) and West Virginia (Widmann et al. 2012). Shirer and Zimmerman (2010) used FIA seedling counts to evaluate regeneration for the state of New York. The National Park Service adopted a similar approach as part of their inventory and monitoring program due to concerns over high deer impacts affecting tree regeneration (National Park Service 2012, Schmit and Nortrup 2013). Increased emphasis on future forests, impacts of changing climate, and species migration have strengthened the need for novel analytics. A prime example of this burgeoning field of inquiry is the work of Woodall et al. (2008) that includes an indicator of oak regeneration as a driver of species migration.

Pennsylvania Regeneration Study—A Precursor to the Regeneration Indicator

In 1989, FIA began the PRS with the Pennsylvania Department of Conservation and Natural Resources, Bureau of Forestry to gauge tree regeneration adequacy in the State. The study was prompted by concerns over the impact of deer and other factors on a perceived lack of regeneration across large areas (Frye 2006). Measuring advance reproduction and competing vegetation was included on all FIA sample plots visited during the summer leaf-on season. Sampling protocols included an evaluation of deer impact on trees, measurement of all established seedlings, measurement of root collar diameter (RCD) for large-seeded species such as oaks, and a complete count of tree seedlings for six length classes. Note that while seedling length is the term used in the NRS-FIA field manual, for simplicity it will be referred to as seedling height in the rest of this report.

Results from the PRS provided the first large-scale empirical data describing the impoverished condition of advance regeneration in the State (McWilliams et al. 1995). The PRS continued with the implementation of the FIA annual inventory system in 2000. Since then, the PRS has documented regeneration adequacy on an annual basis.

Over the past two decades, the Pennsylvania Game Commission has been developing strategies for managing deer populations to improve habitat quality across Pennsylvania. Wildlife Management Units (WMUs) were designed using land characteristics such as land use, ownership, physiography, habitat type, and road networks that are related to game management. The WMUs are used to relate deer harvest goals to habitat quality and available food sources. The current deer management plan uses PRS results as the primary indicator of deer habitat quality in appraisals of prospective harvest for the WMUs (Rosenberry et al. 2009).

Forest Systems of the Midwest and Northeast United States

The Midwest and Northeast span a wide range of physiographic and climatic conditions that support a diverse mix of forest systems with differing requirements for regeneration stocking. The 80 forest types found in the region are assembled into 18 forest-type groups. Detailed types, groups, and forest land estimates are shown in Table 2. The most widespread forest-type groups are oak/hickory and maple/beech/birch, referred to herein as mixed oak and northern hardwoods, respectively.

The distribution of forest land by forest-type group for the Midwest and Northeast United States in 2013 was:

Forest-type group	Percentage of forest land (%)
Mixed oak	36
Northern hardwoods	25
Aspen/birch	9
Spruce/fir	9
Elm/ash/cottonwood	8
White/red/jack pine	5
Other groups	8
	100

The mixed oak and northern hardwood groups dominated 6 out of every 10 acres of the region's forest land. Aspen/birch, spruce/fir, elm/ash/cottonwood, and white/red/jack pine combined for 31 percent of the forest land, with the 12 remaining groups contributing 8 percent of the total. FIA forest-type groups each include multiple forest types. The aggregation of forest types is needed because of the large number of forest types that exist; however, grouping often results in the combining of specific types that have vastly different silvics. For example, the spruce/fir group includes tamarack and northern white-cedar, two forest types that have disparate phenology. Therefore, guidelines for specific types that have established silvicultural guidelines should be considered whenever possible in regeneration assessments.

The work described in this report is aimed at quantifying observed patterns of tree regeneration for forest-type groups. Information about tree species can also be used to compare understory composition to overstory composition; for example, red maple seedlings and saplings under an oak canopy.

Table 2.—Area of forest land by NRS-FIA forest-type group and forest type, Midwest and Northeast, United States, 2013

FIA forest-type groups (in bold) and forest types	Acres[a]
White/red/jack pine	
Jack pine[b]	1,392,696
Red pine	2,476,580
Eastern white pine	3,312,052
Eastern white pine-eastern hemlock	556,489
Eastern hemlock	1,353,054
Spruce/fir	
Balsam fir	3,821,455
White spruce	721,585
Red spruce	1,262,378
Red spruce-balsam fir	1,449,779
Black spruce	2,949,959
Tamarack	1,992,786
Northern white-cedar	3,424,659
Loblolly/shortleaf pine	
Loblolly pine	400,637
Shortleaf pine	293,576
Virginia pine	296,086
Table Mountain pine	9,485
Pitch pine	650,810
Other eastern softwoods	
Eastern redcedar	1,099,929
Pinyon/juniper	
Rocky Mountain juniper	182,262
Douglas-fir	
Douglas-fir	5,313
Ponderosa pine	
Ponderosa pine	1,344,783
Fir/spruce/mountain hemlock	
Blue spruce	25,620
Exotic softwoods	
Scotch pine	387,390
Other exotic softwoods	34,224
Norway spruce	203,516
Introduced larch	51,455
Other softwoods	
Other softwoods	6,047

FIA forest-type groups (in bold) and forest types	Acres
Oak/pine	
Eastern white pine-northern red oak-white ash	2,665,277
Eastern redcedar-hardwood	1,153,390
Shortleaf pine-oak	341,537
Virginia pine-southern oak	384,676
Loblolly pine-hardwood	203,908
Other pine-hardwood	1,169,757
Oak/hickory (mixed oak)	
Post oak-blackjack oak	1,629,485
Chestnut oak	1,919,177
White oak-red oak-hickory	26,735,839
White oak	4,040,223
Northern red oak	4,185,014
Yellow-poplar-white oak-northern red oak	2,380,573
Sassafras-persimmon	639,906
Sweetgum-yellow-poplar	418,094
Bur oak	1,313,496
Scarlet oak	448,713
Yellow-poplar	974,669
Black walnut	897,117
Black locust	759,347
Southern shrub oak	52,710
Chestnut oak-black oak-scarlet oak	3,690,651
Cherry-white ash-yellow-poplar	3,210,612
Elm-ash-black locust	4,081,849
Red maple-oak	2,536,465
Mixed upland hardwoods	5,688,604
Oak/gum/cypress	
Swamp chestnut-cherrybark oak	67,602
Sweetgum-Nuttal oak-willow oak	85,869
Overcup oak-water hickory	91,229
Atlantic white-cedar	35,600
Baldcypress-water tupelo	28,203
Sweetbay-swamp tupelo-red maple	430,415
Elm/ash/cottonwood	
Black ash-American elm-red maple	3,219,966
River birch-sycamore	952,934
Cottonwood	983,068
Willow	482,017
Sycamore-pecan-American elm	911,982
Sugarberry-hackberry-elm-green ash	4,360,058
Silver maple-American elm	1,370,845
Red maple-lowland	1,934,415
Cottonwood-willow	324,291

(continued on next page)

Table 2 (continued).

FIA forest-type groups (in bold) and forest types	Acres
Maple/beech/birch (northern hardwoods)	
Sugar maple-beech-yellow birch	30,847,000
Black cherry	1,460,773
Hard maple-basswood	8,658,191
Red maple-upland	4,738,700
Aspen/birch	
Aspen	12,003,534
Paper birch	3,027,855
Gray birch	343,268
Balsam poplar	850,477
Pin cherry	297,054
Other hardwoods	
Other hardwoods	2,119,359
Exotic hardwoods	
Paulownia	5,979
Other exotic hardwoods	257,860
Nonstocked forest	1,769,685
Total forest land	182,895,106

[a] Estimates of roughly 78,000 acres are associated with a 25 percent sampling error at the 68 percent confidence level and have low reliability. Estimates for smaller areas are not reliable for most uses.

[b] See Appendix I for scientific names.

National Core Sample Design

Competitive oak reproduction following a shelterwood cut. Photo by William H. McWilliams, U.S. Forest Service.

The national FIA annual inventory sampling frame consists of three phases (Bechtold and Patterson 2005). The core measurements are collected using the same protocols and methods across the Nation (U.S. Forest Service 2013b). The development of the national design from differing regional designs has improved FIA's ability to track geospatial relationships across traditional boundaries and to monitor a wider array of forest values and services, such as ecological indicators (Gillespie 1999).

Phase 1

In Phase 1, classified remotely sensed imagery is used to post-stratify sample plots, allowing for stratified estimation, a procedure that can reduce uncertainty (variance) for estimates of population totals (McRoberts et al. 2006, Scott et al. 2005). The stratification layer for NRS-FIA is based on thresholds applied to the 2001 National Land Cover Database (NLCD) canopy density dataset (Homer et al. 2004, 2007; Huang et al. 2001) for all NRS-FIA states through 2012 and for roughly half the states processed for 2013. The other half of 2013 NRS-FIA states and future processing is based on the 2011 Tree Canopy Cover dataset (Coulston et al. 2013) using the same stratum thresholds as previously used for the 2001-based stratifications. The NLCD canopy density classification of 30-meter pixels is used along with sample plot coordinates to stratify NRS-FIA sample locations. This procedure is done in addition to and independent from pre-field aerial photo interpretation, which provides a basis for selecting which plots receive field-crew visits. Field-visited plots include those that were previously forested along with additional plots that now appear to be in or very near forest land.

Phase 2

The Phase 2 sample uses a national grid of hexagons, each occupying roughly 6,000 acres. Figure 2 depicts the hexagonal grid design and the sample footprint. A Phase 2 sample plot is located randomly within each hexagon. Forested sample plots are visited each year using an interpenetrating design that yields statistically independent "panels" of inventory measurement data. The inventory cycle is defined by the number of years (or panels) it takes to measure all of the sample plots in a State; thus, a 5-year cycle yields five independent panels. Although each annual panel can be used individually for estimates, the more panels that are used, the higher the statistical power of the estimates. Multiple inventory cycles provide data for change estimation because the same plots are revisited across cycles if they were in a forested condition previously and are forested at the time of the next visit.

The national FIA program adopted a mapped sample design where each sample plot is examined for boundaries separating forest-nonforest and within-forest condition changes. Separate within-forest conditions are defined by changes in vegetation and ownership that occur along distinct boundaries based on reserved status, owner group, forest type, stand size, stand origin, and stand density (U.S. Forest Service 2013b). Condition boundaries are mapped, condition proportions are calculated, and separate conditions are used to reduce bias and improve classification for Phase 2 sample plots. For example, the assignment of a single forest type to a sample plot that is split between coniferous and broadleaf forest could yield a misleading classification. To delineate condition boundaries, the FIA field staff examines an area of at least 1 acre or at least 120 feet in width for contrasting conditions that affect the plurality of live tree stocking over the total area covered by the sample plot.

The standard Phase 2 inventory provides data and information at the tree, condition, and plot level. Some condition-level variables, such as stand age, are based on field measurements. Other variables, including forest type and stocking class, are developed by classification algorithms that use the individual tree measurements.

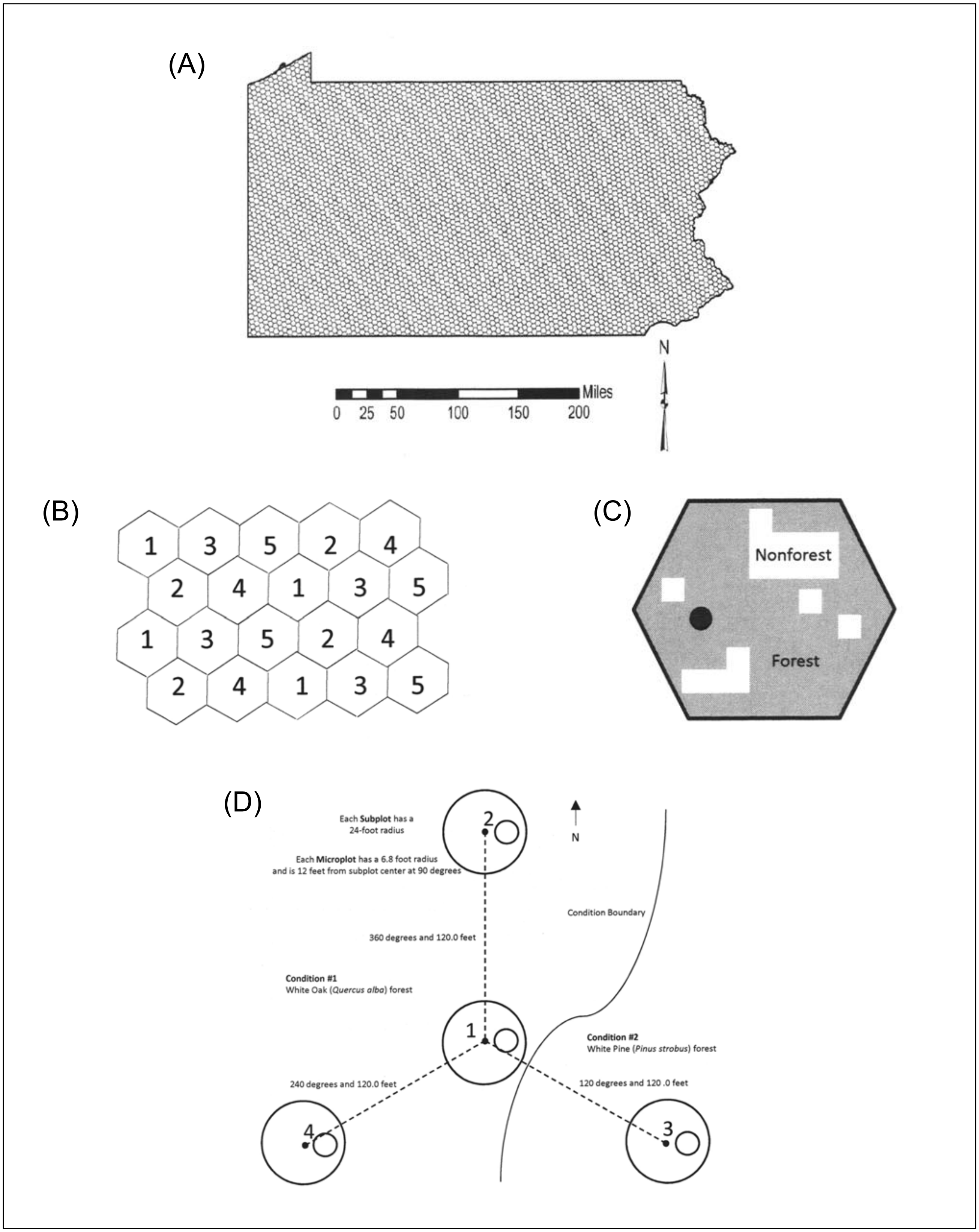

Figure 2.—(A) Pennsylvania Phase 2 hexagonal sample grid (hexagon locations are approximate), (B) 5-year interpenetrating panel design, (C) example of a forested sample plot randomly located within a hexagon, and (D) Phase 2 sample plot footprint spanning two condition classes (U.S. Forest Service 2013b).

The sample of forest vegetation consists of a cluster of four fixed-radius subplots, with one subplot centered on the plot location and three peripheral subplots each centered 120 feet from plot center (Fig. 2d). Each subplot has a radius of 24.0 feet and contains a 6.8-foot radius microplot offset from subplot center. In Phase 2, field crews visit each plot, subplot, and microplot to measure a suite of forest attributes specified in the national core sample design. Trees at least 5.0 inches in diameter at 4.5 feet above ground line (d.b.h.) are measured on the subplot. Trees with a d.b.h from 1 inch to 4.9 inches (saplings) are measured on the microplot. Azimuth from microplot center, distance, species, d.b.h., status (live, dead, or removed), crown class, crown ratio, and total height are measured for each sapling. Tree seedlings (less than 1-inch d.b.h.) are also counted on the microplot. Having both saplings and seedlings measured on the microplot improves the spatial integrity of regeneration estimates that include saplings.

Phase 3

The Phase 3 sample was collected prior to 2012 and encompassed the following ecological indicators: vegetation composition/structure (Schulz et al. 2009), down woody material (Woodall and Monleon 2007), tree-crown condition (Schomaker et al. 2007), tree damage (U.S. Forest Service 2013b), soils (O'Neill et al. 2005), lichens (Jovan 2008), and ozone damage (Smith et al. 2008). In the Midwest and Northeast, these measurements were collected on 6.25 percent of the Phase 2 samples during the summer leaf-on season. Each sample plot represented about 96,000 acres.

Phase 2-plus Regeneration

Painted trillium. Photo by Thomas G. Barnes, U.S. Fish and Wildlife Service, via http://commons.wikimedia.org/wiki.

Beginning with the 2012 field season, Phase 3 ecological indicators were streamlined to gain cost efficiencies based on lessons learned from over a decade of collection (U.S. Forest Service 2013a). The revised set of ecological indicators is vegetation structure, down woody material, tree-crown condition, and soils. The tree damage indicator data are now collected on Phase 2 plots. The vegetation structure indicator consists of a vegetation profile, an invasive plants survey, and the regeneration survey. The vegetation profile and invasive plant survey data are collected on the subplot (Fig. 3). The regeneration indicator survey is conducted on the microplot that is nested within the subplot (Fig. 4). The new approach, referred to as "Phase 2-plus," doubles the number of samples that were previously collected to 12.5 percent, so each plot represents approximately 48,000 acres. The time it takes to complete the entire set of Phase 2-plus samples depends on the inventory cycle length.

Seedling Sample History and Use

The seedling tally is one of the oldest FIA measurements, primarily because the FIA definition of forest land requires at least 10 percent stocking of live trees, and in the absence of saplings or larger trees, seedlings become the basis for the classification. This is important because the number of forested samples is used to estimate the area of forest land in a State, and FIA only conducts field measurements on forested samples.

Historically, the detail of the tree seedling inventory has been limited to the use of the data for estimating the area of forest land. The national core seedling tally has always used minimum height thresholds for defining seedlings. For most of FIA's history, seedlings were defined as at least 6.0 inches in height for softwoods and at least 12.0 inches in height for hardwoods; however, a single 12-inch threshold has also been used. This approach ignored smaller established seedlings that are an important component of reproduction.

The process of implementing the annual inventory system resulted in the consolidation of regional manuals into a single national manual (U.S. Forest Service 2013b), and seedling count was expanded to include all seedlings by species. Although this was a major improvement, the approach lacked any assessment of seedling establishment other than the minimum height thresholds, making it difficult to evaluate regeneration because the best science has shown that seedling height and RCD are better indicators of seedling establishment and competitive status (Brose et al. 2008). The implementation of the regeneration indicator has extended counts to include all established seedlings that are at least 2 inches tall; however, the 6-inch and 12-inch counts have been maintained to ensure temporal consistency for forest land estimates. The NRS-FIA Phase 2-plus regeneration measurements are collected on the sample plot, subplot, and the microplot.

Sample Plot Regeneration Measurements

Browse Impact

The browse impact code indicates the amount of pressure that herbivores are exerting on tree seedlings and other understory flora for the area surrounding the sample plot. Browse is defined as the consumption of tender shoots, twigs, and leaves of trees and shrubs used by animals for food (U.S. Forest Service 2013a). Browse impact is a function of browser population and the amount of available food sources within 1 square mile surrounding the plot. The approach is distinguished from other browse studies that assess impact of browsing on understory plants (Latham et al. 2005). The reason for assessing impact is that it is difficult to identify browse if there are no seedlings or other vegetation present to be browsed (Latham et al. 2009). This

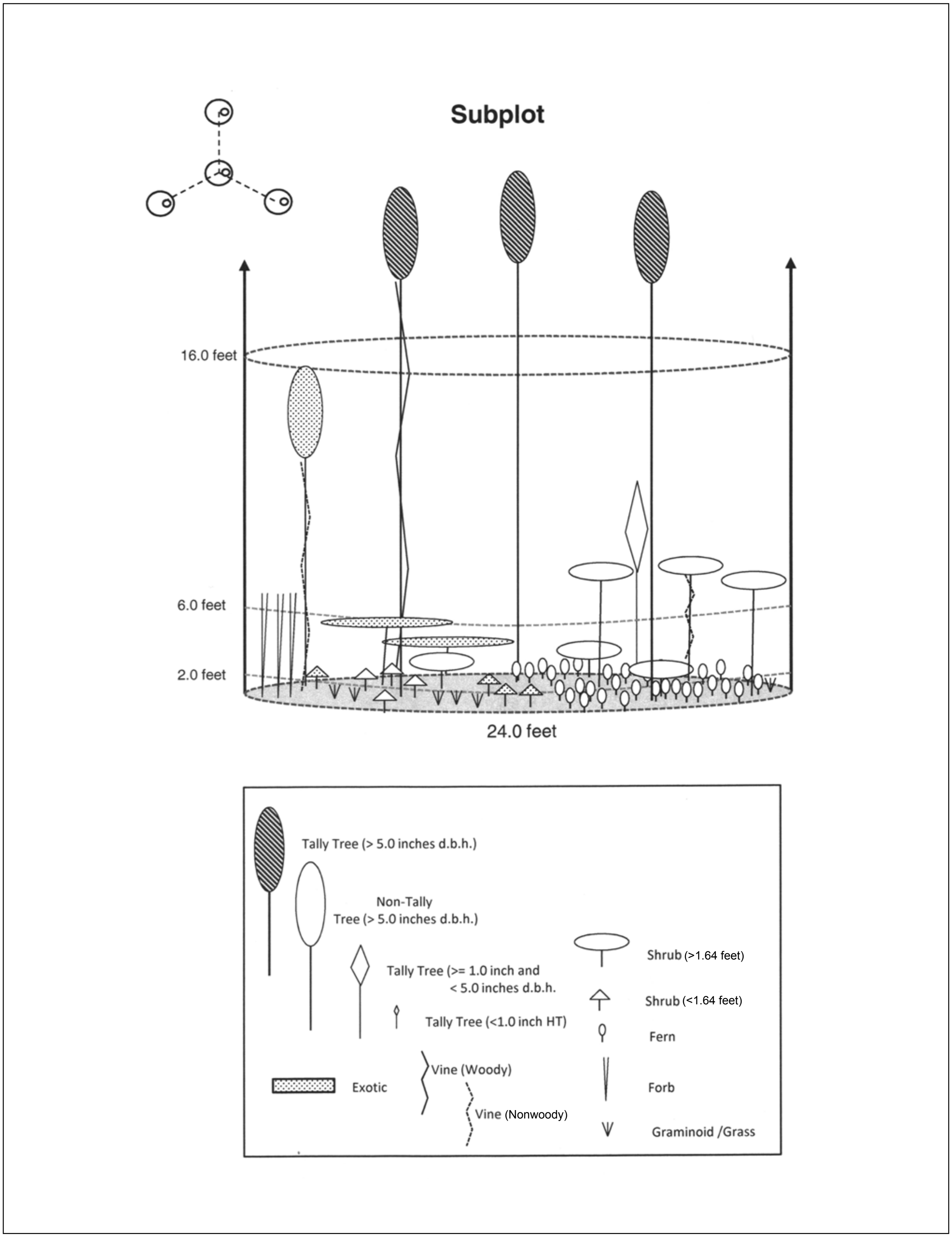

Figure 3.—Subplot vegetation profile (U.S. Forest Service 2013a).

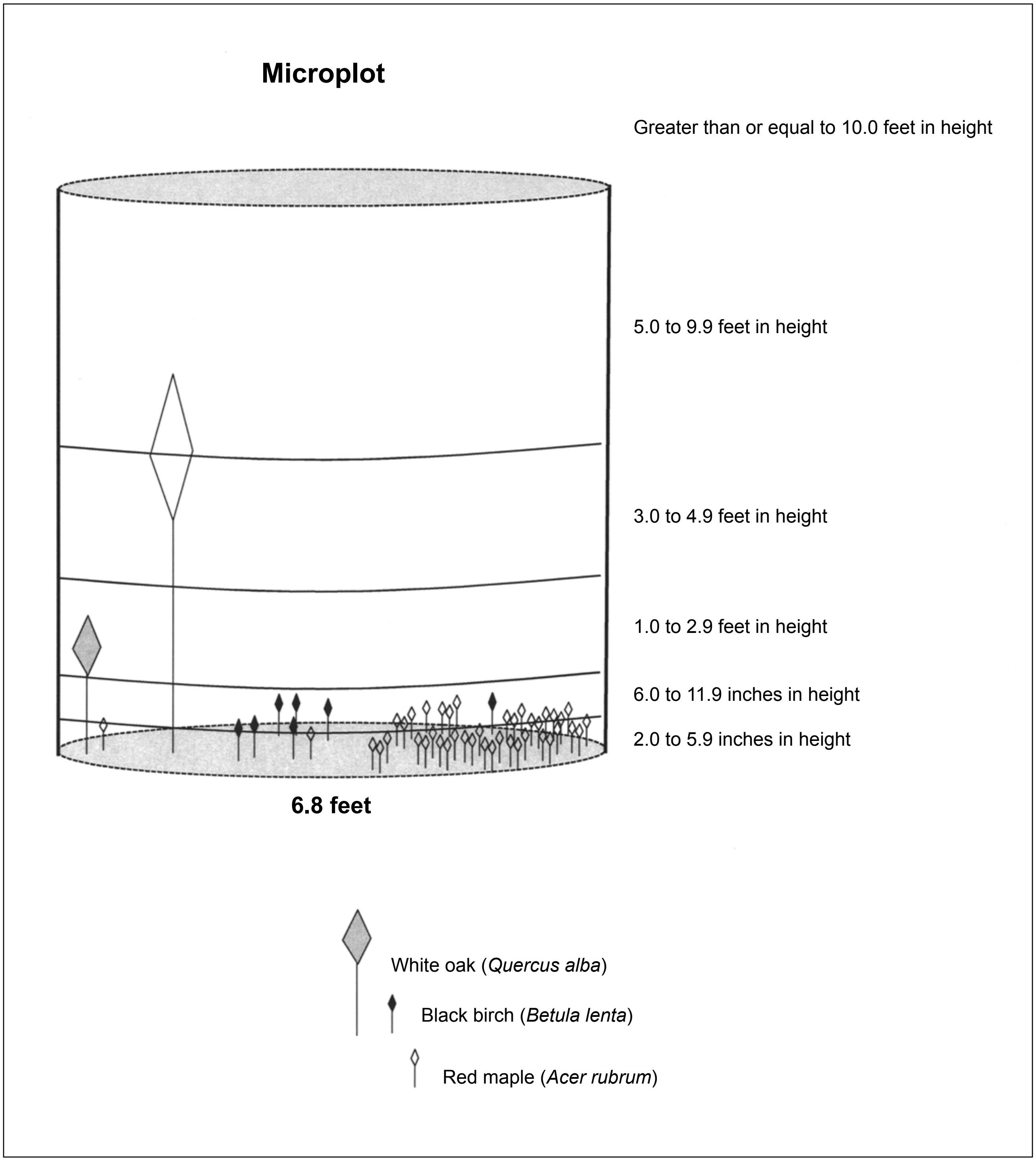

Figure 4.—Microplot tree seedling sample (U.S. Forest Service 2013a).

study examines the existing forest understory vegetation and tree seedling abundance to evaluate browse impact. The following five codes are used:

1 Very low impact—Plot is inside a well-maintained exclosure.
2 Low impact—No browsing observed, vigorous seedlings present (no exclosure present).
3 Medium impact—Browsing evidence observed but not common, seedlings common.
4 High impact—Browsing evidence common.
5 Very high impact—Browsing evidence omnipresent or severe browse line.

Subplot Regeneration Measurements

Subplot Site Limitations

Site limitations that are observable over a minimum of 30 percent of the forested condition are recorded for each subplot. The variable is used to explain why some subplots may have no tree seedlings. The limitations include rocky surfaces with little or no soil and soil that is saturated during the growing season.

Microplot Regeneration Measurements

Microplot Site Limitations

Site limitations that are observable over a minimum of 30 percent of the forested condition of the microplot are also recorded. The limitations are the same as the subplot site limitations with the addition of a duff layer in excess of 2 inches thick. Thick duff layers are not limiting for all species, such as hemlock and spruce.

Tree Seedling Counts

Tree seedlings are counted by species and condition class on each microplot that is in a forested condition within each subplot (U.S. Forest Service 2013a). The tally is designed to capture seedlings that are in their second growing season and are established. Established seedlings have survived for at least a year and are at least 2 inches in height.

The purpose of the NRS-FIA seedling count is to provide estimates of the number of seedlings per unit area for populations of interest. These evaluations require thresholds for the number of seedlings needed to satisfy regeneration stocking requirements for FIA forest types. Seedling height is an important factor for estimating likelihood of survival for naturally and artificially established seedlings, especially in areas with competing vegetation and herbivory (Brose et al. 2008, Oswalt et al. 2006, Sander 1972).

The methodology for tree seedling counts, seedling height measurements, and RCD evaluation were adapted from long-term research for mixed oak (Brose et al. 2008) and northern hardwood (Marquis 1994) forests of the mid-Atlantic region. Most factors that influence tree seedling establishment and development are in play in the region, including competing vegetation, invasive plants, and herbivory. The approach was necessarily simplified to cover the broad conditions of the Midwest and Northeast; however, the methodology is flexible enough to adapt for other forest types and forest-type groups.

Tree seedlings are counted by source and height class (Fig. 5). Seedling source is coded as seedling, stump sprout, or a separate code expressing competitiveness of large-seeded species such as oak, hickory, black walnut, pecan, and butternut. The code for stump sprouts includes stumps at least 2 inches in diameter.

In the case of large-seeded species, the level of establishment is determined primarily by evaluating RCD. A RCD of at least 0.25 inch defines a stem that is established. Stems at least 3.0 feet in height are also included as established. Seedlings with an RCD of at least 0.75 inch and a d.b.h. less than 1.0 inch are coded as competitive. The competitive code is used in the analysis of regeneration stocking

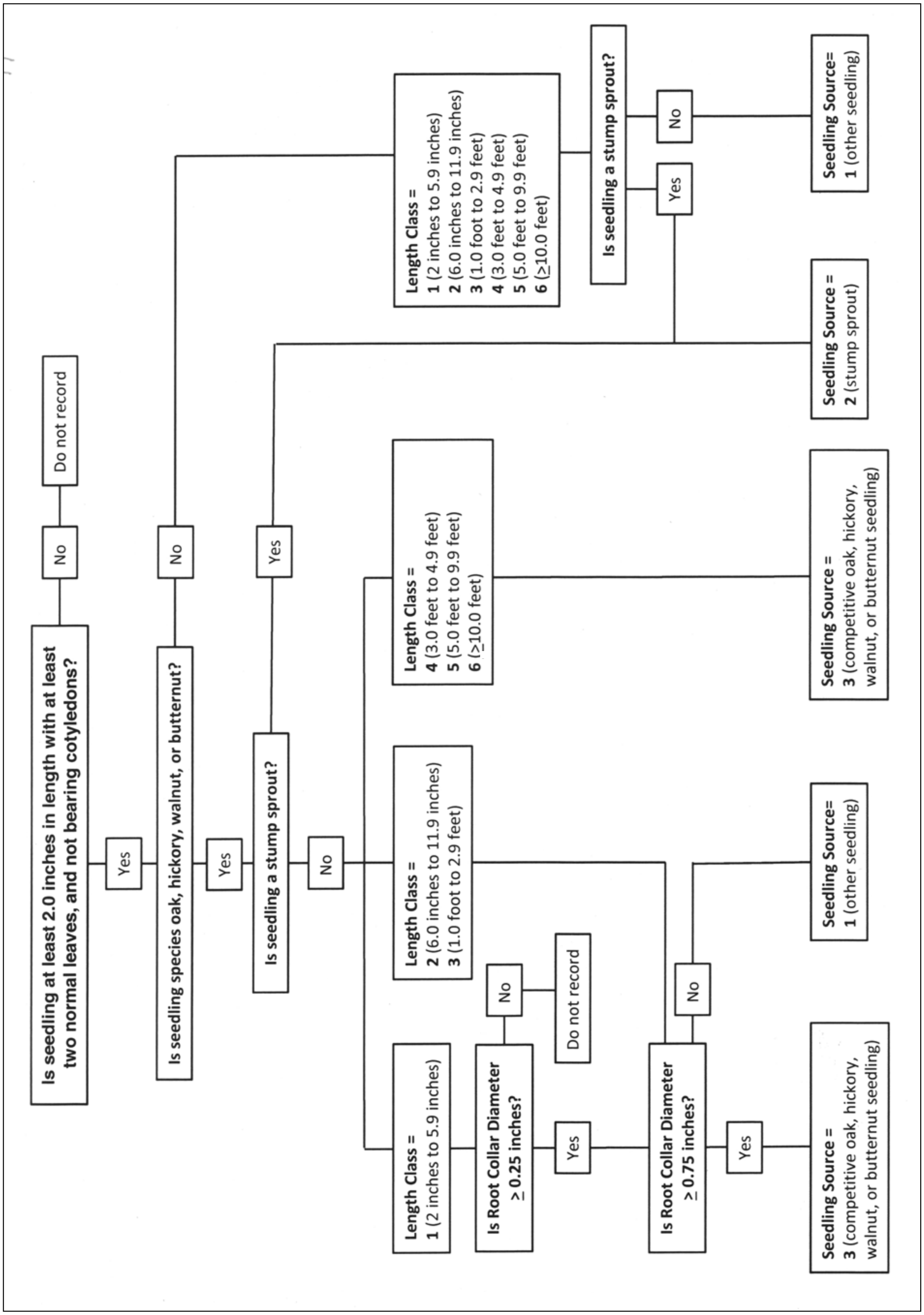

Figure 5.—Tree seedling source count guide (U.S. Forest Service 2013a).

for large-seeded species (see Adequacy of Advance Tree Seedling Regeneration on page 36).

Public Database

All regeneration indicator data are stored both internally and in the FIA public database that is available for download (http://apps.fs.fed.us/fiadb-downloads/datamart.html). The structure follows the three levels of data collection: sample plot, subplot, and microplot. The Oracle® tables, structure, and variable definitions are described in Appendix II.

Estimation and Analytics

Tree-of-heaven seedlings. Photo by Chris Evans, Illinois Wildlife Action Plan, via http://www.forestryimages.org.

Population Estimates

Estimates of the number of seedlings provide critical input for the study of regeneration, wildlife habitat, carbon accounting, species migration, future forest dynamics, and other topics. Scott et al. (2005) describe the details of FIA's post-stratified sampling design and the associated statistical procedures for calculating population estimates. Briefly, estimates are made by summing the numbers of seedlings in the domain of interest for each plot and computing the mean and variance in each stratum. These statistics are then combined across all strata using stratum weights derived from maps of the population area to obtain estimates and sampling errors. Estimates of seedling frequency, volume, weight (biomass), or carbon can be made for unit area and population totals.

The differentiation of seedlings by species and height class provides numerous opportunities to develop core products that address composition and structure of the seedling component (Objective 1). Sampling errors for seedling estimates will be relatively high until the measurement of all the baseline Phase 2-plus sample plots is completed. To illustrate, consider estimates of the number of seedlings by species for Wisconsin using the 2012 and 2013 inventory data (App. III, Table 5). The estimate of the total number of seedlings is 92 billion stems with a sampling error of 11 percent at the 68 percent confidence level. The estimate for the most abundant species, red maple, is 27 billion subject to a 25 percent sampling error. The estimates for some species and height classes are in excess of 50 percent, meaning the results should be used with caution. When all inventory panels are completed, the estimates for the total and for red maple are projected to be 7 percent and 16 percent, respectively. Once the baseline sample is complete, more detailed products, such as the analytics mentioned in this report, can be completed.

Core Reporting Product Examples

Core products are needed to address common issues, and having information available for the regeneration indicator provides the opportunity to analyze results across states, ecoregions, and other areas. This section presents a basic set of reporting products that can be used prior to the completion of the baseline set of samples. Examples are provided for the first 2 years of data collected for Wisconsin (2012 and 2013). Wisconsin was chosen as a case study because it has a relatively large amount of forest land, and it provides the opportunity to develop core reporting products in the early stages of data collection.

Estimates of the number of seedlings and number of seedlings per acre on forest land by species are fundamental tabular products (App. III, Tables 5 and 6). Expanding the reporting template to include graphical summaries of important variables and geospatial visualizations of the results provide interim analytical products. Graphics showing the location of samples and frequency distributions for browse impact, species, and height class offer basic information describing the State's tree seedling inventory (Figs. 6 through 12). Profiles of the number of seedlings per acre by species and height class highlight composition and structure of the seedling component. The six seedling height classes were combined into three groups to take advantage of the larger number of samples and reduce the size of the confidence intervals for species-level estimates. Profiles of per acre estimates for saplings (Fig. 13) and dominant/codominant adult trees (Fig. 14) provide a comparison of stand structural components and indicate differences between understory and overstory composition. The estimates for saplings and adult trees are based on five inventory panels collected from 2009-2013.

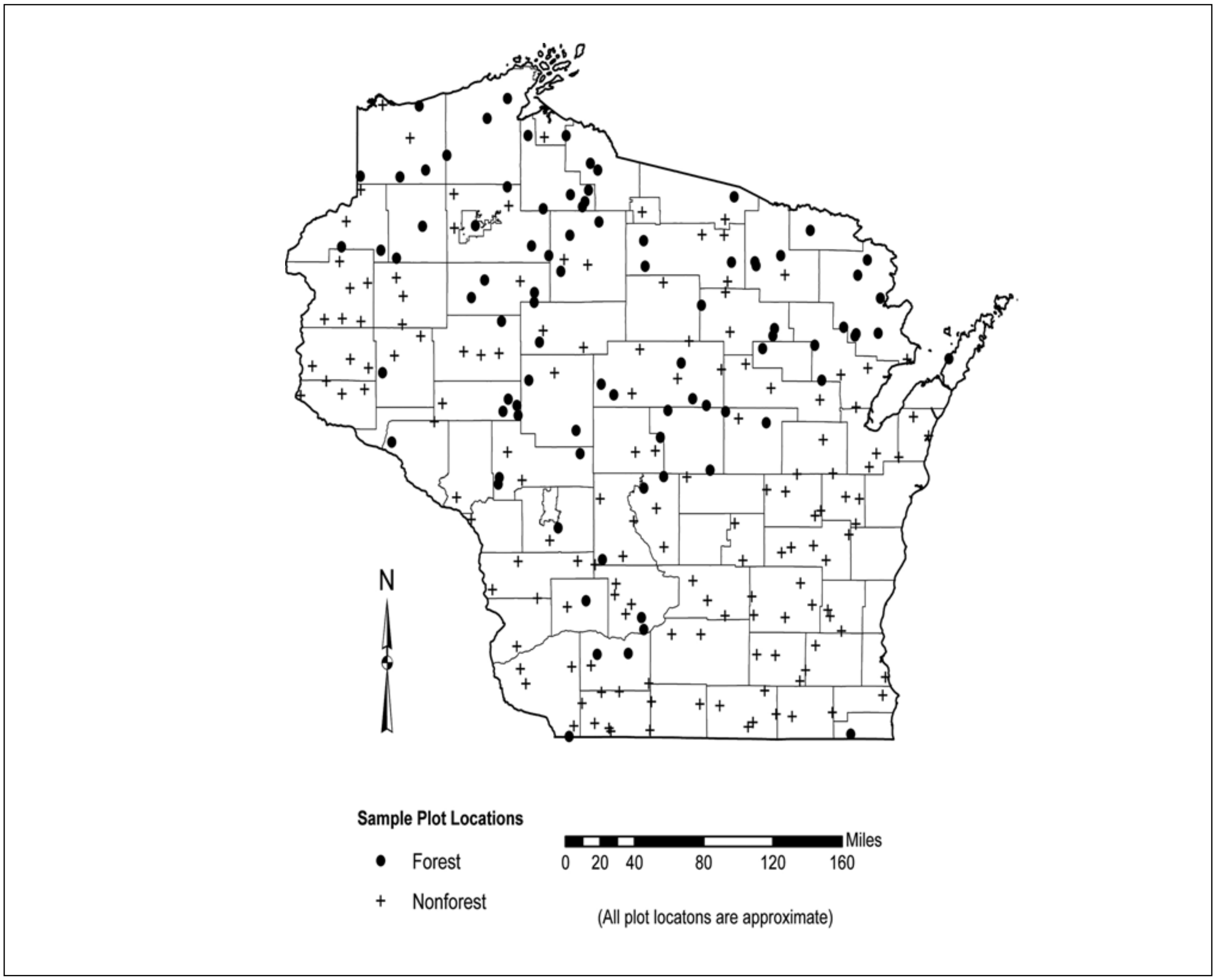

Figure 6.—Distribution of forested Phase 2-plus samples on forest land by land-use class, Wisconsin, 2012-2013.

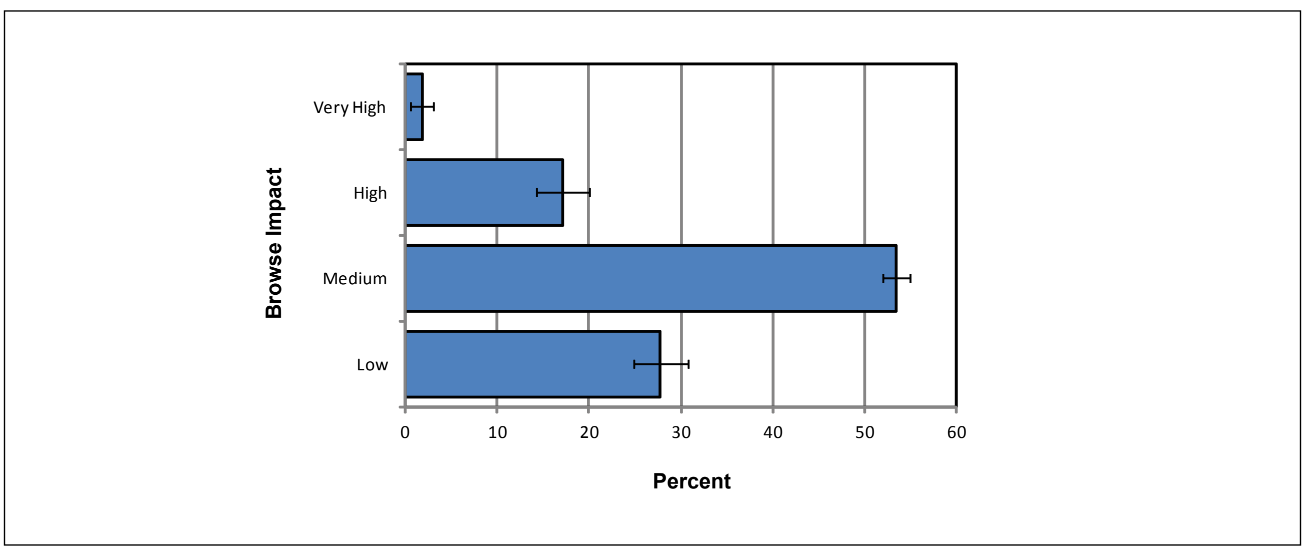

Figure 7.—Percentage of forested Phase 2-plus samples on forest land by browse impact class, Wisconsin, 2012-2013. Sampling errors are shown for the 68 percent confidence level.

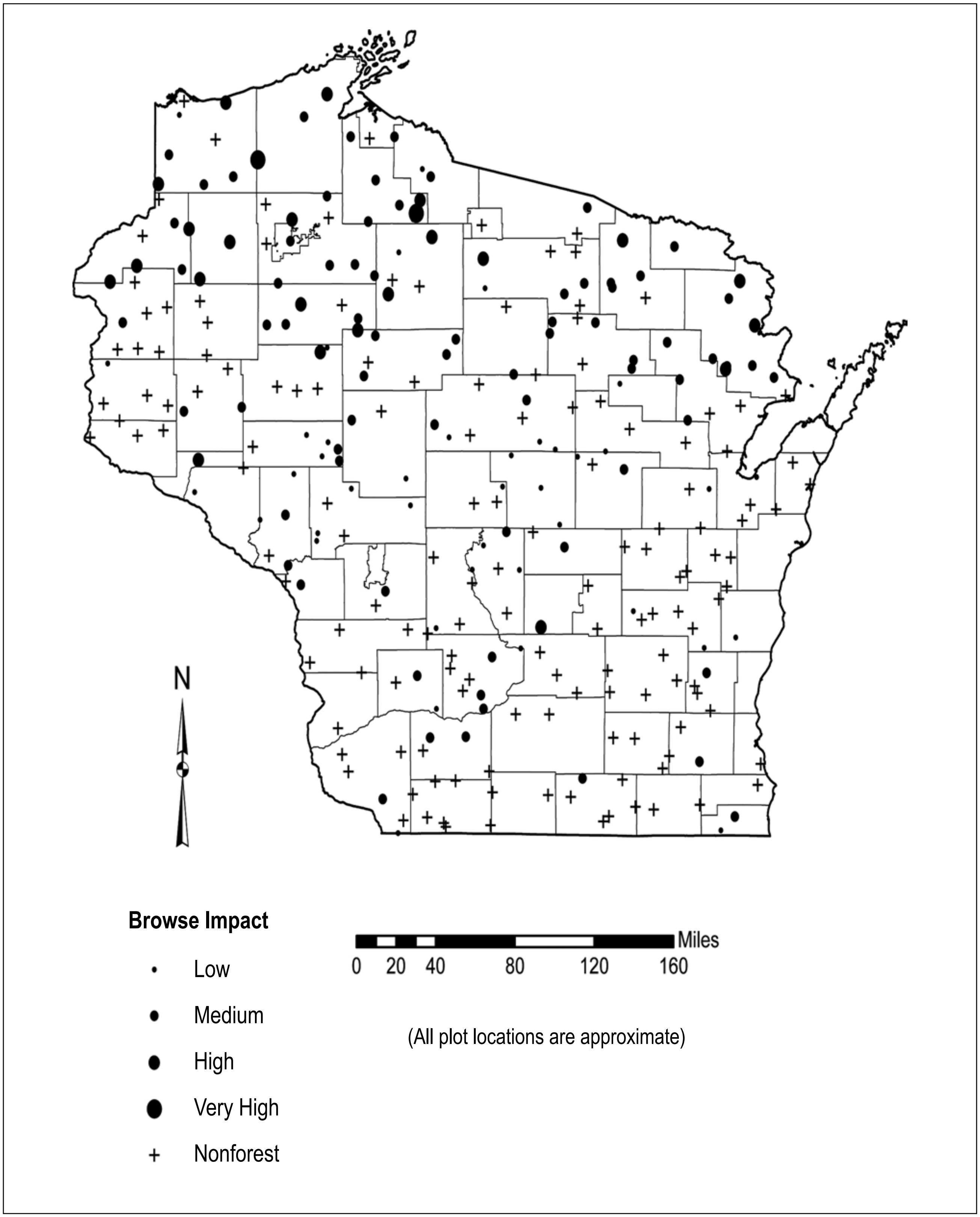

Figure 8.—Distribution of forested Phase 2-plus samples on forest land by browse impact class, Wisconsin, 2012-2013

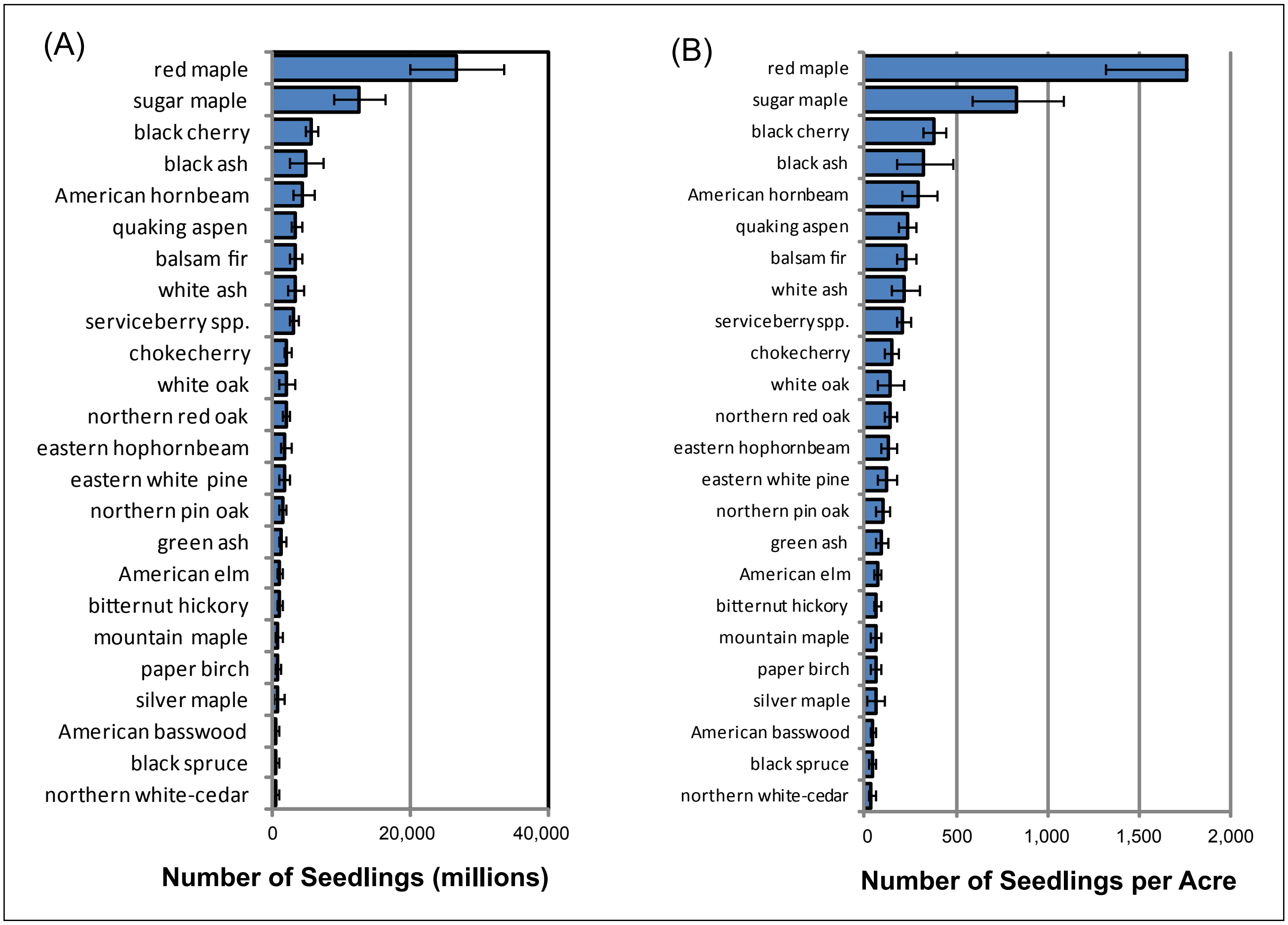

Figure 9.—Total number of seedlings (A) and seedlings per acre (B) on forest land by species for species with at least 1 percent of the total, Wisconsin, 2012-2013. Sampling errors are shown for the 68 percent confidence level.

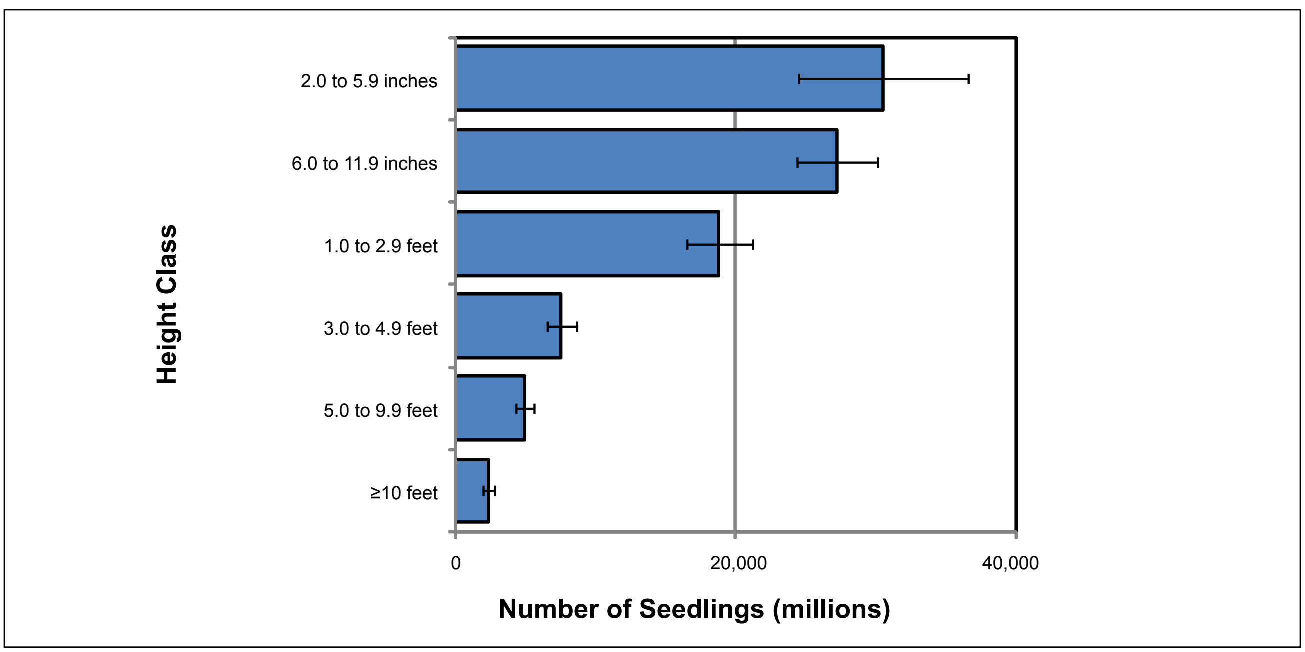

Figure 10.—Number of seedlings on forest land by height class, Wisconsin, 2012-2013. Sampling errors are shown for the 68 percent confidence level.

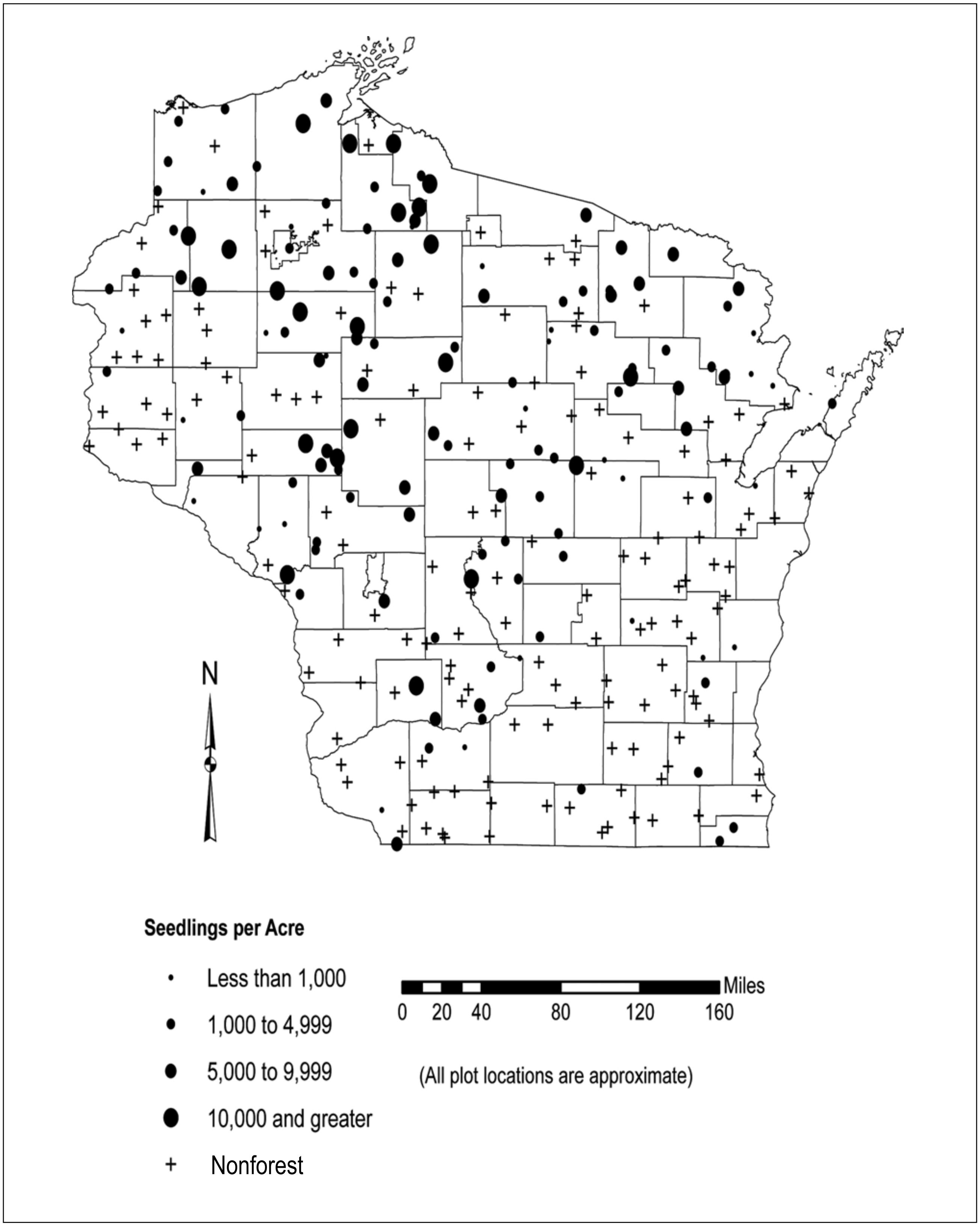

Figure 11.—Distribution of forested Phase 2-plus samples on forest land by number of seedlings per acre, Wisconsin, 2012-2013.

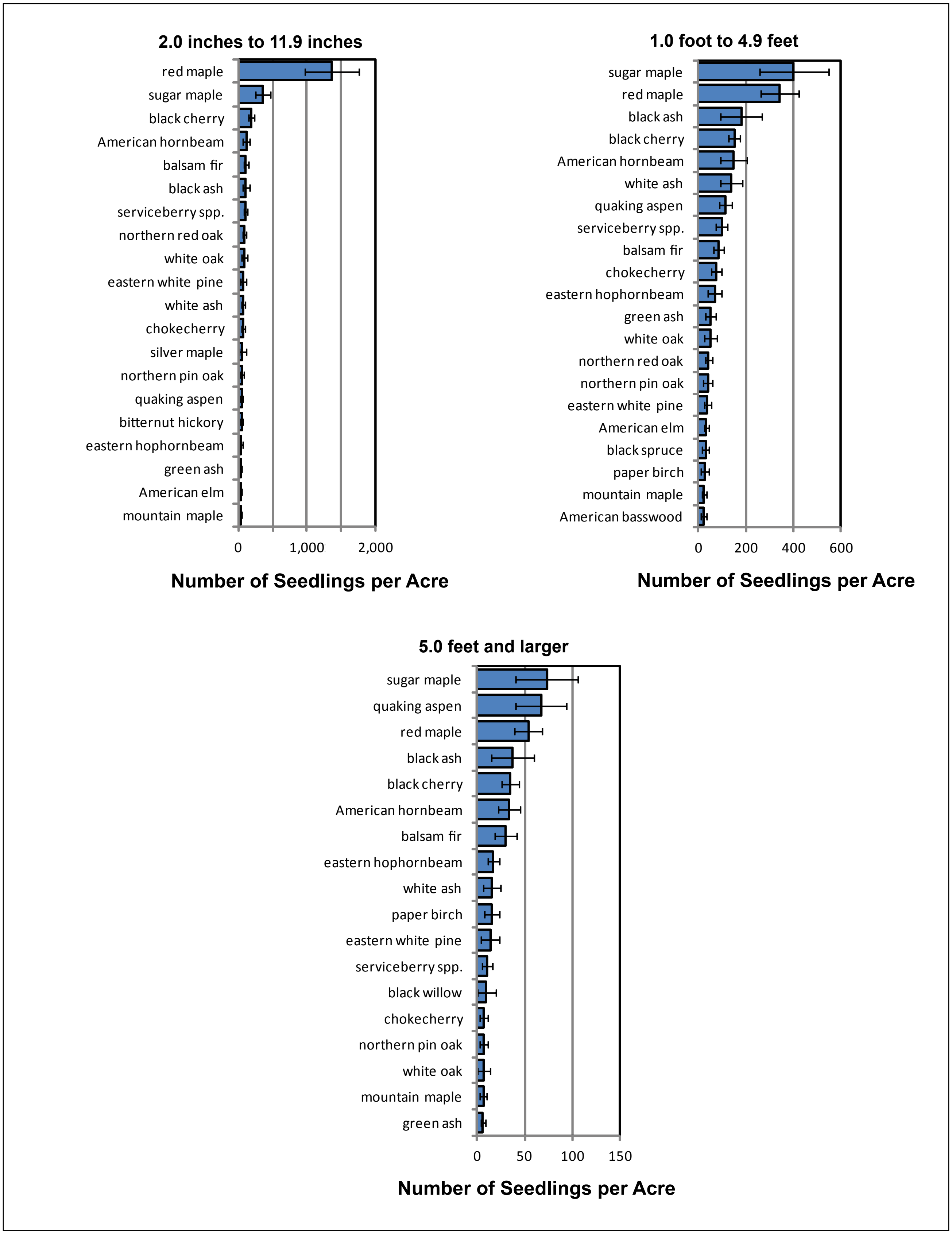

Figure 12.—Number of seedlings per acre on forest land by species and height class for species with at least 1 percent of the total, Wisconsin, 2012-2013. Sampling errors are shown for the 68 percent confidence level.

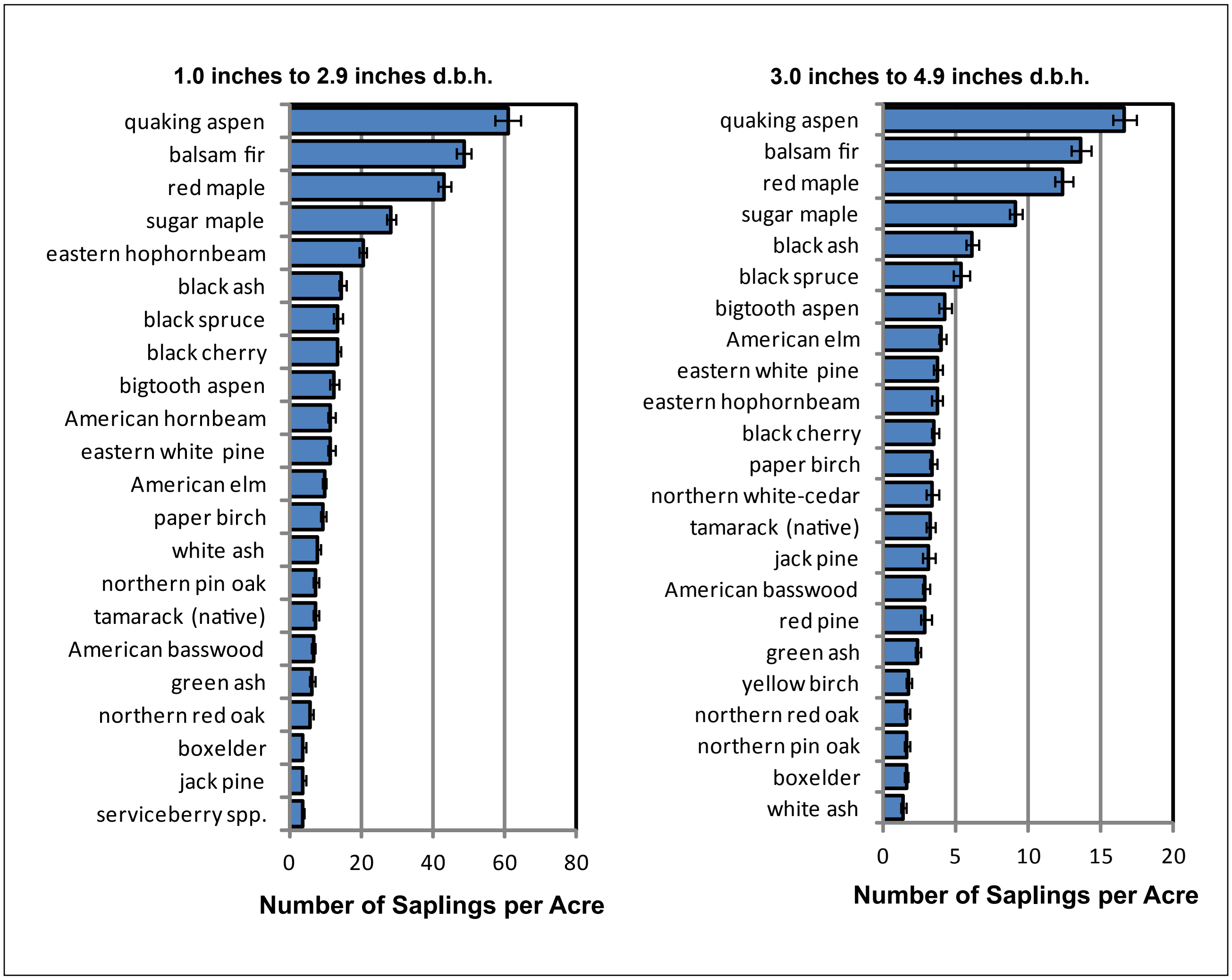

Figure 13.—Number of live saplings per acre on forest land by species and diameter class for species with at least 1 percent of the total, Wisconsin, 2009-2013. Sampling errors are shown for the 68 percent confidence level.

Seedling data used with condition-level variables and classifications provide considerable opportunities to apply analytics for specific domains of interest if associated sample errors are acceptable. These include examining predefined geographic areas such as states, ecoregions, or wildlife management areas, or using sample-based classifications for a particular species or structural type.

Potential Use

According to Leak (2007), one purpose of regeneration surveys is to estimate future tree species composition based on seedlings and saplings. The stand re-initiation and initiation stages of development ultimately impact adult forest composition, structure, and function (Oliver 1980), making the choice of an approach for evaluating

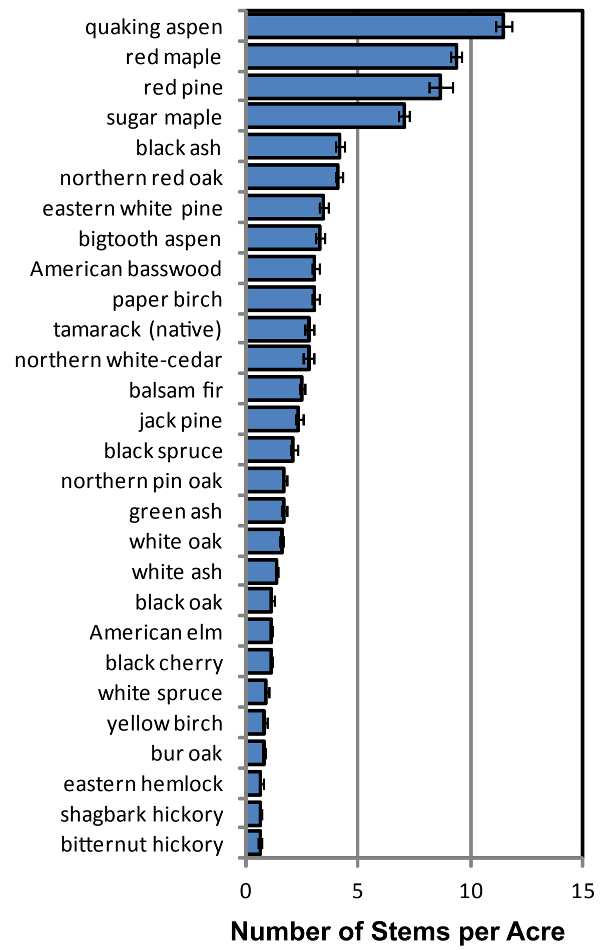

Figure 14.—Number of dominant and codominant growing-stock stems per acre at least 5 inches in diameter on forest land by species and diameter class for species with at least 1 percent of the total, Wisconsin, 2009-2013. Sampling errors are shown for the 68 percent confidence level.

regeneration critical for holistic assessments and models to predict future forest conditions. The regeneration indicator data offer considerable flexibility for designing analytical constructs for the many forest systems of the 24-state region. The NRS-FIA species and other explanatory variables, including forest type and stocking level, provide added detail. This section provides some examples of approaches that have been used and offers suggestions to guide further work.

Regeneration Composition

The FIA definition of a tree includes all perennial woody species that typically produce a single stem and grow to at least 15 feet in height. Because this definition includes such a wide array of phenotypes, simply assuming that a tree seedling of any species is acceptable for adequate regeneration can produce uninformed results.

The FIA species provide the opportunity to characterize regeneration for a wide range of research objectives. Some common analytical questions of interest include evaluating FIA species that are: (1) native, (2) endemic, (3) nonnative, (4) invasive, (5) preferred for timber production, (6) able to achieve high canopy position, (7) match overstory species, and (8) combinations of these and other characteristics. Matching regeneration to the overstory is not always the preferred condition, particularly if the overstory is made up of undesirable species.

To illustrate the use of species to quantify regeneration stocking, consider a stand with a regeneration component containing sugar maple, black cherry, tree-of-heaven, and striped maple where the objective is to evaluate the adequacy of regeneration for future timber production. Both sugar maple and black cherry have the potential to achieve high canopy positions and are preferred for timber. Tree-of-heaven is a nonnative invasive plant that is not a preferred timber species. Striped maple is a low canopy species and is not desirable for timber, but it may dominate regeneration stocking and serve as a competitor to more desirable species (Nyland et al. 2006). In this case, the sugar maple and black cherry seedlings could be used for quantifying regeneration, and the striped maple and tree-of-heaven could be included as a measure of competing vegetation.

The approach used to quantify regeneration in the PRS further illustrates a practical application of using FIA species. The objective of the PRS has been to include all species with the ability to achieve high canopy and that are native to Pennsylvania. Potential canopy position (PCP) was assigned to each species using existing literature, primarily Burns and Honkala (1990). The PRS only considers species with at least 2 percent of the State's total biomass and that are capable of reaching high canopy. The purpose of this definition is to capture common native species that could replace existing high canopy forests with a future forest of similar character. The approach and results of this appraisal are described in the section entitled Adequacy of Advance Tree Seedling Regeneration on page 36.

Another approach is to use PCP as an indicator of quality. Consider a partition of species using low, middle, and high canopy potential, with a maximum height at maturity of at least 80 feet for high canopy species, 60-80 feet for the mid canopy species, and less than 60 feet for low canopy species. It should be noted that FIA species groups interject the unavoidable possibility that some low canopy species are included as high canopy species. For example, mountain ash may be coded as *Fraxinus* spp. The generic genus code is only for sample trees where species is not distinguishable. Also, assessing PCP requires some judgment for species with a wide range of height potential that depend on site productivity, stand history, and other factors. For example, the maximum height for Atlantic white-cedar in the northern United States is 50 to 60 feet; however, the species typically occurs in pure stands where it is the canopy dominant.

Other species-specific issues can be addressed. Exceptions can be made to include species that have special value beyond their contribution to existing biomass or PCP. A good example is black ash, a species used for traditional Native American baskets that is a relatively rare species that usually does not attain a high canopy position throughout much of its range. Because of its special value for nontraditional forest products and high threat of mortality resulting from the emerald ash borer (*Agrilus planipennis*), black ash can be included even though it may not satisfy other objectives. Also, some high canopy species may be encountered outside of their natural range where they do not achieve typical form and height. An example of this is an abandoned Douglas-fir Christmas tree plantation that has reverted to forest.

Phase 2 Explanatory Variables

Other variables from the Phase 2 data can be used to refine regeneration analytics. For example, relative stocking, forest-type group, and site productivity class are important (McWilliams et al. 1995). Condition-level relative stocking percent serves as a proxy for available light. Stocking percent is similar to basal area per acre but takes into consideration site occupancy differences between species (Stout and Nyland 1986). For example, black cherry has the potential to occupy a site with more stems per unit area than sugar maple. This means that individual sugar maple trees are assigned a slightly higher stocking percent than black cherry trees of the same d.b.h. because fewer are needed to achieve full stocking. Stocking percent values are summed across tree species sampled on subplots to yield per acre stocking estimates. Summing basal area per unit area would yield identical values for the two species in this example. Thus, the advantage of relative stocking is that it accounts for variability in crowding tolerance by species in stands with the same average diameter.

Stocking percent is assigned to each sample tree using species-level equations (e.g., Leak et al. 1969, Roach and Gingrich 1962, Stout and Nyland 1986). Stocking values are summed for each sample condition and then grouped into classes. For a full explanation of the FIA stocking algorithm, see Arner et al. (2001).

The FIA stocking classes roughly correspond to silvicultural stocking guides such as those developed by Gingrich (1967), Leak (1981), and Wilson et al. (1999). Stocking classes are: 0 to 34 percent (poor), 35 to 59 percent (moderate), 60 to 99 percent (full), and 100 and greater (overstocked). The moderate, full, and overstocked classes correspond to C, B, and A levels described in most stocking guides; that is, overstocked represents stands above the A level and full stocking represents the area between A and B levels where stocking is considered acceptable (Ernst and Knapp 1985). Moderate stocking corresponds to the area between the B and C levels, a zone where B level stocking is expected to be reached in 10 years. Below the C level, a stand is considered understocked for traditional timber management, but may be adequately stocked for a savanna or woodland management objective.

Stands in the moderate range of stocking are generally assumed to have enough light for establishment and development of juvenile trees across a range of shade tolerances. Very often in areas with regeneration challenges, poorly stocked stands are the result of a failure due to lack of management planning to ensure a future stand to replace harvested trees and control competing vegetation. In the absence of competing vegetation, stands below the C level should eventually regenerate with trees, although often with unplanned undesirable species. These conditions can persist for long periods of time. Stands in the full and overstocked classes have little available light for regeneration establishment and development due to dense shade conditions, such as occurs in eastern hemlock stands.

It is recommended that analyses of advance reproduction adequacy focus on stocking conditions where tree seedlings should be able to establish and develop. For example, the PRS uses a range of 40 to 75 percent stocked that is specific to requirements for the mid-Atlantic region. Seedling counts are conducted across all stocking levels to allow evaluation of any range that meets individual study objectives.

Forest-type group is a broad classification of the composition of forested conditions. Segmenting regeneration analyses by forest-type group facilitates the application of relevant management guides. So far, guides for northern hardwood and mixed-oak forests of the mid-Atlantic States have been used to develop minimum thresholds for seedling stocking found on NRS-FIA microplots (Brose et al. 2008, Marquis 1994). The thresholds gauge the ability of existing advance regeneration to replace overstory trees when they are removed. These thresholds have necessarily been simplified to reflect the wide number of types found in the mid-Atlantic region. For example, regeneration stocking thresholds are not specific to aspen stands, but rather aspen types are treated the same as the northern hardwood group. Future work is needed to widen the geographic scope to include thresholds for other regions, including the Central States, Lake States, and New England (Objective 2).

FIA site productivity classification provides a means for including species-level adaptation to edaphic conditions. For example, oak species generally have a competitive advantage on steep, dry, rocky sites in eastern mountain biomes. Site productivity class is estimated by field measurement of site index. Productivity codes are assigned based on existing site-curve equations and a derivation of the culmination of mean annual increment (MAI) for merchantable trees in fully stocked natural stands (Scott and Voorhis 1986). The codes are grouped into classes based on net growth per acre expressed in cubic feet.

The PRS included an approach using site productivity class to address the competitiveness of advance reproduction based on the premise that fewer large-seeded stems are required for adequate stocking on poorer sites. Stems with a RCD of at least 0.75 inch and a d.b.h. less than 1.0 inch were classified as competitive seedlings. Minimum thresholds were developed using expert opinion to classify microplots as adequately stocked based on the number of competitive seedlings encountered. The thresholds range from one to three:

Site productivity class and description (ft^3/acre)		Minimum number of competitive stems for adequate stocking
1	225+	3
2	165-224	3
3	120-164	3
4	85-119	2
5	50-84	2
6	20-49	1
7	0-19	1

This approach is illustrated in the Examples section on page 37.

Presence of Dominant Trees

For some applications, a dominant adult tree on or in close proximity to the microplot can be used for evaluating stands in need of replacement. A dominant adult is defined as a live tree with at least a 5.0-inch d.b.h. To illustrate, a dominant American beech with a dense crown may preclude the need for the microplot to contain adequate stocking of seedlings. The presence or absence of a dominant tree can be determined from the distance and azimuth recorded for each tree sampled on the subplot, and tree attributes such as crown class can be used to adjust the metrics. Variables attached to adult trees can also be used to make adjustments to the analysis. For example, adult trees with an over-topped crown class code should not be counted.

Adequacy of Advance Tree Seedling Regeneration

It is well documented that advance regeneration is the best indicator of future composition in stands undergoing replacement. The challenge of assessing regeneration adequacy for large landscapes is to develop a credible methodology for evaluating the likelihood that a seedling will survive and attain a high canopy position. Here, a method for evaluating the adequacy of advance tree regeneration is presented based on experience with forest systems of Pennsylvania where the measurements and assumptions have been documented by the PRS. The large number of research questions the regeneration indicator can address precludes full coverage in this report, but the methods described provide a foundation on which to build a more widely applicable approach. The breadth of prospective topics is addressed through examples and suggestions to guide future work. Development of variants for regeneration requirements is a clear research need and will improve the usefulness of the regeneration indicator. The purpose here is to document a template that is flexible enough to accommodate extension to the wider range of forest systems of the Midwest and Northeast.

Seedling height and RCD were chosen as the primary tree regeneration indicators based on the assumption that competitiveness of advance seedlings along with species can be used effectively to quantify whether regeneration is adequate or not for specific management objectives. It is understood that assuming RCD thresholds are similar across diverse local factors, such as ecoregion, type of competing vegetation, amount of invasive species, herbivory pressure, or management level, is a limitation. The competitive code for large-seeded species can be ignored if this limitation obstructs a useful analysis.

Regeneration stocking may be classified as adequate for a particular objective, but the species composition of the understory and overstory components may not necessarily match. For example, stands classified as mixed oak often have regeneration composed of other species (see Examples section on page 37). The new NRS-FIA measurements facilitate comparison of understory and overstory composition to evaluate success or failure of management objectives. For example, if the NRS-FIA forest type is classified as eastern white pine-eastern hemlock, one approach might be to limit the assessment to white pine and eastern hemlock seedlings. Another example is to consider the actual existing canopy dominants and use them to compare with regeneration composition as an indicator of overstory replacement. The number of permutations leaves the analyst with many options; hence, the use of broad groupings in the strategy described in this report.

Weighting factors were developed for the six seedling-height classes to account for the positive relationship between seedling height and likelihood of long-term survival. The weighting factors shown below are based on an adaptation of existing science for all forest types of Pennsylvania where herbivory stress is common (McWilliams et al. 1995). Each seedling is assigned a stem weight according to height (see Equation 1):

Height class	Stem weight
2.0 to 5.9 inches	1
6.0 to 11.9 inches	1
1.0 foot to 2.9 feet	2
3.0 to 4.9 feet	20
5.0 to 9.9 feet	50
>10.0 feet	50

The formula for summing the weighted number of stems per microplot (WNS) is:

$$WNS = \sum_{i=1}^{6} W_i * NS_i \qquad (1)$$

where W is the stem weight and NS is the number of seedlings tallied by height class (i).

WNS is compared to thresholds developed for the PRS expressed as the minimum number of seedlings needed for adequate stocking by browse level (see Incorporating Browse Impact on page 38). The thresholds were developed by consensus of silvicultural experts as part of the PRS study design. The minimum thresholds are:

Browse impact	Minimum threshold
Very low	15
Low	30
Medium	50
High	100
Very High	200

The broad assumption that a single weighting scheme is applicable across all species groups may not be appropriate for all forest types found in the Midwest and Northeast. These thresholds should be adjusted if other weighing schemes are more applicable or herbivory is not an issue.

Examples for Mixed-oak and Northern Hardwood Forests

Two examples using microplot seedling tallies demonstrate the assessment of regeneration adequacy using the WNS framework. The first example is an NRS-FIA sample located in a mixed-oak forest dominated by white oak and other species. The sample plot is split by a boundary between two distinct forest conditions. All but one microplot is located in the condition dominated by white oak. Microplot 3 is in a reverting field with abundant white pine and other species. The overstory of the oak forest condition is 54 percent stocked following selection cutting of white oak. The white pine condition is 48 percent stocked. Site productivity class is from 20-49 cubic feet per acre per year at the culmination of MAI. Browse impact is medium. The seedling component is made up of white oak, black birch, red maple, black cherry, sassafras, white pine, and tree-of-heaven. Although sparse, oak stump

Incorporating Browse Impact

The impact of ungulate browsing on forest regeneration has been a growing concern in many states in the NRS region. While browsing is a natural forest process, too much browsing can eliminate palatable tree seedlings like oaks that are often a preferred species for the next generation forest. Most of the concern has been over the impact of white-tailed deer, but browsing by moose and other mammals can also be a concern.

Incorporating the impact of browsing into studies of regeneration quality and abundance is difficult because deer density estimates are nonexistent or lack the spatial detail or statistical confidence needed for developing useful analytics. Also, extrapolating data measured from within deer exclosures can lead to erroneous results because deer move freely through landscapes with varying degrees of disturbance and alternate food sources (Horsley et al. 2003). For areas under browse pressure, this means it inhibits the ability to evaluate potential success using FIA measurements. To overcome these limitations, a browse impact code was included in the Phase 2-plus suite of regeneration indicator measurements.

The effectiveness of traditional approaches for evaluating browse of understory plants is limited if there are no palatable plants to evaluate. The browse code was designed to be effective across the wide diversity of conditions found on NRS-FIA sample plots. The code introduces the ability to account for browsing in analyses using site-specific information not available from other sources. This report provides a means of using the code along with regeneration stocking guides expressing the number of seedlings required for success. Typically, the higher the browse impact, the greater the number of seedlings required. If the impact of browsing is not considered important in the analysis of tree seedlings and other understory vegetation, the browse code can be ignored.

White-tailed deer. Photo by Scott Bauer, USDA Agricultural Research Service, via http://commons.wikimedia.org/wiki.

sprouts and seedlings are present. Table 3 contains a tally of seedlings for this example. The computation of the weighted number of stems (Equation 1) for each microplot is:

Microplot 1: WNS = [(12+3)*1] + [(2+4)*1] + [(1+1+1)*2] = 27

Microplot 2: WNS = [(10+22)*1] + [(5+1)*1] + [(1)*2] + [(1)*20] = 60

Microplot 3: WNS = [(19+9+11+5)*1] + [(24+6+5+1)*1] + [(1+4)*2] + [(1)*20] = 110

Microplot 4: WNS = [(8+23)*1] + [(11+9+5)*1] + [(2+2+1)*2] + [(1)*50] = 116

The results indicate that the weighted number of stems for microplots 2, 3, and 4 meet the WNS minimum threshold of 50 stems for adequate regeneration; however, microplot 1 contains a competitive white oak seedling with a RCD larger than 0.75 inch. For site productivity class 6, only one competitive seedling is required, so microplot 1 is also considered adequately stocked with tree seedlings. Tree-of-heaven was excluded from the tally because it is an undesirable species.

Table 3.—Tree seedling and sapling tally by microplot, height class, and species for an NRS-FIA sample plot classified as mixed-oak forest

	Species							
Subplot number and height class	White oak	Black birch	Red maple	Black cherry	Sassafras	White pine	Tree-of-heaven	Total
Microplot 1:								
2.0 inches to 5.9 inches	0	12	3	0	0	0	0	15
6.0 inches to 11.9 inches	0	2	4	0	0	0	0	6
1.0 foot to 2.9 feet	1	0	1	1	0	0	0	3
3.0 feet to 4.9 feet	0	0	0	0	0	0	0	0
5.0 feet to 9.9 feet	0	0	0	0	0	0	0	0
Greater than or equal to 10.0 feet	0	0	0	0	0	0	0	0
Total	1	14	8	1	0	0	0	24
Competitive	1	0	0	0	0	0	0	1
Saplings	0	0	0	0	0	0	0	0
Microplot 2:								
2.0 inches to 5.9 inches	0	10	0	22	0	0	0	32
6.0 inches to 11.9 inches	0	0	5	0	1	0	0	6
1.0 foot to 2.9 feet	0	0	0	0	1	0	0	1
3.0 feet to 4.9 feet	0	0	1	0	0	0	0	1
5.0 feet to 9.9 feet	0	0	0	0	0	0	0	0
Greater than or equal to 10.0 feet	0	0	0	0	0	0	0	0
Total	0	10	6	22	2	0	0	40
Competitive	0	0	0	0	0	0	0	0
Saplings	0	0	0	0	0	0	0	0
Microplot 3:								
2.0 inches to 5.9 inches	0	19	9	11	0	5	0	44
6.0 inches to 11.9 inches	0	0	24	6	5	1	2	38
1.0 foot to 2.9 feet	0	0	0	0	1	4	1	6
3.0 feet to 4.9 feet	0	0	0	0	0	1	0	1
5.0 feet to 9.9 feet	0	0	0	0	0	0	1	1
Greater than or equal to 10.0 feet	0	0	0	0	0	0	0	0
Total	0	19	33	17	6	11	4	90
Competitive	0	0	0	0	0	0	0	0
Saplings	0	0	0	0	0	0	1	0
Microplot 4:								
2.0 inches to 5.9 inches	0	8	23	0	0	0	0	31
6.0 inches to 11.9 inches	0	11	9	0	5	0	0	25
1.0 foot to 2.9 feet	2	0	2	1	0	0	0	5
3.0 feet to 4.9 feet	0	0	0	0	0	0	0	0
5.0 feet to 9.9 feet	0	0	1	0	0	0	0	1
Greater than or equal to 10.0 feet	0	0	0	0	0	0	0	0
Total	2	19	35	1	5	0	0	62
Competitive	1	0	0	0	0	0	0	1
Saplings	0	0	0	0	0	0	0	0

The second example is a northern hardwoods stand with an overstory dominated by sugar maple with some interspersed beech. FIA algorithms generate a relative stocking percent of 68 percent following mortality of mature black cherry. Site productivity class is 50-84 cubic feet per acre per year at the culmination of MAI. Browse impact is high with numerous beech root suckers and a few sugar maple seedlings. The understory flora includes dense patches of rhizomatous ferns (*Dennstaedtia punctilobula* and *Thelypteris oveboracensis*).

Table 4 contains the tally of seedlings for this example. The computation of WNS for each microplot is:

Microplot 1: WNS = [(1+147+42)*1] + [(57+26)*1] + [(1)*50] = 323

Microplot 2: Nonforest plot; no tally

Microplot 3: WNS = [(12)*1] + [(21+6)*1] + [(1)*2] + [(2)*20] = 81

Microplot 4: WNS = [(9)*1] + [6*1] + [(3+3)*2] + [(1)*20] = 47

Table 4.—Tree seedling and sapling tally by microplot, height class, and species for an NRS-FIA sample plot classified as northern hardwood forest

Subplot number and height class	Species: Sugar maple	American beech	Black cherry	Red maple	Striped maple	Total
Microplot 1:						
2.0 inches to 5.9 inches	1	0	147	42	9	199
6.0 inches to 11.9 inches	0	0	57	26	5	88
1.0 foot to 2.9 feet	0	0	0	0	1	1
3.0 feet to 4.9 feet	0	0	0	0	0	0
5.0 feet to 9.9 feet	0	0	1	0	0	1
Greater than or equal to 10.0 feet	0	0	0	0	0	0
Total	1	0	205	68	15	289
Competitive	0	0	0	0	0	0
Saplings	0	0	0	0	0	0
Microplot 2:			Nonforest—No Tally			
Microplot 3:						
2.0 inches to 5.9 inches	0	0	12	0	2	14
6.0 inches to 11.9 inches	0	0	21	6	5	32
1.0 foot to 2.9 feet	0	1	0	0	4	5
3.0 feet to 4.9 feet	0	2	0	0	0	2
5.0 feet to 9.9 feet	0	0	0	0	0	0
Greater than or equal to 10.0 feet	0	0	0	0	0	0
Total	0	3	33	6	11	53
Competitive	0	0	0	0	0	0
Saplings	0	0	0	0	0	0
Microplot 4:						
2.0 inches to 5.9 inches	0	0	0	9	0	9
6.0 inches to 11.9 inches	0	0	0	6	14	20
1.0 foot to 2.9 feet	0	3	0	3	1	7
3.0 feet to 4.9 feet	1	0	0	0	1	2
5.0 feet to 9.9 feet	0	0	0	0	0	0
Greater than or equal to 10.0 feet	0	0	0	0	0	0
Total	1	3	0	18	16	38
Competitive	0	0	0	0	0	0
Saplings	0	0	0	0	0	0

The northern hardwood example has three microplots in a forested condition. Only microplot 1 exceeded the 100-stem threshold. Although sugar maple was sampled on two microplots, black cherry and red maple were most prevalent. Striped maple was abundant on all the forested microplots, but it was not included in the weighted sum because it is a low canopy species.

Role of Saplings as Advance Regeneration

Saplings can be added to the evaluation of regeneration stocking for the microplot. For example, the PRS used two saplings from 1.0 to 1.9 inches d.b.h. or one sapling at least 2.0 inches d.b.h. as the minimum thresholds for adequate regeneration for timber management species. In some cases this approach can overestimate the regeneration adequacy because some saplings, such as sugar maple or American beech, are suppressed shade tolerant species that may not respond fast enough to increased light to achieve high canopy. As with seedlings, the choice of species and thresholds to use for saplings depends on the forest types being studied and the assumptions regarding regeneration stocking. The mixed oak example is a case where including the tree-of-heaven (a nonnative invasive plant) sapling would change the composition of the regeneration component of microplot 3 from mostly black cherry, black birch, and red maple regeneration to tree-of-heaven.

Population Proportions

For each sample plot, the proportion of microplots with adequate regeneration is defined as the number of microplots meeting seedling thresholds divided by the number of microplots sampled in forested conditions. In the previous example for mixed-oak forests, the proportion is 1.00 because all of the forested microplots have adequate regeneration. For the northern hardwood forest example, the proportion is 0.33.

At the population level, the overall rate of advance regeneration adequacy can be estimated as the proportion of the microplots sampled in the state or subregion that qualify as adequately stocked (Westfall and McWilliams 2012). It is important to consider sample sizes when making population estimates because specifying subsets of the population, either geographically or via classification variables, reduces the precision of the estimate.

Sampling Error and Trend Estimation

Detecting change in the population is a primary need for regeneration monitoring (Objective 3). When conducting statistical analyses, hypothesis tests should consider both Type I and II sources of error (Westfall and McWilliams 2012). In this context, the null hypothesis is that no change in the population parameter has occurred, while the research hypothesis is that some specified amount of change has transpired. A Type I error occurs when the actual change in the population does not cross the threshold value specified in the research hypothesis but the research hypothesis is accepted as true due to the sample statistics. Similarly, a Type II error is committed when the actual change in the population crosses the threshold value specified in the research hypothesis but the null hypothesis of no change is accepted as true (Di Stefano 2001). Low error rates are sought to minimize the probability of drawing erroneous conclusions. Type I and II errors are inversely related, which challenges the analyst to balance the two error types based on the negative consequences of each. Westfall and McWilliams (2012) demonstrate that when the change in the proportion of adequately stocked forested samples is less than 0.05, it is likely not statistically different from zero (i.e., the null hypothesis of no change is accepted). The problem is exacerbated for substate regions as sample sizes become smaller. In these cases, it may be useful to consider other metrics and indicators, such as a direct analysis of the sum of weighted seedlings.

To illustrate the evaluation of change estimates for substate regions, Wildlife Management Unit (WMU) 2G in Pennsylvania was used (Fig. 15). WMU 2G is a major deer hunting area that has been heavily impacted by numerous, interacting regeneration stressors. Figure 15 shows estimates and sampling errors of the proportion of adequately stocked forest land located on WMU 2G using nine full sets of five inventory panels. Estimates for sets of remeasured inventory panels are not

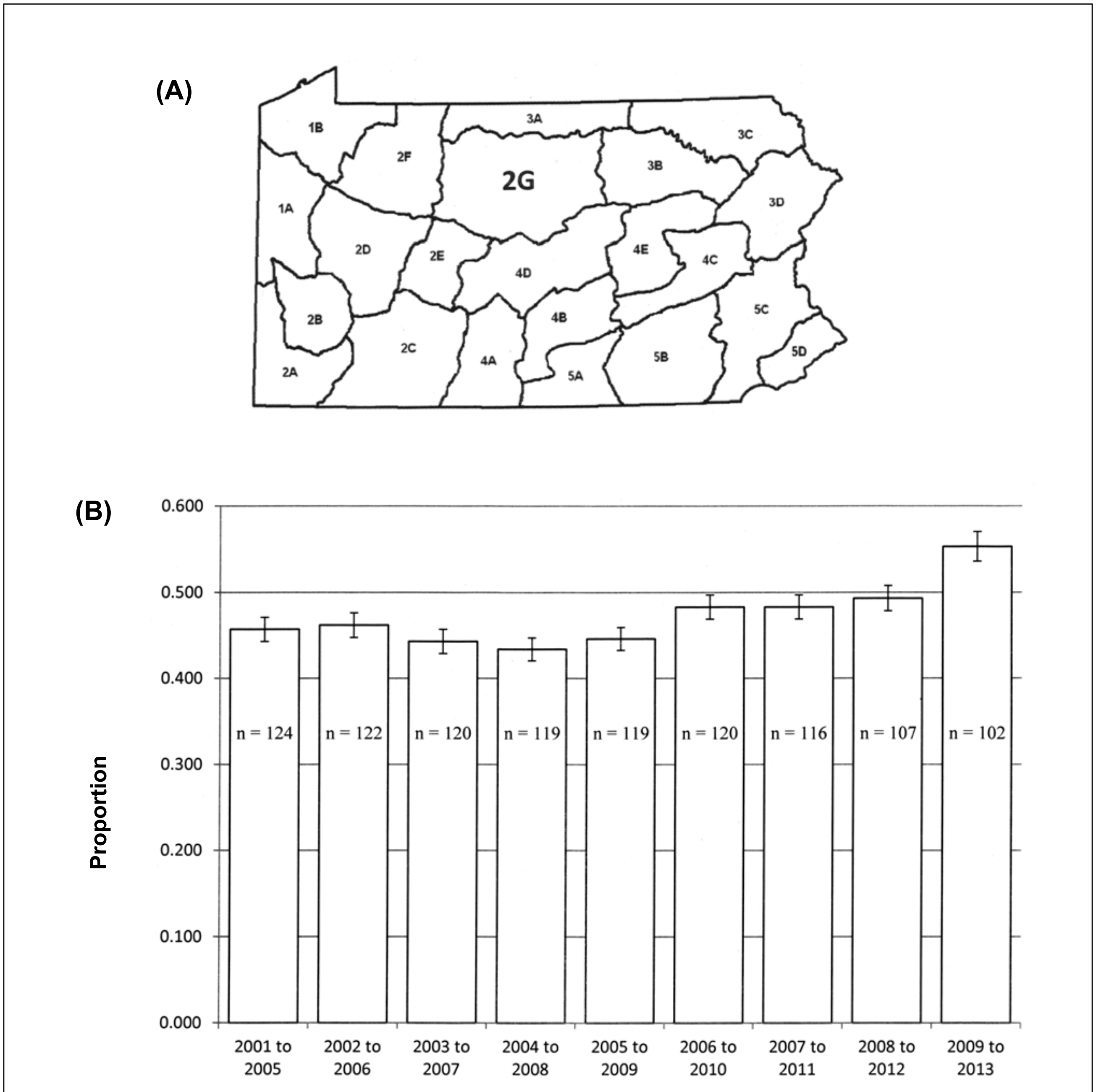

Figure 15.—(A) Pennsylvania Wildlife Management Units (WMU), and (B) the proportion of forest land adequately stocked with advance tree seedling and sapling regeneration for canopy replacement species and samples 40 to 75 percent stocked with trees, Wildlife Management Unit 2G, Pennsylvania, 2001-2005 to 2009-2013. Sampling errors are shown for the 68 percent confidence level. Number of samples (n) is shown for each estimate.

independent because most of the sample plots were measured (Westfall et al. 2013). Examining the change between remeasurements of the same inventory panels requires accounting for this in the calculation of standard errors. The longest trend data available for Pennsylvania are the 2001-2005 and 2009-2013 inventory panels. The results for WMU 2G indicate an increase from 0.46 to 0.55 in the proportion of forest land area with adequate advance regeneration. The standard error of the difference was calculated using the variances of the estimates at each time period, as well as the covariance between the two, which was derived from Cochran (1977). The p-value associated with this test for significant differences was 0.0093. Assuming a null hypothesis that no change has occurred, the small p-value indicates strong statistical evidence that the proportion of forest land with adequate regeneration has increased, and there is a low likelihood that the null hypothesis of no change is true.

Geospatial Products

Exploring regeneration analytics in a geospatial (mapped) context offers the ability to search for spatial patterns, or the lack of patterns, for indicators of interest (Objective 4). Options for mapping attributes include thematic, grid, and modeled products. Examples of grid maps for Pennsylvania show the result of applying the PRS approach to mixed-oak forests (Fig. 16) and northern hardwood forests (Fig. 17) in Pennsylvania for 2009 through 2013. The grid points depict NRS-FIA samples (sample locations approximate) coded as having 50 percent or more of the subplots adequately stocked with advance regeneration. All of the samples shown are for plots in the 40 to 74 percent range of relative stocking. Neither map shows a visually strong spatial pattern. This information is useful to managers and policymakers as they consider actions.

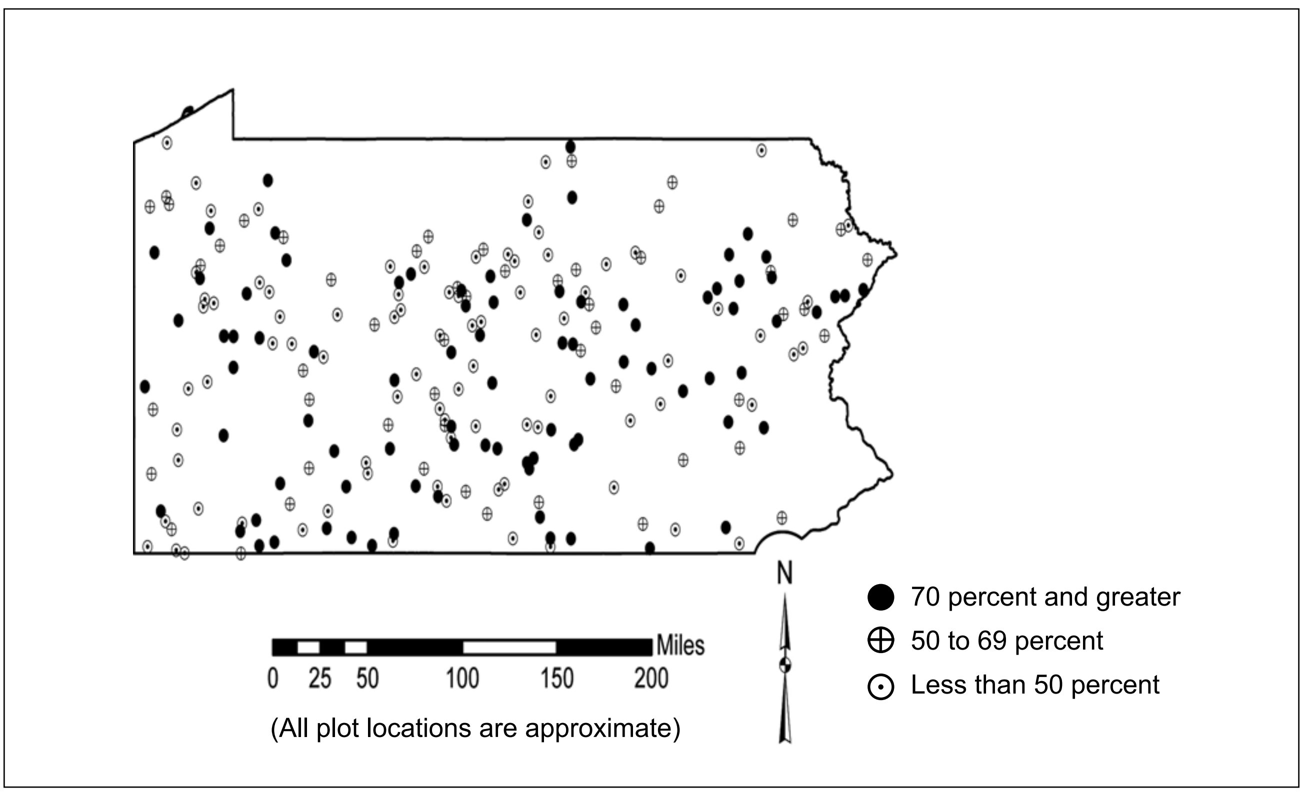

Figure 16.—Distribution of samples on forest land classified as the mixed oak forest-type group and 40 to 75 percent stocked with live trees by percentage of microplots with adequate advance regeneration of canopy replacement species, Pennsylvania, 2009 and 2013.

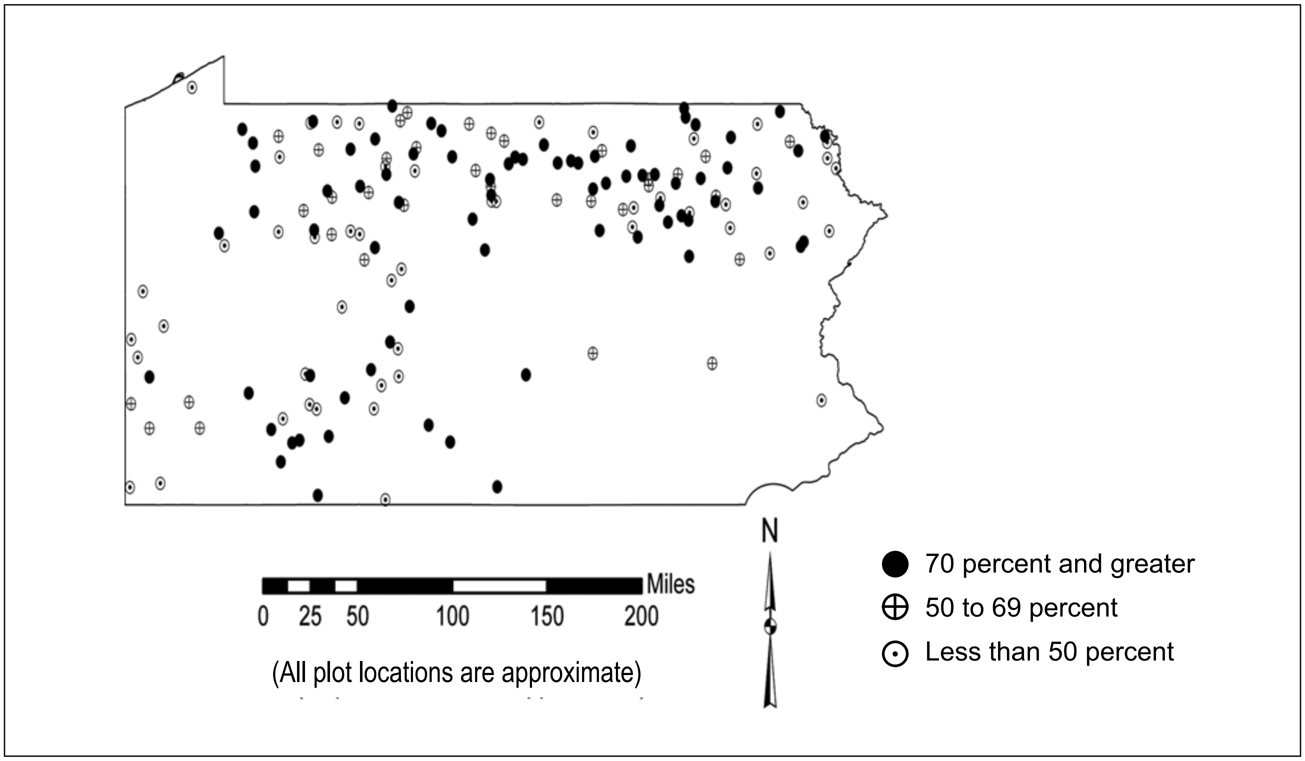

Figure 17.—Distribution of samples on forest land classified as the northern hardwood forest-type group and 40 to 75 percent stocked with live trees by percentage of microplots with adequate advance regeneration of canopy replacement species, Pennsylvania, 2009 and 2013.

Opportunities for spatial analyses include a wide array of potential products and will continue to multiply as the first full baseline set of inventory panels and remeasurements are completed and distributed publicly. Examples of the types of maps NRS-FIA produces can be found in standard state-level reports (Perry et al. 2012) online at the NRS-FIA map Web portal (http://www.nrs.fs.fed.us/fia/maps/default.asp). The Forest Inventory Data Online (FIDO) tool (http://apps.fs.fed.us/fia/fido/index.html) also generates user-defined maps (Wilson et al. 2012). The new seedling measurements have yet to be included in the online map products.

Modeling Applications

Broad-scale forest projection models, such as the Forest Vegetation Simulator (FVS) (Crookston and Dixon 2005), typically require a method to account for initial seedling recruitment. Existing models often include input parameters that are too costly or ephemeral to collect over large areas. The seed production used in FOREGEN (Solomon and Leak 2002) is an example. In the past, forest system modelers have had limited tree seedling data available to construct recruitment models that are consistent across large regions. The new NRS-FIA seedling measurements were developed to fill this gap (Objective 5). Brief discussions of two prominent models of forest dynamics are presented to illustrate potential applications. This is followed by a discussion of models to predict abundance of advance regeneration.

SORTIE-Neighborhood Dynamics (SORTIE-ND) is an individual tree simulation model with integrated components for seedling recruitment, light availability, tree growth, and tree mortality (Pacala et al. 1996). The recruitment functions in SORTIE-ND were developed to compare seedling and adult tree population distributions, thus, eliminating the challenge of identifying the specific parent for each recruit (Ribbens et al. 1994). The approach has further advantages of adding a spatial component to the model and the ability to use more readily available field data. Recent work refined the model by parameterizing tree growth functions using FIA plot data (Canham et al. 2006). The recruitment function uses basal area of adult trees within the immediate neighborhood of the microplots to incorporate shading. These developments have allowed a variety of scenarios to be incorporated within the SORTIE-ND model to study large regions.

The Forest Vegetation Simulator is a stand-level growth and yield model that simulates forest dynamics to project future characteristics. The FVS model has a variety of options for simulating different management regimes, including intermediate cuttings and regeneration harvests, and allows adjustments to the timing of treatments over the projection period. Although FVS has been calibrated for most of the United States, the flexibility of the model provides many opportunities for improving projections by customizing models and inputs (Dixon 2002). For example, Crookston et al. (2010) summarized methods for using FVS to address impacts of climate change on forest dynamics.

An advantage of FVS is the ability to download and input FIA data directly from the national data portal (http://apps.fs.fed.us/fiadb-downloads/datamart.html). These features allow the user to make improvements in forest projections that go beyond the default regeneration parameters, thus improving regeneration estimates that are such important factors affecting the composition and stocking of future forest stands. Adding seedling height, level of establishment for large-seeded species, and browse impact to the FIA measurements provides the opportunity for improving simulation models for the stand initiation and re-initiation stages of development.

The regeneration establishment component used in the northeast FVS variant has three options for stand initiation: planting, stump sprouts, and user input (Dixon and Keyser 2008). Currently, users making landscape-level projections need more detailed empirical data, particularly for tree seedlings. Statistical models that predict regeneration composition and structure have been developed for the Rocky Mountains (Ferguson and Carlson 1993), but elsewhere more models for advance regeneration are needed due to complexities and challenges such as those mentioned herein for northern forest systems.

Research is also being directed towards models that predict the quality of advance regeneration using PRS regeneration measurements as the dependent variable and other stand characteristics as independent variables. The focus is to provide a stochastic model of regeneration that can be used in FVS projections. Although challenging due to the many factors that determine regeneration quality, developing reliable models would represent a major advancement for predicting future stand character.

The new FIA measurements fit well with efforts to predict future composition of dominant and codominant trees. Vickers et al. (2011, 2013) developed the REGEN expert system that addresses the complexity of dynamic interactions of species, height, and density. REGEN uses existing stand conditions along with literature and expert opinion to assign competitive ranking factors to advance reproduction for hardwood species. The ranking factors range from 1 to 20 and are assigned to each seedling by species for four height classes and for potential stump sprouts. These parameters make up Regeneration Knowledge Bases (RKB) developed for the southern and central Appalachian hardwoods. The model uses the information in the RKBs to predict which stems will grow to dominate future species composition, and hence, the future stand.

Research Extensions (Objective 6)

Wildlife Habitat

Ripley and McClure (1963) describe the use of forest inventory data for assessing deer browse resources of North Georgia. Three attributes of browse were recorded by field crews: (1) the dominant tree or shrub species making up the greatest winter browse dry biomass within each plot, (2) the total winter browse dry biomass within each plot, and (3) presence or absence of deer browsing activity. These data were used to produce estimates of percentage of plots dominated by desirable and undesirable deer browse species, and winter dry biomass for desirable and undesirable deer browse species. Estimates were stratified by ownership category, forest type, and stand size.

A timber resource inventory was used to assess deer browse resources of the Uwharrie National Forest in North Carolina (Moore and Strode 1966). Data collection included frequency sampling for the occurrence and utilization of woody understory plants and estimates of the weight of annual growth. Browse species were assigned to one of four preference categories: preferred, staple, emergency, or stuffing. Sample data were stratified by major forest type, age class, stand size, and management class. Estimates were produced for occurrence, utilization, and weight (biomass). Estimates of daily browse were applied to deer population estimates.

Pearson and Sternitzke (1976) augmented forest survey protocols with additional attributes of deer browse availability and quality in the Louisiana Coastal Plain. Browse resources were classified into one of three categories of desirability: good, fair, and poor. The study compared browse resources among forest types. They concluded that cattle grazing and deer browsing did not unduly restrict timber production.

McWilliams et al. (1995) used FIA data to determine that advance tree seedling regeneration in Pennsylvania was inadequate for new stand establishment across most of the state. Although specific causal factors were not quantified, it was surmised that high deer densities likely were the most pervasive obstacle to regeneration.

Didier and Porter (2003) used FIA data to calculate an index of sugar maple reproductive success in northern New York State, which they related to relative deer densities via regression analysis. They concluded that high deer densities were not necessarily associated with poor maple reproductive success within the range of densities observed within their study area.

Phase 2-plus regeneration data and estimators will provide deer browse information similar to the historical approaches described above. This capability previously has not been available at regional or national scales. Additional work is needed to provide estimates of seedling and sapling biomass, with linkages to deer carrying capacity. Regeneration information products likely will support assessments for other species of wildlife as well.

Carbon Accounting

Forest carbon monitoring is another potential application of the regeneration indicator. First, more robust estimates of seedling attributes may inform efforts to estimate understory vegetation carbon pools (Russell et al. 2014). Second, domestic energy policies are currently exploring the carbon consequences of using forest biomass as feed stocks for bioenergy efforts versus managing forests for maximizing carbon sequestration in ecosystem components such as soils (Mitchell et al. 2013). In the face of future prospective disturbances, reproductive capacity will be critical to maintaining ecosystem processes and carbon stocks (Woodall et al. 2013a). Although tree regeneration is a minor carbon pool compared to total carbon stocks, the new measurements will inform future carbon stock estimates and questions regarding the sustainability of the ecosystem process of carbon sequestration.

Tree Species Migration

Methods for estimating migration of forest vegetation were outlined by Leak and Graber (1974) and more recently by Iverson et al. (2008) using FIA Phase 2 data to consider the impact of climate change scenarios. Woodall et al. (2009) proposed an indicator of tree-range dynamics where the attributes and location of trees greater than 1.0 or 5.0 inches (i.e., microplot and subplot trees respectively) were compared to seedling metrics across large scales using FIA data for the conterminous United States. The basic indicator that explores divergences between tree and seedling metrics has been extended to numerous studies that have expanded fundamental information for monitoring tree ranges across the United States (Bell et al. 2014; Woodall et al. 2013b; Zhu et al. 2012, 2014). The additional seedling measurements improve the ability to assess tree regeneration beyond that of basic seedling abundance because all seedlings are assumed to be equal when using existing Phase 2 data. Two critical pieces of information missing from previous studies are height and status of individual seedlings. Collecting more detailed measurements will refine and improve the monitoring of tree ranges across the large scales used for estimating climate change impact on vegetation.

SUMMARY

The Phase 2-plus regeneration indicator fills a void for information on tree seedlings and completes the NRS-FIA goal of tracking trees from birth, to adulthood, to death, to down woody material, and eventually, to components of soil. The indicator provides basic information on composition and structure of the regeneration component that can be used along with information on saplings and adult trees to construct a full profile of forest systems of the region. In the early years of data collection, the ability to fully address information needs will be limited to geographic areas with enough forested samples to develop estimates with acceptable sampling errors. Once the full set of baseline measurements is complete, the process for building credible trend estimates can begin, and results can be used to improve state- and region-level assessments of forest sustainability.

One of the more important uses of the regeneration indicator is for quantifying and assessing the character of advance regeneration and shifts in tree species composition. Species, seedling height, and browse impact data offer the flexibility to evaluate a wide array of metrics that can be used to predict future forest conditions; however, new approaches need to be developed for forest types and forest-type groups currently not covered. Developing and testing models to predict regeneration are noteworthy opportunities for research. The data can also be included in research on carbon accounting, species migration, and wildlife habitat.

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Oak seedlings emerging from fern dominated understory. Photo by Will McWilliams, U.S. Forest Service.

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APPENDIX I
Common and Scientific Names of Tree Species Measured on FIA Plots

Common name	Scientific name[a]
ailanthus	*Ailanthus altissima*
American basswood	*Tilia americana*
American beech	*Fagus grandifolia*
American chestnut	*Castanea dentata*
American elm	*Ulmus americana*
American holly	*Ilex opaca*
American hornbeam	*Carprinus caroliniana*
American mountain-ash	*Sorbus americans*
American plum	*Prunus americana*
American sycamore	*Platanus occidentalis*
apple spp.	*Malus* spp.
ash spp.	*Fraxinus* spp.
Atlantic white-cedar	*Chamaecyparis thyoides*
Austrian pine	*Pinus nigra*
baldcypress	*Taxodium distichum*
balsam fir	*Abies balsamea*
balsam poplar	*Populus balsamifera*
balsam willow	*Salix pyrifolia*
basswood spp.	*Tilia* spp.
Bebb willow	*Salix bebbiana*
bigleaf magnolia	*Magnolia macrophylla*
bigtooth aspen	*Populus grandidenta*
bitternut hickory	*Carya cordiformis*
black ash	*Fraxinus nigra*
black cherry	*Prunus serotina*
black hickory	*Carya texana*
black locust	*Robinia pseudoacacia*
black maple	*Acer nigrum*
black oak	*Quercus velutina*
black spruce	*Picea mariana*
black walnut	*Juglans nigra*
black willow	*Salix nigra*
blackgum	*Nyssa silvatica*
blackjack oak	*Quercus marilandica*
blue ash	*Fraxinus quadrangulata*
blue spruce	*Picea pungens*
boxelder	*Acer negundo*
buckeye, horsechestnut spp.	*Aesculus spp.*
bur oak	*Quercus macrocarpa*
butternut	*Juglans cinerea*
Canada plum	*Prunus nigra*
catalpa spp.	*Catalpa* spp.
cherry and plum spp.	*Prunus* spp.
cherrybark oak	*Quercus pagoda*
chestnut oak	*Quercus prinus*
chestnut spp.	*Castanea* spp.
Chinese chestnut	*Castanea mollissima*
chinkapin oak	*Quercus muehlenbergii*
chittamwood, gum bumelia	*Sideroxylon lanuginosum*
chokecherry	*Prunus virginiana*
coastal plain willow	*Salix caroliniana*
cockspur hawthorn	*Crataegus crus-galli*

Common name	Scientific name
common persimmon	*Diospyros virginiana*
common serviceberry	*Amelanchier arborea*
cottonwood and poplar spp.	*Populus* spp.
cucumbertree	*Magnolia acuminata*
Douglas-fir	*Pseudotsuga menzeisii*
downy hawthorn	*Crataegus mollis*
dwarf chinkapin oak	*Quercus prinoides*
eastern cottonwood	*Populus deltoides*
eastern hemlock	*Tsuga canadensis*
eastern hophornbeam	*Ostrya virginiana*
eastern redbud	*Cercis canadensis*
eastern redcedar	*Juniperus virginiana*
eastern white pine	*Pinus strobus*
elm spp.	*Ulmus* spp.
European alder	*Alnus glutenosa*
European mountain ash	*Sorbus aucuparia*
fir spp.	*Abies* spp.
flowering dogwood	*Cornus florida*
Fraser fir	*Abies fraseri*
ginkgo, maidenhair tree	*Ginkgo biloba*
gray birch	*Betula populifolia*
green ash	*Fraxinus pennsylvanica*
hackberry	*Celtis occidentalis*
hackberry spp.	*Celtis* spp.
hawthorn spp.	*Craetagus* spp.
hickory spp.	*Carya* spp.
honeylocust	*Gleditsia triancanthos*
jack pine	*Pinus banksiana*
Kentucky coffeetree	*Gymnogladus dioicus*
larch spp.	*Larix* spp.
laurel oak	*Quercus laurifolia*
loblolly pine	*Pinus taeda*
Lombardy poplar	*Populus nigra*
magnolia spp.	*Magnolia* spp.
maple spp.	*Acer* spp.
mimosa, silktree	*Albizia julibrissin*
mockernut hickory	*Carya alba*
mountain maple	*Acer spicatum*
mountain or Fraser magnolia	*Magnolia fraseri*
mountain-ash spp.	*Sorbus* spp.
mulberry spp.	*Morus* spp.
northern catalpa	*Catalpa speciosa*
northern mountain-ash	*Sorbus decora*
northern pin oak	*Quercus ellipsoidalis*
northern red oak	*Quercus rubra*
northern white-cedar	*Thuja occidentalis*
Norway maple	*Acer platanoides*
Norway spruce	*Picea abies*
Nuttal oak	*Quercus nuttallii*
oak spp.	*Quercus* spp.
Ohio buckeye	*Aesculus glabra*
Osage-orange	*Maclura pomifera*

(continued on next page)

APPENDIX I (continued)

Common name	Scientific name
overcup oak	*Quercus lyrata*
paper birch	*Betula papyrifera*
paulownia, empress-tree	*Paulownia tomentosa*
pawpaw	*Asimina triloba*
peachleaf willow	*Salix amygdaloides*
pecan	*Carya illinoinensis*
persimmon spp.	*Diospyros* spp.
pignut hickory	*Carya glabra*
pin cherry	*Prunus pensylvanica*
pin oak	*Quercus palustris*
pitch pine	*Pinus rigida*
pond pine	*Pinus serotina*
ponderosa pine	*Pinus ponderosa*
post oak	*Quercus stellata*
prairie crab apple	*Malus ioensis*
pumpkin ash	*Fraxinus profuna*
quaking aspen	*Populus tremuloides*
red hickory	*Carya ovalis*
red maple	*Acer rubrum*
red mulberry	*Morus rubra*
red pine	*Pinus resinosa*
red spruce	*Picea rubens*
redcedar/juniper spp.	*Juniperus* spp.
river birch	*Betula nigra*
rock elm	*Ulmus thomasii*
Rocky Mountain juniper	*Junipoerus scopulorum*
roundleaf serviceberry	*Amelanchier sanguinea*
Russian olive	*Elaeangnus augustifolia*
sand hickory	*Carya pallida*
sassafras	*Sassafras albidum*
scarlet oak	*Quercus coccinea*
Scotch pine	*Pinus sylvestris*
scrub oak	*Quercus ilicifolia*
serviceberry spp.	*Amelanchier* spp.
shagbark hickory	*Carya oovata*
shellbark hickory	*Carya laciniosa*
shingle oak	*Quercus imbricaria*
shortleaf pine	*Pinus echinata*
Shumard oak	*Quercus shumardii*
Siberian elm	*Ulmus pumila*
silver maple	*Acer saccharinum*
slippery elm	*Ulmus rubra*
smoketree	*Cotinus obovatus*
sourwood	*Oxydendron arboreum*
southern catalpa	*Catalpa bignoniodes*

Common name	Scientific name
southern crab apple	*Malus angustifolia*
southern red oak	*Quercus falcata*
spruce spp.	*Picea* spp.
striped maple	*Acer pensylvanicum*
sugar maple	*Acer saccharum*
sugarberry	*Celtis laevagata*
swamp chestnut oak	*Quercus michauxii*
swamp cottonwood	*Populus heterophylla*
swamp tupelo	*Nyssa biflora*
swamp white oak	*Quercus bicolor*
sweet birch	*Betula lenta*
sweet cherry, domesticated	*Prunus avium*
sweet crab apple	*Malus coronaria*
sweetbay	*Magnolia virginiana*
sweetgum	*Liquidambar styraciflua*
Table Mountain pine	*Pinus pungens*
tamarack (native)	*Larix larcinia*
Texas buckeye	*Aesculus glabra* var. *arguta*
Texas red oak	*Quercus texana*
umbrella magnolia	*Magnolia tripetala*
Virginia pine	*Pinus virginiana*
water hickory	*Carya aquatica*
water oak	*Quercus nigra*
water tupelo	*Nyssa aquatica*
waterlocust	*Gledistia aquatica*
weeping willow	*Salix sepulcralis*
western soapberry	*Sapindus saponaria* var. *drummondii*
white ash	*Fraxinus americana*
white basswood	*Tilia americana* var. *heterophylla*
white fir	*Abies concolor*
white mulberry	*Morus alba*
white oak	*Quercus alba*
white spruce	*Picea glauca*
white willow	*Salix alba*
willow oak	*Quercus phellos*
willow spp.	*Salix* spp.
winged elm	*Ulmus alata*
yellow birch	*Betula alleghaniensis*
yellow buckeye	*Aesculus flava*
yellow-poplar	*Liriodendron tulipifera*
yellowwood	*Cladrastis kentukea*

[a] Common names are from the PLANTS database (Natural Resources Conservation Service 2014).

APPENDIX II
Forest Inventory and Analysis Database Documentation

Background

The regeneration indicator protocols include a small number of variables collected at the PLOT, SUBPLOT, and SEEDLING levels of information. These data are organized by topic into a new group of Oracle® REGEN tables in the Forest Inventory and Analysis database (U.S. Forest Service 2014).

If additional variables related to forest regeneration are collected in the future, they can be organized in this table group. The following is draft documentation for these data tables (December 9, 2014). References to any appendices in this documentation refer to appendices in the database document (U.S. Forest Service 2014).

Regeneration Data Table (PLOT_REGEN)

Column Order	Column name	Descriptive name	Data type
1	CN	Sequence number	VARCHAR2(34)
2	PLT_CN	Plot sequence number	VARCHAR2(34)
3	INVYR	Inventory year	NUMBER(4)
4	STATECD	State code	NUMBER(4)
5	UNITCD	Survey unit code	NUMBER(2)
6	COUNTYCD	County code	NUMBER(3)
7	PLOT	Phase 2 plot number	NUMBER(5)
8	BROWSE_IMPACT	Browse impact code	NUMBER(1)
11	CREATED_BY	Created by	VARCHAR2(30)
12	CREATED_DATE	Created date	DATE
13	CREATED_IN_INSTANCE	Created in instance	VARCHAR2(6)
14	MODIFIED_BY	Modified by	VARCHAR2(30)
15	MODIFIED_DATE	Modified date	DATE
16	MODIFIED_IN_INSTANCE	Modified in instance	VARCHAR2(6)
17	CYCLE	Inventory cycle number	NUMBER(2)
18	SUBCYCLE	Inventory subcycle number	NUMBER(2)

Type of key	Column(s) order	Tables to link	Abbreviated notation
Primary	CN	N/A	PLTREGEN_PK
Unique	STATECD, COUNTYCD, PLOT, INVYR	N/A	PLTREGEN_UK1
Unique	STATECD, COUNTYCD, PLOT, CYCLE, SUBCYCLE	N/A	PLTREGEN_UK2
Foreign	PLT_CN	PLOT_REGEN to PLOT	PLTREGEN_PLT_FK

1.	CN	Sequence number. A unique sequence number used to identify a Regeneration Plot record.
2.	PLT_CN	Plot sequence number. Foreign key linking the Regeneration Plot record to the Plot record for this location.
3.	INVYR	Inventory year. See SURVEY.INVYR description for definition.
4.	STATECD	State code. Bureau of the Census Federal Information Processing Standards (FIPS) two-digit code for each State. Refer to appendix B.
5.	UNITCD	Survey unit code. Forest Inventory and Analysis survey unit identification number. Survey units are usually groups of counties within each State. For periodic inventories, Survey units may be made up of lands of particular owners. Refer to appendix B for codes.
6.	COUNTYCD	County code. The identification number for a county, parish, watershed, borough, or similar governmental unit in a State. FIPS codes from the Bureau of the Census are used. Refer to appendix B for codes.
7.	PLOT	Phase 2 plot number. An identifier for a plot. Along with STATECD, INVYR, UNITCD, COUNTYCD and/or some other combinations of variables, PLOT may be used to uniquely identify a plot.
8.	BROWSE_IMPACT	A code designating the amount of ungulate browse pressure exerted on regeneration of the forest. Pressure need not be exerted only by deer, but by other wildlife as well including but not limited to deer, elk, feral hogs, livestock, moose and others.
9.	CREATED_BY	Created by. See SURVEY.CREATED_BY description for definition.
10.	CREATED_DATE	Created date. See SURVEY.CREATED_DATE description for definition.
11.	CREATED_IN_INSTANCE	Created in instance. See SURVEY.CREATED_IN_INSTANCE description for definition.
12.	MODIFIED_BY	Modified by. See SURVEY.MODIFIED_BY description for definition.
13.	MODIFIED_DATE	Modified by. See SURVEY.MODIFIED_BY description for definition.
14.	MODIFIED_IN_INSTANCE	Modified in instance. See SURVEY.MODIFIED_IN_INSTANCE description for definition.
15.	CYCLE	Inventory cycle number. See SURVEY.CYCLE description for definition.
16.	SUBCYCLE	Inventory subcycle number. See SURVEY.SUBCYCLE description for definition.

Browse Impact Codes Table (Browse_Impact)

Code	Definition
1	Very Low - Plot is inside a well-maintained exclosure.
2	Low - No browsing observed, vigorous seedlings present (no exclosure present).
3	Medium - Browsing evidence observed but not common, seedlings common.
4	High - Browsing evidence common OR seedlings are rare.
5	Very High - Browsing evidence omnipresent OR forest floor bare, severe browse line.

Subplot Regeneration Table (SUBPLOT_REGEN)

Column Order	Column name	Descriptive name	Data type
1	CN	Sequence number	VARCHAR2(34)
2	PLT_CN	Plot sequence number	VARCHAR2(34)
3	SBP_CN	Subplot sequence number	VARCHAR2(34)
4	INVYR	Inventory year	NUMBER(4)
5	STATECD	State code	NUMBER(4)
6	UNITCD	Survey unit code	NUMBER(2)
7	COUNTYCD	County code	NUMBER(3)
8	PLOT	Phase 2 plot number	NUMBER(5)
9	SUBP	Subplot number	NUMBER(1)
10	REGEN_SUBP_STATUS_CD	Regeneration subplot status code	NUMBER(1)
11	REGEN_SUBP_NONSAMPLE_ REASN_CD	Regeneration subplot nonsampled reason code	NUMBER(2)
12	SUBPLOT_SITE_LIMITATIONS	Subplot site limitations	NUMBER(1)
13	MICROPLOT_SITE_LIMITATIONS	Microplot site limitations	NUMBER(1)
14	CREATED_BY	Created by	VARCHAR2(30)
15	CREATED_DATE	Created Date	DATE
16	CREATED_IN_INSTANCE	Created in Instance	VARCHAR2(6)
17	MODIFIED_BY	Modified by	VARCHAR2(30)
18	MODIFIED_DATE	Modified Date	DATE
19	MODIFIED_IN_INSTANCE	Modified in Instance	VARCHAR2(6)
20	CYCLE	Inventory cycle number	NUMBER(2)
21	SUBCYCLE	Inventory subcycle number	NUMBER(2)

Type of key	Column(s) order	Tables to link	Abbreviated notation
Primary	CN	N/A	SBPREGEN_PK
Unique	STATECD, COUNTYCD, PLOT, SUBP, INVYR	N/A	SBPREGEN_UK
Foreign	PLT_CN	SUBPLOT_REGEN to PLOT	SBPREGEN_PLT_FK
Foreign	SBP_CN	SUBPLOT_REGEN to SUBPLOT	SBPREGEN_SBP_FK

1.	CN	Sequence number. A unique sequence number used to identify a Regeneration Subplot record.
2.	PLT_CN	Plot sequence number. Foreign key linking the Regeneration Subplot record to the Plot record for this location.
3.	SBP_CN	Subplot sequence number. Foreign key linking the Regeneration Subplot record to the Subplot record for this location.
4.	INVYR	Inventory year. See SURVEY.INVYR description for definition.
5.	STATECD	State code. Bureau of the Census Federal Information Processing Standards (FIPS) two-digit code for each State. Refer to appendix B.
6.	UNITCD	Survey unit code. Forest Inventory and Analysis survey unit identification number. Survey units are usually groups of counties within each State. For periodic inventories, Survey units may be made up of lands of particular owners. Refer to appendix B for codes.
7.	COUNTYCD	County code. The identification number for a county, parish, watershed, borough, or similar governmental unit in a State. FIPS codes from the Bureau of the Census are used. Refer to appendix B for codes.
8.	PLOT	Phase 2 plot number. An identifier for a plot. Along with STATECD, INVYR, UNITCD, COUNTYCD and/or some other combinations of variables, PLOT may be used to uniquely identify a plot.
9.	SUBP	Subplot number. The number assigned to the subplot. The national plot design (PLOT.DESIGNCD = 1) has subplot number values of 1 through 4. Other plot designs have various subplot number values. See PLOT. DESIGNCD and appendix I for information about plot designs. For more explanation about SUBP, contact the appropriate FIA work unit.
10.	REGEN_SUBP_ STATUS_CD	A code indicating whether or not the subplot was sampled for advanced regeneration.
11.	REGEN_SUBP_ NONSAMPLE_ REASN_CN	A code designating the reason why a subplot was not sampled for advanced regeneration.
12.	SUBPLOT_SITE_ LIMITATIONS	A code indicating if the site (as defined by the subplot) has a limitation that would inhibit or preclude the presence of regenerating seedlings.
13.	MICROPLOT_ SITE_ LIMITATION	A code indicating if the site (as defined by the microplot) has a limitation that would inhibit or preclude the presence of regenerating seedlings.
14.	CREATED_BY	Created by. See SURVEY.CREATED_BY description for definition.
15.	CREATED_DATE	Created date. See SURVEY.CREATED_DATE description for definition.
16.	CREATED_IN_ INSTANCE	Created in instance. See SURVEY.CREATED_IN_INSTANCE description for definition.
17.	MODIFIED_BY	Modified by. See SURVEY.MODIFIED_BY description for definition.
18.	MODIFIED_DATE	Modified by. See SURVEY.MODIFIED_BY description for definition.
19.	MODIFIED_IN_ INSTANCE	Modified in instance. See SURVEY.MODIFIED_IN_INSTANCE description for definition.
20.	CYCLE	Inventory cycle number. See SURVEY.CYCLE description for definition.
21.	SUBCYCLE	Inventory subcycle number. See SURVEY.SUBCYCLE description for definition.

Regeneration Subplot Status Code Definitions Table (REGEN_SUBP_STATUS_CD)

Code	Definition
1	Subplot sampled for advanced regeneration
2	Subplot not sampled for advanced regeneration

Subplot Site Limitations Definitions Table (SUBPLOT_SITE_LIMITATIONS)

Code	Definition
1	No site limitation
2	Rocky surface with little or no soil
3	Water-saturated soils (during the growing season)

Microplot Site Limitations Definitions Table (MICROPLOT_SITE_LIMITATIONS)

Code	Definition
1	No site limitation
2	Rocky surface with little or no soil
3	Water-saturated soil (during the growing season)
4	Thick duff layer (in excess of two-inches thick)

Seedling Regeneration Table (SEEDLING_REGEN)

Column Order	Column name	Descriptive name	Oracle data type
1	CN	Sequence number	VARCHAR2(34)
2	PLT_CN	Plot sequence number	VARCHAR2(34)
3	CND_CN	Condition sequence number	VARCHAR2(34)
4	SCD_CN	Subplot-condition sequence number	VARCHAR2(34)
5	INVYR	Inventory year	NUMBER(4)
6	STATECD	State code	NUMBER(4)
7	UNITCD	Survey unit code	NUMBER(2)
8	COUNTYCD	County code	NUMBER(3)
9	PLOT	Phase 2 plot number	NUMBER(5)
10	SUBP	Subplot number	NUMBER(1)
11	CONDID	Condition number	NUMBER(1)
12	SPCD	Species code	NUMBER
13	SPGRPCD	Species group code	NUMBER(2)
14	SEEDLING_SOURCE_CD	Seedling source code	VARCHAR2(2)
15	LENGTH_CLASS_CD	Length class code	NUMBER(1)
16	TREECOUNT	Count of qualifying seedlings	NUMBER(3)
17	CREATED_BY	Created by	VARCHAR2(30)
18	CREATED_DATE	Created date	DATE
19	CREATED_IN_INSTANCE	Created in Instance	VARCHAR2(6)
20	MODIFIED_BY	Modified by	VARCHAR2(30)
21	MODIFIED_DATE	Modified date	DATE
22	MODIFIED_IN_INSTANCE	Modified in Instance	VARCHAR2(6)
23	CYCLE	Inventory cycle number	NUMBER(2)
24	SUBCYCLE	Inventory subcycle number	NUMBER(2)

Type of key	Column(s) order	Tables to link	Abbreviated notation
Primary	CN		SDLREGEN_PK
Unique	STATECD, COUNTYCD, PLOT, SUBP, INVYR, SPCD, CONDID, SEEDLING_ SOURCE_CD, LENGTH_ CLASS_CD		SDLREGEN_UK
Foreign	CND_CN	SEEDLING_REGEN to COND	SDLREGEN_CND_FK
Foreign	PLT_CN	SEEDLING_REGEN to PLOT	SDLREGEN_PLT_FK
Foreign	SCD_CN	SEEDLING_REGEN to	SDLREGEN_SCD_FK

1.	CN	Sequence number. A unique sequence number used to identify a Regeneration Subplot record.
2.	PLT_CN	Plot sequence number. Foreign key linking the Regeneration Seedling record to the Plot record for this location.
3.	CND_CN	Condition sequence number. Foreign key linking the Regeneration Seedling record to the Condition record for this location.
4.	SCD_CN	Subplot-condition sequence number. Foreign key linking the Regeneration Seedling record to the Subplot-condition record for this location.
5.	INVYR	Inventory year. See SURVEY.INVYR description for definition.
6.	STATECD	State code. Bureau of the Census Federal Information Processing Standards (FIPS) two-digit code for each State. Refer to appendix B.
7.	UNITCD	Survey unit code. Forest Inventory and Analysis survey unit identification number. Survey units are usually groups of counties within each State. For periodic inventories, Survey units may be made up of lands of particular owners. Refer to appendix B for codes.
8.	COUNTYCD	County code. The identification number for a county, parish, watershed, borough, or similar governmental unit in a State. FIPS codes from the Bureau of the Census are used. Refer to appendix B for codes.
9.	PLOT	Phase 2 plot number. An identifier for a plot. Along with STATECD, INVYR, UNITCD, COUNTYCD and/or some other combinations of variables, PLOT may be used to uniquely identify a plot.
10.	SUBP	Subplot number. The number assigned to the subplot. The national plot design (PLOT.DESIGNCD = 1) has subplot number values of 1 through 4. Other plot designs have various subplot number values. See PLOT.DESIGNCD and appendix I for information about plot designs. For more explanation about SUBP, contact the appropriate FIA work unit.
11.	CONDID	Condition class number. The unique identifying number assigned to a condition that exists on the subplot, and is defined in the COND table. See COND. CONDID for details on the attributes which delineate a condition.
12.	SPCD	Species code. An FIA tree species code. Refer to appendix F for codes.
13.	SPGRPCD	Species group code. A code assigned to each tree species in order to group them for reporting purposes on presentation tables. Codes and their associated names (see REF_SPECIES_GROUP.NAME) are shown in appendix E. Individual tree species and corresponding species group codes are shown in appendix F.
14.	SEEDLING_ SOURCE_CD	A code designating the source of the seedlings.
15.	LENGTH_ CLASS_CD	A code designating the length class of the seedlings.
16.	TREECOUNT	A count of the number of established live tally tree seedlings at least 2-inches in length (with at least two normal-size leaves that do not still bear the cotelyledons) and less than 1.0-inch at d.b.h.
17.	CREATED_BY	Created by. See SURVEY.CREATED_BY description for definition.
18.	CREATED_DATE	Created date. See SURVEY.CREATED_DATE description for definition.

19.	CREATED_IN_ INSTANCE	Created in instance. See SURVEY.CREATED_IN_INSTANCE description for definition.
20.	MODIFIED_BY	Modified by. See SURVEY.MODIFIED_BY description for definition.
21.	MODIFIED_DATE	Modified by. See SURVEY.MODIFIED_BY description for definition.
22.	MODIFIED_IN_ INSTANCE	Modified in instance. See SURVEY.MODIFIED_IN_INSTANCE description for definition.
23.	CYCLE	Inventory cycle number. See SURVEY.CYCLE description for definition.
24.	SUBCYCLE	Inventory subcycle number. See SURVEY.SUBCYCLE description for definition.

Seedling Source Definitions Table (SEEDLING_SOURCE_CD)

Code	Definition
1	Other seedling
2	Stump sprout
3	Competitive oak, hickory, walnut, or butternut seedling[1]

[1]Research indicates that competitive seedlings are highly likely to become dominant or codominant stems in the next stand during forest succession. To be classified as competitive, stems must have a root collar diameter (RCD) > 0.75 inch or have a length of at least 3 feet. In situations with a relatively high tally, check at least 10% of RCDs.

Seedling Length Class Table (LENGTH_CLASS_CD)

Code	Definition
1	2.0 to 5.9 inches
2	6.0 to 11.9 inches
3	1.0 to 2.9 feet
4	3.0 to 4.9 feet
5	5.0 to 9.9 feet
6	Greater than or equal to 10.0 feet

APPENDIX III

Table 5.—Number of seedlings by species and height class on forest land, Wisconsin, 2012-2013

Common name[a]	2.0 to 5.9 in	SE[b]	6.0 to 11.9 in	SE	1.0 to 2.9 ft	SE	3.0 to 4.9 ft	SE	5.0 to 9.9 ft	SE	≥10.0 ft	SE	Total	SE
red maple	15,856,996,489	33.0	4,835,520,211	24.3	4,433,388,226	24.7	747,077,671	29.4	484,101,337	31.0	331,520,202	31.0	26,688,604,137	25.3
sugar maple	3,105,183,933	33.8	2,323,931,871	29.4	4,409,237,725	34.0	1,678,349,917	48.6	697,087,102	53.3	412,449,094	38.4	12,626,239,642	30.1
black cherry	1,524,576,982	33.5	1,386,564,656	16.4	1,829,739,252	16.8	479,855,550	22.2	397,162,604	24.8	129,660,268	34.8	5,747,559,312	16.7
black ash	930,682,257	44.1	746,280,773	59.4	1,995,076,666	47.5	722,769,918	55.8	353,601,607	68.1	211,513,751	51.7	4,959,924,972	47.4
American hornbeam	1,011,148,854	49.8	777,048,839	38.1	1,744,369,486	38.1	484,898,235	47.0	313,009,468	32.8	192,206,118	42.9	4,522,681,000	33.1
quaking aspen	240,894,930	45.5	522,296,870	29.5	1,383,371,153	24.5	359,557,060	34.2	457,944,402	37.3	556,289,180	45.5	3,520,353,594	20.6
balsam fir	1,009,761,968	29.8	677,317,175	32.0	888,830,925	28.0	411,524,503	31.9	443,217,160	38.2	10,116,111	100.4	3,440,767,842	24.0
white ash	181,165,416	37.8	824,898,188	40.0	1,800,151,163	35.2	312,212,570	46.0	157,697,125	50.7	77,692,824	78.3	3,353,817,286	32.9
serviceberry spp.	576,113,495	32.2	988,562,590	29.2	1,322,084,495	26.9	149,764,798	34.2	137,842,069	61.0	20,232,223	70.6	3,194,599,670	19.7
chokecherry	474,532,649	54.6	521,877,139	34.5	902,074,329	26.8	224,349,247	49.6	99,774,229	58.7	9,653,816	102.2	2,232,261,409	25.6
white oak	473,900,097	57.1	787,499,553	69.7	705,311,468	56.6	69,888,190	75.3	70,812,780	87.1	40,464,446	100.4	2,147,876,534	52.0
northern red oak	442,748,953	32.8	999,135,085	27.4	564,525,369	32.0	80,928,892	46.0	0	0	0	0	2,087,338,298	23.9
eastern hophornbeam	354,063,902	34.6	283,251,122	34.9	708,127,805	46.4	343,485,495	41.8	222,092,157	40.9	40,464,446	49.4	1,951,484,927	35.1
eastern white pine	787,669,810	77.1	252,440,492	35.4	362,793,127	38.6	201,859,934	55.4	121,393,338	85.1	91,045,003	74.5	1,817,201,705	42.4
northern pin oak	217,006,908	59.1	557,256,335	40.9	494,710,485	48.3	99,774,229	44.7	90,582,708	62.0	20,232,223	70.6	1,479,562,887	36.0
green ash	131,509,449	43.3	382,897,658	38.7	614,686,195	37.3	160,933,193	48.2	80,004,301	46.4	10,116,111	100.4	1,380,146,908	35.8
American elm	230,359,087	49.5	280,939,645	41.6	402,247,854	26.6	100,698,820	63.4	49,655,967	44.5	10,116,111	100.4	1,074,017,484	25.8
bitternut hickory	340,711,723	48.6	390,325,125	41.1	251,011,041	41.4	40,002,151	80.0	10,116,111	100.4	0	0	1,032,166,151	34.4
mountain maple	303,483,345	51.7	192,206,118	53.4	333,831,679	45.3	10,116,111	100.4	60,696,669	57.3	40,464,446	60.9	940,798,369	44.0
paper birch	181,457,454	52.4	70,307,921	37.5	167,350,941	52.3	264,308,833	62.0	188,507,755	56.6	50,118,262	52.8	922,051,166	43.6
silver maple	875,777,878	83.7	28,961,448	100.2	0	0	0	0	0	0	0	0	904,739,326	84.2
American basswood	141,625,561	57.6	141,163,265	46.9	316,781,137	52.4	19,307,632	70.4	19,307,632	102.2	9,653,816	102.2	647,839,043	35.8
black spruce	141,625,561	93.4	40,464,446	49.4	310,363,388	50.5	151,279,377	48.1	0	0	0	0	643,732,772	43.3
northern white-cedar	131,509,449	56.6	171,973,895	55.6	182,090,007	79.8	30,348,334	74.5	50,580,557	72.0	0	0	566,502,244	57.3
bur oak	20,232,223	100.4	100,236,524	44.4	140,238,675	60.1	137,002,607	61.5	40,002,151	61.5	0	0	437,712,179	46.7
boxelder	241,807,697	92.1	28,961,448	100.2	40,002,151	61.6	60,234,374	71.2	10,116,111	100.4	9,653,816	102.2	390,775,597	67.8
hackberry	177,169,103	57.5	48,731,376	66.4	129,362,318	61.4	0	0	10,073,547	103.9	0	0	365,336,343	52.9
hawthorn spp.	40,464,446	100.4	91,045,003	80.9	89,658,117	66.4	19,769,928	71.6	40,002,151	61.6	0	0	280,939,645	68.8
black oak	0	0	90,120,413	53.4	99,774,229	58.8	9,653,816	102.2	10,116,111	100.4	19,769,928	70.9	229,434,496	47.6
bigtooth aspen	101,161,115	57.9	30,348,334	74.5	30,348,334	74.5	10,116,111	100.4	0	0	48,731,376	83.6	220,705,271	38.0
black willow	0	0	19,307,632	100.2	19,307,632	100.2	28,961,448	100.2	144,807,241	100.2	0	0	212,383,954	100.2
eastern hemlock	151,103,208	103.9	40,379,317	62.8	20,232,223	100.4	0	0	0	0	0	0	211,714,749	84.9
red pine	19,769,928	71.6	29,886,039	75.5	98,387,342	53.2	28,961,448	74.6	10,116,111	100.4	0	0	187,120,869	55.5
tamarack (native)	0	0	30,348,334	74.5	29,886,039	57.7	59,772,078	75.2	50,580,557	82.5	10,116,111	100.4	180,703,121	65.1
Siberian elm	0	0	0	0	125,499,609	100.2	38,615,264	100.2	9,653,816	100.2	0	0	173,768,689	100.2
yellow birch	10,116,111	100.4	30,348,334	74.5	80,928,892	49.4	10,116,111	100.4	10,116,111	100.4	0	0	141,625,561	50.9
shagbark hickory	0	0	59,309,783	46.9	40,002,151	50.0	0	0	9,653,816	102.2	0	0	108,965,749	43.2
rock elm	10,116,111	100.4	0	0	50,580,557	100.4	0	0	20,232,223	100.4	20,232,223	100.4	101,161,115	100.4
jack pine	0	0	0	0	28,961,448	102.2	19,307,632	102.2	28,961,448	102.2	0	0	77,230,529	102.2
black walnut	0	0	9,653,816	102.2	29,423,744	57.7	0	0	9,653,816	102.2	0	0	48,731,376	66.4
white mulberry	28,961,448	75.0	0	0	9,653,816	102.2	9,653,816	102.2	0	0	0	0	48,269,080	73.2
Bebb willow	10,116,111	100.4	20,232,223	100.4	10,116,111	100.4	0	0	0	0	0	0	40,464,446	100.4
eastern redcedar	19,769,928	71.6	0	0	0	0	9,653,816	102.2	9,653,816	100.2	0	0	39,077,560	50.0
American beech	0	0	0	0	10,116,111	100.4	0	0	10,116,111	100.4	10,116,111	100.4	30,348,334	100.4
pin cherry	0	0	10,116,111	100.4	0	0	0	0	10,116,111	100.4	0	0	20,232,223	70.6
red mulberry	0	0	9,653,816	102.2	9,653,816	102.2	0	0	0	0	0	0	19,307,632	102.2
white spruce	0	0	0	0	0	0	10,116,111	100.4	0	0	0	0	10,116,111	100.4
slippery elm	0	0	0	0	10,116,111	100.4	0	0	0	0	0	0	10,116,111	100.4
Scotch pine	0	0	9,653,816	100.2	0	0	0	0	0	0	0	0	9,653,816	100.2
black locust	0	0	9,653,816	102.2	0	0	0	0	0	0	0	0	9,653,816	102.2
Total	30,495,293,581	19.8	18,851,106,558	12.2	27,224,403,344	10.7	7,595,225,221	14.5	4,939,158,331	12.8	2,382,628,018	17.7	91,487,815,053	11.2

[a] Scientific names for all species are listed in Appendix I.
[b] Sampling error (SE) expressed as a percent are shown for the 68 percent confidence level and are not applicable for estimates of zero.

Appendix III (continued).

Table 6.—Number of seedlings per acre by species and height class on forest land, Wisconsin, 2012-2013

Common name[a]	2 in to 6 in	SE[b]	6 in to 1 ft	SE	1 ft to 3 ft	SE	3 ft to 5 ft	SE	5 ft to 10 ft'	SE	≥10 ft	SE	Total	SE
red maple	1,046	33.0	319	24.2	293	24.6	49	29.4	32	30.9	22	30.9	1,761	25.3
sugar maple	205	33.8	153	29.4	291	34.0	111	48.5	46	53.3	27	38.3	833	30.1
black cherry	101	33.1	91	16.1	121	16.7	32	22.1	26	24.8	9	34.7	379	16.4
black ash	61	44.2	49	59.3	132	47.4	48	55.7	23	68.1	14	51.7	327	47.4
American hornbeam	67	49.8	51	38.0	115	38.1	32	46.9	21	32.7	13	42.8	298	33.0
quaking aspen	16	45.5	34	29.5	91	24.6	24	34.5	30	37.3	37	45.4	232	20.6
balsam fir	67	29.7	45	32.0	59	28.0	27	31.9	29	38.3	1	100.3	227	24.0
white ash	12	37.7	54	39.9	119	35.1	21	46.0	10	50.5	5	78.1	221	32.8
serviceberry spp.	38	32.1	65	29.0	87	26.3	10	33.8	9	61.0	1	70.6	211	19.3
chokecherry	31	54.6	34	34.3	60	26.2	15	48.9	7	58.7	1	102.2	147	25.1
white oak	31	57.0	52	69.6	47	56.4	5	75.1	5	87.0	3	100.3	142	51.9
northern red oak	29	32.7	66	27.3	37	31.9	5	46.0	0	0	0	0	138	23.8
eastern hophornbeam	23	34.6	19	34.8	47	46.4	23	41.8	15	40.9	3	49.4	129	35.1
eastern white pine	52	77.0	17	35.3	24	38.4	13	55.3	8	85.1	6	74.5	120	42.3
northern pin oak	14	58.5	37	40.3	33	48.0	7	44.4	6	61.9	1	70.6	98	35.5
green ash	9	43.4	25	38.6	41	37.2	11	48.1	5	46.4	1	100.5	91	35.7
American elm	15	49.3	19	41.4	27	26.4	7	63.4	3	44.5	1	100.3	71	25.5
bitternut hickory	22	48.6	26	41.0	17	41.4	3	80.0	1	100.3	0	0	68	34.3
mountain maple	20	51.8	13	53.5	22	45.3	1	100.6	4	57.4	3	61.0	62	44.1
paper birch	12	52.3	5	37.2	11	51.6	17	61.2	12	56.0	3	52.5	61	43.0
silver maple	58	83.6	2	100.0	0	0	0	0	0	0	0	0	60	84.1
American basswood	9	57.6	9	46.9	21	52.2	1	70.1	1	102.0	1	102.0	43	35.6
black spruce	9	93.4	3	49.3	20	50.4	10	48.0	0	0	0	0	42	43.2
northern white-cedar	9	56.6	11	55.6	12	79.8	2	74.5	3	72.0	0	0	37	57.2
bur oak	1	100.3	7	44.3	9	60.0	9	60.8	3	61.1	0	0	29	46.3
boxelder	16	91.4	2	99.4	3	61.7	4	71.2	1	100.3	1	102.2	26	67.1
hackberry	12	57.1	3	66.3	9	61.3	0	0	1	103.8	0	0	24	52.6
hawthorn spp.	3	100.3	6	80.9	6	66.3	1	71.4	3	61.5	0	0	19	68.7
black oak	0	.	6	53.4	7	58.5	1	102.2	1	100.3	1	70.6	15	47.4
bigtooth aspen	7	57.9	2	74.5	2	74.5	1	100.3	0	0	3	83.4	15	37.9
black willow	0	.	1	99.4	1	99.4	2	99.4	10	99.4	0	0	14	99.4
eastern hemlock	10	103.7	3	62.6	1	100.3	0	0	0	0	0	0	14	84.6
red pine	1	71.4	2	75.4	6	52.7	2	74.4	1	100.3	0	0	12	55.1
tamarack (native)	0	0	2	74.5	2	57.3	4	74.9	3	82.5	1	100.3	12	64.9
Siberian elm	0	0	0	0	8	100.0	3	100.0	1	100.0	0	0	11	100.0
yellow birch	1	100.5	2	74.6	5	49.4	1	100.3	1	100.3	0	0	9	51.0
shagbark hickory	0	0	4	46.9	3	50.2	0	0	1	102.2	0	0	7	43.3
rock elm	1	100.3	0	0	3	100.3	0	0	1	100.3	1	100.3	7	100.3
jack pine	0	0	0	0	2	102.0	1	102.0	2	102.0	0	0	5	102.0
black walnut	0	0	1	102.0	2	57.6	0	0	1	102.0	0	0	3	66.2
white mulberry	2	74.3	0	0	1	102.2	1	102.2	0	0	0	0	3	72.8
Bebb willow	1	100.6	1	100.6	1	100.6	0	0	0	0	0	0	3	100.6
eastern redcedar	1	71.6	0	0	0	0	1	102.0	1	100.0	0	0	3	49.8
American beech	0	0	0	0	1	100.3	0	0	1	100.3	1	100.3	2	100.3
pin cherry	0	0	1	100.3	0	0	0	0	1	100.3	0	0	1	70.6
red mulberry	0	0	1	102.2	1	102.2	0	0	0	0	0	0	1	102.2
white spruce	0	0	0	0	0	0	1	100.3	0	0	0	0	1	100.3
slippery elm	0	0	0	0	1	100.3	0	0	0	0	0	0	1	100.3
Scotch pine	0	0	1	99.4	0	0	0	0	0	0	0	0	1	99.4
black locust	0	0	1	102.2	0	0	0	0	0	0	0	0	1	102.2
Total	2,012	19.7	1,244	11.9	1,796	10.3	501	14.1	326	12.4	157	17.5	6,036	10.9

[a] Scientific names for all species are listed in Appendix I.
[b] Sampling error (SE) expressed as a percent are shown for the 68 percent confidence level and are not applicable for estimates of zero.

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The density and composition of regeneration drives future forest character for forests in need of replacement. Forested ecosystems face numerous regeneration stressors including invasive plants, insects and diseases, herbivory, lack of management, and climate change. As stands that make up these systems age, it is imperative to track the viability of forest reproduction. The information required for understanding the complexity of forest dynamics during the stand establishment stage has been lacking in our Nation's forest inventory. This poses a particular problem for analysts working with the major deciduous forest systems of the Midwest and Northeast United States that require detailed information on advance reproduction. To address this need, the Forest Inventory and Analysis (FIA) program of the U.S. Forest Service, Northern Research Station (NRS) has added protocols for measuring all established tree seedlings and for assessing browse impact. This information is compiled using new NRS-FIA forest sampling and analytical methodologies—the regeneration indicator. The regeneration indicator is described along with examples and suggestions to guide research on the difficult question of whether the region's forests are able to regenerate in the face of numerous stressors.

KEY WORDS: forest sustainability, forest management, forest regeneration, tree reproduction, mixed oaks, northern hardwoods

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