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MODELING PRESCRIBED FIRE EFFECTS ON VEGETATION DYNAMICS IN MID-ATLANTIC OAK AND PITCH PINE FORESTS

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ABSTRACT

Fire is an important natural disturbance that drives ecosystem dynamics and is a valuable tool in forest management. Fire regimes and fire effects vary widely among and within regions. Historical data suggest that fire was an important disturbance agent in mid-Atlantic forests prior to widespread logging and other land use changes in the 18th and 19th centuries. These events were then followed by a period of fire suppression management through the 20th century. Exclusion of fire has altered forest composition, and there is increasing interest in using prescribed fire as a tool to restore fire as an important ecological process in these forests. However, the wide range of human-influenced forest conditions suggests that prescribed fire implementation could lead to a variety of ecological outcomes. This research uses simulation modeling to test the effects of varying forest conditions and fire regimes on potential ecological outcomes of prescribed fire. Field data on structure and composition of fire-dependent forests and the Forest Vegetation Simulator (FVS) are used to simulate forest response to variation in fire regimes, specifically fire frequency and duration of fire application.

Modeling results suggest that for management of oaks such as in Pennsylvania, recurrent burning at low to medium frequencies, i.e. with a fire return interval of 10-30 years, applied over the long term would generally be effective towards maintaining or restoring oak and controlling the establishment of mesophytic competitors, as well as maintaining healthy forest structure within oak stands. Appropriate regime treatments, however, depend on present stand conditions. More frequent burning, e.g. at a five-year return interval, may be necessary to successfully promote regeneration and establishment of oak in stands that comprise a large mesophyte component. Relative pine dominance was directly and positively related to the presence and recurrence of fire, and increased both with shorter return intervals and with a longer period of fire application. Conversely, relative dominance of mesophytic hardwood species was directly but negatively related to the presence and recurrence of fire, and decreased with shorter return intervals and with a longer period of fire application.

For management of pitch pine such as in the Pine Barrens of New Jersey, results show that recurrent burning maintained abundant pine establishment and was necessary to control hardwood establishment in pine stands. Frequent burning, especially over a longer period, increased relative pitch pine dominance and decreased the prevalence and establishment of hardwoods. A long-term regime of relatively frequent recurrent burning is therefore necessary towards maintaining the health and integrity of the pitch pine communities of the Pine Barrens.

By exploring the ecological outcomes of prescribed fire, this research aims to provide tangible guidance for local forest management specialists implementing prescribed fire in oak and pitch pine forests in the mid-Atlantic region. Informed fire management will better promote the current and future health of vegetation communities and dynamics.

Keywords: Prescribed Fire, Oak Forests, Pitch Pine Forests, Mid-Atlantic, Modeling, Forest Management

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CHAPTER 1 – Introduction

Ecological disturbances are important processes that shape natural landscape patterns, and research on disturbance regimes is a central focus of biogeographic and ecological research (Turner 2010). Disturbances renew limiting resources and generate spatial and temporal heterogeneity that promote regeneration and local biodiversity, and also shape long-term ecosystem dynamics through legacy effects (Levin and Paine 1974, Turner 2010). Fire is a particularly ubiquitous and significant disturbance agent because it occurs in all terrestrial biomes, where it may shape plant community structure and function. Fire frequency, severity, seasonality, and extent together characterize a fire regime of a particular location (Bond and Keeley 2005). Fire regimes drive both short- and long-term forest succession and are capable of changing tree species composition and forest type (Johnstone et al. 2010, Buma et al. 2013). In fire-driven ecosystems, effects of recurrent fire on vegetation composition and functional traits depend on time since last fire, number of fires, and time interval between multiple successive fires (Schaffhauser et al. 2008). Disturbances such as fire play well-established ecological roles in promoting species diversity and maintaining the structure and function of plant communities worldwide.

Disturbance regimes are currently undergoing rapid change from large-scale drivers such as climate change and fire suppression (Turner 2010). Changes in disturbance regime characteristics can generate new ecosystem states that differ considerably in structure, function, composition, and provision of services (Johnstone et al. 2016, Seidl et al. 2016), with changes in fire frequency in particular having the potential to significantly impact forest ecosystem recovery and resilience at the landscape scale (Seidl et al. 2014). For example, reductions in fire frequency caused by fire suppression in California have led to increased fuels, higher-severity fires, and subsequent vegetation shifts from forests to shrublands that are maintained by future fires as a result of high shrub flammability (Lauvaux et al. 2016). The suppression of fire in fire-adapted systems may also facilitate eventual dominance of less flammable, late-successional species over early-successional species, reducing flammability and fire occurrence in that system (Kitzberger et al. 2012). For example, fire suppression in upland oak and pine ecosystems in the Missouri Ozarks has reduced forest flammability by permitting establishment of low-flammability, fire-sensitive tree species that reinforce low flammability (Hanberry et al. 2012). Understanding these dynamics is important because there is potential for such systems to exceed ecological thresholds and experience permanent shifts in forest ecosystem structure (Adams 2013).

The degree of alteration from historical conditions may be an important consideration in informed management (Hobbs et al. 2014). Ecosystems such as forests may retain ecological memory of past states, such as disturbance-adapted life-history traits in vegetation and post-disturbance material legacies such as surviving trees, seeds, and nitrogen pools; this memory enhances present resilience to historical disturbance regimes and to potential reintroduction of these disturbances (Johnstone et al. 2016). Such knowledge of ecological history can be used to better manage for resilience; a keen understanding of both contemporary disturbance processes (Attiwill 1994) and historical ecology (Swetnam et al. 1999) is important in guiding effective management of forests.

The mid-Atlantic region of the United States (U.S.) supports a multitude of historically fire-dependent forest ecosystems. Oaks (*Quercus* spp.) have historically dominated much of the region's hardwood forests, and oak dominance is related to recurring natural and anthropogenic fire (Abrams 1992). However, with over a century of fire suppression, oaks are being outcompeted and replaced by later-successional, fire-sensitive hardwood species such as maples (*Acer* spp.) (Abrams 1996, Hutchinson et al. 2008). Fire-adapted pines (*Pinus* spp.) are also dominant on drier sites throughout the region, and are being replaced by hardwoods without sufficient fire. Frequent, widespread fire has long played a vital role in maintaining pitch pine (*P. rigida*) forests in the New Jersey Pine Barrens (Little 1946, Givnish 1981) and the yellow pine, e.g. pitch pine, Table Mountain pine (*P. pungens*), Virginia pine (*P. virginiana*), and shortleaf pine (*P. echinata*), and mixed pine-hardwood forests of the central and southern Appalachian Mountains (Grissino-Mayer 2016). Yellow pines, including pitch pine, have serotinous cones that require the high temperatures of fire to release their seeds for regeneration, and have thick bark that provides them with fire resistance (Givnish 1981, Grissino-Mayer 2016). These pine-dominated forests are unlikely to persist without recurring fire.

A variety of fire regimes historically influenced vegetation in eastern North America, with differences in regimes largely related to differences in vegetation type, local topography, climate, human population density, and occurrence of drought (Guyette et al. 2006). During the late 19th and early 20th centuries, frequent and widespread fires related to the human activities of logging and land clearance facilitated development of oak dominance in eastern mixed-oak forests (McEwan et al. 2007). Fire suppression initiated in the early 20th century has drastically impacted fire-dependent oak and pine forest ecosystems in the eastern U.S., where fire-adapted, shade-intolerant oaks are being replaced by fire-sensitive, shade-tolerant mesophytic species, particularly maples. Mesophytic species alter micro-environmental conditions such as surface fuel structure and litter moisture, reducing flammability and the likelihood of future fire occurrence (Nowacki and Abrams 2008, Kreye et al. 2018, Dyer and Hutchinson 2019, Knott et al. 2019).

Human-set fire was historically common in central Pennsylvania's Ridge and Valley province. Low- and moderate-severity, dormant season fires with mean return intervals as short as three to seven years characterized local fire regimes throughout the period of Euro-American settlement; the dynamics of these regimes were strongly linked to settlement patterns, resource exploitation, and industrialization (Stambaugh et al. 2018). Fire played an important role in establishing dominance of white oak (*Quercus alba*) from the late 18th century until the early 20th century, when logging decreased and fire suppression was initiated (Abrams and Nowacki 1992). Fire also historically supported pitch pine communities in this region, which in the present day exist only as remnants as a result of long-term fire suppression (Marschall et al. 2016). Fire has also been a frequent recurring disturbance in the upland pine and pine-oak forests of the New Jersey Pine Barrens, where fire burned with variable severity (Little 1946). In the Pine Barrens, fire frequency influences both forest composition and structure across the landscape (Little 1979) and local levels of plant serotiny that exhibit a high degree of spatial variability (Givnish 1981). Similar to the history in central Pennsylvania, the majority of fires that occurred in the Pine Barrens between the 17th and 20th centuries were human-caused and are directly linked to Euro-American settlement and industrial practices (Wacker 1979). However, fire suppression policy initiated in 1940 drastically reduced the total area burned each year, as well as average fire size and fire frequency at any given site; this has resulted in considerable increases in abundance of less fire-adapted hardwoods and a decrease in abundance of fire-adapted species and genotypes (Forman and Boerner 1981). Similarly, in the central and southern Appalachian Mountains, frequent and extensive fires have maintained pine- and oak-dominated forests across the landscape for centuries, and fire suppression has facilitated the expansion of mesophytic hardwoods into these historically pyrogenic forests (Aldrich et al. 2010, Flatley et al. 2013, Grissino-Mayer 2016, Lafon et al. 2017). More fires tend to occur at lower elevations, and a greater number of natural ignitions occur in the Blue Ridge province than in the Ridge and Valley province and the Appalachian Plateau (Lafon and Grissino-Mayer 2007). Overall, fire plays an integral role in maintaining fire-adapted oak and pine forests throughout the mid-Atlantic region. The recent lack of fire has important implications for ecosystem changes and future forest conditions, and for management efforts to maintain dominance of desired fire-adapted species such as oaks and pines.

The potential for controlled fire as a forest management tool to promote dominance of fire-adapted species has been recognized for decades (Wright 1974). Periodic prescribed burning reduces forest fuel loads and decreases the likelihood of potential large-scale, community-shifting wildfires from occurring in fire-suppressed forests (Adams 2013). Prescribed burning has also been used as an ecosystem restoration tool in the U.S. to reduce abundance of fire-sensitive species and to alter forest composition, despite associated ecological unknowns and socio-political constraints surrounding its use (Ryan et al. 2013). Implementation of prescribed fire at any given location is complicated by a variety of site-specific ecological parameters (Freeman et al. 2017), such as immediate and long-term differential impacts on the local wildlife community (Harper et al. 2016, Campbell et al. 2018, Greenberg et al. 2018, Hromada et al. 2018). Within the past decade, new state legislation has increased opportunities for prescribed burning in both Pennsylvania (Haluska et al. 2009) and New Jersey (Dancer et al. 2018) for the purposes of healthy ecosystem management, public safety, and protection of resource value. Limited empirical studies on prescribed burning have demonstrated a range of ecological outcomes in eastern oak and pine forests, depending on implemented fire regime factors such as frequency, severity, and seasonality. Although skepticism exists regarding the effective use of prescribed burning in the eastern U.S. (Matlack 2013), there is consensus that careful implementation is ultimately beneficial to forest management (Stambaugh et al. 2015). Periodic burning is vital to the maintenance and restoration of eastern oak forests (Abrams 2005); however, past studies involving prescribed fire in oak forests have yielded varied levels of success of competitive oak regeneration, especially with single, low-intensity burns in mature forests (Brose et al. 2006). Effective use of fire in managing for oaks requires a clear understanding of fire's potential role at a given site and its effects at particular scales; it should consider tree life history, burn frequency, any need to couple fire use with overstory reduction, seasonality and intensity, and fire-free periods for overstory recruitment (Brose et al. 2006, 2013, Arthur et al. 2012, Brose 2014, Dey 2014). Understanding of the role of fire in eastern oak ecosystem dynamics remains limited due to a paucity of longer-term studies. Consequently, establishing local restoration goals that use prescribed fire as a management tool is challenging and can be a contentious issue (Varner et al. 2016).

Periodic prescribed burning has been determined to facilitate pine regeneration and establishment and reduce fuel accumulation in the New Jersey Pine Barrens (Little and Moore 1949, Boerner 1981). However, prescribed fire must be used with care; without additional burning or selective removal of hardwoods, infrequent prescribed burning in local mixed pine-oak forests has the potential to facilitate succession toward oak dominance that is undesirable for forest managers (Boerner et al. 1988). Nevertheless, careful implementation of a prescribed fire regime coupled with overstory removal can exclude most undesirable hardwood species from pine and pine-oak stands (Olson 2011). Prescribed burning remains a feasible tool in reducing hazardous fuel accumulation and maintaining fire-dependent plant communities throughout the mid-Atlantic (Clark et al. 2014). However, long-term ecological studies on the impacts of varying prescribed fire regimes that involve recurrent burning over many decades have not been conducted, and potential ecological outcomes remain poorly understood. Long-term research on repeated prescribed burning over six decades in a Missouri Ozark oak-hickory forest (Knapp et al. 2015, 2017) shows that repeated burning reduced overstory density and canopy cover and favored white oak species, e.g. *Quercus alba* and *Q. stellata*, over red oak species, e.g. *Q. coccinea*, *Q. falcata*, and *Q. velutina*, and hickories (*Carya* spp.) in the overstory, especially at a four-year fire return interval compared to annual burning or no fire. No burning enabled ingrowth of fire-sensitive hardwood species over time. Reduced tree regeneration and recruitment associated with repeated burning demonstrated that fire-free periods are necessary for overstory tree replacement (Knapp et al. 2015, 2017). Additional investigation of the multi-decadal effects of different fire regimes on fire-dependent forest ecosystems in the mid-Atlantic is needed to improve our understanding of the potential long-term ecological impacts of fire, and to guide the use of prescribed fire for vegetation management across the region.

Simulation modeling provides a powerful means of predicting the potential effects of fire on forest ecosystems, and can help to inform policy and management concerning the use of prescribed fire when empirical studies are lacking and short-term (Perera and Cui 2010, Shive et al. 2014, Loudermilk et al. 2017). Forest fire regimes and their effects on vegetation can be modeled and simulated with different initial conditions and under various weather conditions to identify potential vegetation changes associated with prescribed burning. Simulation experiments can be used in conjunction with empirical research and other information to inform fire and forest management. This type of modeling has been conducted over large spatial and temporal scales on eastern forest ecosystems, including southern Appalachian yellow pine and oak forests (Lafon et al. 2007) and the New Jersey Pine Barrens (Scheller et al. 2008, 2011). However, modeling research has been limited in terms of the scope of fire regimes tested; investigation of an expanded range of potential regimes and fine-grained, tree- and stand-level forest response using simulation modeling will improve understanding of the potential role of fire in forest dynamics and the use of prescribed fire as a restoration tool in the mid-Atlantic U.S.

The goal of this research was to investigate the potential multi-decadal effects of different fire regime treatments on composition and structure of oak and pitch pine forest stands in Pennsylvania and New Jersey, two states within the mid-Atlantic U.S. Specifically, this research tests how initial forest conditions, fire frequency, and duration of fire regime influence long-term dominance of pines and oaks in mid-Atlantic forests using a simulation modeling approach. I test the hypothesis that oak and pitch pine dominance, as measured by relative basal area (BA), would be facilitated by higher initial BA proportion, repeated burning over longer durations, and burning at medium fire frequency for oaks and at high fire frequency for pitch pine. This research advances our understanding of fire effects and forest dynamics from ecological and geographical standpoints, and enables an assessment of the management implications and value of prescribed fire as a forest and landscape management tool.

CHAPTER 2 – Study Regions

Forest inventory data used for this research were originally collected by state and federal agencies in public forest lands within or near the Pine Barrens, or Pinelands, in central and southern New Jersey (NJ) and across Pennsylvania (PA), although only data from eastern and central PA were used for the simulation experiments for PA. The Pine Barrens are officially designated as a national reserve and are managed by the NJ Pinelands Commission; within the national reserve are several state forests managed by the New Jersey Department of Environmental Protection (NJDEP) Division of Parks and Forestry. Much of the forested land across PA is managed as state forests by the PA Department of Conservation and Natural Resources (DCNR) Bureau of Forestry, and as state game lands by the PA Game Commission (PGC) (Figure 2.1).

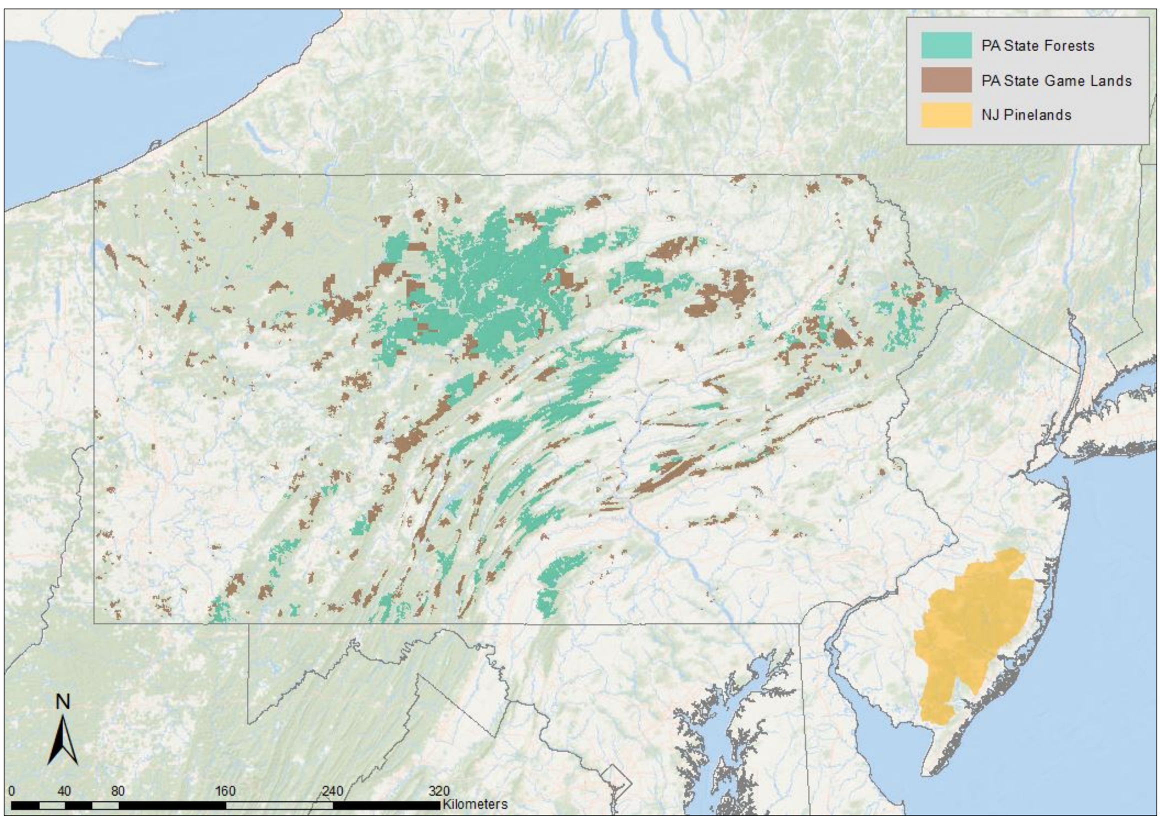


Figure 2.1. Locations of state forests and state game lands in Pennsylvania and the Pinelands in New Jersey. Forest inventory data used for this research were originally collected at forested sites within or near these locations.

The study area spans four physiographic provinces: the Atlantic Coastal Plain in central and southern NJ and southeastern PA; the Piedmont in southeastern PA; the Ridge and Valley in eastern and central PA; and the Appalachian Plateaus in northern, central, and western PA. Elevations range from 0 m in southern NJ by the Atlantic Ocean, to ~950 m in the Ridge and Valley in central PA. A warm to hot humid continental climate is found throughout PA, where annual temperature averages 8-13 °C and ranges between -5 and 25 °C. In the Pine Barrens region of NJ, a hot humid continental climate predominates, although it is moderated by the ocean; annual temperature averages 11-12 °C and ranges between -1 and 24 °C. Both locations experience year-round precipitation; annual precipitation throughout PA is 900-1200 mm, and is 1100-1200 mm in the NJ Pine Barrens ("Climate-Data.org", "PlantMaps").

Forest types in the regions include temperate deciduous forest comprised of oaks and other hardwoods, mixed broadleaf-conifer forest comprised of oaks and pines, and temperate coniferous forest in the Pine Barrens that is comprised of predominantly pitch pine. Forest vegetation characteristics today reflect climate, physiographic province, historical and contemporary patterns of land use, resource exploitation, and associated fire occurrence (Vankat 1979, Greller 1988). In PA, oak-dominant and oak-pine forests occupy drier sites, where chestnut oak (*Quercus montana*) is very common. Other oak species found in these forests include black oak (*Q. velutina*), northern red oak (*Q. rubra*), scarlet oak (*Q. coccinea*), and white oak. Within oak-pine forests, pitch pine dominates small areas comprising xeric and rocky sites. Mixed oak-hardwood forests, consisting of mixtures of oaks and non-oak hardwoods, are common and widespread in PA. In addition to oaks, common hardwood species include red maple (*Acer rubrum*), blackgum (*Nyssa sylvatica*), sweet birch (*Betula lenta*), black cherry (*Prunus serotina*), American beech (*Fagus grandifolia*), bigtooth aspen (*Populus grandidentata*), and sassafras (*Sassafras albidum*). One or more of these species are often prevalent in mixed-hardwood forests that do not contain a sizeable oak component. Within the NJ Pine Barrens, pitch pine is the predominant species in pine-dominant forests, but shortleaf pine can be found in these forests as well, to a much lesser extent. In addition to pitch pine and shortleaf pine, several oak species including chestnut oak, black oak, white oak, scarlet oak, and scrub oak (*Q. ilicifolia*), a small and shrubby oak species, are found in mixed forests of pine and oak. In mixed-species forests where neither pines nor oaks are dominant, common hardwood species include red maple, blackgum, and sweetbay (*Magnolia virginiana*). Atlantic white cedar (*Chamaecyparis thyoides*) dominates lower-elevation wetland areas in the Pine Barrens.

CHAPTER 3 – Methods

Data Collection

Data used for the simulation modeling of forest response to burning were gathered and compiled from external collaborators and online databases. Field data of forest structure and composition formed the basis for modeling and included plot-level forest inventory data, estimates of surface fuel loading, and prescribed burn weather conditions. Forest inventory data included location, sampling date, number of plots sampled, and plot layout including size dimensions for sampling large/mature trees, small trees/saplings, and seedlings, and breakpoint diameter at breast height (DBH). Across all data sources, individual stems were grouped into three size classes: overstory/mature trees that reached or exceeded breakpoint DBH, mid-canopy/understory trees, or saplings, below the breakpoint DBH but greater than a certain height, and seedlings. Tree-level information included plot identification, species, DBH, height, live or dead status, and recorded damage; plot-level seedling counts and height measurements were included as well.

Forest inventory data were gathered from several sources that used distinct data collection protocols (Table 3.1, Appendix Figures 1-7). In PA, Continuous Forest Inventory (CFI) data from forested lands across the state were obtained from the DCNR Bureau of Forestry and the PGC; in addition, the PGC provided pre- and post-burn forest monitoring data from ongoing prescribed fire effects monitoring in state game lands (SGLs). In NJ, forest inventory data collected in the Pine Barrens were obtained from the New Jersey Forest Service (NJFS); inventory data were also obtained from the U.S. Forest Service (USFS) Forest Inventory and Analysis Program (FIA) DataMart online database (USDA Forest Service, accessed 3/26/2018) and from the U.S. North American Carbon Program (NACP) biometric database associated with landscape-scale carbon monitoring sites (Cole et al. 2015, accessed 11/30/2017).

Table 3.1. Sources of forest inventory data collected for PA and the Pine Barrens in NJ. Data sources utilized distinct data collection protocols, including plot size dimensions and breakpoint DBH. *Note: Only one seedling plot was established for each large tree plot in SGL 176 Unit 2; four seedling plots were established for each large tree plot in each of the other units within SGL 176 and in other SGLs.

State	Data Provider	Data Type	Large Tree Plot Size (m^2) or Basal Area Factor (m^2 ha^{-1})	Small Tree Plot Size (m^2)	Breakpoint DBH (cm)	Seedling Plot Size (m^2)
PA	DCNR Bureau of Forestry	CFI	810	200	11.4	4.0 (5 per large tree plot)
	Game Commission	CFI	810	200	11.4	4.0 (5 per large tree plot)
		Burn Monitoring	500	50	10.2	5.0 (4 per large tree plot*)
NJ	NJ Forest Service	Inventory	2.3 (BAF)	80	10.2	8.0
	NACP (FIA)	Inventory	168	13	12.7	13
	FIA	Inventory	168	13	12.7	13

Simulation Modeling

The Forest Vegetation Simulator (FVS) was used to simulate and model the effects of prescribed fire on forest dynamics at each location. FVS is a growth and yield model used widely throughout the U.S. by various government agencies and by other researchers. It is used to predict forest stand dynamics under various management alternatives and is applicable to a wide range of forest management practices. Model variants have been developed for specific geographic regions within the U.S., to account for regional variation in tree growth, mortality, and forest volume. The Northeast (NE) variant of FVS was used in this research. Multiple model extensions exist for FVS that permit evaluation of forest response to disturbances such as harvesting, disease, insect damage, and fire (Dixon 2002). The Fire and Fuels Extension (FFE) to FVS simulates fire effects, fuel dynamics, and potential fire behavior on stand dynamics (Rebain 2010), and was used to model prescribed fire treatments in this research. FFE-FVS has been used by many studies to examine the interactions between fuel dynamics, fire behavior, and forest development, mainly in the western U.S. (Finney et al. 2007, Johnson et al. 2007, 2011, Seli et al. 2007, Vaillant et al. 2013, Noonan-Wright et al. 2014).

I. Initialization

A. Initial Forest Conditions

Simulation input data were selected, filtered, and processed in preparation for FVS modeling. Microsoft (MS) Excel was used to import, organize, process, and standardize all forest inventory data. Specific vegetation plots were selected from the original inventory data, and the plot selection procedure varied among data sources. As previously indicated, plot-level data varied among sources due to distinct data collection protocols and forest type classification schemes (Table 3.2).

Table 3.2. Inventory plot information and preliminary selection criteria for plot inclusion in forest simulations of prescribed fire effects.

Data Source	Source Sub-Category	Inventory Year	Post-Burn Inventory Year	Selected Forest Types	Additional Criteria	Number of Preliminary Plots
DCNR Bureau of Forestry CFI	N/A	2003-2006 (Cycle 2)	N/A	Oak and Pine Forests	New and re-measured plots; Hydric plots excluded	1075
Game Commission CFI	N/A	2006-2010 (Cycle and Measurement No. 1)	N/A	Oak and Pine Forests and Woodlands	New plots; Active plots; Hydric plots excluded	460
Game Commission Burn Monitoring	SGL 55	2013	2013	N/A	N/A	15
	SGL 141	2013	2014	N/A	N/A	16
	SGL 210	2013	2014	N/A	N/A	13
	SGL 176 Unit 1	2009	2011	N/A	N/A	14
	SGL 176 Unit 2	2009	2011	N/A	N/A	14
	SGL 176 Unit 3	2009	2011	N/A	N/A	16
	SGL 176 Unit 9	2013	N/A	N/A	N/A	10
NJ Forest Service Inventory	N/A	2016-2017	N/A	Pine, Pine-Oak, Oak-Pine, Pitch Pine Lowland	N/A	1122
NACP Inventory	N/A	2004-2009	N/A	N/A	N/A	218
FIA Inventory	N/A	2004-2008 (First Annual Cycle)	N/A	N/A	7 Pineland counties; Publicly-owned land under federal, state, and local government jurisdiction	339

Within the FIA DataMart inventory data, FIA subplots were designated as FVS plots. Field-designated forest types included code 160, the loblolly/shortleaf pine group that includes pitch pine, and codes 400, 500, and 600, groups that include oak; these forest type categorizations were used as the basis for the delineation of pine and oak stands from the FIA inventory data. All other forest types were classified as miscellaneous, and plots of this group were used to generate a miscellaneous, mixed-species stand for FVS. Each available subplot, up to four within each FIA plot, was classified as pine (code 160), oak (code 400/500/600), or other (other codes), based on the largest condition proportion for each subplot.

Selected vegetation plots were used to delineate preliminary input stands based on the original plot classification scheme used in each inventory data source, e.g. forest type (Table 3.3). A single stand comprised one or more plots, and a single plot contained individual tree observations. Since the input tree list for a single stand is limited to a maximum of 3000 tree records in FVS (Dixon 2002), resultant stands comprising more than 3000 tree records were divided into constituent stands that comprised approximately equal numbers of plots.

Table 3.3. Method of preliminary stand delineation and numbers of stands from each data source.

Data Source	Basis for Stand Delineation	Stands Split	Number of Stands
DCNR Bureau of Forestry CFI	Ecoregion	Yes	28
Game Commission CFI	Ecoregion	Yes	19
Game Commission Burn Monitoring	SGL and Unit	No	7
NJ Forest Service Inventory	Forest Type and Property	Yes	14
NACP Inventory	Monitoring Site	No	3
FIA Inventory	Forest Type Group (160, 400/500/600, other)	No	3
			Total: 74

For each preliminary stand, stand-level input data included inventory year; location (latitude and longitude); elevation (feet); plot dimensions (large trees and small trees/saplings), including basal area factor (BAF) when applicable; breakpoint DBH; and number of sampled plots. Inventory year was set as 2000 for every stand, logically representing year 0. For stands in PA, the National Forest approximation was set to the Allegheny National Forest in northwestern PA, due to geographical proximity. For stands in the NJ Pine Barrens, the approximation was set to Wayne National Forest in southeastern Ohio, since this National Forest has the lowest elevation of the National Forests recognized by the NE variant of FVS; the Pine Barrens region is low in elevation as well, and is situated at a latitude similar to that of Wayne National Forest (Dixon and Keyser 2008).

Tree-level input data for each stand in FVS were a list of individual tree records for plots that comprised a stand, and included stand and plot identification; tree count; tree status (live or dead); species; DBH; height (if available); height to top kill (if available); live crown ratio (if available); and crown damage (if available). Tree count was usually set to one to represent a single tree per tree record, but was occasionally higher if tree observations, especially smaller trees, in the corresponding plot were grouped into a single record during inventory. Only stems with a DBH of ≥ 2.54 cm (1 inch) were included in the tree list for each stand; smaller stems were considered seedlings and used to parameterize regeneration. Therefore, the input tree list included saplings/mid-canopy trees in addition to mature/overstory trees; seedlings were not included in the input tree list. The crown ratio code represented an approximate ratio of live crown length to total tree height and is used to predict diameter increment (Dixon 2002). This metric was calculated and included in the input tree list if total tree height and height to live crown measurements were available; otherwise, FVS-computed values were used by default. Any measurements that were reported in metric units in the original inventory data were converted to English units, as required by FVS.

Each preliminary stand was classified into a forest type based on its basal area (BA) composition. The FVS base model (version 2392, revision no. 20180611) was used to compute average BA per acre and total per-acre BA of pines (*Pinus* spp.), of oaks (*Quercus* spp.), and of other species for each stand. These calculations were used to determine proportional BA composition for pine, oak, and other species. Stand BA composition was then subsequently used to classify each stand into one of six broad forest types, as initial forest types for the simulations. The stands were additionally divided by state to account for regional differences. This ultimately led to eight forest classes, grouped by percent BA of oak, pine, and other, and by geographic location (Table 3.4).

Table 3.4. Initial forest classes were formed based on the combination of forest type determined by relative BA composition, and state location. Each preliminary stand was then categorized into a forest class.

Forest Type	BA Specifications	State	Number of Stands
Pine-Dominant	Pines ≥ 70%	NJ	15
Pine-Oak	Pines 50-69%; Oaks 10-49%	NJ	1
Oak-Pine	Oaks 50-69%; Pines 10-49%	NJ	1
		PA	1
Oak-Dominant	Oaks ≥ 70%	PA	4
Mixed-Oak	Oaks 50-69%; Pines < 10%	PA	43
Mixed-Species	Pines < 50%; Oaks < 50%; other spp. present	NJ	3
		PA	6
			Total: 74

Among the 74 preliminary stands, 18 were ultimately selected for experimentation. Stand selection was based on within-group BA composition and number of plots sampled. Up to three stands from each forest class were selected; the first stand exhibited a relatively low BA proportion for pine, oak, or other species; the second stand exhibited a medium-level BA proportion; and the third stand exhibited a relatively high BA proportion. Stands that comprised relatively high numbers of inventory plots, compared to other stands from the same class, were filtered first for selection. Then, relative pine BA was used as the second filter for the pine-dominant group from NJ; relative oak BA was used as the second filter for oak-dominant and mixed-oak groups from PA; and relative BA of other species was considered for the mixed-species groups (Table 3.4). In a few instances, a single stand was initially classified into a forest class and was available to represent that class; this was the case for the pine-oak type from NJ and the oak-pine type in both states.

B. Potential Fire Behavior

Surface fuel loading was estimated through selection of standard fire behavior surface fuel models (Scott and Burgan 2005) based upon consultation with burn experts from each state. Standard surface fuel models were used in potential fire behavior simulations in each stand. One or two fuel models were assigned to each forest class, with relative weights (percentages) based on the experience of prescribed fire specialists in each region (Table 3.5). The initial fuel models represented initial stand conditions only; FFE automatic fuel model selection logic was invoked in the second simulation cycle of every simulation run, which automatically selects surface fuel models for subsequent simulation cycles, based on projected stand conditions (Rebain 2010). Canopy fuel characteristics, including canopy base height and canopy bulk density, also play a role in estimating fire effects on forest structure and composition. These variables were automatically calculated by FFE based on the tree list, and the default values for both conifers and hardwoods were used to simulate fire behavior (Rebain 2010).

Table 3.5. Surface fuel models (Scott and Burgan 2005) and relative weights that were assigned to each forest class based on expert opinion.

	Pine-Dominant	Pine-Oak	Oak-Pine	Oak-Dominant	Mixed-Oak	Mixed-Species
NJ	SH9 (70%), TU2 (30%)	SH9 (60%), TU2 (40%)	SH8 (50%), TU2 (50%)	N/A	N/A	TU2 (100%)
PA	N/A	N/A	TL6 (70%), SH4 (30%)	TL6 (75%), SH4 (25%)	TL6 (80%), SH4 (20%)	TL3 (100%)

Prescribed burn weather variables included wind speed at 6 m (20 feet) above the vegetation, moisture of live and dead fuel that served as a proxy for relative humidity, and air temperature. Burn weather information was obtained through consultation with prescribed fire practitioners in PA and weather data collected between 2005 and 2016 at the Cedar Bridge monitoring site within the Silas Little Experimental Forest for the NJ Pine Barrens. For simulated spring fire weather in PA, wind speed was set to ~13 km/h (8 mph), fuel moisture was classified as dry to represent a realistic condition for prescribed burning, and air temperature was set to 18.3 °C (65 °F). For simulated early spring fire weather in NJ, wind speed was set to 8 km/h (5 mph), fuel moisture was also classified as dry, and air temperature was set to 4.4 °C (40 °F).

C. Regeneration and Mortality

The NE variant of FVS incorporates the "partial establishment model" for tree regeneration, which automatically incorporates stump and root sprouting for hardwoods into the simulation but requires the user to specify and schedule natural seedling regeneration when desired, including species and amounts to be added (Dixon 2002). Regeneration through seedling establishment was therefore manually incorporated into the simulation experiment, and was parameterized using seedling counts and height measurements from the forest inventory data. Each stand in the experiment possessed its own unique regeneration parameters, based on the empirical data and extrapolation to conform to the regeneration action in FVS. Regeneration was parameterized at the species level; seedling density, average seedling height, and survival rate were specified for each species being regenerated. Both density and average height to the nearest foot were extrapolated from the empirical seedling data corresponding to the plots for each stand. Seedling survival rate for each species was parameterized based upon seedling height class, species type, and forest community type for oaks (Keane et al. 2001, Vickers et al. 2019) (Table 3.6, Appendix Tables 1 and 2). Although seedling survival rates are specified by the user in every simulation, eventual recruitment of seedlings into the large tree population is impacted by present stand structure, including total density and BA, at each given simulation cycle.

Table 3.6. Estimated seedling survival rates (%) that were derived on the basis of seedling height, tree species type, and additionally forest community type for oaks.

	Tree Species Type				
Seedling Height (m)	Pines	Oaks (Mixed with Pines)	Oaks (Mixed with Other Hardwoods)	Hickories	Other Hardwoods
≤ 0.3	5	5	5	5	5
0.6	19	19	19	19	19
0.9	39	39	39	39	39
1.2	39	39	39	39	39
1.5-2.7	74	74	73	73	73
≥ 3.0	99	99	99	99	98

Post-fire seedling regeneration represented a separate class of regeneration input, and empirical data for post-burn regeneration was relatively sparse. These parameters were thus extrapolated by species and forest class for most stands. Post-burn regeneration values were determined by computing the differences between empirical post-burn and baseline, i.e. pre-burn, regeneration values for plots of applicable stands. Both weighted means among stands of the same forest class, based on number of inventory plots, and individual stand values were incorporated into the calculations, as applicable to each species. Empirical post-burn regeneration data were available from certain PA SGLs where post-fire monitoring was conducted, and also from the George Washington and Jefferson National Forests (GWJNFs) and Shenandoah National Park (SNP) in the Virginia Appalachians (Table 3.7). Since the plots in SGLs 141 and 210 included empirical post-burn regeneration data, these data were directly used to parameterize post-burn regeneration for the two corresponding stands.

Table 3.7. **Top:** Empirical post-burn monitoring data were available from PA SGLs, and were used to parameterize post-burn regeneration for corresponding stands and forest types. **Bottom:** Empirical data were also obtained from the George Washington and Jefferson National Forests (GWJNFs) and Shenandoah National Park (SNP) in the Virginia Appalachians, and provided additional post-burn regeneration parameters for individual species and stands.

Forest Type	Stand	Additional Notes
Oak-Dominant	SGL 141	Used in conjunction with SNP xeric oak values
Mixed-Oak	SGL 176 Unit 1	Weighted means were used for species occurring in both stands
	SGL 176 Unit 2	
Mixed-Species	SGL 176 Unit 3	Weighted means were used for species occurring in both stands; applied to mixed-species stands in NJ
	SGL 210	

Location	Forest Type	Stand Parameterization	Additional Notes
GWJNFs	Oak-Pine	Oak-Pine in NJ and PA	
SNP	Pine Oak	Pine-Dominant and Pine-Oak in NJ	Original forest type designations from inventory data
	Xeric Oak	Oak-Dominant in PA (partial)	

In some cases, seedlings of certain species were not present within the empirical pre-burn plots but appeared post-burn; for these observations, the post-burn seedling density relative to pre-burn BA for the corresponding species was determined, and used to parameterize post-burn regeneration. This was done for pitch pine for stands in PA. Weighted means among stands of the same forest class were used for individual species as applicable. If the particular species was not present in the stand, and therefore no corresponding BA value was present, then no post-burn regeneration was specified for that species. Post-burn regeneration of pitch pine and shortleaf pine in the NJ Pine Barrens was determined using a separate approach, based on the number of observed post-burn seedlings relative to the number of mature trees. Empirical pine seedling and tree densities reported by Boerner (1981) one year after a prescribed burn were used to set a ratio of 17 post-burn pine seedlings per mature pine tree. This ratio was subsequently used to estimate post-burn seedling densities for pitch pine and shortleaf pine for stands in the Pine Barrens. In addition, fire-related mortality for pitch pine was reduced to 20% of the default FFE-predicted mortality rate in order to more accurately approximate the species' strong resistance to fire (Gallagher 2017, Gallagher et al. 2017).

II. Experimentation

Fire management scenarios that included no burning, a single prescribed burn, and repeated burning at varying frequencies and durations were simulated in each stand. All simulations were conducted over 60 years using the FVS base model and FFE (version 2572, revision no. 20181126), with measurements obtained at 10-year time steps. Potential ecological outcomes were investigated in relation to the inclusion of fire, the inclusion of repeated fire, fire return interval, and fire regime duration. Ten regime treatments, ranging from no burning, to infrequent fire at 30-year and 20-year return intervals, to frequent fire at five-year and two-year return intervals, were applied to each stand (Table 3.8).

Table 3.8. Four broad fire management strategies, comprising of 10 distinct fire regime treatments, were applied to each stand in the simulation experiment.

Broad Management Strategy	Fire Regime Treatment
No Fire	No fire
Single Burn	Single burn at initial year
60-Year Fire Regime Duration	30-year return interval
	20-year return interval
	10-year return interval
	5-year return interval
	2-year return interval
30-Year Fire Regime Duration	10-year return interval
	5-year return interval
	2-year return interval

Short return intervals provided insight on the effects of frequent fire, while the longer intervals provided insights needed for successful regeneration of target tree species such as oaks. Shortened regimes that concluded by year 30 were tested to provide insight on the long-term ecological effects of relatively limited periods of fire application compared to long-term repeated burning (i.e. over 60 years). Three experimental replications were included for each specific management scenario, based on random number generation of large tree diameter growth within FVS. The simulations thus included stochastic variation in projected stand conditions for each stand. Each fire was scheduled during the “before greenup” season, or spring, the most common period for prescribed fire, and burned 100% of the stand to emphasize fire effects on forest development.

Background and post-fire regeneration were incorporated into each simulation. Six decadal seedling establishment events were scheduled from year 0, the initial inventory period when seedlings were tallied in the field, to year 50. Stems taller than 0.6 m (2 feet) were only added into the simulation at year 0 and thus represented an initial forest condition, while stems that were 0.3 m and 0.6 m in height were recurrently added in all treatments. Baseline regeneration was scheduled whenever the stand was not burned, including in years 30-50 for 30-year fire regimes. Post-burn regeneration was scheduled whenever the stand was burned at a decadal time step, i.e. at years 0, 10, 20, 30, 40, and/or 50, and was only scheduled in years 0-20 for 30-year fire regimes. In accordance with post-burn observations, post-burn regeneration events were scheduled to occur one year post-fire, i.e. at years 1, 11, 21, 31, 41, and/or 51. The model automatically incorporated post-burn hardwood stump and root re-sprouting. A sensitivity analysis of seedling regeneration was performed for a subset of stands to better understand the influence of the amount and frequency of recurrent regeneration on FVS-projected stand conditions. Results indicated that minor adjustments to decadal regeneration densities (±5%, ±10%, ±15%, and ±20%) for key regenerating species had little impact on long-term outcomes; for instance, ±20% resulted in a 0-4% difference in total stand BA relative to baseline regeneration, across all stands and simulation cycles, and in a 4-18% difference in stem density. The presence or absence of recurrent regeneration had a greater impact on long-term outcomes; recurrent regeneration at baseline densities for key species was tested at intervals of 5, 10, 15, 20, and 25 years, alongside a no-regeneration control. Frequently-recurring regeneration considerably influenced density and species composition, but not total stand BA, relative to intermediate or infrequent regeneration. Relative to the no-regeneration control, BA difference was 0-9% and density difference was 0-205% across all stands and simulation cycles for 25-year regeneration interval; 0-10% BA difference and 0-171% density difference for 20-year interval; 0-12% BA difference and 1-225% density difference for 15-year interval; 0-11% BA difference and 2-294% density difference for 10-year interval; and 0-15% BA difference and 7-580% density difference for 5-year interval. Overall, it was evident that FVS projections of stand BA are noticeably less sensitive to the inclusion and frequency of seedling regeneration than density projections, demonstrating the greater stability of BA and further justifying its selection as the ecological variable of interest in this research.

To obtain model output results, FVS and FFE were instructed to compute and generate specified output variables for each stand and for each forest group. The variables pertinent to the analysis of fire effects on forest composition were total stand per-acre BA and computed relative BA proportions for pines, oaks, and other species; total per-acre tree density; quadratic mean diameter (QMD) measurements for all trees, for pines, and for oaks; and stand composition, indicated by the most prevalent species and their corresponding proportions relative to total stand BA and density. Forest group-level measurements included weighted means, based on number of inventory plots, for BA, tree density, and QMD. Individual stand-level measurements included BA, tree density, QMD, and species-level BA and density proportions. The top four species by both BA and density, and their corresponding proportions relative to total stand BA and density, respectively, were determined from the species-level output.

Analyses

Ecological response variables were extracted from the FVS and FFE output using the rio package (Chan et al. 2018) in R version 3.4.3 (R Core Team, 2017), and measurement units were converted to metric units. Observed differences in outcomes were determined across forest classes and fire regime treatments at years 30 and 60; means and standard deviations (SDs), representing descriptive statistical measurements from the output, were assessed. The main ecological variable of interest was relative BA composition for pines, oaks, and/or other species, of which the weighted means from the forest groups represented both composition and structure for each applicable forest class. The other ecological variable of interest was species composition, a stand-specific response. Specifically, identifying the top four species by BA provided information about stand composition and dominance, and complemented BA composition information for pines, oaks, and other species. Identifying the top four species by density provided an additional perspective on stand composition and dominance, and could be used to identify potential evidence for species shifts. Obtaining species composition information corresponding to simulation years 0, 30, and 60 enabled the assessment of forest composition dynamics over six decades under a variety of fire management scenarios. Other extracted metrics related to forest group- and stand-level BA, tree density, and QMD were also reported.

CHAPTER 4 – Results

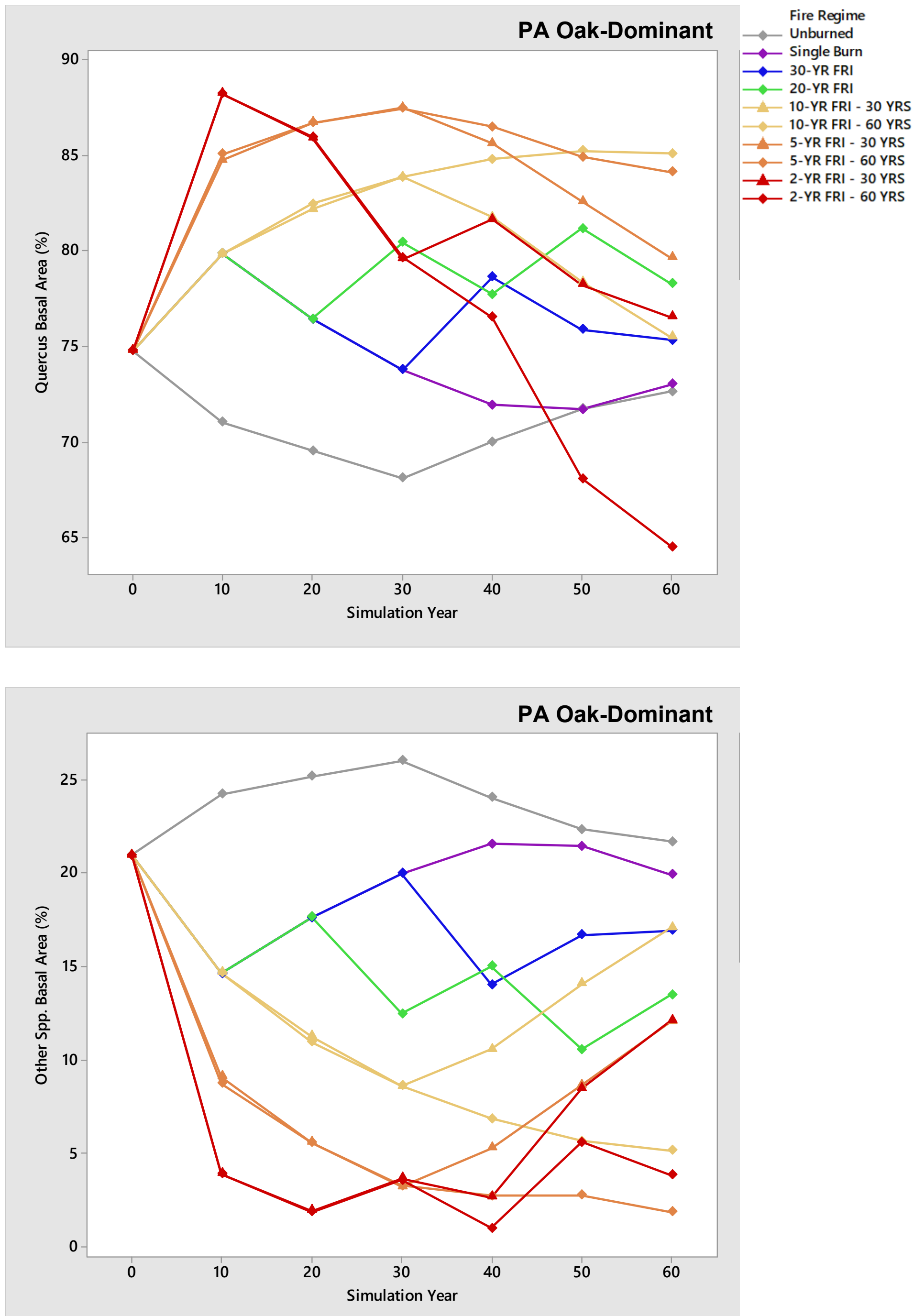
Basal Area

Relative BA composition for pines, oaks, and other species, based upon the weighted means within each forest group as applicable, varied among the forest classes at initial inventory (Table 4.1).

Table 4.1. Relative BA composition for pines, oaks, and other species for each forest class at initial inventory, based upon weighted means within each group as applicable. In each case, standard deviation among replicates = 0.

State	Forest Type	Oak BA (%)	Other Species BA (%)	Pine BA (%)	Total BA (m^2 ha^{-1})
PA	Oak-Dominant	74.8	20.9	4.3	26.6
	Mixed-Oak	59.3	38.9	1.8	27.5
	Mixed-Species	42.7	56.3	0.9	26.2
	Oak-Pine	61.1	23.4	15.5	27.5
		Pine BA (%)	Oak BA (%)	Other Species BA (%)	
NJ	Pine-Dominant	81.8	7.8	10.4	20.7
	Pine-Oak	69.1	30.6	0.4	17.4
	Oak-Pine	29.5	67.6	2.9	19.5
	Mixed-Species	21.2	19.6	59.2	26.2

The different fire regime treatments impacted relative BA composition throughout the course of the simulation for each forest class. For PA oak-dominant at year 30, oak BA was highest with five-year and 10-year fire return intervals (FRIs), at ~87% and ~84%, respectively, and lowest with unburned at 68%; BA for other species was highest with unburned at 26%, was at or below 20% with all other treatments, including below 10% with 10-year, five-year, and two-year FRIs, and was lowest with two-year and five-year FRIs, at ~4% and ~3%, respectively; pine BA was by far the highest with two-year FRI at 17%, while remaining below 10% with all other treatments, being lowest with unburned at 6%. At year 60, oak BA was highest with 10-year FRI over 60 years (hereafter referred to as 10-60) at 85% and five-year FRI over 60 years (hereafter referred to as 5-60) at 84%, by far the lowest with two-year FRI over 60 years (hereafter referred to as 2-60) at 65%, and between 70% and 80% with all other treatments; BA for other species was highest with unburned at 22% and single burn at 20%, lowest with 10-60 at 5%, 2-60 at 4%, and 5-60 at 2%, and was between 10% and 20% with all other treatments; pine BA was by far the highest with 2-60 at 32%, while remaining below 15% with all other treatments, being lowest with unburned at 6% (Figure 4.1).



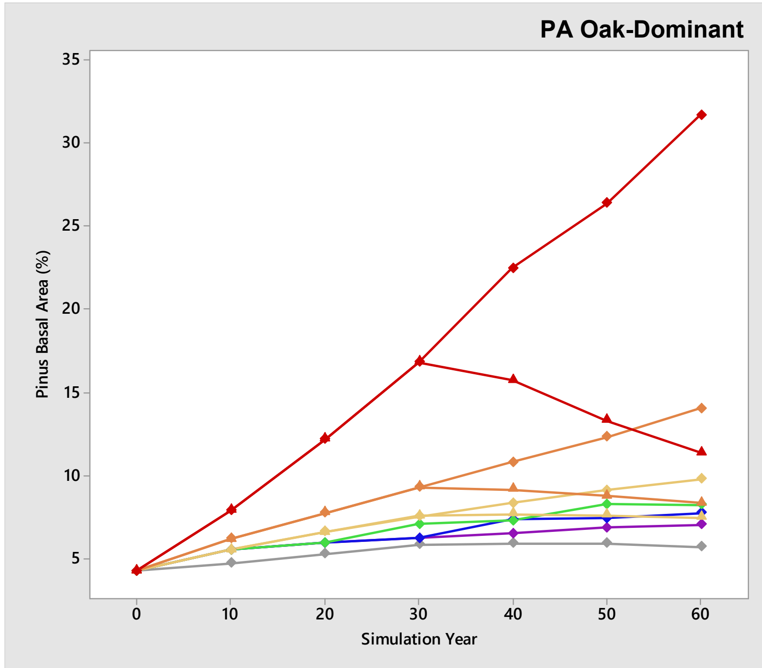
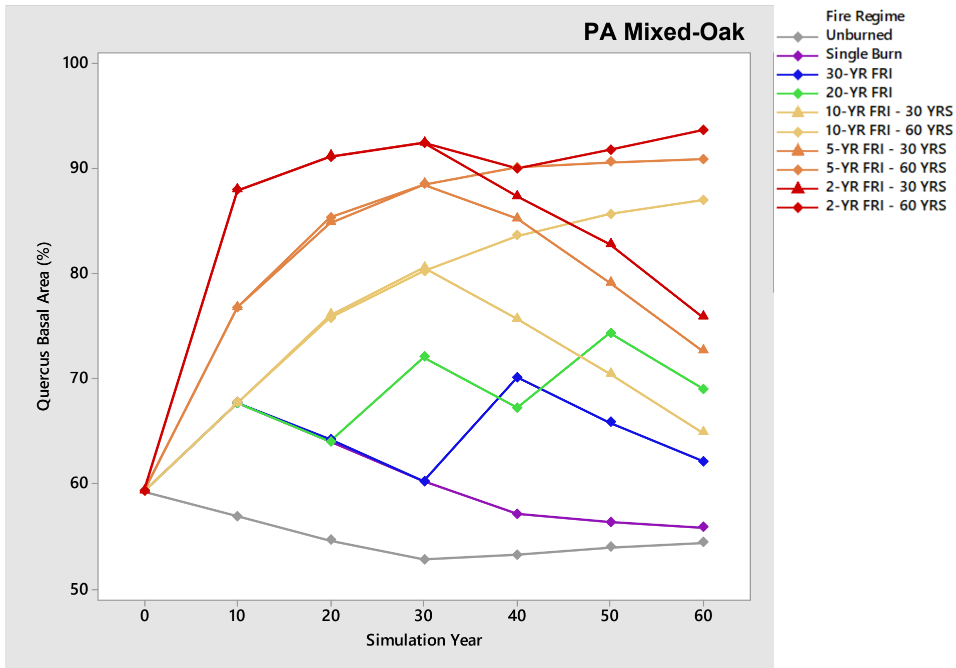
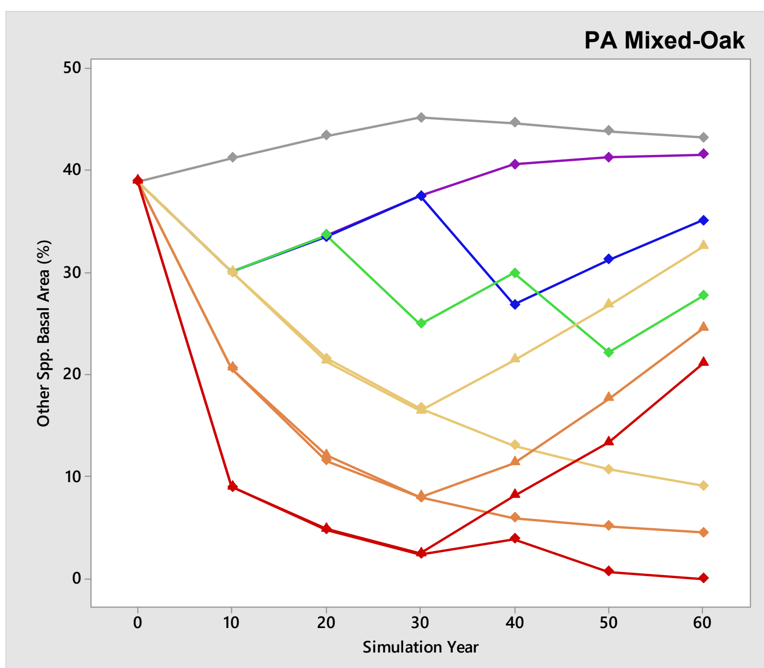


Figure 4.1. Projected changes in relative BA over 60 years for oaks (*Quercus* spp.), non-oak and non-pine species, and pines (*Pinus* spp.) for the PA oak-dominant forest group with different fire regime treatments, based upon weighted means among the constituent stands. Standard deviation among replicates was 0.0-1.0% across all means. Corresponding total BA values (m^2 ha^{-1}) are included in Appendix Table 3.

For PA mixed-oak at year 30, oak BA was highest with two-year and five-year FRIs, at ~92% and ~88%, respectively, and lowest with unburned at 53%; BA for other species was highest with unburned at 45%, and was below 40% with all other treatments, including below 20% with 10-year, five-year, and two-year FRIs, and was lowest with two-year and five-year FRIs, at ~2% and ~8%, respectively; pine BA, which was a very small initial component of this forest class, was highest with two-year FRI at ~5%, and was below 4% with all other treatments, including being lowest with unburned at 2%. At year 60, oak BA was highest with 2-60 at 94%, 5-60 at 91%, and 10-60 at 87%, lowest with unburned and single burn, at 54% and 56%, respectively, and was between 60% and 80% with all other treatments, including above 70% with two-year FRI over 30 years (hereafter referred to as 2-30) and five-year FRI over 30 years (hereafter referred to as 5-30); BA for other species was highest with unburned and single burn, at 43% and 42%, respectively, and was below 40% with all other treatments, including being lowest with 10-60 at 9%, 5-60 at 5%, and 2-60 at 0%; pine BA was by far the highest with 2-60 at 9%, and was below 5% with all other treatments, including being lowest with unburned at 2% (Figure 4.2).





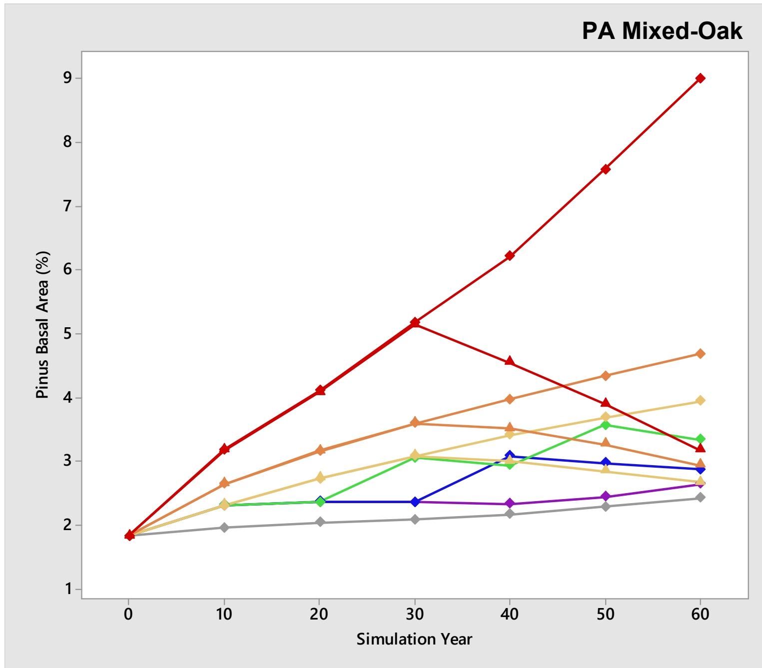
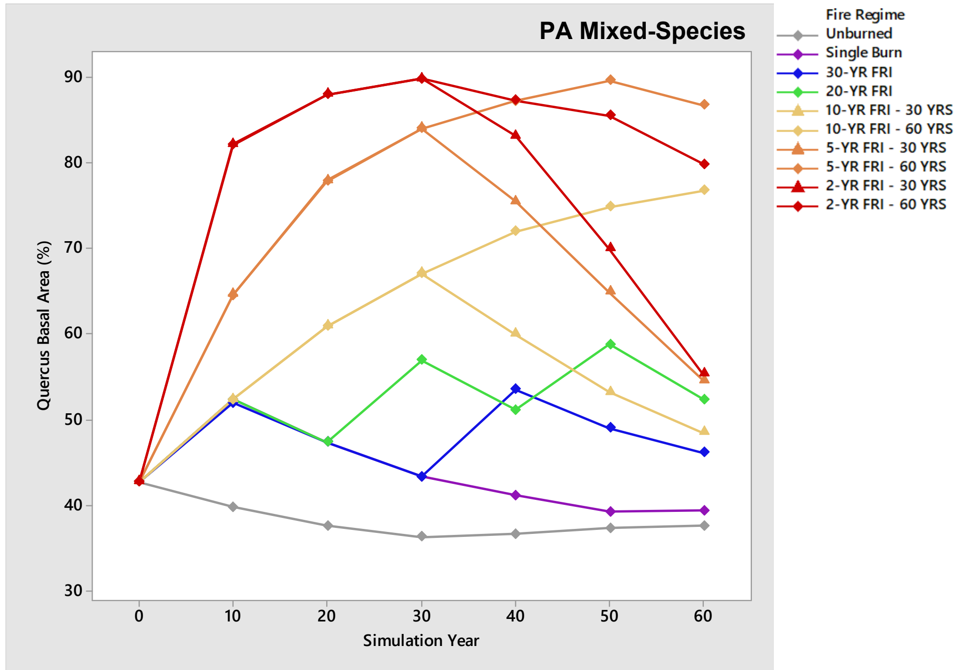
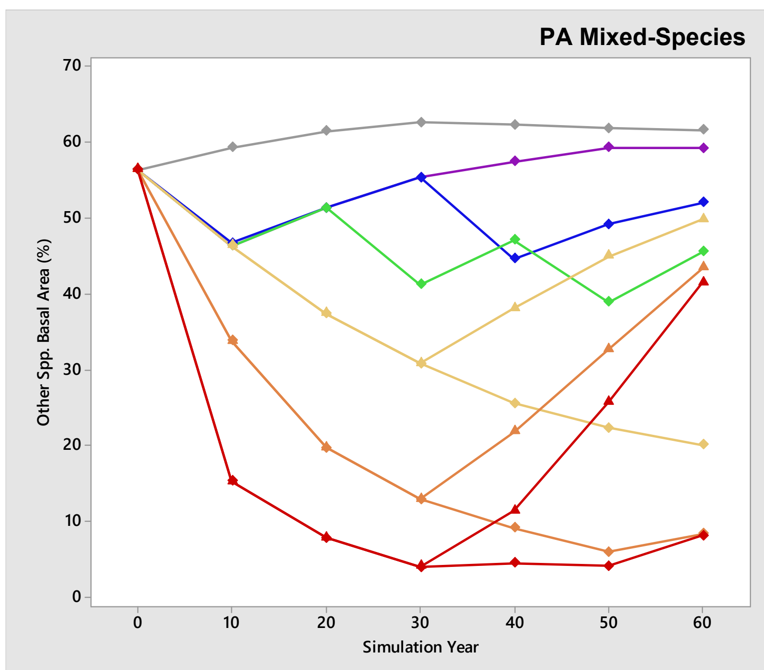


Figure 4.2. Projected changes in relative BA over 60 years for oaks (*Quercus* spp.), non-oak and non-pine species, and pines (*Pinus* spp.) for the PA mixed-oak forest group with different fire regime treatments, based upon weighted means among the constituent stands. Standard deviation among replicates was 0.0-0.6% across all means. Corresponding total BA values (m^2 ha^{-1}) are included in Appendix Table 3.

For PA mixed-species at year 30, oak BA was highest with two-year and five-year FRIs, at ~90% and ~84%, respectively, and was below 70% with all other treatments, including being lowest with unburned at 36%; BA for other species was highest with unburned at 63%, and below 40% with 10-year, five-year, and two-year FRIs, being by far the lowest with two-year and five-year FRIs, at ~4% and ~13%, respectively; pine BA, which was a very small initial component of this forest class as well, was by far the highest with two-year FRI at 6%, and was below 4% with all other treatments, including being lowest with unburned at 1%. At year 60, oak BA was by far the highest with 5-60 at 87%, 2-60 at 80%, and 10-60 at 77%, lowest with unburned and single burn, at 38% and 39%, respectively, and was between 45% and 60% with all other treatments; BA for other species was highest with unburned and single burn, at 62% and 59%, respectively, was lowest with 5-60 and 2-60 at 8%, was at 20% with 10-60, and was between 40% and 55% with all other treatments; pine BA was by far the highest with 2-60 at 12%, and was below 5% with all other treatments, including being lowest with unburned at 1% (Figure 4.3).


PA Mixed-Species
Quercus Basal Area (%)
Simulation Year
Fire Regime
Unburned
Single Burn
30-YR FRI
20-YR FRI
10-YR FRI - 30 YRS
10-YR FRI - 60 YRS
5-YR FRI - 30 YRS
5-YR FRI - 60 YRS
2-YR FRI - 30 YRS
2-YR FRI - 60 YRS


PA Mixed-Species
Other Spp. Basal Area (%)
Simulation Year

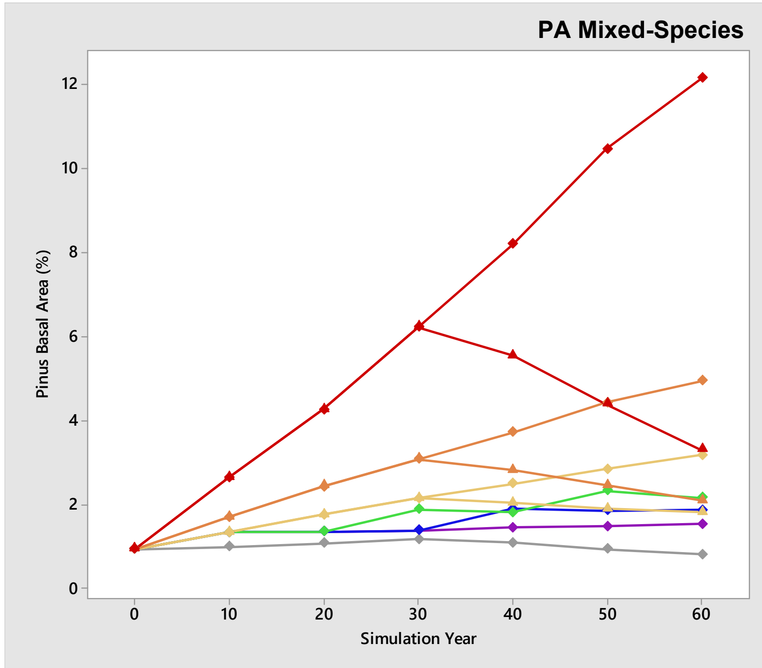
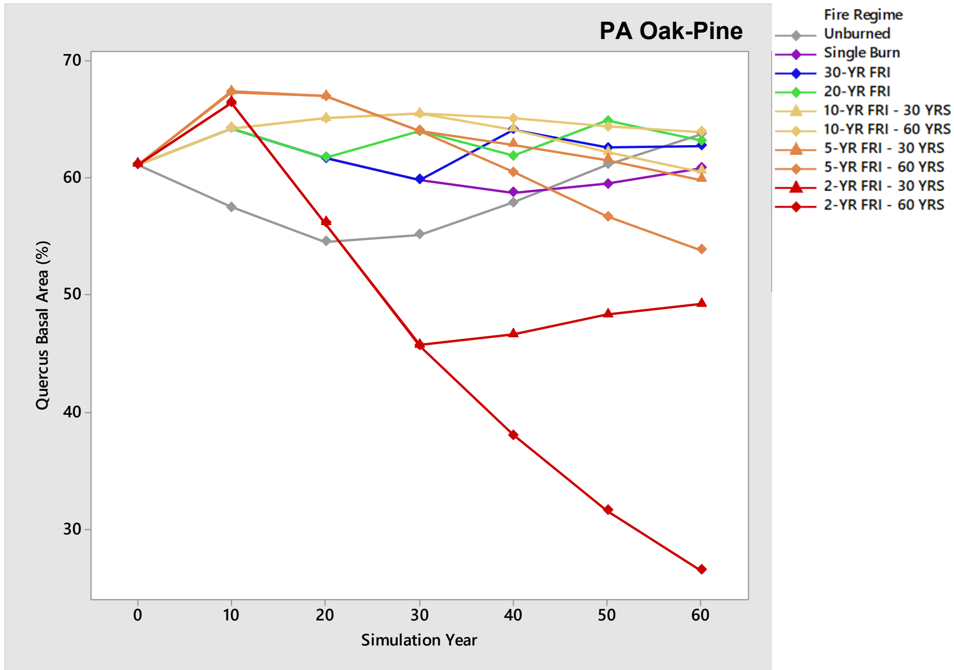
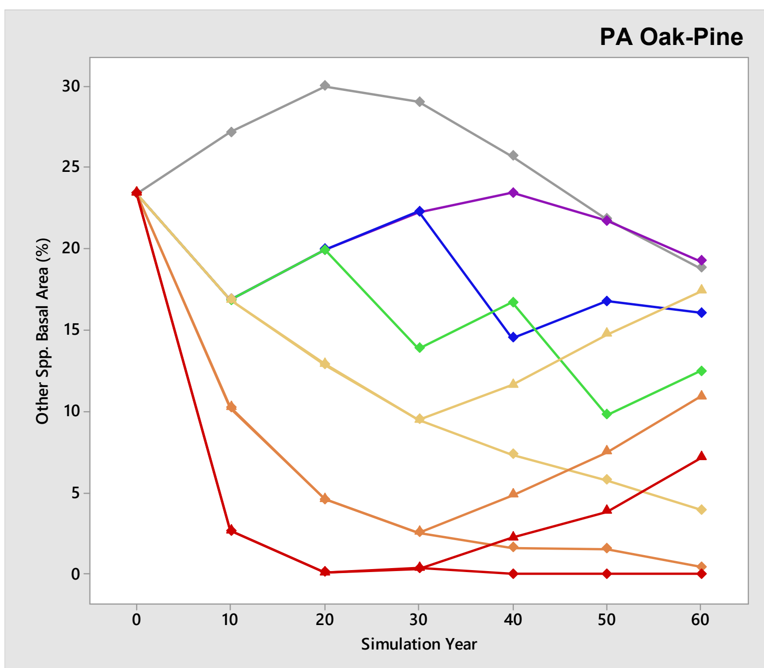


Figure 4.3. Projected changes in relative BA over 60 years for oaks (*Quercus* spp.), non-oak and non-pine species, and pines (*Pinus* spp.) for the PA mixed-species forest group with different fire regime treatments, based upon weighted means among the constituent stands. Standard deviation among replicates was 0.0-1.7% across all means. Corresponding total BA values (m^2 ha^{-1}) are included in Appendix Table 3.

For PA oak-pine at year 30, oak BA was highest with 10-year FRI followed by both five-year and 20-year FRIs, at ~66% and ~64%, respectively, was below 60% with all other treatments, including being lowest with two-year FRI at ~46%; BA for other species was highest with unburned at 29%, and was below 10% with 10-year, five-year, and two-year FRIs, including being lowest with two-year and five-year FRIs, at ~0% and ~3%, respectively; pine BA was by far the highest with two-year FRI at ~54%, was at 33% with five-year FRI, and was below 30% with all other treatments, including being lowest with unburned at 16%. At year 60, oak BA was ~60-64% with all treatments except for 54% with 5-60, 49% with 2-30, and by far the lowest at 27% with 2-60; BA for other species was highest at ~19% with both single burn and unburned, and below 10% with 10-60, 5-60, 2-30, and 2-60, including being lowest at ~0% with both 2-60 and 5-60; pine BA was by far the highest with 2-60 at 74%, was between 40% and 50% with 2-30 and 5-60, was at approximately 30% with 5-30 and 10-60, and was below 25% with all other treatments, including being lowest with unburned at 18% (Figure 4.4).


PA Oak-Pine
Quercus Basal Area (%)
Simulation Year
Fire Regime
Unburned
Single Burn
30-YR FRI
20-YR FRI
10-YR FRI - 30 YRS
10-YR FRI - 60 YRS
5-YR FRI - 30 YRS
5-YR FRI - 60 YRS
2-YR FRI - 30 YRS
2-YR FRI - 60 YRS


PA Oak-Pine
Other Spp. Basal Area (%)
Simulation Year

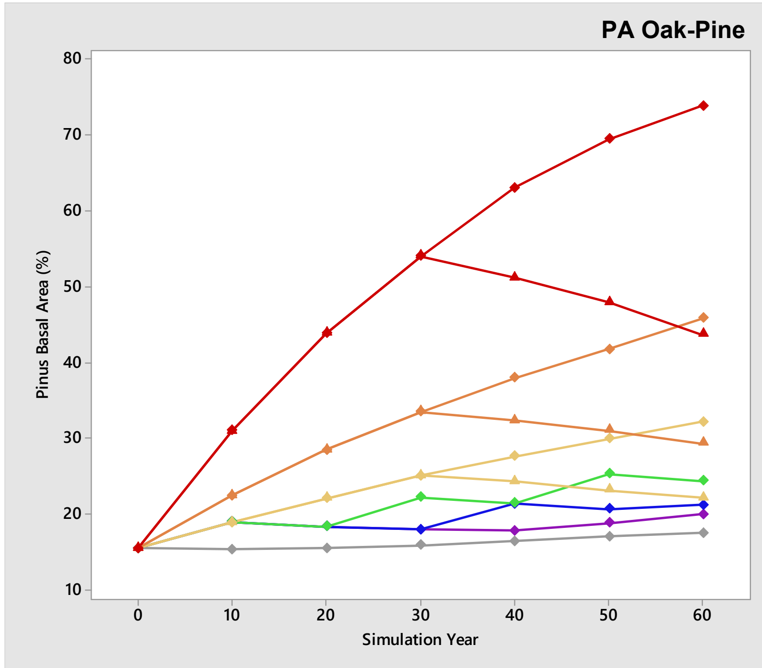
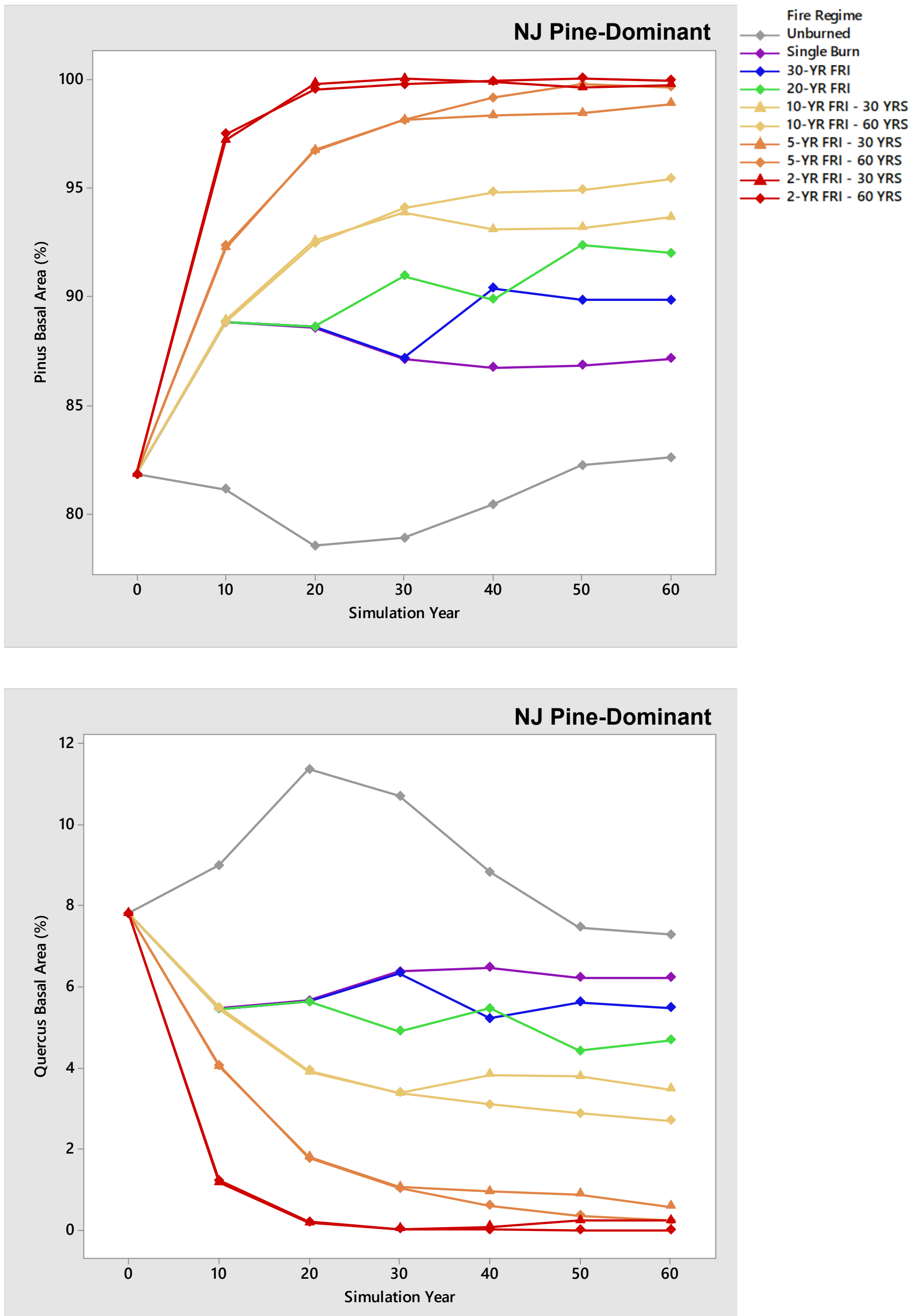


Figure 4.4. Projected changes in relative BA over 60 years for oaks (*Quercus* spp.), non-oak and non-pine species, and pines (*Pinus* spp.) for the PA oak-pine forest stand, with different fire regime treatments. Standard deviation among replicates was 0.0-0.8% across all means. Corresponding total BA values (m^2 ha^{-1}) are included in Appendix Table 3.

For NJ pine-dominant at year 30, pine BA was highest with two-year and five-year FRIs, at ~100% and 98% respectively, was above 90% with two-year, five-year, 10-year, and 20-year FRIs, and was by far the lowest with unburned at 79%; oak BA was highest with unburned at 11%, was at 6% with single burn and 30-year FRI, and was below 5% with all other treatments, including being lowest with five-year and two-year FRIs, at ~1% and ~0%, respectively; BA for other species was by far the highest with unburned at 10%, was at 7% with single burn and 30-year FRI, and was below 5% with all other treatments, including below 1% with two-year and five-year FRIs. At year 60, pine BA was above 98% with both two-year and five-year FRIs of both 60-year and 30-year regime durations, and was lowest with unburned at 83% while being above 85% with all other treatments; oak BA was highest with unburned at 7%, was at 6% with single burn and 30-year FRI, and was below 5% with all other treatments, including below 1% with both two-year and five-year FRIs of both 60-year and 30-year regime durations; BA for other species was by far the highest with unburned at 10%, was at 7% with single burn, and was below 5% with all other treatments, including below 1% with both two-year and five-year FRIs of both 60-year and 30-year regime durations (Figure 4.5).



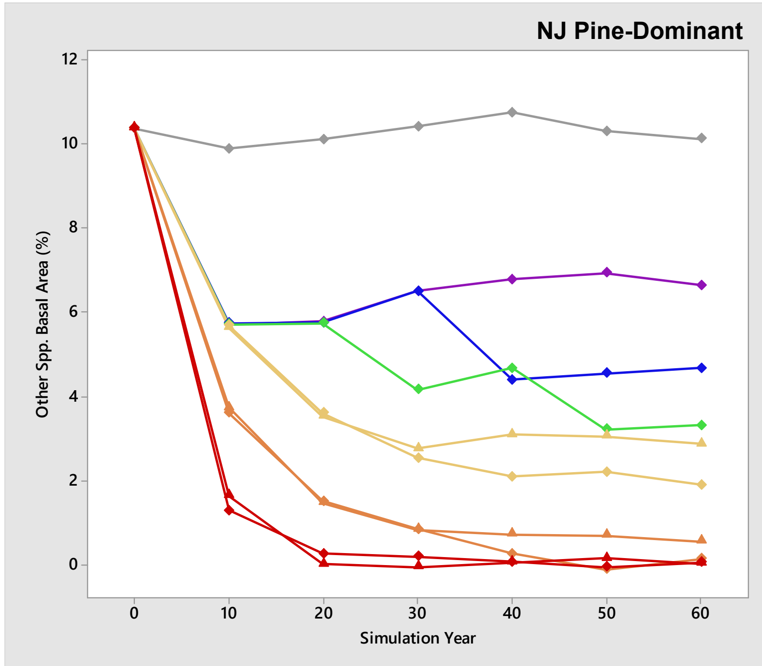
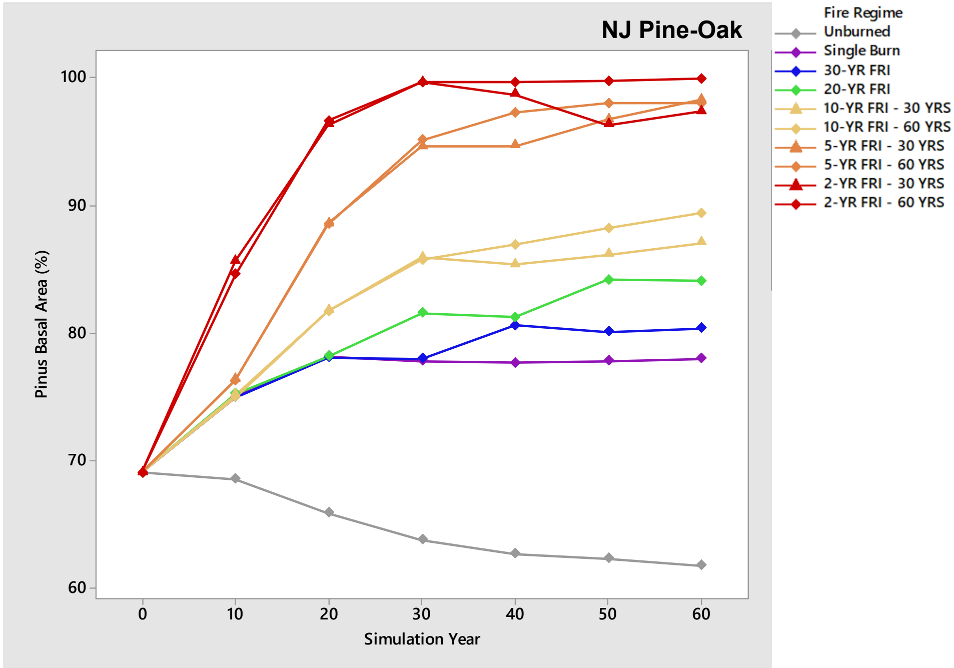
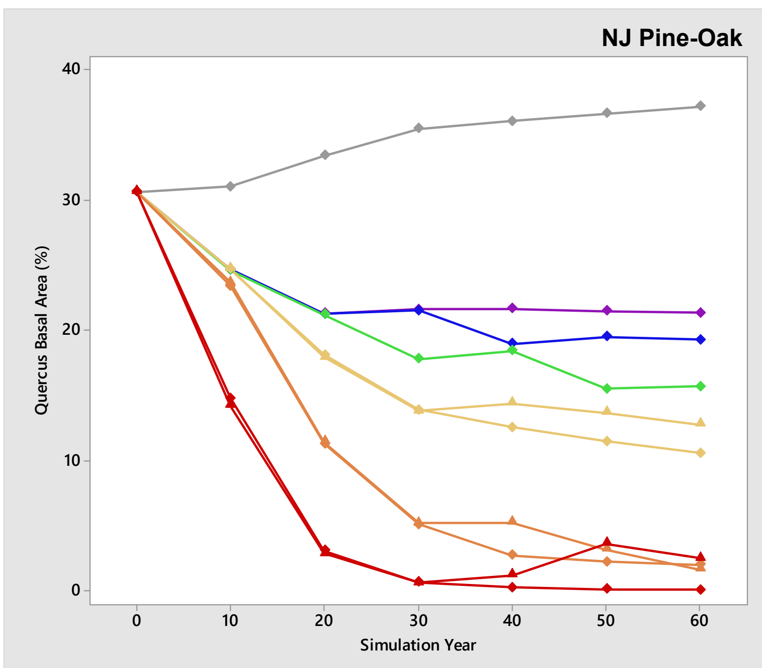


Figure 4.5. Projected changes in relative BA over 60 years for pines (*Pinus* spp.), oaks (*Quercus* spp.), and non-pine and non-oak species for the NJ pine-dominant forest group with different fire regime treatments, based upon weighted means among the constituent stands. Standard deviation among replicates was 0.0-0.7% across all means. Corresponding total BA values (m^2 ha^{-1}) are included in Appendix Table 3.

For NJ pine-oak at year 30, pine BA was highest with two-year and five-year FRIs, at 100% and ~95%, respectively, and was by far the lowest with unburned at 64% while being above 75% with all other treatments; oak BA was by far the highest with unburned at 35%, was below 10% with five-year and two-year FRIs, including below 1% with two-year FRI, and was between 10% and 25% with all other treatments; BA for other species, which was an extremely small initial component of this forest class, remained at or below 1% with all treatments. At year 60, pine BA exceeded 97% and was by far the highest with both two-year and five-year FRIs of both 60-year and 30-year regime durations, and was by far the lowest with unburned at 62%, while being between 75% and 90% with the remaining treatments; oak BA was by far the highest with unburned at 37%, was below 3% with both two-year and five-year FRIs of both 60-year and 30-year regime durations, being at ~0% with 2-60, and was between 10% and 25% with all other treatments; BA for other species was highest with unburned and single burn at 1%, and was ~0% with all other treatments (Figure 4.6).


NJ Pine-Oak
Pinus Basal Area (%)
100
90
80
70
60
0
10
20
30
40
50
60
Simulation Year
Fire Regime
Unburned
Single Burn
30-YR FRI
20-YR FRI
10-YR FRI - 30 YRS
10-YR FRI - 60 YRS
5-YR FRI - 30 YRS
5-YR FRI - 60 YRS
2-YR FRI - 30 YRS
2-YR FRI - 60 YRS


NJ Pine-Oak
Quercus Basal Area (%)
40
30
20
10
0
0
10
20
30
40
50
60
Simulation Year

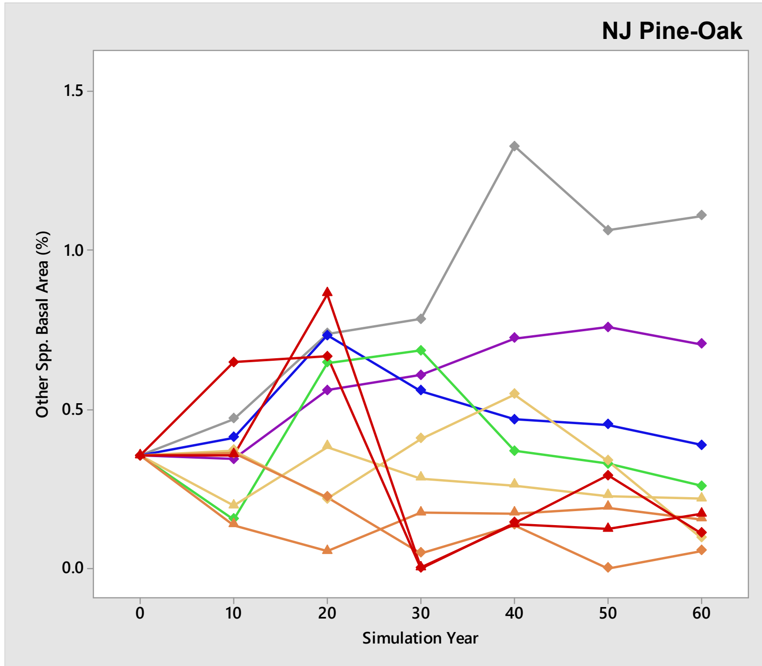
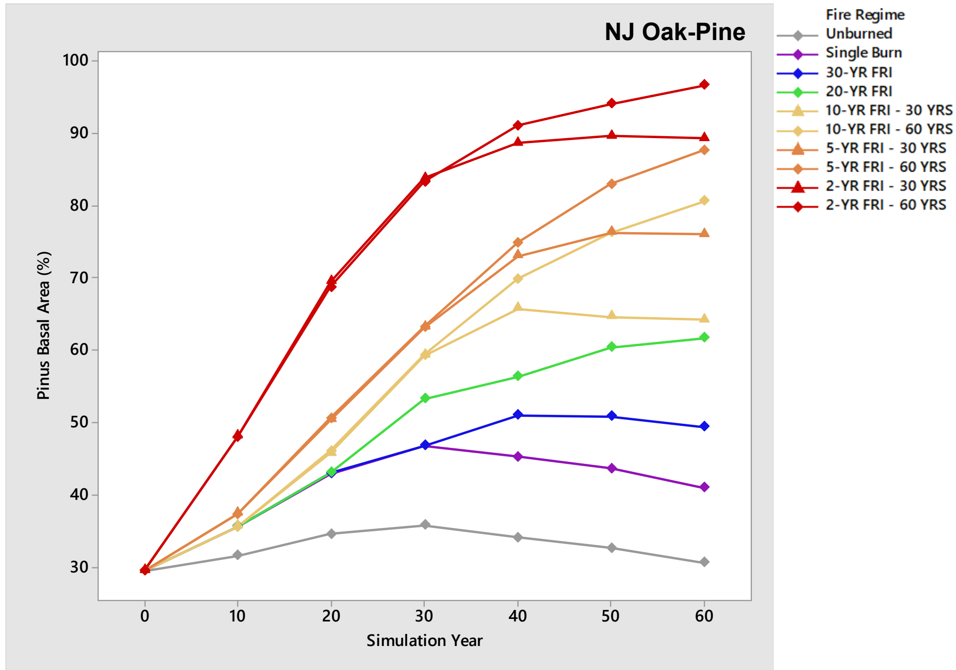
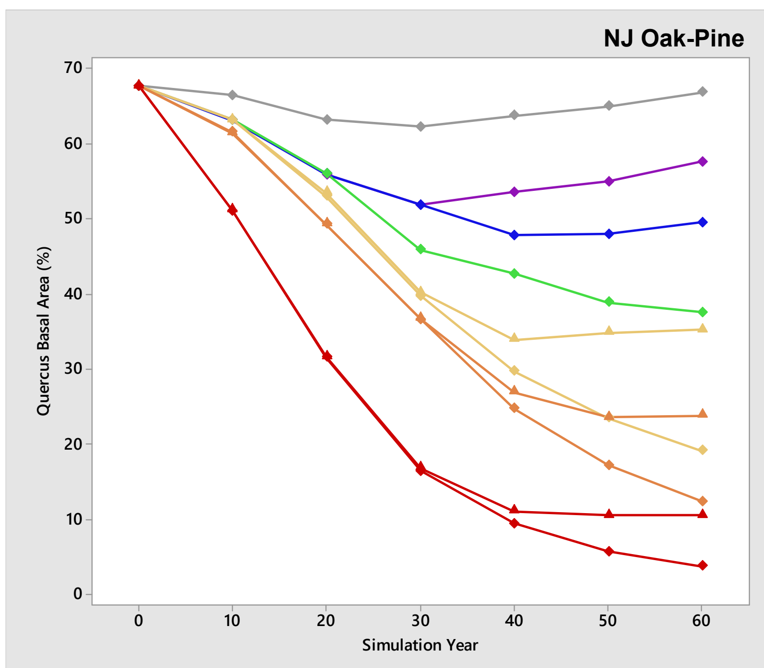


Figure 4.6. Projected changes in relative BA over 60 years for pines (*Pinus* spp.), oaks (*Quercus* spp.), and non-pine and non-oak species for the NJ pine-oak forest stand, with different fire regime treatments. Standard deviation among replicates was 0.0-1.2% across all means. Corresponding total BA values (m^2 ha^{-1}) are included in Appendix Table 3.

For NJ oak-pine at year 30, pine BA was highest with two-year FRI at ~83%, lowest with unburned at 36%, and between 45% and 65% with all other treatments; oak BA was highest with unburned at 62%, was at ~52% with single burn and 30-year FRI, and was by far the lowest with two-year FRI at ~16%; BA for other species, which was a very small initial component of this forest class as well, was highest with unburned at 2%, was at ~1% with single burn and 30-year FRI, and was below 1% with all other treatments. At year 60, pine BA was highest with 2-60 at 97%, 2-30 at 89%, and 5-60 at 88%, was at 81% with 10-60 and at 76% with 5-30, was lowest with unburned at 31%, and was between 40% and 65% with the other treatments; oak BA was highest with unburned at 67%, single burn at 58%, and 30-year FRI at 50%, and lowest with 2-60 at 4%, 2-30 at 11%, and 5-60 at 12%; BA for other species was highest with unburned at 3%, was at 2% with single burn and at 1% with 30-year FRI, and was below 1% with all other treatments (Figure 4.7).


NJ Oak-Pine
Pinus Basal Area (%)
Simulation Year
Fire Regime
Unburned
Single Burn
30-YR FRI
20-YR FRI
10-YR FRI - 30 YRS
10-YR FRI - 60 YRS
5-YR FRI - 30 YRS
5-YR FRI - 60 YRS
2-YR FRI - 30 YRS
2-YR FRI - 60 YRS


NJ Oak-Pine
Quercus Basal Area (%)
Simulation Year

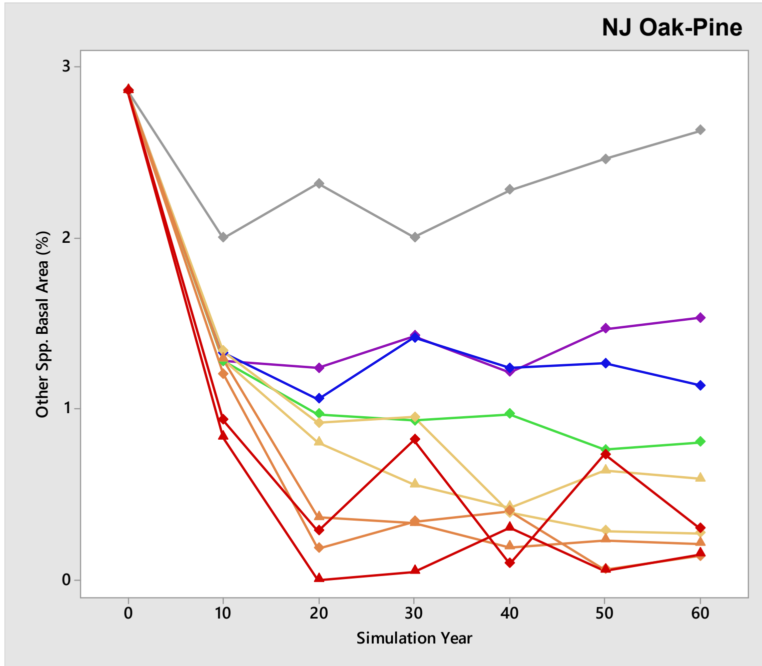
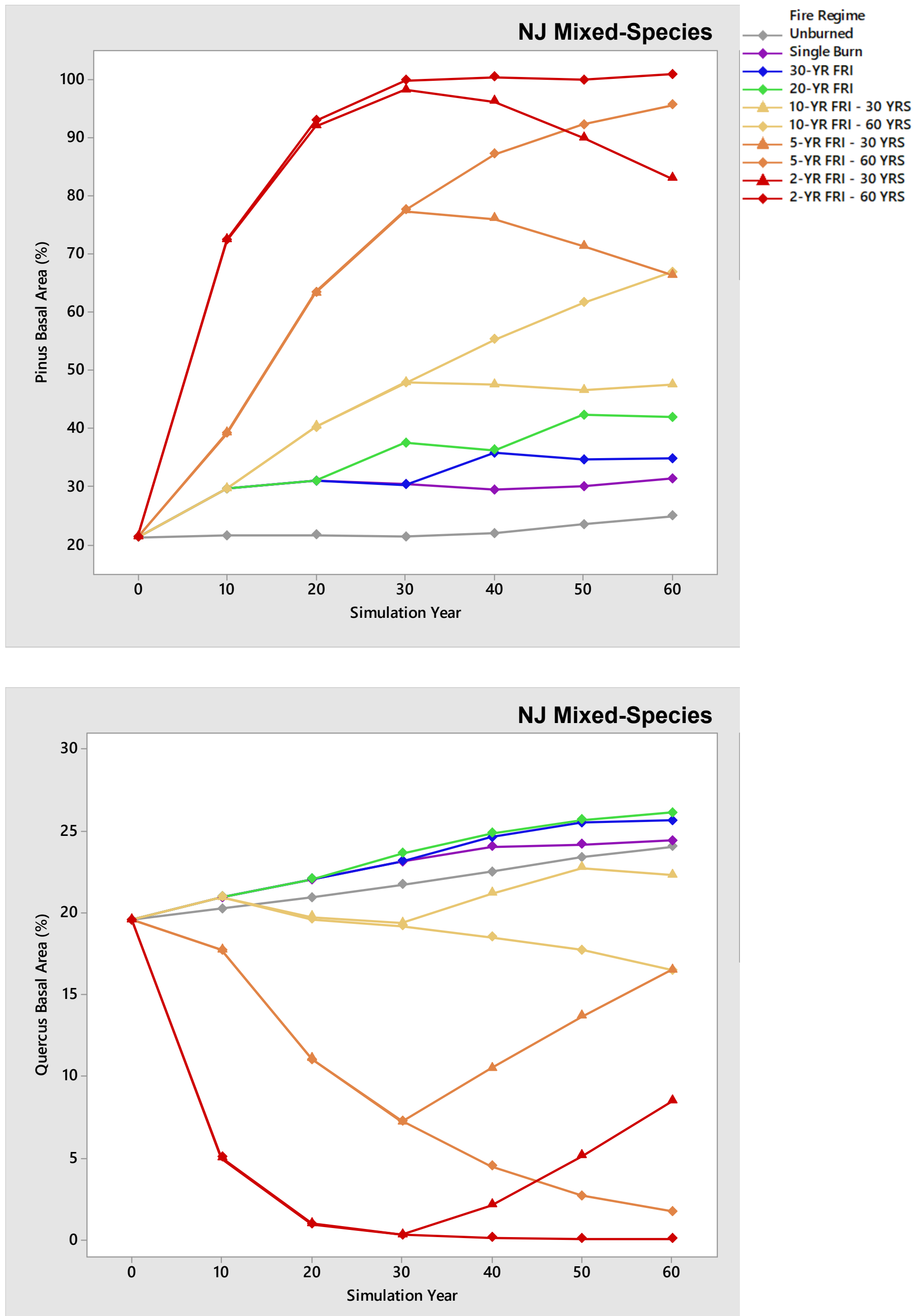


Figure 4.7. Projected changes in relative BA over 60 years for pines (*Pinus* spp.), oaks (*Quercus* spp.), and non-pine and non-oak species for the NJ oak-pine forest stand, with different fire regime treatments. Standard deviation among replicates was 0.0-2.9% across all means. Corresponding total BA values (m^2 ha^{-1}) are included in Appendix Table 3.

For NJ mixed-species at year 30, pine BA was highest with two-year and five-year FRIs, at ~99% and ~77%, respectively, and was below 50% with all other treatments, including being lowest with unburned at 21%; oak BA was between 19% and 24% with all treatments except for five-year and two-year FRIs, being highest with 20-year FRI at 24%, and was below 10% with five-year and two-year FRIs, including below 1% with two-year FRI; BA for other species was highest with unburned at 57%, was at 47% with single burn and 30-year FRI, and was below 40% with all other treatments, including below 20% with five-year and two-year FRIs and being lowest with two-year FRI at ~1%. At year 60, pine BA was highest with 2-60 and 5-60, at 100% and 96% respectively, was at 83% with 2-30 and at ~66% with 5-30 and 10-60, and was below 50% with all other treatments, including being lowest with unburned at 25%; oak BA was above 20% with unburned, single burn, 30-year FRI, 20-year FRI, and 10-year FRI over 30 years (hereafter referred to as 10-30), including being highest at ~26% with both 20-year FRI and 30-year FRI, was at ~17% with 5-30 and 10-60, and was below 10% with 2-30, 5-60, and 2-60, including being lowest with 2-60 at 0% and 5-60 at 2%; BA for other species was highest with unburned at 51% and was below 10% with 2-30, 5-60, and 2-60, including being lowest with 2-60 at 0% and 5-60 at 3% (Figure 4.8).



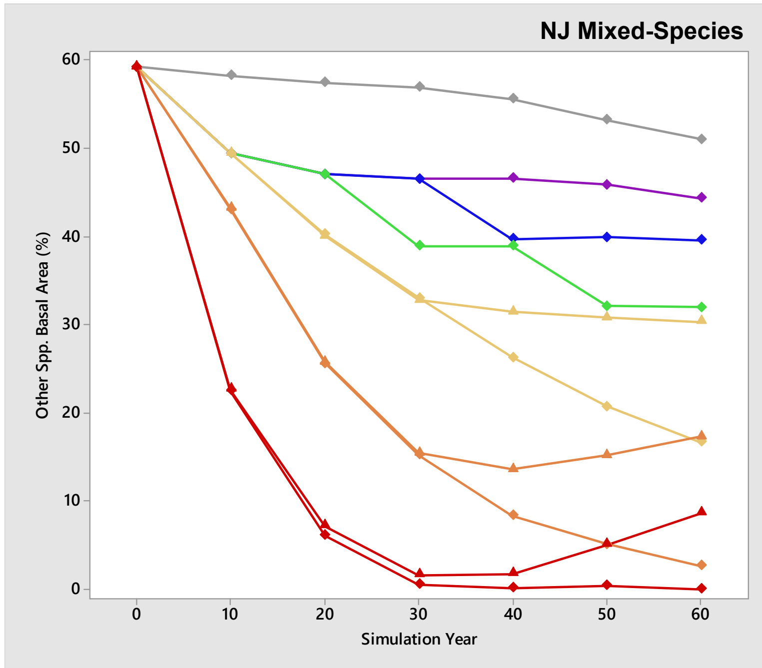


Figure 4.8. Projected changes in relative BA over 60 years for pines (*Pinus* spp.), oaks (*Quercus* spp.), and non-pine and non-oak species for the NJ mixed-species forest group with different fire regime treatments, based upon weighted means among the constituent stands. Standard deviation among replicates was 0.0-2.1% across all means. Corresponding total BA values (m^2 ha^{-1}) are included in Appendix Table 3.

Overall, the relative BA proportion for pine was directly and positively related to the presence and recurrence of fire, and increased both with shorter FRIs and with a longer period of fire application. Conversely, the relative BA proportion for non-pine and non-oak species, comprised mainly of other hardwood species, was also directly, but negatively, related to the presence and recurrence of fire, and decreased with shorter FRIs and a longer period of fire application. Higher variability was observed for the relative BA proportion for oak among the forest classes with the different fire regimes. In general, in PA, greater relative BA proportions for oaks persisted with short to intermediate FRIs, depending on the forest type, and a longer period of fire application. However, relative to other treatment scenarios, high-frequency fire regimes, characterized by short FRIs, increased relative BA of oaks in the mixed-oak and mixed-species forest types. In contrast, application of the same high-frequency fire regimes over 60 years decreased relative BA of oaks, relative to other treatment scenarios, in the oak-dominant and oak-pine forest types that were characterized by greater relative BA of pyrophilic pines, namely *Pinus rigida* (pitch pine). For these forest types, greater relative BA proportions for oaks were maintained with less frequent burning, at intermediate to longer FRIs, with shorter FRIs promoting pine establishment. Unburned and single burn scenarios resulted in relatively low oak BA over the long-term for PA forest types. In NJ, by contrast, greater BA proportions for oaks were maintained with less fire, and oak BA remained relatively high in unburned scenarios, in comparison to burned scenarios. Oak BA decreased with presence and recurrence of fire, and with shorter FRIs and a longer period of fire application. Relative to other treatment scenarios, infrequent burning at longer FRIs resulted in increased relative BA of oaks in the mixed-species forest type that was characterized by a very high proportion of more pyrophobic species.

Species Composition

I. Forest Classes

A. Basal Area

For PA oak-dominant as a group, the unburned treatment resulted in *Quercus montana* remaining as the most dominant species over time, although *Acer rubrum* increased in relative BA over time. Oaks generally remained prominent in relative BA with fire presence and recurrence, and remained most dominant with long to intermediate FRI and a longer period of fire application. *Pinus rigida*, when present, increased considerably in relative BA with shorter FRIs and a longer period of fire application, while other species decreased in relative BA with fire presence and recurrence (Appendix Table 4).

For PA mixed-oak as a group, the unburned treatment resulted in *A. rubrum* increasing in relative BA over time, and slight decreases in the relative BA of individual oak species over time. Oak dominance was facilitated by the presence and recurrence of fire, and oaks increased in relative BA dominance with long to intermediate FRI and a longer period of fire application. Other hardwoods such as *A. rubrum* decreased with shorter FRIs and a longer period of fire application. Pines, when present, increased in relative BA with shorter FRIs and a longer period of fire application (Appendix Table 4).

For PA mixed-species as a group, the unburned treatment resulted in the increased BA dominance over time of non-oak hardwoods such as *A. rubrum* and *Prunus serotina*, and either no change or slight decreases in the relative BA of individual oak species over time. Oak BA persistence was facilitated by the presence and recurrence of fire, and relative BA dominance increased with intermediate to short FRIs and a longer period of fire application. *Populus* spp., *P. serotina*, and *Sassafras albidum*, when present, could remain or become dominant over oaks with long to intermediate FRIs, or with a shorter period of fire application. *P. rigida*, when present, increased in relative BA with shorter FRIs and a longer period of fire application (Appendix Table 4).

For PA oak-pine, the unburned treatment resulted in *Q. montana* remaining as the most dominant species over time, with *A. rubrum* increasing in relative BA while *Nyssa sylvatica* dropping from the top four species by year 60, and *P. rigida* relative BA decreasing slightly over time. *P. rigida* increased in relative BA with shorter FRIs and a longer period of fire application, and considerably so with intermediate to short FRIs coupled with a longer period of fire application. Oak primary dominance and *P. rigida* secondary dominance together was facilitated with somewhat long to intermediate FRIs and a longer period of fire application, or with burning as frequently as every five years with a shorter period of fire application; *P. rigida* became dominant over oaks with short FRIs and a longer period of fire application. *N. sylvatica* decreased in relative BA with increasing fire frequency and a longer period of fire application, but could re-establish with a shorter period of fire application, even with shorter FRIs (Appendix Table 4).

For NJ pine-dominant as a group, the unburned treatment resulted in *P. rigida* still remaining as the dominant species over time, with *A. rubrum* and *N. sylvatica* increasing somewhat in relative BA over time; *Chamaecyparis thyoides*, when present, decreased in relative BA over time. In all treatment scenarios, *P. rigida* remained as the most dominant species, increasing in relative BA with more frequent burning and with a longer period of fire application. Other species, including oaks and *C. thyoides* when present, decreased in relative BA with more frequent burning and with a longer period of fire application as a consequence of the increasing relative BA of *P. rigida*. Oak species did surpass *A. rubrum* in relative BA with intermediate and short FRIs and a longer period of fire application. Other *Pinus* species such as *P. serotina* and *P. virginiana*, when present, increased in relative BA with short FRIs and with a longer period of fire application, surpassing the relative BA of oak species. Intermediate to short FRIs resulted in nearly or completely pure pine BA by year 30, whereas *A. rubrum* and *N. sylvatica* increased somewhat in relative BA with less fire (Appendix Table 4).

For NJ pine-oak, the unburned treatment resulted in *P. rigida* remaining as the dominant species over time, with a decrease in the relative BA of *P. echinata* by year 60 to approximately equivalent to that of *Q. velutina*. In all treatment scenarios, *P. rigida* remained as the most dominant species, with increasing relative BA with more frequent burning and with a longer period of fire application. The relative BA of oak decreased even with infrequent burning at long FRIs, as a consequence of increasing relative BA of pine; the relative BA of oak nearly or completely disappeared with short FRIs, and experienced greater decrease with a longer period of fire application in comparison to a shorter period of fire application. Short FRIs resulted in nearly or completely pure pine BA, with oak BA nearly or completely excluded without re-establishment (Appendix Table 4).

For NJ oak-pine, the unburned treatment resulted in a BA composition profile at year 60 that was similar to that at initial inventory, although the relative BA of *P. echinata* increased by year 30, and subsequently decreased to roughly the initial proportion by year 60. The relative BA of both *P. echinata* and *P. rigida* increased with fire presence and recurrence, especially for the latter species, with subsequent decrease in oak relative BA. Pine species surpassed oak species in relative BA even with infrequent burning at long FRIs, although a small BA component of oak was maintained with infrequent burning. Pine BA dominance increased considerably by year 60 with intermediate FRIs, and by year 30 with short FRIs, as well as with a longer period of fire application in general; *P. rigida* became heavily dominant by year 60 with very frequent burning at short FRIs, and with a longer period of fire application (Appendix Table 4).

For NJ mixed-species as a group, the unburned treatment resulted in an increase in relative BA of *A. rubrum*, a decrease for *C. thyoides* when present, persistence or increase for *P. rigida*, and a slight increase for oak species when present. The relative BA of both *P. rigida* and oak species was facilitated by the presence and recurrence of fire, and could eventually surpass that of *A. rubrum* and other fire-sensitive species, even with infrequent burning at long FRIs; *A. rubrum* decreased in relative BA with increasing fire occurrence. Greater relative BA for pine was attained with shorter FRIs and with a longer period of fire application, but pine BA could also persist after burning had ceased under the shorter regime. Although the process is dependent on the individual stand and corresponding initial BA compositions, pine species, followed by oak species when present, could attain considerable BA dominance with long to intermediate FRIs, with pyrophobic species subsequently disappearing (Appendix Table 4).

B. Tree Density/Abundance

For PA oak-dominant as a group, the unburned treatment resulted in an increase in the relative density of *A. rubrum* to the point it became the most abundant species, surpassing relative abundances of individual oak species and of other hardwoods. *Q. montana* remained more abundant than other hardwood species with recurrent burning, particularly at short FRIs and with a longer period of fire application whenever *A. rubrum* was also abundant. *A. rubrum* persisted over time with long to intermediate FRIs, if initial density was high relative to oaks and other species. *N. sylvatica*, when present, surpassed *A. rubrum* in relative abundance with intermediate to short FRIs and a longer period of fire application. Relative abundance of *S. albidum*, when present, was also facilitated by the presence and recurrence of fire (Appendix Table 5).

For PA mixed-oak as a group, the unburned treatment resulted in the persistence of, or increase in, relative abundance of *A. rubrum* over other species over time, and also the increase in relative abundance of *A. pensylvanicum* over time. With burning, *A. rubrum* generally persisted in high relative abundance, although relative abundance decreased sharply with short FRIs and with a longer period of fire application. Oak species, which increased in relative abundance with more burning, equaled or surpassed *A. rubrum* in relative abundance with short FRIs and with a longer period of fire application. Relative abundances of oaks surpassed those of other hardwood species, such as *Acer* spp., *Fagus grandifolia*, and *S. albidum*, with short FRIs and a longer period of fire application. Relative abundance of *S. albidum* was also facilitated by the presence and recurrence of fire, especially with long to intermediate FRIs and a longer period of fire application (Appendix Table 5).

For PA mixed-species as a group, the unburned treatment resulted in increased relative abundances for *A. rubrum* and *P. serotina*, and reinforced dominance of these species over oaks and other hardwoods such as *F. grandifolia*, *Populus grandidentata*, and *N. sylvatica*. Relative abundances of oak species could fluctuate, but generally decreased over time. The presence and recurrence of fire facilitated the relative abundance of *Betula lenta*, and fire recurrence maintained the relative abundance of *P. serotina* over those of other species. Relative abundance of *S. albidum*, when present, was facilitated by the presence and recurrence of fire, and it surpassed those of other species such as *A. rubrum* and *N. sylvatica* with shorter FRIs and a longer period of fire application. Relative abundances of oak species increased with shorter FRIs and with a longer period of fire application, particularly with two-year FRI coupled with a longer period of fire application; however, oaks remained dominated by multiple non-oak hardwood species under most treatment scenarios for this forest type (Appendix Table 5).

For PA oak-pine, the unburned treatment resulted in the sharp decrease in relative abundance of *N. sylvatica* over time, while that of *A. rubrum* increased; *A. rubrum* had surpassed *N. sylvatica* in relative abundance by year 60. *Q. montana* increased in relative abundance over time with no burning. However, *N. sylvatica* persisted as the most abundant species with 20-year and 10-year FRIs; *A. rubrum* became the second-most abundant species with these FRIs, surpassing individual oak species by a small margin. Oak species increased in relative abundance with frequent fire; *Q. montana* surpassed other species, including *N. sylvatica* and *A. rubrum*, in relative abundance with short FRIs and a longer period of fire application (Appendix Table 5).

For NJ pine-dominant as a group, the unburned treatment resulted in *P. rigida* still remaining as the most abundant species in the long-term, although with temporary short-term increase and dominance of miscellaneous *Quercus* spp. (likely *Q. ilicifolia*) at year 30. The relative dominance of *A. rubrum* increased, relative abundance of *C. thyoides* decreased when it was present, and relative abundance of oak eventually decreased over the long-term. *P. rigida* remained as the most abundant species in the long-term with all treatment scenarios, with relative abundance being highest with frequent burning at short FRIs. If *N. sylvatica* was present, *P. rigida* remained more abundant with a shorter period of fire application than with a longer period, due to increased abundance of *N. sylvatica* with prolonged burning at intermediate or short FRIs. Oak species such as *Q. ilicifolia* (categorized as "other oak" within the simulations) could increase in relative abundance by year 60 with a shorter period of fire application, resulting in lower relative abundance of pine by year 60, when *N. sylvatica* was not abundant (Appendix Table 5).

For NJ pine-oak, the unburned treatment resulted in oak species surpassing *P. rigida* and *P. echinata* in relative abundance by year 30; *P. rigida* and *P. echinata* maintained greater abundance over oaks, and also over *S. albidum*, with the presence and recurrence of fire (Appendix Table 5).

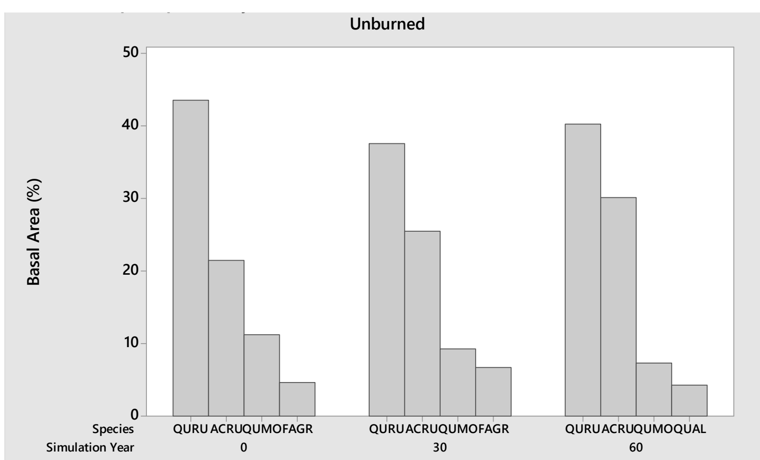
For NJ oak-pine, the unburned treatment resulted in *Q. montana* remaining as the most abundant species over the long-term, despite increased *P. echinata* abundance by year 30. *P. echinata* was also abundant relative to *P. rigida* and other oak species, with *P. rigida* decreasing in relative abundance over time. With burning, *P. echinata* became the most abundant species, and increased in relative abundance with shorter FRIs and with a longer period of fire application. *P. rigida* became the second-most abundant species, surpassing each individual oak species in relative abundance with 20-year FRI, but it never surpassed *P. echinata* in abundance. *P. rigida* decreased in relative abundance as *P. echinata* increased with shorter FRIs and a longer period of fire application (Appendix Table 5).

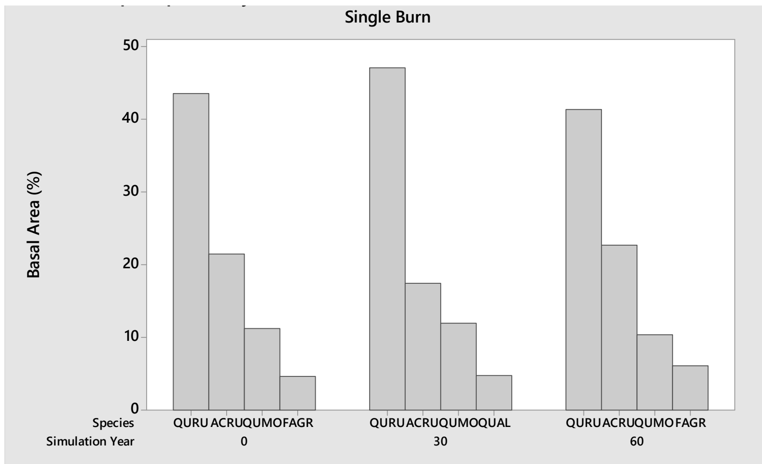
For NJ mixed-species as a group, the unburned treatment resulted in variation in the dominant species among the individual stands within the group; generally, *C. thyoides* and *N. sylvatica* decreased in relative abundance over time, whereas *A. rubrum* increased in relative abundance. *P. echinata* and *P. rigida*, when present, became or remained as the most abundant species with intermediate and short FRIs and with a longer period of fire application, followed by oak species if they were present; more fire-sensitive species such as *A. rubrum* and *C. thyoides* decreased in relative abundance with increased fire frequency and with a longer period of fire application. When neither pine species was present, *Q. montana* and *N. sylvatica* surpassed *A. rubrum* in relative abundance with short FRIs and a longer period of fire application, with *Q. montana* remaining more abundant than *N. sylvatica* by year 60 with a longer period of fire application. However, when oaks were not present and pines were present, *A. rubrum* was observed to persist in relative abundance over other non-pine species such as *N. sylvatica*. Ultimately, even given the same treatment scenarios and density measurement years, the top four most abundant species were nevertheless highly dependent on stand-specific characteristics for this highly-varied forest group (Appendix Table 5).

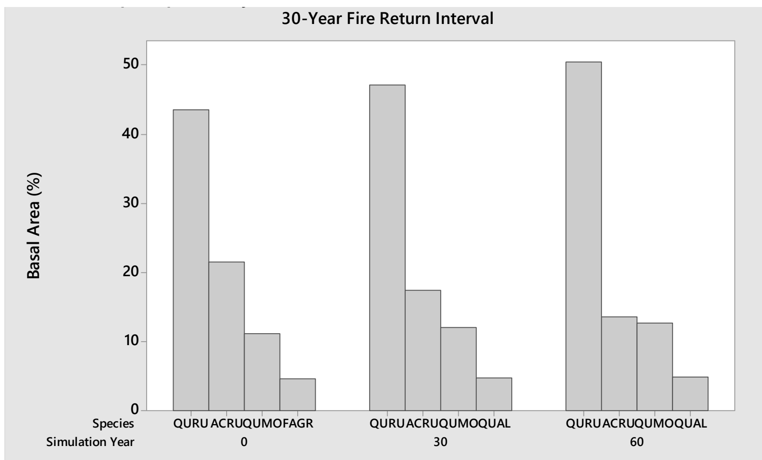
II. Individual Stand: PA Mixed-Oak

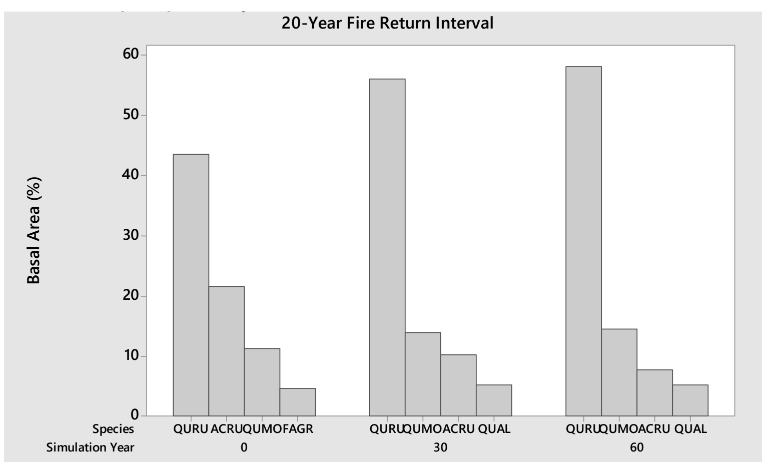
PA mixed-oak was by far the largest forest type of PA among the initial preliminary stands, and therefore represents a very large proportion of managed oak forests throughout PA. This section reports on the experimental outcomes that correspond specifically to one of the three experimental stands from this group (*Stand ID*: BOFCFI_ECOREG04I), characterized by an initial relative BA composition of 60% oak, 1% pine, and 39% other species. This particular stand was selected from the group on the basis of its medium-level BA proportions for both oak and other species, relative to the other two stands in the group, thereby yielding results that are better for potential extrapolation to other stands of this forest type. The numbers of inventory plots were similar among the three stands, and were thus not considered during selection. The reported results in this section ultimately provide a finer degree of detail in the form of species-level responses to the range of fire regime treatments tested for PA forests.

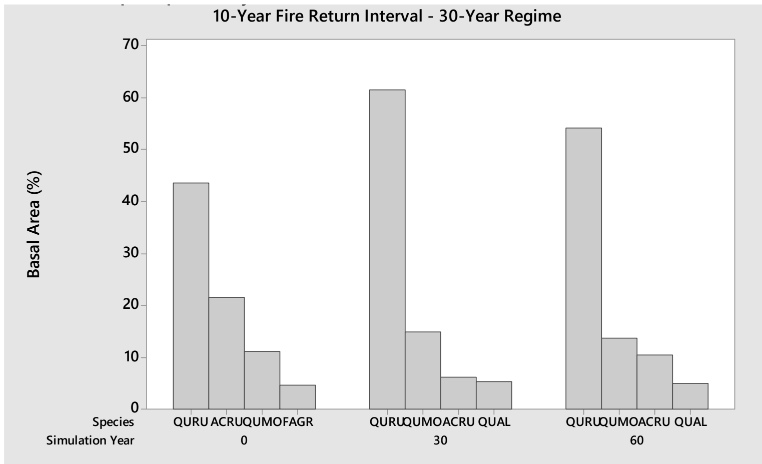
In terms of BA, the unburned treatment resulted in *Q. rubra* and *A. rubrum* remaining as the dominant species; relative BA of *A. rubrum* increased over time, while relative BA of *Q. montana* decreased slightly over time. *Q. rubra* remained the most dominant species over time in all treatment scenarios. Shorter FRIs facilitated oak BA dominance and decreased relative BA dominance of other hardwood species. For instance, *Q. montana* surpassed *A. rubrum* in relative BA to become the second-most dominant species by year 30 with FRIs of 20 years and shorter, and remained as the second-most dominant species through year 60. *Q. alba* surpassed *A. rubrum* in relative BA by year 60 with 10-60, and by year 30 with five-year and two-year FRIs, resulting in the top three most dominant species all being oak species. *A. rubrum* dropped from the top four species by year 30 with 5-60 and the two-year FRI treatments, although it re-established as the fourth-most dominant species by year 60 with 5-30. In addition, fire application over 60 years also facilitated oak BA dominance and decreased relative BA dominance of other hardwood species. For instance, *Q. alba* surpassed *A. rubrum* in relative BA by year 60 with 10-60, but not with 10-30; *Q. rubra* attained greater relative BA, and *Q. montana* attained slightly greater relative BA, by year 60 with 10-60, compared to 10-30; *Q. rubra* attained greater relative BA by year 60 with 5-60, compared to 5-30; and *F. grandifolia* surpassed *Q. alba* in relative BA by year 60 with 2-30, but not with 2-60 (Figure 4.9).

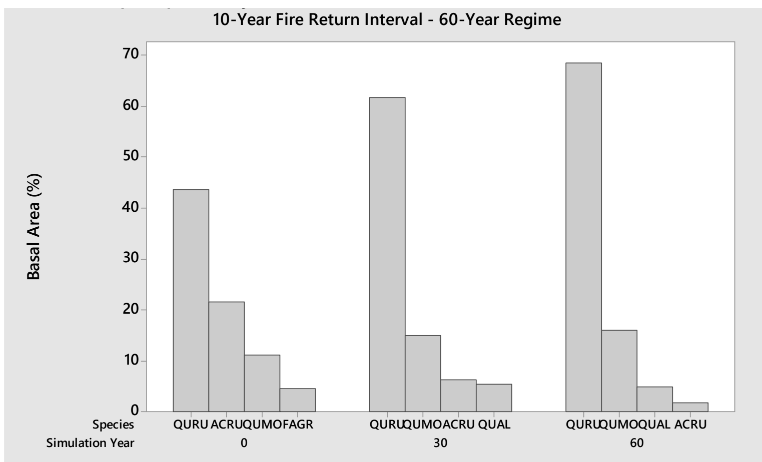


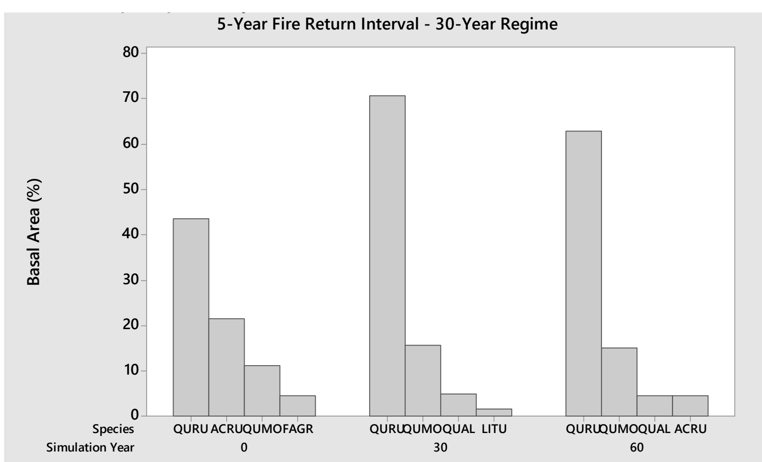

Single Burn
Basal Area (%)
50
40
30
20
10
0
Species
Simulation Year
QURU ACRU QUMO FAGR
0
QURU ACRU QUMO QUAL
30
QURU ACRU QUMO FAGR
60

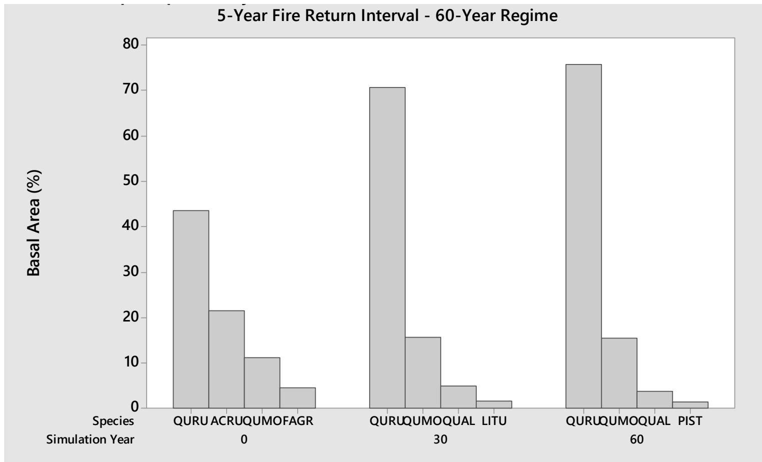

30-Year Fire Return Interval
Basal Area (%)
50
40
30
20
10
0
Species
Simulation Year
QURU ACRU QUMO FAGR
0
QURU ACRU QUMO QUAL
30
QURU ACRU QUMO QUAL
60


20-Year Fire Return Interval
Basal Area (%)
60
50
40
30
20
10
0
Species
Simulation Year
QURU ACRU QUMO FAGR
0
QURU QUMO ACRU QUAL
30
QURU QUMO ACRU QUAL
60

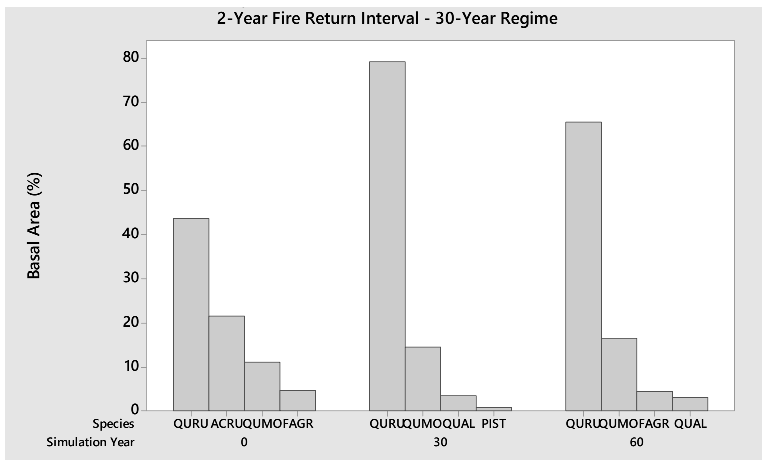

10-Year Fire Return Interval - 30-Year Regime
Basal Area (%)
70
60
50
40
30
20
10
0
Species
Simulation Year
QURU ACRU QUMO FAGR
0
QURU QUMO ACRU QUAL
30
QURU QUMO ACRU QUAL
60


10-Year Fire Return Interval - 60-Year Regime
Basal Area (%)
70
60
50
40
30
20
10
0
Species
Simulation Year
QURU ACRU QUMO FAGR
0
QURU QUMO ACRU QUAL
30
QURU QUMO QUAL ACRU
60

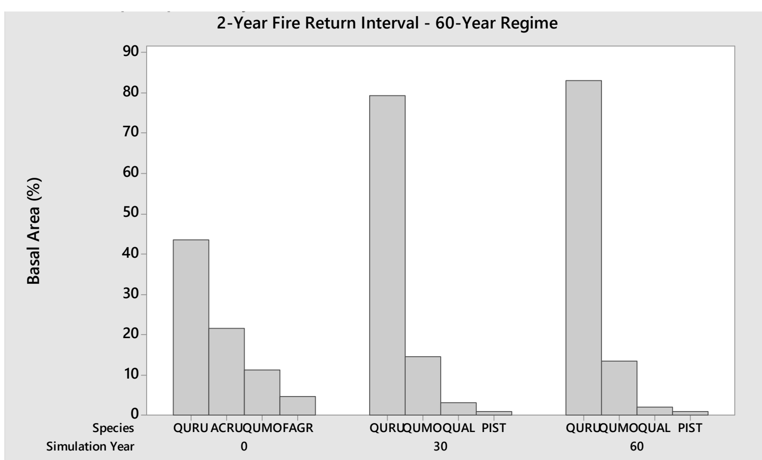

5-Year Fire Return Interval - 30-Year Regime
Basal Area (%)
80
70
60
50
40
30
20
10
0
Species
Simulation Year
QURU ACRU QUMO FAGR
0
QURU QUMO QUAL LITU
30
QURU QUMO QUAL ACRU
60



5-Year Fire Return Interval - 60-Year Regime
Basal Area (%)
Species
Simulation Year
QURU ACRU QUMO FAGR
QURU QUMO QUAL LITU
QURU QUMO QUAL PIST
0
30
60



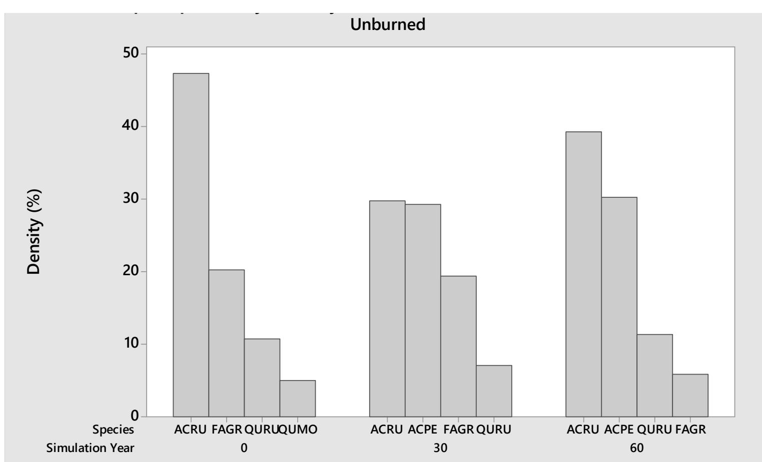
2-Year Fire Return Interval - 30-Year Regime
Basal Area (%)
Species
Simulation Year
QURU ACRU QUMO FAGR
QURU QUMO QUAL PIST
QURU QUMO FAGR QUAL
0
30
60

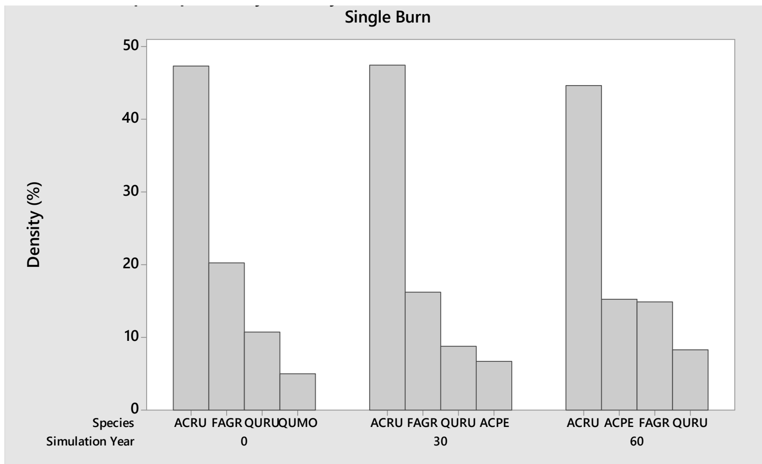


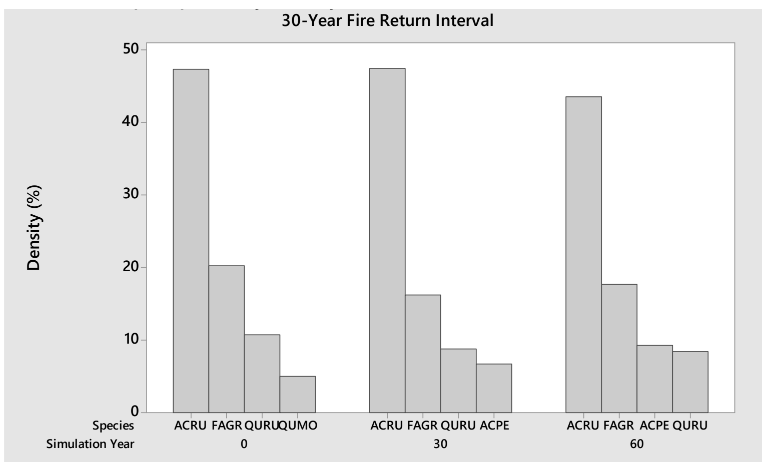
2-Year Fire Return Interval - 60-Year Regime
Basal Area (%)
Species
Simulation Year
QURU ACRU QUMO FAGR
QURU QUMO QUAL PIST
QURU QUMO QUAL PIST
0
30
60

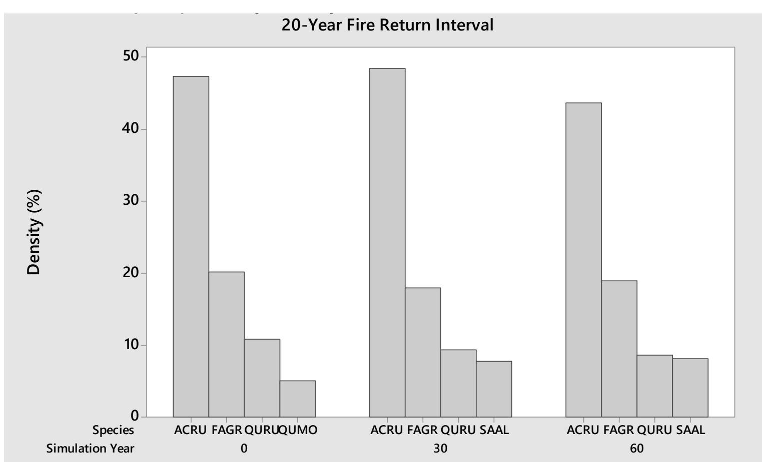
Figure 4.9. Top four most dominant species in terms of BA and corresponding BA proportions relative to total stand BA at initial inventory, year 30, and year 60 for an initial PA mixed-oak forest stand, with different fire regime treatments. Species are displayed using the corresponding United States Department of Agriculture (USDA) Natural Resources Conservation Service PLANTS symbols, with numbers omitted. Standard deviation among replicates was 0.0-0.5% across all means. In cases where the identified species differed within any of the four positions among the replicates, the greater-identified species, i.e. identified in two of the three replicates, was selected; in the very rare instance when each replicate projected a different species, species were selected to avoid overlap with the other species present within the set. Corresponding stand total BA values (m^2 ha^{-1}) are included in Appendix Table 4.

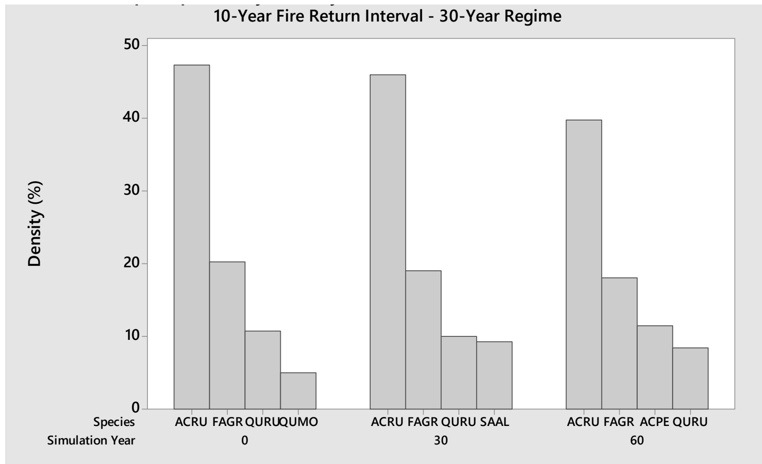
In terms of density/abundance, the unburned treatment resulted in *Acer* spp. becoming the most abundant over time, with the relative abundance of *Q. rubra* remaining fairly stable at ~10% of the total stand density, the relative abundance of *F. grandifolia* decreasing over time, including a drastic decline by year 60, and *Q. montana* dropping from the top four species by year 30. In most treatment scenarios, *A. rubrum* and *F. grandifolia* remained relatively abundant over time. Relative abundance of *A. rubrum* decreased over time with shorter FRIs and with a longer period of fire application; relative abundance of *F. grandifolia* remained fairly constant with most recurrent burn scenarios, i.e. burning at long and intermediate FRIs, but increased over time with 5-60 and drastically increased, followed by a drastic decrease, with two-year FRI over both 30-year and 60-year regime durations. Oak (*Q. montana*) abundance only surpassed those of the *Acer* spp. and *F. grandifolia* with 2-60 (Figure 4.10).

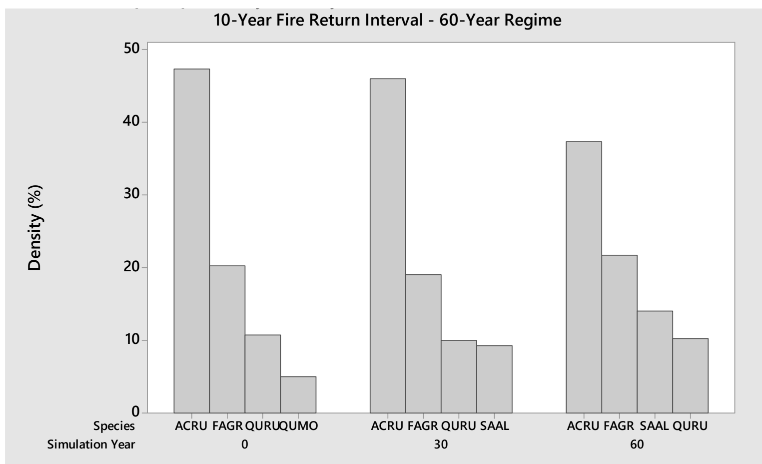


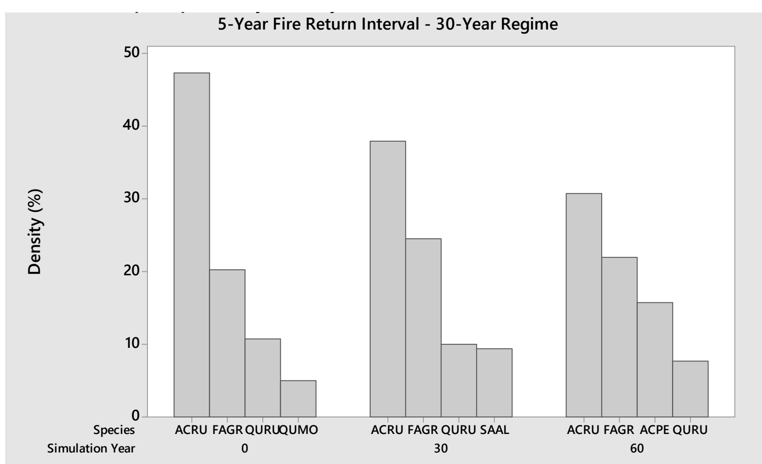

Single Burn
Density (%)
50
40
30
20
10
0
Species
Simulation Year
ACRU FAGR QURU QUMO
0
ACRU FAGR QURU ACPE
30
ACRU ACPE FAGR QURU
60

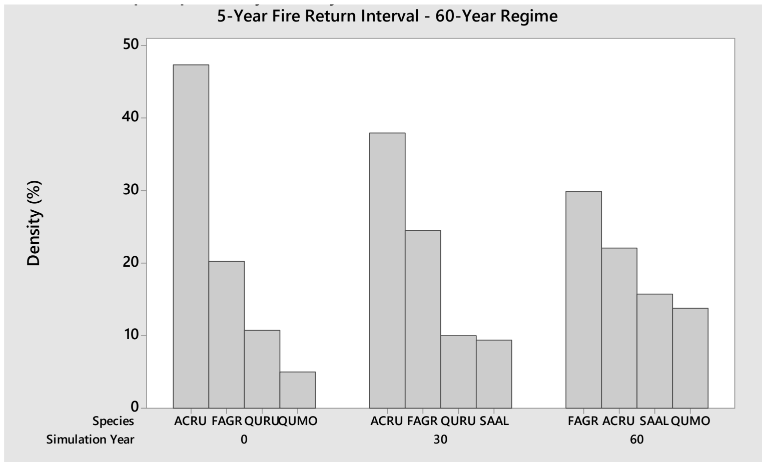

30-Year Fire Return Interval
Density (%)
50
40
30
20
10
0
Species
Simulation Year
ACRU FAGR QURU QUMO
0
ACRU FAGR QURU ACPE
30
ACRU FAGR ACPE QURU
60

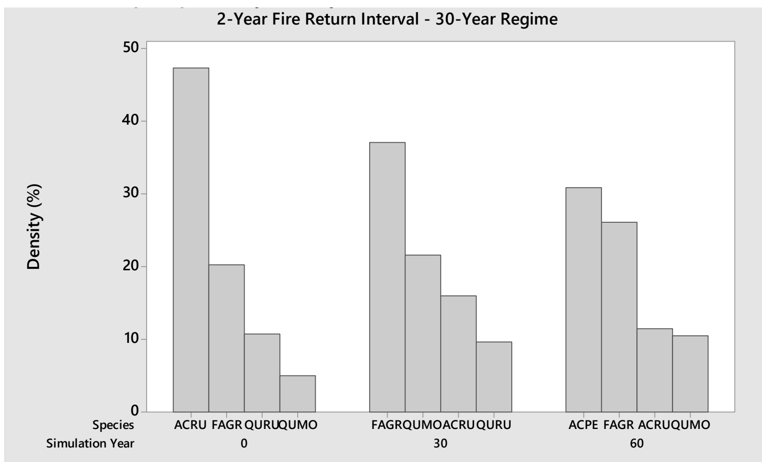

20-Year Fire Return Interval
Density (%)
50
40
30
20
10
0
Species
Simulation Year
ACRU FAGR QURU QUMO
0
ACRU FAGR QURU SAAL
30
ACRU FAGR QURU SAAL
60


10-Year Fire Return Interval - 30-Year Regime
Density (%)
0
10
20
30
40
50
Species
Simulation Year
ACRU FAGR QURU QUMO
0
ACRU FAGR QURU SAAL
30
ACRU FAGR ACPE QURU
60


10-Year Fire Return Interval - 60-Year Regime
Density (%)
0
10
20
30
40
50
Species
Simulation Year
ACRU FAGR QURU QUMO
0
ACRU FAGR QURU SAAL
30
ACRU FAGR SAAL QURU
60


5-Year Fire Return Interval - 30-Year Regime
Density (%)
0
10
20
30
40
50
Species
Simulation Year
ACRU FAGR QURU QUMO
0
ACRU FAGR QURU SAAL
30
ACRU FAGR ACPE QURU
60


5-Year Fire Return Interval - 60-Year Regime
Density (%)
50
40
30
20
10
0
Species
ACRU FAGR QURU QUMO
ACRU FAGR QURU SAAL
FAGR ACRU SAAL QUMO
Simulation Year
0
30
60


2-Year Fire Return Interval - 30-Year Regime
Density (%)
50
40
30
20
10
0
Species
ACRU FAGR QURU QUMO
FAGR QUMO ACRU QURU
ACPE FAGR ACRU QUMO
Simulation Year
0
30
60

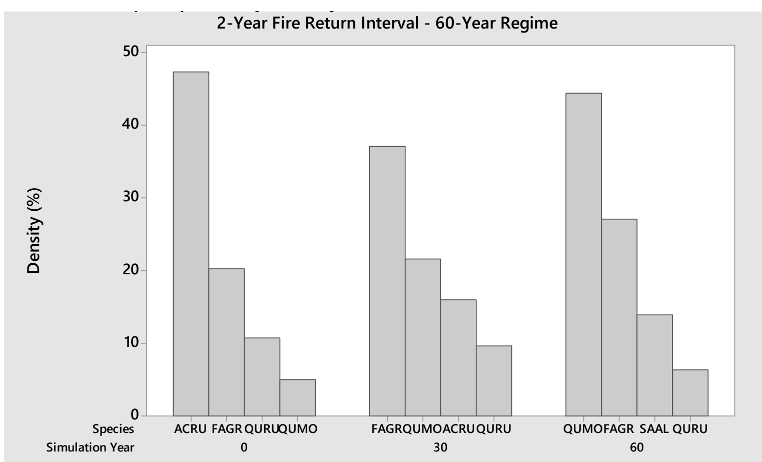
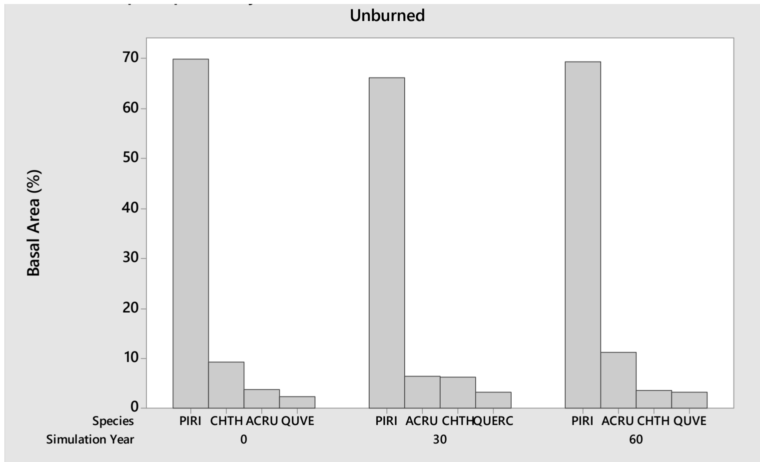

2-Year Fire Return Interval - 60-Year Regime
Density (%)
50
40
30
20
10
0
Species
ACRU FAGR QURU QUMO
FAGR QUMO ACRU QURU
QUMO FAGR SAAL QURU
Simulation Year
0
30
60

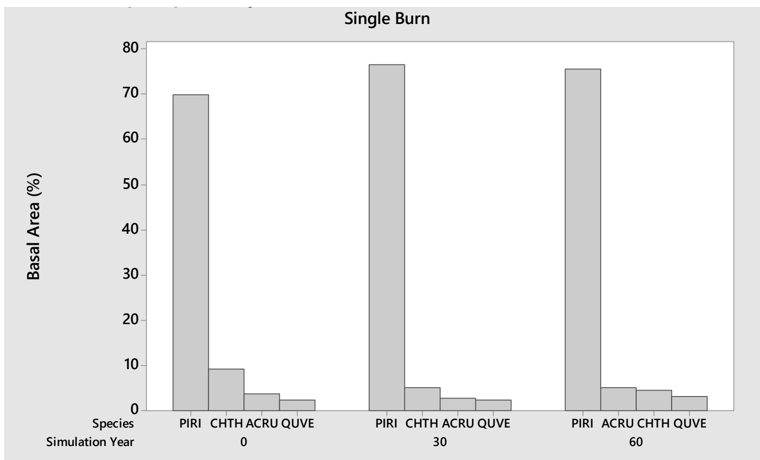
Figure 4.10. Top four most abundant species in terms of density and corresponding density proportions relative to total stand density at initial inventory, year 30, and year 60 for an initial PA mixed-oak forest stand, with different fire regime treatments. Species are displayed using the corresponding United States Department of Agriculture (USDA) Natural Resources Conservation Service PLANTS symbols, with numbers omitted. Standard deviation among replicates was 0.0-0.2% across all means. In cases where the identified species differed within any of the four positions among the replicates, the greater-identified species, i.e. identified in two of the three replicates, was selected; in the very rare instance when each replicate projected a different species, species were selected to avoid overlap with the other species present within the set. Corresponding stand total density values (trees ha^{-1}) are included in Appendix Table 5.

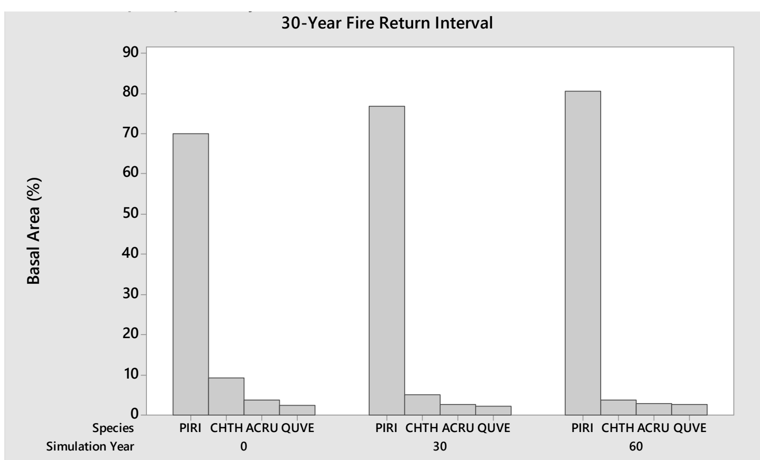
III. Individual Stand: NJ Pine-Dominant

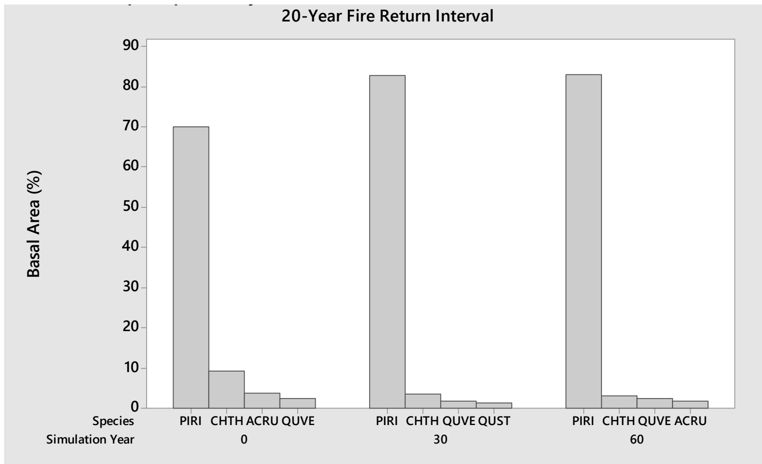
NJ pine-dominant was by far the largest forest type of the NJ Pine Barrens region among the initial preliminary stands, and therefore represents a very large proportion of the pitch pine forests that dominate this region. This section reports on the experimental outcomes that correspond specifically to one of the three experimental stands from this group (*Stand ID*: FIA_NJ_160), characterized by an initial relative BA composition of 73% pine, 10% oak, and 17% other species. This particular stand was selected from the group on the basis of its very strong relative weight in terms of number of inventory plots; this stand comprised 182 plots, compared to a combined total of 156 plots for the other two stands in the group. Consequently, this stand potentially better captured the natural variability that is present among the region's pitch pine forests. The reported results in this section ultimately provide a finer degree of detail in the form of species-level responses to the range of fire regime treatments tested for the forests of the NJ Pine Barrens.

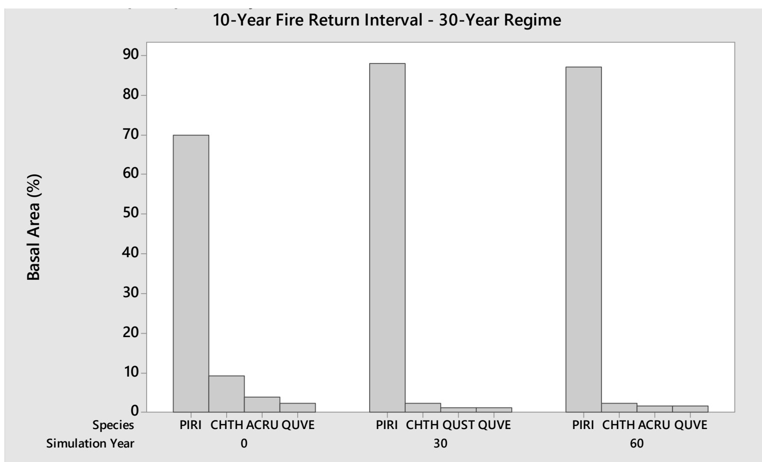
In terms of BA, the unburned treatment resulted in *P. rigida* still remaining as by far the most dominant species; the relative BA of *A. rubrum* increased over time and surpassed that of *C. thyoides* by year 30, while the relative BA of *C. thyoides* decreased over time. In all treatment scenarios, *P. rigida* remained as by far the most dominant species over time. Shorter FRIs increased pine BA dominance and decreased BA dominance of other species, including *C. thyoides* and hardwoods. Infrequent burning at long FRIs, and burning at intermediate FRIs over a shorter period, maintained the relative BA of *C. thyoides* over those of *A. rubrum* and oaks over the long-term. Oaks surpassed *A. rubrum* in relative BA with intermediate FRIs; pines surpassed oaks and the other species in relative BA with short FRIs, resulting in nearly or completely pure pine BA by year 60 with 5-60, and by year 30 with a two-year FRI. Pine BA dominance increased with a longer period of fire application, and BA dominance of other species subsequently decreased (Figure 4.11).

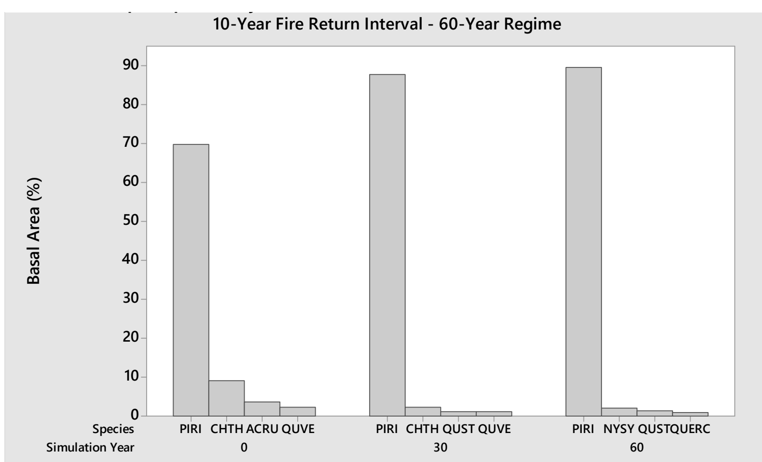

Unburned
Basal Area (%)
70
60
50
40
30
20
10
0
Species
Simulation Year
PIRI CHTH ACRU QUVE
0
PIRI ACRU CHTH QUERC
30
PIRI ACRU CHTH QUVE
60

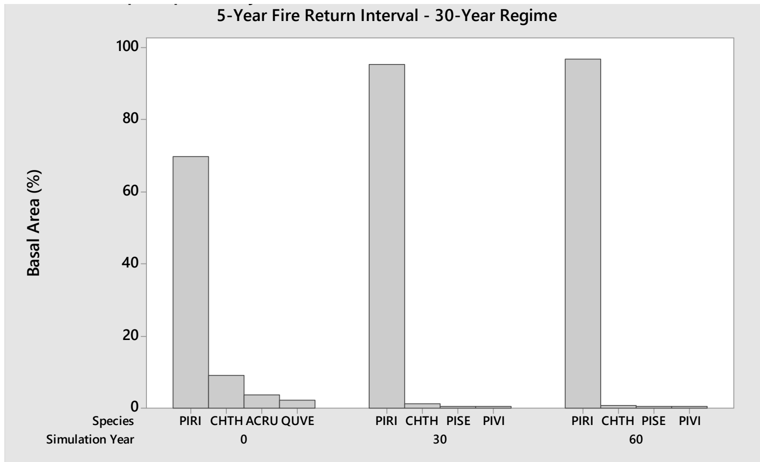

Single Burn
Basal Area (%)
80
70
60
50
40
30
20
10
0
Species
Simulation Year
PIRI CHTH ACRU QUVE
0
PIRI CHTH ACRU QUVE
30
PIRI ACRU CHTH QUVE
60

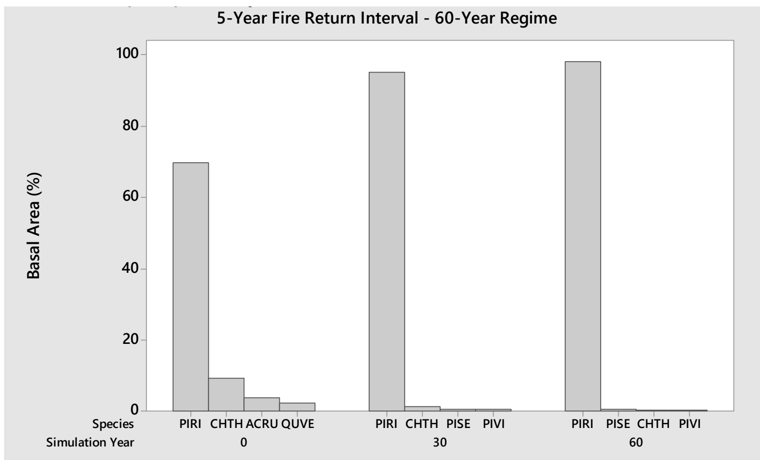

30-Year Fire Return Interval
Basal Area (%)
90
80
70
60
50
40
30
20
10
0
Species
Simulation Year
PIRI CHTH ACRU QUVE
0
PIRI CHTH ACRU QUVE
30
PIRI CHTH ACRU QUVE
60

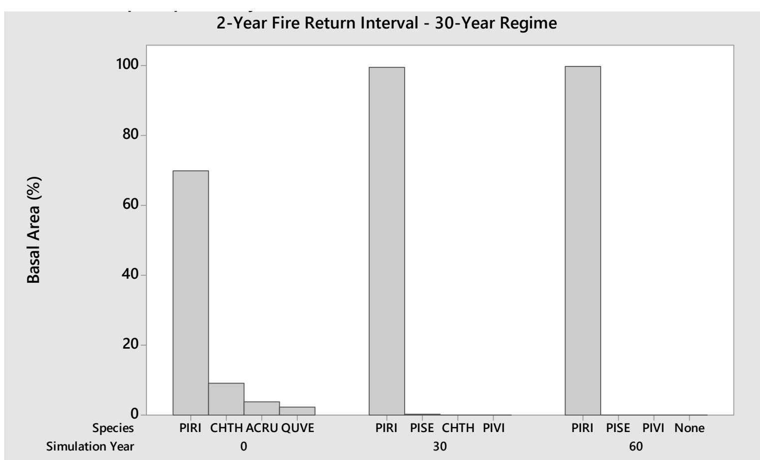

20-Year Fire Return Interval
Basal Area (%)
90
80
70
60
50
40
30
20
10
0
Species
PIRI CHTH ACRU QUVE
PIRI CHTH QUVE QUST
PIRI CHTH QUVE ACRU
Simulation Year
0
30
60


10-Year Fire Return Interval - 30-Year Regime
Basal Area (%)
90
80
70
60
50
40
30
20
10
0
Species
PIRI CHTH ACRU QUVE
PIRI CHTH QUST QUVE
PIRI CHTH ACRU QUVE
Simulation Year
0
30
60


10-Year Fire Return Interval - 60-Year Regime
Basal Area (%)
90
80
70
60
50
40
30
20
10
0
Species
PIRI CHTH ACRU QUVE
PIRI CHTH QUST QUVE
PIRI NYSY QUSTQUERC
Simulation Year
0
30
60


5-Year Fire Return Interval - 30-Year Regime
Basal Area (%)
Species
Simulation Year
PIRI CHTH ACRU QUVE
PIRI CHTH PISE PIVI
PIRI CHTH PISE PIVI
0
30
60


5-Year Fire Return Interval - 60-Year Regime
Basal Area (%)
Species
Simulation Year
PIRI CHTH ACRU QUVE
PIRI CHTH PISE PIVI
PIRI PISE CHTH PIVI
0
30
60


2-Year Fire Return Interval - 30-Year Regime
Basal Area (%)
Species
Simulation Year
PIRI CHTH ACRU QUVE
PIRI PISE CHTH PIVI
PIRI PISE PIVI None
0
30
60

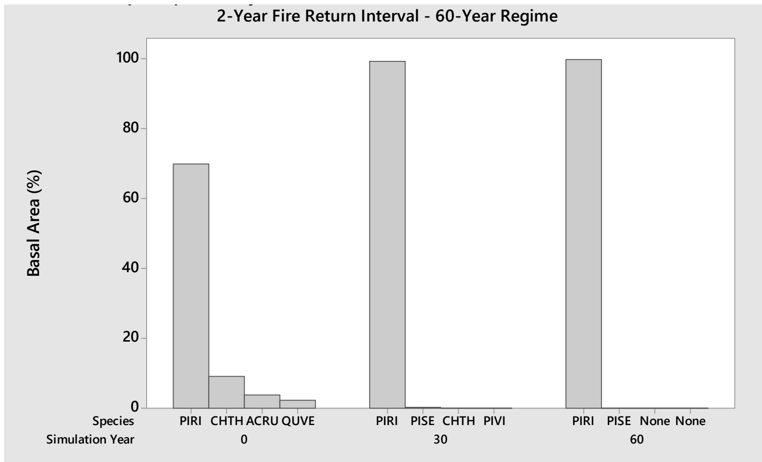
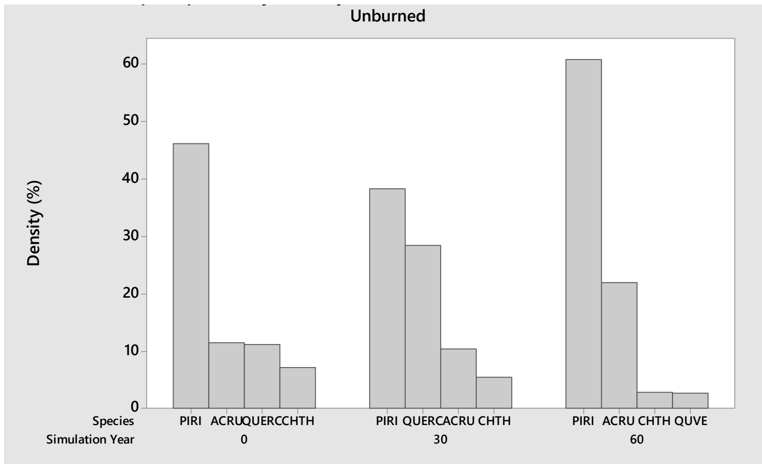
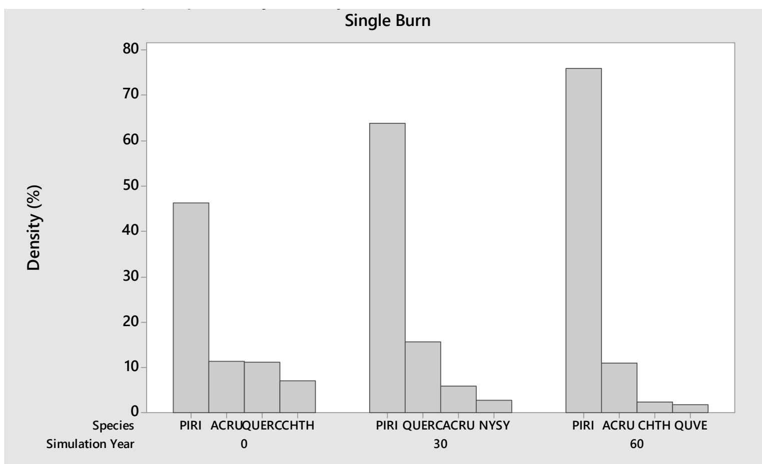
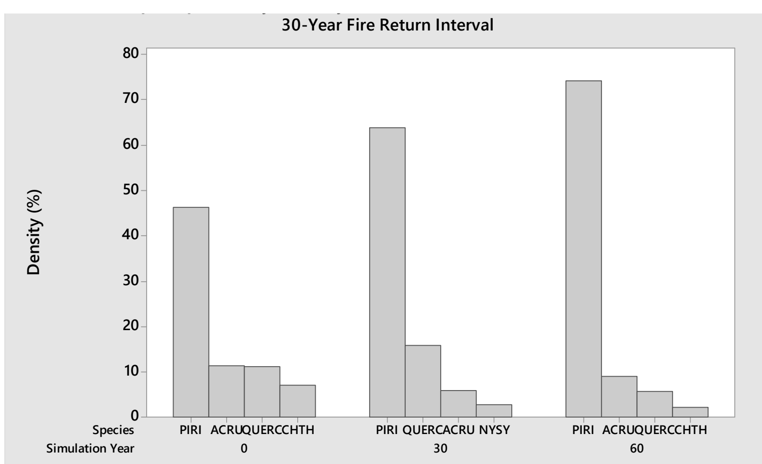


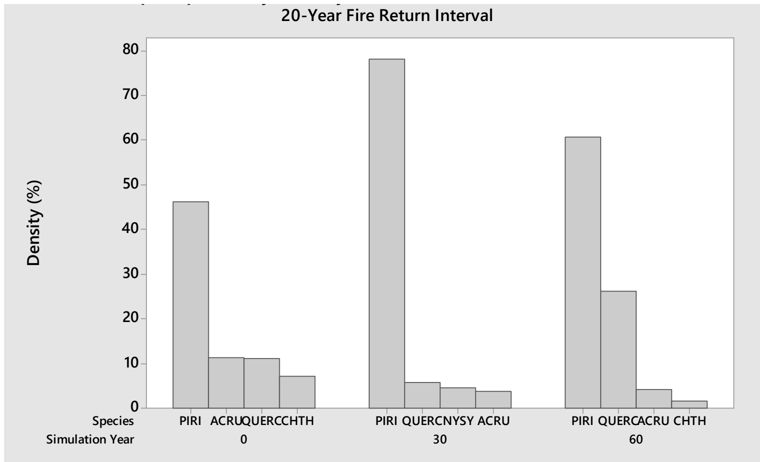
Figure 4.11. Top four most dominant species in terms of BA and corresponding BA proportions relative to total stand BA at initial inventory, year 30, and year 60 for an initial NJ pine-dominant forest stand, with different fire regime treatments. Species are displayed using the corresponding United States Department of Agriculture (USDA) Natural Resources Conservation Service PLANTS symbols, with numbers omitted. Standard deviation among replicates was 0.0-1.0% across all means. In cases where the identified species differed within any of the four positions among the replicates, the greater-identified species, i.e. identified in two of the three replicates, was selected; in the very rare instance when each replicate projected a different species, species were selected to avoid overlap with the other species present within the set. Corresponding stand total BA values (m^2 ha^{-1}) are included in Appendix Table 4.

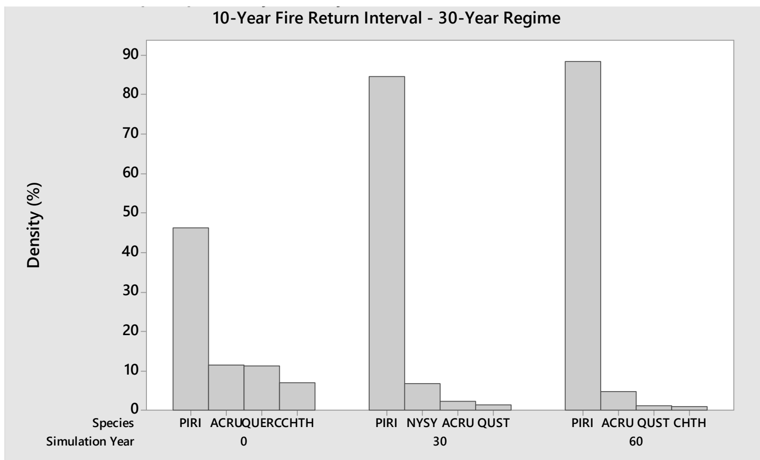
In terms of density/abundance, the unburned treatment resulted in *P. rigida* remaining as the most abundant species over time in all scenarios. By year 60 with the unburned treatment, *A. rubrum* had increased in relative abundance, oaks had drastically decreased in relative abundance, and *C. thyoides* had decreased in relative abundance as well. Relative abundance of oaks was facilitated with the 20-year FRI; less frequent burning favored *A. rubrum* over oaks, while more frequent burning favored *N. sylvatica* over oaks. *N. sylvatica* became more abundant than *A. rubrum* by year 60 with short to intermediate FRIs coupled with a longer period of fire application. With short to intermediate FRIs, *P. rigida* became more abundant with a shorter period of fire application, as a result of the high relative abundance of *N. sylvatica* attained with a longer period of fire application (Figure 4.12).

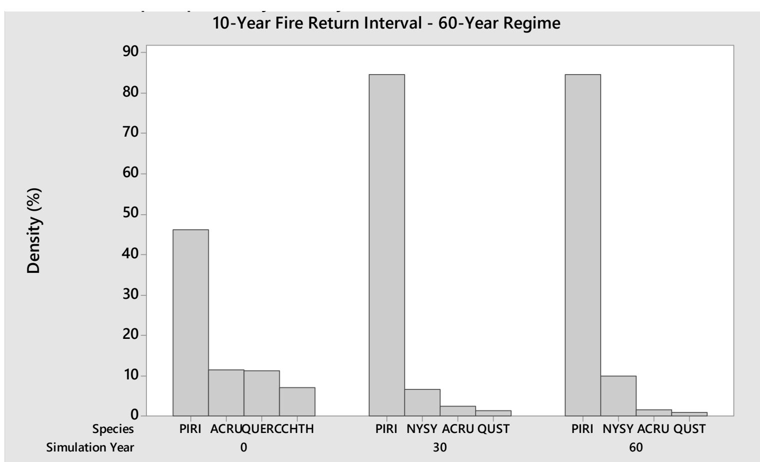

Unburned
Density (%)
60
50
40
30
20
10
0
Species
Simulation Year
PIRI ACRU QUERC CHTH
0
PIRI QUERC ACRU CHTH
30
PIRI ACRU CHTH QUVE
60

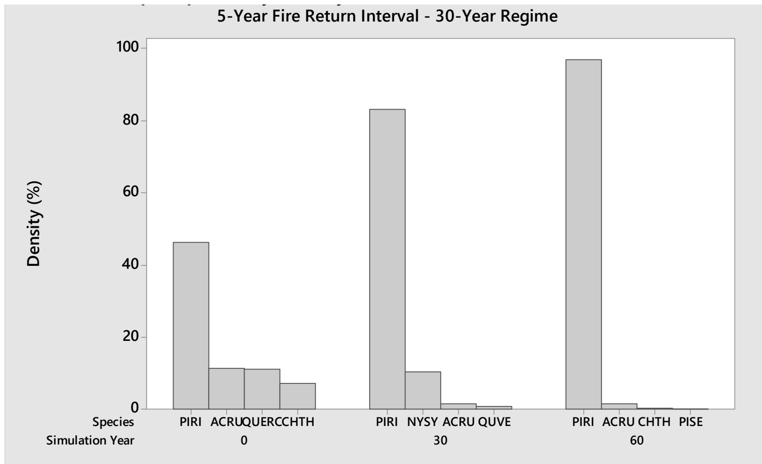

Single Burn
Density (%)
80
70
60
50
40
30
20
10
0
Species
Simulation Year
PIRI ACRU QUERC CHTH
0
PIRI QUERC ACRU NYSY
30
PIRI ACRU CHTH QUVE
60

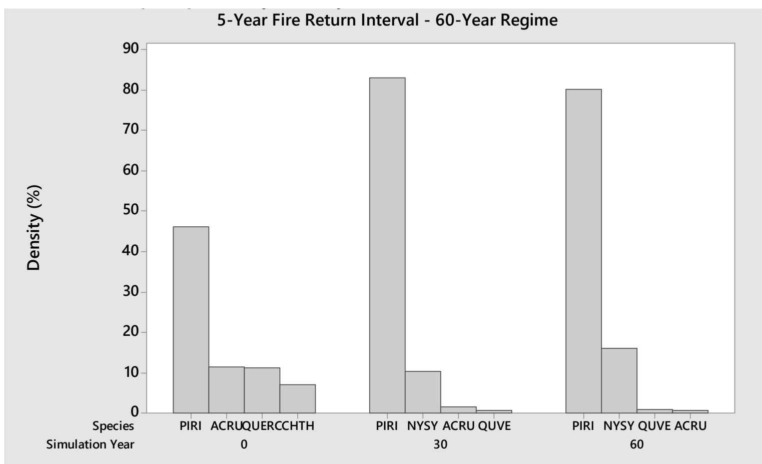

30-Year Fire Return Interval
Density (%)
80
70
60
50
40
30
20
10
0
Species
Simulation Year
PIRI ACRU QUERC CHTH
0
PIRI QUERC ACRU NYSY
30
PIRI ACRU QUERC CHTH
60

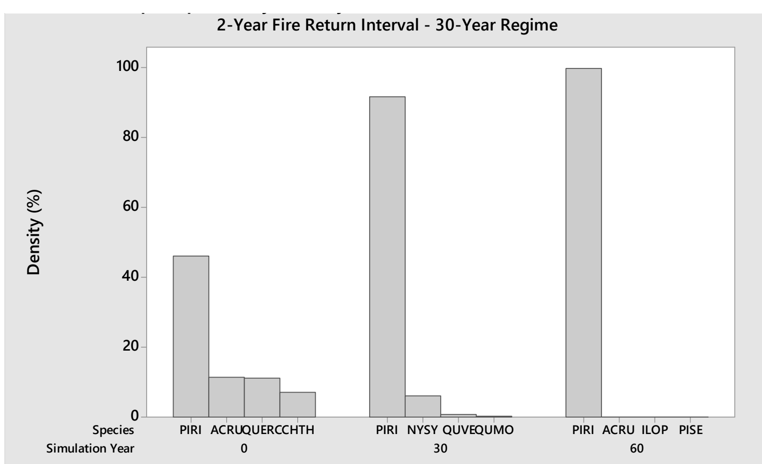

20-Year Fire Return Interval
Density (%)
Species
Simulation Year
PIRI ACRU QUERC CHTH
PIRI QUERC NYSY ACRU
PIRI QUERC ACRU CHTH
0
30
60


10-Year Fire Return Interval - 30-Year Regime
Density (%)
Species
Simulation Year
PIRI ACRU QUERC CHTH
PIRI NYSY ACRU QUST
PIRI ACRU QUST CHTH
0
30
60


10-Year Fire Return Interval - 60-Year Regime
Density (%)
Species
Simulation Year
PIRI ACRU QUERC CHTH
PIRI NYSY ACRU QUST
PIRI NYSY ACRU QUST
0
30
60


5-Year Fire Return Interval - 30-Year Regime
Density (%)
100
80
60
40
20
0
Species
Simulation Year
PIRI ACRU QUERC CHTH
0
PIRI NYSY ACRU QUVE
30
PIRI ACRU CHTH PISE
60


5-Year Fire Return Interval - 60-Year Regime
Density (%)
90
80
70
60
50
40
30
20
10
0
Species
Simulation Year
PIRI ACRU QUERC CHTH
0
PIRI NYSY ACRU QUVE
30
PIRI NYSY QUVE ACRU
60


2-Year Fire Return Interval - 30-Year Regime
Density (%)
100
80
60
40
20
0
Species
Simulation Year
PIRI ACRU QUERC CHTH
0
PIRI NYSY QUVE QUMO
30
PIRI ACRU ILOP PISE
60

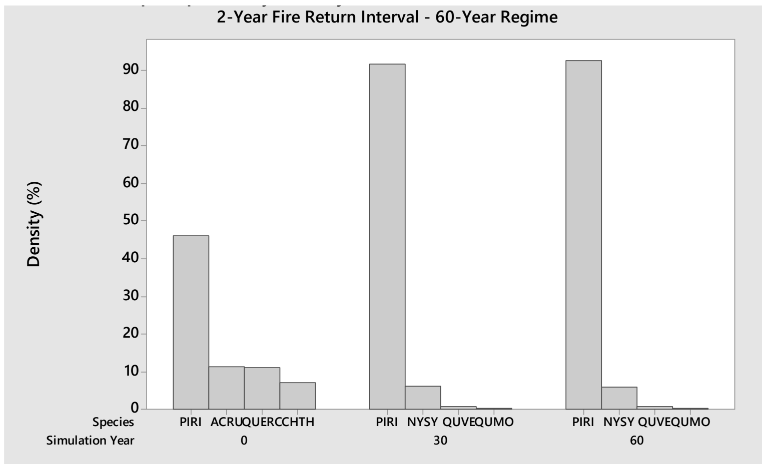


Figure 4.12. Top four most abundant species in terms of density and corresponding density proportions relative to total stand density at initial inventory, year 30, and year 60 for an initial NJ pine-dominant forest stand, with different fire regime treatments. Species are displayed using the corresponding United States Department of Agriculture (USDA) Natural Resources Conservation Service PLANTS symbols, with numbers omitted. Standard deviation among replicates was 0.0-4.7% across all means. In cases where the identified species differed within any of the four positions among the replicates, the greater-identified species, i.e. identified in two of the three replicates, was selected; in the very rare instance when each replicate projected a different species, species were selected to avoid overlap with the other species present within the set. Corresponding stand total density values (trees ha^{-1}) are included in Appendix Table 5.

CHAPTER 5 – Discussion

High variation in BA compositional proportions existed among the eight forest classes at initial inventory (Table 4.1); this variation effectively captured the wide range of initial forest conditions present across the two regions. Below I discuss the fire regime simulation results within the context of current prescribed fire use in forest management, limitations of the approach, and if the simulation results supported my hypotheses of how forests would respond to different fire regimes.

Management in Pennsylvania

In PA, management is largely oak-focused, with some attention to managing for pitch pine communities within the oak-pine forest type. Overall, short FRIs dramatically decreased total stand BA over multiple decades of fire application; total stand BA increased with infrequent to no burning. With the 20-year FRI treatment, total stand BA remained fairly stable for more mesic types, i.e. mixed-oak and mixed-species, while increasing for more xeric types, i.e. oak-dominant and oak-pine, due to the relative degree of fire adaptation of the species present. Total stand BA also increased after cessation of burning at year 30 (Appendix Table 3).

For the oak-dominant forest type, management focuses on maintaining oak dominance. The highest oak BA proportions resulted with the 5-60 and 10-60 treatments, and therefore these treatments were best for promoting relative oak BA dominance; however, total stand BA was reduced with both treatments, especially with 5-60 (Appendix Table 3). In terms of initial stand classification criteria, all treatments except for 2-60 maintained oak BA dominance, defined as occupying at least 70% of the total stand BA, by year 60; all treatments except for single burn, unburned, and 2-60 resulted in equal or greater oak BA proportion relative to the initial proportion (~75%) by year 60. Infrequent and no burning still maintained oak BA dominance due to the initial dominance of oaks at inventory; oaks were already mature and relatively large in size, and so seedlings of other species could not easily establish and outcompete oak. Very frequent burning, except for 2-60, also maintained oak BA dominance due to oak being better able to survive fire than other hardwoods, and also due to the very large degree of dominance of oaks over pines (Figure 4.1, Appendix Table 3).

For the mixed-oak forest type, management focuses on restoring oak dominance. The highest oak BA proportions resulted with the 2-60, 5-60, and 10-60 treatments, and therefore these treatments were best for promoting oak BA dominance; however, total stand BA was considerably reduced with 10-60, and 2-60 essentially destroyed the stand by year 60, with 5-60 closely behind (Appendix Table 3). In terms of initial stand classification criteria, the two-year FRI, five-year FRI, and 10-60 treatments achieved oak BA dominance by year 60, although 20-year FRI was very close with 69% and an additional burn at year 60 would certainly achieve oak dominance immediately afterward. However, cessation of burning at year 30 for two-year and five-year FRIs resulted in sharp declines in relative oak BA, likely to continue decreasing after year 60. All repeated burn treatments resulted in greater oak BA proportion relative to the initial proportion (~59%) by year 60, while the unburned and single burn treatments resulted in decreased relative oak BA by year 60. Short to intermediate FRIs promoted oak BA dominance due to being the most effective at eliminating the other hardwood species initially present; sustained fire application prevented these species from outcompeting oaks. The pine component was far too small, i.e. < 2% of the total stand BA, to surpass oak within the time frame (Figure 4.2, Appendix Table 3).

For the mixed-species forest type, restoration of oak dominance might be a potential management objective, although it would be relatively difficult. Once again, the 2-60, 5-60, and 10-60 treatments resulted in the highest oak BA proportions and in oak BA dominance; however, total stand BA was considerably reduced with 10-60, and 2-60 and 5-60 essentially destroyed the stand by year 60 (Appendix Table 3). In terms of initial stand classification criteria, oak BA dominance was achieved by year 60 with the 2-60, 5-60, and 10-60 treatments; cessation of burning at year 30 with these FRIs resulted in sharp declines in relative oak BA, likely to continue decreasing after year 60. All repeated burn treatments resulted in greater oak BA proportion relative to the initial proportion (~43%) by year 60, while the unburned and single burn treatments resulted in decreased relative oak BA by year 60. Short to intermediate FRIs promoted oak BA dominance due to being the most effective at eliminating other hardwood species initially present; sustained fire application prevented these species from remaining dominant over oaks. The pine component was almost non-existent, i.e. ~1% of the total stand BA, far too small to surpass oak within the time frame (Figure 4.3, Appendix Table 3).

For the oak-pine forest type, management focuses on maintaining oak while also potentially restoring or maintaining pitch pine. In terms of initial stand classification criteria, all treatments except for 2-60 and 2-30 maintained oak-pine BA composition at year 60; 2-60 resulted in a pine-dominant composition, while 2-30 resulted in a mixed-species composition that moved toward oak-pine again at year 60. Infrequent and no burning still maintained a relatively large oak BA component due to initial dominance of oaks at inventory; seedlings of other species could not easily establish and outcompete oak in the long term. The 2-60 treatment promoted pine BA dominance, and 5-60 developed conditions toward pine BA dominance, due to abundant post-burn pine regeneration and mature trees being better able to survive fire than hardwoods, including oaks. Pines were not as competitive with less frequent burning or no burning (Figure 4.4, Appendix Table 3).

Ultimately, to maintain a dominant oak component within the relatively xeric oak-dominant and oak-pine forest types, frequent burning at short FRIs was unsuitable because it both drastically decreased total stand BA and also began promoting pine over oak, particularly with 2-60. Although still maintaining oak dominance, not burning or only burning once increased the risk of future mesophyte establishment within these forests, relative to repeated burning, as did the shorter period of fire application relative to the longer period. Therefore, recurrent burning but at a frequency that is relatively low, e.g. 30-year to 20-year FRI, to medium, e.g. 10-year FRI, without cessation would be the most suitable option to maintain oak and also to potentially maintain or restore pine. Burning more frequently promotes pine establishment, in congruence with empirical observations (Stambaugh et al. 2019); however, burning at intermediate FRI still decreased total stand BA over time, so this treatment should be implemented with caution. However, in cases when such forest types have degraded and are comprised with a larger mesophyte component, more frequent burning may be necessary to successfully promote oak and hard pine regeneration. Higher-intensity fires may also be necessary for hard pine regeneration and promotion of oak regeneration over that of competing hardwoods (Arthur et al. 1998, Elliott et al. 1999, Gilbert et al. 2003).

To restore oak within the relatively mesic mixed-oak forest type, frequent burning at short FRIs was unsuitable because it also dramatically decreased total stand BA. Not burning or only burning once was ineffective in restoring oak and reducing the prevalence of other hardwood species; with repeated burning, the shorter period of fire application subsequently enabled mesophyte re-establishment relative to the longer period. Therefore, recurrent burning that alternates between short and intermediate, and potentially long, FRIs, with consideration of both relative oak BA and total stand BA, and without indefinite cessation, may be the best approach to restore oak within these forests. This idea is supported by the long-term studies by Knapp et al. (2015, 2017), who reported that fire-free periods were important for canopy recruitment, as long-term frequent burning inhibited successful regeneration and recruitment, and that a prescribed fire regime with variation in FRI may be appropriate for managing oaks. Short and intermediate FRIs decreased total stand BA over time, and therefore should be implemented with caution; however, a long FRI will likely enable mesophyte re-establishment, and therefore should not be the principle approach (McGee et al. 1995). Empirical research has shown that although repeated burning enhances oak regeneration in hardwood forests (Barnes and Van Lear 1998, Clatterbuck 1998, Adams and Rieske 2001, Royse et al. 2010), it would likely need to be coupled with additional overstory removal to further increase light availability and decrease competition (Franklin et al. 2003, Signell et al. 2005, Blankenship and Arthur 2006, Brose et al. 2013).

For the mixed-species forest type, only intermediate to short FRIs without cessation have any possibility of restoring or maintaining oak. Oak restoration would be very difficult in this case and unlikely to be successful within six decades; recurrent burning that alternates between short and intermediate FRIs, with consideration of both relative oak BA and total stand BA, without indefinite cessation but likely with fire-free periods following removal of other hardwood species to allow for oak establishment in their absence, could be a feasible option to restore oak. However, short and intermediate FRIs considerably decreased total stand BA over time, and should therefore be alternated and supplemented with fire-free periods. Overall, oak restoration within this forest type would not be feasible within the simulation time frame, considering management resource availability; nevertheless, a small oak component could still be maintained with periodic burning.

At the species level, recurrent burning was necessary to control the establishment of *A. rubrum* and other non-oak hardwood species, and to restore or maintain the relative dominance of oaks. Species-level results further support the recommendation of applying long, e.g. 30-year to 20-year, to intermediate, e.g. 10-year, FRIs without cessation over many decades for stands still largely dominated by oaks; this approach maintains oaks, prevents establishment of mesophytes, and avoids potential future dominance of pitch pine if present. To maintain or restore historic pitch pine communities in xeric sites, more frequent burning, i.e. with at least intermediate FRI, without cessation, or potentially with short, i.e. five-year, FRI, coupled with crucial fire-free periods to maintain oak, would be necessary. More frequent burning, e.g. at intermediate and potentially short FRIs in extreme cases, at least for a period and followed by a regime of less frequent burning when appropriate, may be necessary to increase oak dominance in stands with a large mesophyte component, i.e. a degree of restoration would be necessary. In the example mixed-oak stand, which is representative of a large proportion of forests in PA, *A. rubrum* remained relatively dominant without burning, with relative dominance increasing over time. *Quercus rubra* did remain as the dominant species due to initial relative dominance over other species. Relatively frequent burning increased relative oak dominance; at least somewhat intermediate FRI, e.g. between 10 and 20 years, without indefinite cessation, would be effective in restoring oak. When burning ceased, *A. rubrum* re-established within a few decades. Due to observed decrease in total stand BA over time, fire-free periods may be necessary for forest recovery when burning rather frequently, and may therefore be used carefully in conjunction with relatively frequent burning to best restore oak and limit prevalence of mesophytic competitors (Figure 4.9, Appendix Table 4).

Although burning at a historic, site-specific regime interval (e.g. 10-15 years) over the long term is important to maintaining oaks and controlling mesophyte establishment (Holzmueller et al. 2009), empirical research has demonstrated the limited success of short-term repeated burning on oak establishment in mixed-hardwood forests, and the additional need for silvicultural treatment and fire-free periods (Hutchinson et al. 2005, 2012, Alexander et al. 2008, Fan et al. 2012, Arthur et al. 2015, Keyser et al. 2017). The results of this research further support the idea that recurrent burning over many decades should yield greater success in long-term oak establishment and restoration, and that historical fire regimes in the region can be used in part to inform current forest management (Lafon et al. 2017, Stambaugh et al. 2018).

Management in the New Jersey Pine Barrens

In the NJ Pine Barrens, management is largely pitch pine-focused, with some attention to managing for oaks within pine-oak and oak-pine forests. Overall, total stand BA increased with most or all treatment scenarios among the forest types; BA decreased with short FRIs for types with a smaller initial pitch pine component. BA increased relatively quickly with infrequent to no burning, and experienced smaller increases, or decreases, with shorter FRIs, over multiple decades of fire application. BA also increased more after cessation of burning at year 30, relative to the longer period of fire application (Appendix Table 3).

For the pine-dominant forest type, management focuses on maintaining hard (primarily pitch) pine dominance. Both shorter FRIs and a longer period of fire application directly resulted in higher relative pine BA, with FRI having a greater effect than duration of fire application for short and intermediate FRIs. Total stand BA increased over time with all treatments, due to the strong ability of pitch pine to resist and survive fire (Appendix Table 3). In terms of initial stand classification criteria, all treatments maintained pine BA dominance, defined as occupying at least 70% of the total stand BA, by year 60; pine BA percentage with no burning remained relatively constant in the high 70s and low 80s, while increasing considerably from the initial proportion (~82%) at year 60 with all burn treatment scenarios. Infrequent and no burning still maintained pine BA dominance due to initial dominance of pitch pine at time of inventory; pitch pine stems were already mature and relatively large in size, and so seedlings of other species could not easily establish and outcompete the pines (Figure 4.5, Appendix Table 3).

For the pine-oak forest type, management focuses on maintaining pine dominance over oak, but may potentially aim to maintain a limited oak component as well. In terms of initial stand classification criteria, all burn treatments resulted in pine BA dominance before year 10; this was hardly surprising as initial pine BA was already at 69%. With no burning, relative pine BA steadily decreased over time, while increasing from the initial proportion with all burn treatment scenarios. A single burn and infrequent burning still maintained pine BA dominance due to the relative dominance of pitch pine at inventory, and also due to high shortleaf pine and pitch pine seedling densities measured at inventory and subsequently used to parameterize baseline regeneration. No burning reduced relative pine BA and increased relative oak BA, likely primarily due to high initial *Q. ilicifolia* seedling density that was used to parameterize baseline regeneration. Due to initial degree of BA dominance, relative pine BA decreased gradually over many decades, and likewise relative oak BA increased only slowly over the decades (Figure 4.6, Appendix Table 3).

For the oak-pine forest type, management may aim to restore pine dominance over oak, or to maintain oak dominance but with an ecologically-significant pine component present. In terms of initial stand classification criteria, the two-year FRI, five-year FRI, and 10-60 treatments achieved pine BA dominance by year 60; other treatments resulted in mixed pine-oak or oak-pine forest types at year 60. A single burn and infrequent burning still increased pine BA dominance, and subsequently lowered oak BA dominance, due to the very high derived post-burn seedling density for shortleaf pine that was based on the inventory data and used to parameterize post-burn regeneration. No burning maintained relative pine BA, and prevented additional domination by oak, largely likely due to very high initial seedling density for shortleaf pine that was used to parameterize baseline regeneration. Even without burning, pine ultimately persisted within the stand (Figure 4.7, Appendix Table 3).

For the mixed-species forest type, the experimental aim was to test the effects of fire on pyrophobic species; these stands would most likely not normally be burned like pine- and oak-dominant stands. Thus, this forest group represented a true miscellaneous category, and the "averaged" stand would not exist in reality due to the mixture of stand community types. A mixture of non-oak hardwoods and Atlantic white cedar comprised a large component of the initial stand BA; this component decreased more rapidly with greater fire application, from gradually decreasing without fire to decreasing very sharply with intermediate and short FRIs. However, this decrease slowed or converted to an increase following cessation of fire at year 30. Along with oaks, this component essentially became ecologically insignificant by year 60 with very frequent burning, i.e. at five-year and two-year FRIs, without cessation, as pines became the overwhelmingly dominant species group. Short FRIs without fire cessation resulted in pine BA dominance by year 60 (Figure 4.8, Appendix Table 3).

A direct relationship existed between shorter FRI, longer period of fire application, and pine dominance. Although still maintaining pine dominance, no burning or only burning once for the pine-dominant forest type seemed to increase the risk of future hardwood establishment relative to repeated burning, due to survival, growth, and regeneration of hardwoods in the absence of recurrent fire. Similarly for the pine-oak forest type, no burning still maintained pine-oak BA composition, but seemed to increase the likelihood of potential oak establishment in the future, relative to burn treatment. The shorter duration of fire application did not have much effect on BA relative to the longer duration, indicating strong establishment of pine within just a few decades. Therefore, recurrent burning at a frequency that is determined by site factors and/or resource availability, and without indefinite cessation, may be the most suitable option to maintain pine dominance in presently pine-dominant stands; more fire resulted in greater pine dominance, but could require more burn resources. For pine-oak stands, at least one burn, or infrequent recurrent burning, likely without indefinite fire cessation, may be appropriate to maintain dominance of pine over oak; fire-free periods could be used to maintain a limited oak component if desired. Although no burning for the oak-pine forest type still maintained oak-pine BA composition and avoided development toward oak dominance, baseline shortleaf pine regeneration was likely overestimated in the simulation, and not burning in reality would likely increase oak dominance to a greater degree, relative to burn treatment. Shorter period of fire application did have considerable effect on relative pine and oak BA, relative to the longer period, indicating the dependence of pines on recurrent burning in this forest type. Therefore, recurrent burning with short FRIs supplemented with fire-free periods to allow for periodic stand BA recovery as needed, or with intermediate FRIs without cessation, may be suitable approaches toward promoting the eventual dominance of pine over oak. Fire-free periods could be used to maintain a limited oak component within a pine-dominant stand if desired; similarly, infrequent burning at long FRIs may be useful to maintain relative oak dominance over pine, but with an ecologically-significant pine component present, if desired. For the mixed-species stands within and surrounding the Pine Barrens, shorter FRI and a longer period of fire application both resulted in the decline of non-pine and non-oak species, in congruence with a mainly positive effect on relative pine BA. These stands would never be burned for pine restoration as it would be irrelevant and unrealistic for this forest type; at best, it would be extremely challenging and costly to convert such communities to pine-dominant composition.

At the species level, recurrent burning was necessary to control the establishment of hardwoods in pitch pine stands, including the relatively fire-adapted oaks as well as mesophytic species such as *A. rubrum*. Species-level results further demonstrate the positive effects of frequent burning, especially over longer periods, on relative pitch pine dominance, and negative effects on hardwood prevalence and establishment. Furthermore, the results indicate that at least temporary cessation of burning will not quickly replace pitch pine with oaks or other hardwoods, but potential replacement may occur sometime after 60 years if burning is ceased indefinitely. Infrequent burning at long FRIs, and/or fire-free periods, may sustain a limited oak component in mixed oak-pine stands if desired. However, even burning at intermediate FRIs could eventually promote pitch pine over oaks in stands with a large oak component. Stand development toward pitch pine dominance is more rapid with short FRIs and without fire cessation, whereas less fire will maintain a larger oak component in oak-pine stands. The example pine-dominant stand, which is representative of a large proportion of forests in the NJ Pine Barrens, was very much a synthetic stand by design – an aggregation and subsequent average of likely non-spatially-contiguous plots distributed across the entire Pine Barrens region of central and southern NJ; as such, species richness of this stand was likely higher than typical for a spatially-contiguous pitch pine-dominant stand from the region. *A. rubrum*, in this case generally representative of hardwoods in a pitch pine stand, increased in relative BA over time without burning. Pitch pine did remain as the dominant species due to strong initial stand dominance; even infrequent burning at long FRIs was sufficient in considerably controlling hardwood establishment over time, due to the high degree of pitch pine dominance over every other species at initial inventory. Very frequent burning at short FRIs could eventually achieve near-total or total pitch pine stand composition, with no hardwoods or Atlantic white cedar present. This condition could be achieved even with cessation of burning after a few decades, although indefinite cessation would likely increase the likelihood of future hardwood re-establishment, beyond the simulation time frame. Total stand BA increased over time with all treatment scenarios, and increased more rapidly with less, or no, fire, including after cessation of burning at year 30 (Figure 4.11, Appendix Table 4).

These results corroborate the well-established knowledge that frequent and severe fire has a positive impact on pitch pine dominance in local forests, with less frequent fire promoting oak establishment, and that frequent low-intensity burning promotes strong pine regeneration and establishment (Little 1946, Little and Moore 1949, Somes and Moorhead 1950). For oak-pine stands in particular, infrequent or occasional prescribed burning may favor eventual oak dominance over pitch pine (Boerner et al. 1988); therefore, a long-term regime of frequent recurrent burning is necessary towards maintaining the health and integrity of the pitch pine communities of the NJ Pine Barrens.

Stand Groups

Within each of the five forest classes that comprised three separate stands, considerable differences existed among the individual stands regarding species composition and stand BA. However, notable intra-group commonalities were evident. In PA, very limited to no pine was present in the stands within each of the three groups; among the oak-dominant stands, *Q. montana* was consistently the most dominant oak species, presumably due to xeric site conditions; among the mixed-oak stands, *Q. montana* and *Q. rubra* were the most dominant and widespread oak species, and *A. rubrum* was consistently the most prevalent non-oak hardwood species. Among the pine-dominant stands of the NJ Pine Barrens, pitch pine was consistently and overwhelmingly dominant over other pine species such as shortleaf pine, as well as over hardwoods and Atlantic white cedar. However, despite the grouping and averaging of stands for the purposes of this research and the basic similarities among the stands within each group, site- and stand-specific characteristics nonetheless remain critical to the real-world management of specific forest types across a particular region, including the use of prescribed burning.

Density

In terms of tree density, management in PA focuses on regenerating oaks and enhancing their abundance for future stand dominance. Periodic fire has been empirically demonstrated to increase oak regeneration density (Arthur et al. 1998, Elliott et al. 1999, Signell et al. 2005, Holzmueller et al. 2009), and springtime burning can promote the abundance of oak over that of competing hardwoods (Brose et al. 1999, Huddle and Pallardy 1999); the simulation results indicated that recurrent burning was indeed necessary to control the establishment of *A. rubrum* and other maples, if present, and to maintain abundant oak establishment. Empirical research has also demonstrated that short-term application of periodic fire may not adequately reduce abundance of non-oak competitors, and thus fail to successfully establish oak (Hutchinson et al. 2005, 2012, Blankenship and Arthur 2006, Arthur et al. 2015). More frequent burning at short FRIs and without cessation are necessary if initial abundance of *A. rubrum* is high, and if other non-oak hardwoods are present in considerable numbers (Kuddes-Fischer and Arthur 2002). Frequent burning, at least for a set period, would be essential in restoring oak abundance in stands with greater relative abundance of mesophytic species, and restoration may not be feasible for stands already dominated by mesophytes. Less frequent burning may sustain relative abundance of other species such as *Nyssa sylvatica*, *Sassafras albidum*, *Betula lenta*, and *Prunus serotina*, which recruit with fire more successfully than *A. rubrum*. These species may also re-establish with cessation of fire. In the example mixed-oak stand, *A. rubrum* remained fairly abundant with fire, due to parameterization of post-burn regeneration from limited post-fire seedling data where *A. rubrum* seedling abundance increased post-fire. Persisting abundance of *A. rubrum* and *Fagus grandifolia* is more likely a result of automatic post-fire re-sprouting, which can be prolific with frequent burning. Post-burn re-sprouting can help maintain sizeable relative density of many hardwood species (Figure 4.10, Appendix Table 5).

In the NJ Pine Barrens, management is oriented towards maintaining adequate pitch pine regeneration. In general, recurrent burning without cessation was necessary to control the establishment of hardwoods in pitch pine stands and to maintain abundant pine establishment into the future. More frequent fire resulted in greater relative abundance of pine, in congruence with the well-established knowledge that fire promotes pine seedling abundance in the Pine Barrens (Little and Moore 1949, Boerner 1981, Olson 2011).

A high abundance observed for *N. sylvatica* post-fire was the direct result of post-burn regeneration parameterization using limited post-fire seedling data from the Virginia Appalachians, where *N. sylvatica* seedling abundance had been observed to increase dramatically post-fire. This outcome may not accurately reflect local conditions in the NJ Pine Barrens (Olson 2011). For the oak-pine stand, the high abundance of shortleaf pine projected to establish was the direct result of the very high abundance of seedlings measured at inventory and subsequently used to parameterize regeneration in the model. In the example pine-dominant stand, recurrent burning at intermediate and short FRIs maintained a very high degree of pitch pine abundance relative to hardwoods; however, as discussed previously, *N. sylvatica* post-burn abundance was likely higher than it would be due to model parameterization with limited post-fire data from a Virginia Appalachian pine-oak stand (Figure 4.12, Appendix Table 5).

Compared to BA, stem density was overall less suitable and relevant as a metric for assessing stand species composition and relative dominance. Total stand density values, expressed as $m^2 ha^{-1}$, were very high, and fluctuated widely over time, in comparison to total stand BA. This was due to periodic seedling establishment, post-burn hardwood re-sprouting, and mortality of small stems from competition that occurred when maximum stand BA values were reached. Individual seedlings and sprouts were included in the total stem count, but were essentially negligible for total BA since larger trees were weighted much more heavily. Therefore, stem density was not as useful as BA for assessing and comparing relative species dominance, as larger-sized stems have higher survivorship and a clear competitive advantage over smaller-sized stems, and contribute more toward dominance of a particular species.

Research Objectives and Hypotheses

This research investigated the potential multi-decadal effects of various fire regime treatments on composition and structure of oak and pitch pine forest stands in PA and NJ. A simulation modeling approach was used to test the influence of initial forest conditions, fire frequency, and fire regime duration on the long-term dominance of pines and oaks in these mid-Atlantic forests. My hypotheses were largely supported by my results; higher initial BA dominance and repeated burning without cessation generally facilitated long-term BA dominance of oaks and pitch pine within their respective stands. Low to medium fire frequency can be implemented to promote or maintain oak dominance, depending on initial BA composition, with limited use of high-frequency burning for stands with greater mesophytic competition. Although pitch pine BA dominance could be maintained with infrequent or short-term burning, higher fire frequencies did better promote pitch pine dominance relative to less frequent fire.

Assumptions and Limitations

This research utilized data from multiple sources that incorporated different data collection protocols; however, the model input metrics were standardized across all input forest data while adhering to the original information as closely as possible, and therefore minimized the impact of differing protocol on output calculations and projections regarding BA and density. Estimation of initial surface fuel loading, although informed, was approximate, and assumed the same profile within each designated forest class. In reality, each individual stand would likely possess its own distinct surface fuel profile, but this simplification was necessary to run simulations using FVS for large groups of plots in each stand.

The FFE automatic fuel model selection logic is relatively limited for the NE variant of FVS; fuel models and weights are selected solely based on fuel loading that is projected for each simulation cycle. The logic then determines resulting fire behavior for each fuel model, and calculates the weighted mean of the results based on the relative fuel model weights (Rebain 2010). Scott and Burgan (2005) fuel models were used instead of Anderson (1982) fuel models in this research due to the greater number of available models and thus finer degree of fuel model assignment that potentially led to more accurate prediction of fire behavior and effects, at each given simulation cycle. Fuel model selection directly impacts simulated fire effects, and subsequently affects the predicted ecological outcomes in all cases. Although the logic was not specifically tested, results likely remain adequate for assessing relative differences in fire effects among the simulated fire regimes.

The partial establishment model for tree regeneration used by the NE variant does not automatically incorporate natural seedling regeneration, unlike some FVS variants for western U.S. forest types (Dixon 2002). Manual incorporation of natural seedling regeneration was highly simplified; for each stand, inventory regeneration data were used, or provided the basis, for every establishment pulse over the entire simulation period. Parameterization thus assumed a constant regeneration profile, as temporal changes in the regeneration profile could not be accounted for in the experiment. Incorporation of decadal pulses was based on the approaches used by Fulé et al. (2004), Cheek et al. (2012), and Schwenk et al. (2012). Seedling survival rate estimates were assumed to be the same among species within the same species group, e.g. pines, oaks, and hickories, for a given height class; ultimately, estimates were the same or very close among the different species groups for each height class. Empirical post-burn regeneration data were very limited, and values extrapolated from these limited data were used for the vast majority of experimental stands; consequently, regeneration may have been inaccurate in certain cases. It was also assumed that species-level post-fire regeneration patterns in the Virginia Appalachians were sufficient to use across our study region. Nevertheless, this parameterization approach utilized empirical data, and were thus supported by actual fire effects data, rather than having been estimated without any empirical basis. The partial establishment model incorporated sprouting of hardwoods only; post-disturbance sprouting of pines was not explicitly incorporated, although seedling regeneration densities post-burn were nonetheless considerably higher than those of the baseline for pitch and shortleaf pines, thereby likely reducing the importance of including pine re-sprouting.

Management Implications

Results of this research supplement recommendations and guidelines toward sustainable management of eastern pitch pine and oak-dominated forests. Oak management is multi-faceted and complex, and long-term commitment to active management is required, particularly if fire is used to assist with maintenance or restoration of oak (Arthur et al. 2012, Brose 2014, Dey 2014). Ecological restoration, including the restoration of oak in degraded hardwood forests, is inherently site-specific in nature (Hart and Buchanan 2012), and the guidelines that stem from this research provide insight on how prescribed fire could be applied to meet guidelines. In addition to managing for present forest health, managing for resilience to future environmental stressors is also very important (Vose and Elliott 2016). One factor not considered in this research was seasonality of burn, which can be influential in managing for oak. However, as Brose (2014) reported, season of burn is ultimately not very critical due to the necessity of repeated burning over the long term, although growing-season fires in mid- to late spring do open the understory more quickly than dormant-season fires, and are thus more effective in facilitating oak regeneration. The relatively high severity of springtime fires and their effectiveness at promoting oak advance regeneration have been reported for oak-dominated shelterwood stands that were burned post-harvest (Brose and Van Lear 1998, 1999). Edgar and Griscom (2017) reported that season of burn was not as important as burn frequency for promoting oak regeneration in xeric pine-oak forests. Keyser et al. (2019) reported that in the case of a single fire within a closed-canopy oak-hickory forest, burn season had little effect on forest composition and structure; instead, recurrent growing season burns, likely coupled with additional overstory reduction, may be necessary to promote oak regeneration and recruitment. Future simulation modeling studies could explore the influence of seasonality on prescribed fire effects in fire-dependent oak or pine forest communities.

Additional considerations for local fire management include the addition of variation within the characteristics of the prescribed burn regime, e.g. in burn frequency, seasonality, firing technique, ignition location, and weather conditions, in order to better approximate natural and historical variability of fire occurrence that could better maintain the heterogeneity of forest composition and structure (Lashley et al. 2014). Periodic prescribed burning may also need to be used in conjunction with mechanical thinning of mid- and overstory trees to successfully regenerate and recruit oak in mature mixed-oak forests where competitors are abundant (Iverson et al. 2008, Holzmueller et al. 2014); where tree harvest is not a viable option, the occasional higher-severity fire may be used as an alternative to control the re-sprouting of competitors (Albrecht and McCarthy 2006). Finally, broad-scale approaches to management should be considered; beyond the scale of a single forest stand, a landscape management framework that is flexible, integrated, holistic, and capable of addressing rapid ecological change, will be highly beneficial to contemporary ecosystem management (Hobbs et al. 2014). Ecological restoration efforts must consider the important role of ecological history and how historical information is and should be used (Higgs et al. 2014), and accordingly utilize active and adaptive management over the long term to restore desired ecological functions and disturbances for the future (Hanberry et al. 2015). Informed and appropriate management of fire as a fundamental disturbance agent in fire-dependent ecosystems will ultimately yield desirable outcomes toward promoting the current and future health of vegetation communities and dynamics across landscapes.

REFERENCES

Abrams, M. D. 1992. Fire and the development of oak forests. BioScience 42:346–353.

Abrams, M. D. 1996. Distribution, historical development and ecophysiological attributes of oak species in the eastern United States. Annals of Forest Science 53:487–512.

Abrams, M. D. 2005. Prescribing fire in eastern oak forests: Is time running out? Northern Journal of Applied Forestry 22:190–196.

Abrams, M. D., and G. J. Nowacki. 1992. Historical variation in fire, oak recruitment, and post-logging accelerated succession in central Pennsylvania. Bulletin of the Torrey Botanical Club 119:19–28.

Adams, A. S., and L. K. Rieske. 2001. Herbivory and fire influence white oak (*Quercus alba* L.) seedling vigor. Forest Science 47:331–337.

Adams, M. A. 2013. Mega-fires, tipping points and ecosystem services: managing forests and woodlands in an uncertain future. Forest Ecology and Management 294:250–261.

Albrecht, M. A., and B. C. McCarthy. 2006. Effects of prescribed fire and thinning on tree recruitment patterns in central hardwood forests. Forest Ecology and Management 226:88–103.

Aldrich, S. R., C. W. Lafon, H. D. Grissino-Mayer, G. G. DeWeese, and J. A. Hoss. 2010. Three centuries of fire in montane pine-oak stands on a temperate forest landscape. Applied Vegetation Science 13:36–46.

Alexander, H. D., M. A. Arthur, D. L. Loftis, and S. R. Green. 2008. Survival and growth of upland oak and co-occurring competitor seedlings following single and repeated prescribed fires. Forest Ecology and Management 256:1021–1030.

Anderson, H. E. 1982. Aids to determining fuel models for estimating fire behavior. Gen. Tech. Rep. INT-122. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT. 22p.

Arthur, M. A., H. D. Alexander, D. C. Dey, C. J. Schweitzer, and D. L. Loftis. 2012. Refining the oak–fire hypothesis for management of oak-dominated forests of the eastern United States. Journal of Forestry 110:257–266.

Arthur, M. A., B. A. Blankenship, A. Schorgendorfer, D. L. Loftis, and H. D. Alexander. 2015. Changes in stand structure and tree vigor with repeated prescribed fire in an Appalachian hardwood forest. Forest Ecology and Management 340:46–61.

Arthur, M. A., R. D. Paratley, and B. A. Blankenship. 1998. Single and repeated fires affect survival and regeneration of woody and herbaceous species in an oak-pine forest. Journal of the Torrey Botanical Society 125:225–236.

Attiwill, P. M. 1994. The disturbance of forest ecosystems: the ecological basis for conservative management. Forest Ecology and Management 63:247–300.

Barnes, T. A., and D. H. Van Lear. 1998. Prescribed fire effects on advanced regeneration in mixed hardwood stands. Southern Journal of Applied Forestry 22:138–142.

Blankenship, B. A., and M. A. Arthur. 2006. Stand structure over 9 years in burned and fire-excluded oak stands on the Cumberland Plateau, Kentucky. Forest Ecology and Management 225:134–145.

Boerner, R. E. J. 1981. Forest structure dynamics following wildfire and prescribed burning in the New Jersey Pine Barrens. The American Midland Naturalist 105:321–333.

Boerner, R. E. J., T. R. Lord, and J. C. Peterson. 1988. Prescribed burning in the oak-pine forest of the New Jersey Pine Barrens: effects on growth and nutrient dynamics of two *Quercus* species. The American Midland Naturalist 120:108–119.

Bond, W. J., and J. E. Keeley. 2005. Fire as a global "herbivore": the ecology and evolution of flammable ecosystems. Trends in Ecology and Evolution 20:387–394.

Brose, P. H. 2014. Development of prescribed fire as a silvicultural tool for the upland oak forests of the eastern United States. Journal of Forestry 112:525–533.

Brose, P. H., D. C. Dey, R. J. Phillips, and T. A. Waldrop. 2013. A meta-analysis of the fire-oak hypothesis: Does prescribed burning promote oak reproduction in eastern North America? Forest Science 59:322–334.

Brose, P. H., and D. H. Van Lear. 1998. Responses of hardwood advance regeneration to seasonal prescribed fires in oak-dominated shelterwood stands. Canadian Journal of Forest Research 28:331–339.

Brose, P. H., T. M. Schuler, and J. S. Ward. 2006. Responses of oak and other hardwood regeneration to prescribed fire: What we know as of 2005. Pages 123–135 *in* M. B. Dickinson, editor. Fire in Eastern Oak Forests: Delivering Science to Land Managers. USDA Forest Service, Northern Research Station, Newtown Square, PA.

Brose, P., and D. Van Lear. 1999. Effects of seasonal prescribed fires on residual overstory trees in oak-dominated shelterwood stands. Southern Journal of Applied Forestry 23:88–93.

Brose, P., D. Van Lear, and R. Cooper. 1999. Using shelterwood harvests and prescribed fire to regenerate oak stands on productive upland sites. Forest Ecology and Management 113:125–141.

Buma, B., C. D. Brown, D. C. Donato, J. B. Fontaine, and J. F. Johnstone. 2013. The impacts of changing disturbance regimes on serotinous plant populations and communities. BioScience 63:866–876.

Campbell, J. W., S. M. Grodsky, O. Keller, C. C. Vigueira, P. A. Vigueira, E. S. Waite, and C. H. Greenberg. 2018. Response of beetles (Coleoptera) to repeated applications of prescribed fire and other fuel reduction techniques in the southern Appalachian Mountains. Forest Ecology and Management 429:294–299.

Chan, Chung-hong, Geoffrey CH Chan, Thomas J. Leeper, and Jason Becker (2018). rio: A Swiss-army knife for data file I/O. R package version 0.5.16.

Cheek, J. W., F. Biondi, J. S. Sibold, and R. Tausch. 2012. Fuel analysis and potential fire behavior in mixed conifer woodlands of the Great Basin, Nevada, USA. Physical Geography 33:205–228.

Clark, K. L., N. Skowronski, H. Renninger, and R. Scheller. 2014. Climate change and fire management in the mid-Atlantic region. Forest Ecology and Management 327:306–315.

Clatterbuck, W. K. 1998. Use of prescribed fire to promote oak regeneration. Pages 315–318 *in* T. A. Waldrop, editor. Proceedings of the Ninth Biennial Southern Silvicultural Research Conference. USDA Forest Service, Southern Research Station, Asheville, NC.

Climate-Data.org. https://en.climate-data.org.

Cole, Jason, A.; Johnson, Kristofer D.; Birdsey, Richard A.; Pan, Yude; Wayson, Craig A.; McCullough, Kevin; Hoover, Coeli M.; Hollinger, David Y.; Bradford, John B.; Ryan, Michael G.; Kolka, Randall K.; Weishampel, Peter; Clark, Kenneth L.; Skowronski, Nicholas S.; Hom, John; Ollinger, Scott V.; McNulty, Steven G.; Gavazzi, Michael J. 2015. North American Carbon Program biometric database. 2nd Edition. USDA Forest Service, Northern Research Station. https://doi.org/10.2737/RDS-2013-0008-2

Dancer, R. S., H. Conaway, M. Caride, P. Space, J. Beach, B. Smith, H. J. Wirths, and C. Bateman. 2018. Prescribed Burn Act. New Jersey Legislature.

Dey, D. C. 2014. Sustaining oak forests in eastern North America: regeneration and recruitment, the pillars of sustainability. Forest Science 60:926–942.

Dixon, G. E. 2002. Essential FVS: A user's guide to the Forest Vegetation Simulator. Internal Rep. U.S. Department of Agriculture, Forest Service, Forest Management Service Center, Fort Collins, CO. 226p. (Revised: June 13, 2017)

Dixon, G. E., and C. E. Keyser. 2008. Northeast (NE) variant overview - Forest Vegetation Simulator. Internal Rep. U.S. Department of Agriculture, Forest Service, Forest Management Service Center, Fort Collins, CO. 55p. (Revised: April 6, 2017)

Dyer, J. M., and T. F. Hutchinson. 2019. Topography and soils-based mapping reveals fine-scale compositional shifts over two centuries within a central Appalachian landscape. Forest Ecology and Management 433:33–42.

Edgar, B. E., and H. P. Griscom. 2017. The effect of controlled burns on abundance of woody species in Appalachian pine-oak forests at Buck Mountain, West Virginia. Natural Areas Journal 37:30–38.

Elliott, K. J., R. L. Hendrick, A. E. Major, J. M. Vose, and W. T. Swank. 1999. Vegetation dynamics after a prescribed fire in the southern Appalachians. Forest Ecology and Management 114:199–213.

Fan, Z., Z. Ma, D. C. Dey, and S. D. Roberts. 2012. Response of advance reproduction of oaks and associated species to repeated prescribed fires in upland oak-hickory forests, Missouri. Forest Ecology and Management 266:160–169.

Finney, M. A., R. C. Seli, C. W. McHugh, A. A. Ager, B. Bahro, and J. K. Agee. 2007. Simulation of long-term landscape-level fuel treatment effects on large wildfires. International Journal of Wildland Fire 16:712–727.

Flatley, W. T., C. W. Lafon, H. D. Grissino-Mayer, and L. B. LaForest. 2013. Fire history, related to climate and land use in three southern Appalachian landscapes in the eastern United States. Ecological Applications 23:1250–1266.

Forman, R. T. T., and R. E. Boerner. 1981. Fire frequency and the Pine Barrens of New Jersey. Bulletin of the Torrey Botanical Club 108:34–50.

Franklin, S. B., P. A. Robertson, and J. S. Fralish. 2003. Prescribed burning effects on upland *Quercus* forest structure and function. Forest Ecology and Management 184:315–335.

Freeman, J., L. Kobziar, E. W. Rose, and W. Cropper. 2017. A critique of the historical-fire-regime concept in conservation. Conservation Biology 31:976–985.

Fulé, P. Z., J. E. Crouse, A. E. Cocke, M. M. Moore, and W. W. Covington. 2004. Changes in canopy fuels and potential fire behavior 1880-2040: Grand Canyon, Arizona. Ecological Modelling 175:231–248.

Gallagher, M. R. 2017. Monitoring fire effects in the New Jersey Pine Barrens with burn severity indices. Diss. Rutgers, The State University of New Jersey - School of Graduate Studies.

Gallagher, Michael R.; Clark, Kenneth L.; Thomas, Jan Christian; Mell, William E.; Hadden, Rory M.; Mueller, Eric V.; Kremens, Robert L.; El Houssami, Mohamad; Filkov, Alexander I.; Simeoni, Albert A.; Skowronski, Nicholas S. 2017. New Jersey fuel treatment effects: Pre- and post-burn biometric data. Forest Service Research Data Archive, Fort Collins, CO. https://doi.org/10.2737/RDS-2017-0061

Gilbert, N. L., S. L. Johnson, S. K. Gleeson, B. A. Blankenship, and M. A. Arthur. 2003. Effects of prescribed fire on physiology and growth of *Acer rubrum* and *Quercus* spp. seedlings in an oak-pine forest on the Cumberland Plateau, KY. Journal of the Torrey Botanical Society 130:253–264.

Givnish, T. J. 1981. Serotiny, geography, and fire in the Pine Barrens of New Jersey. Evolution 35:101–123.

Greenberg, C. H., J. Tomcho, A. Livings-Tomcho, J. D. Lanham, T. A. Waldrop, D. Simon, and D. Hagan. 2018. Long-term avian response to fire severity, repeated burning, and mechanical fuel reduction in upland hardwood forest. Forest Ecology and Management 424:367–377.

Greller, A. M. 1988. Deciduous forest. Pages 287–316 *in* M. G. Barbour and W. D. Billings, editors. North American Terrestrial Vegetation. Cambridge University Press, New York.

Grissino-Mayer, H. D. 2016. Fire as a once-dominant disturbance process in the yellow pine and mixed pine-hardwood forests of the Appalachian Mountains. Pages 123–146 *in* C. H. Greenburg and B. S. Collins, editors. Natural disturbances and historic range of variation. Springer International Publishing Switzerland.

Guyette, R. P., D. C. Dey, M. C. Stambaugh, and R.-M. Muzika. 2006. Fire scars reveal variability and dynamics of eastern fire regimes. Pages 20–39 *in* M. B. Dickinson, editor. Fire in Eastern Oak Forests: Delivering Science to Land Managers. USDA Forest Service, Northern Research Station, Newtown Square, PA.

Haluska, Barrar, Benninghoff, Beyer, Carroll, Fleck, Godshall, Goodman, Hutchinson, Levdansky, Readshaw, Rohrer, Siptroth, Staback, Brennan, Walko, Watson, Geist, K. Smith, Kortz, and Caltagirone. 2009. Prescribed Burning Practices Act. Pennsylvania General Assembly.

Hanberry, B. B., D. C. Dey, and H. S. He. 2012. Regime shifts and weakened environmental gradients in open oak and pine ecosystems. PLoS ONE 7:e41337.

Hanberry, B. B., R. F. Noss, H. D. Safford, S. K. Allison, and D. C. Dey. 2015. Restoration is preparation for the future. Journal of Forestry 113:425–429.

Harper, C. A., W. M. Ford, M. A. Lashley, C. E. Moorman, and M. C. Stambaugh. 2016. Fire effects on wildlife in the Central Hardwoods and Appalachian regions, USA. Fire Ecology 12:127–159.

Hart, J. L., and M. L. Buchanan. 2012. History of fire in eastern oak forests and implications for restoration. Pages 34–51 *in* D. C. Dey, M. C. Stambaugh, S. L. Clark, and C. J. Schweitzer, editors. Proceedings of the 4th Fire in Eastern Oak Forests Conference. USDA Forest Service, Northern Research Station, Newtown Square, PA.

Higgs, E., D. A. Falk, A. Guerrini, M. Hall, J. Harris, R. J. Hobbs, S. T. Jackson, J. M. Rhemtulla, and W. Throop. 2014. The changing role of history in restoration ecology. Frontiers in Ecology and the Environment 12:499–506.

Hobbs, R. J., E. Higgs, C. M. Hall, P. Bridgewater, F. S. Chapin, E. C. Ellis, J. J. Ewel, L. M. Hallett, J. Harris, K. B. Hulvey, S. T. Jackson, P. L. Kennedy, C. Kueffer, L. Lach, T. C. Lantz, A. E. Lugo, J. Mascaro, S. D. Murphy, C. R. Nelson, M. P. Perring, D. M. Richardson, T. R. Seastedt, R. J. Standish, B. M. Starzomski, K. N. Suding, P. M. Tognetti, L. Yakob, and L. Yung. 2014. Managing the whole landscape: historical, hybrid, and novel ecosystems. Frontiers in Ecology and the Environment 12:557–564.

Holzmueller, E. J., J. W. Groninger, and C. M. Ruffner. 2014. Facilitating oak and hickory regeneration in mature central hardwood forests. Forests 5:3344–3351.

Holzmueller, E. J., S. Jose, and M. A. Jenkins. 2009. The response of understory species composition, diversity, and seedling regeneration to repeated burning in Southern Appalachian oak-hickory forests. Natural Areas Journal 29:255–262.

Hromada, S. J., C. A. F. Howey, M. B. Dickinson, R. W. Perry, W. M. Roosenburg, and C. M. Gienger. 2018. Response of reptile and amphibian communities to the reintroduction of fire in an oak/hickory forest. Forest Ecology and Management 428:1–13.

Huddle, J. A., and S. G. Pallardy. 1999. Effect of fire on survival and growth of *Acer rubrum* and *Quercus* seedlings. Forest Ecology and Management 118:49–56.

Hutchinson, T. F., R. P. Long, R. D. Ford, and E. K. Sutherland. 2008. Fire history and the establishment of oaks and maples in second-growth forests. Canadian Journal of Forest Research 38:1184–1198.

Hutchinson, T. F., R. P. Long, J. Rebbeck, E. K. Sutherland, and D. A. Yaussy. 2012. Repeated prescribed fires alter gap-phase regeneration in mixed-oak forests. Canadian Journal of Forest Research 42:303–314.

Hutchinson, T. F., E. K. Sutherland, and D. A. Yaussy. 2005. Effects of repeated prescribed fires on the structure, composition, and regeneration of mixed-oak forests in Ohio. Forest Ecology and Management 218:210–228.

Iverson, L. R., T. F. Hutchinson, A. M. Prasad, and M. P. Peters. 2008. Thinning, fire, and oak regeneration across a heterogeneous landscape in the eastern U.S.: 7-year results. Forest Ecology and Management 255:3035–3050.

Johnson, M. C., M. C. Kennedy, and D. L. Peterson. 2011. Simulating fuel treatment effects in dry forests of the western United States: testing the principles of a fire-safe forest. Canadian Journal of Forest Research 41:1018–1030.

Johnson, M. C., D. L. Peterson, and C. L. Raymond. 2007. Managing forest structure and fire hazard — a tool for planners. Journal of Forestry 105:77–83.

Johnstone, J. F., C. D. Allen, J. F. Franklin, L. E. Frelich, B. J. Harvey, P. E. Higuera, M. C. Mack, R. K. Meentemeyer, M. R. Metz, G. L. W. Perry, T. Schoennagel, and M. G. Turner. 2016. Changing disturbance regimes, ecological memory, and forest resilience. Frontiers in Ecology and the Environment 14:369–378.

Johnstone, J. F., E. J. B. McIntire, E. J. Pedersen, G. King, and M. J. F. Pisaric. 2010. A sensitive slope: estimating landscape patterns of forest resilience in a changing climate. Ecosphere 1:Article 14.

Keane, R. E., M. Austin, C. Field, A. Huth, M. J. Lexer, D. Peters, A. Solomon, and P. Wyckoff. 2001. Tree mortality in gap models: application to climate change. Climatic Change 51:509–540.

Keyser, T. L., M. Arthur, and D. L. Loftis. 2017. Repeated burning alters the structure and composition of hardwood regeneration in oak-dominated forests of eastern Kentucky, USA. Forest Ecology and Management 393:1–11.

Keyser, T. L., C. H. Greenberg, and W. H. McNab. 2019. Season of burn effects on vegetation structure and composition in oak-dominated Appalachian hardwood forests. Forest Ecology and Management 433:441–452.

Kitzberger, T., E. Aráoz, J. H. Gowda, M. Mermoz, and J. M. Morales. 2012. Decreases in fire spread probability with forest age promotes alternative community states, reduced resilience to climate variability and large fire regime shifts. Ecosystems 15:97–112.

Knapp, B. O., M. A. Hullinger, and J. M. Kabrick. 2017. Effects of fire frequency on long-term development of an oak-hickory forest in Missouri, U.S.A. Forest Ecology and Management 387:19–29.

Knapp, B. O., K. Stephan, and J. A. Hubbart. 2015. Structure and composition of an oak-hickory forest after over 60 years of repeated prescribed burning in Missouri, U.S.A. Forest Ecology and Management 344:95–109.

Knott, J. A., J. M. Desprez, C. M. Oswalt, and S. Fei. 2019. Shifts in forest composition in the eastern United States. Forest Ecology and Management 433:176–183.

Kreye, J. K., J. M. Varner, G. W. Hamby, and J. M. Kane. 2018. Mesophytic litter dampens flammability in fire-excluded pyrophytic oak-hickory woodlands. Ecosphere 9:e02078.

Kuddes-Fischer, L. M., and M. A. Arthur. 2002. Response of understory vegetation and tree regeneration to a single prescribed fire in oak-pine forests. Natural Areas Journal 22:43–52.

Lafon, C. W., and H. D. Grissino-Mayer. 2007. Spatial patterns of fire occurrence in the central Appalachian Mountains and implications for wildland fire management. Physical Geography 28:1–20.

Lafon, C. W., A. T. Naito, H. D. Grissino-Mayer, S. P. Horn, and T. A. Waldrop. 2017. Fire history of the Appalachian region: a review and synthesis. Gen. Tech. Rep. SRS-219. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC. 97p.

Lafon, C. W., J. D. Waldron, D. M. Cairns, M. D. Tchakerian, R. N. Coulson, and K. D. Klepzig. 2007. Modeling the effects of fire on the long-term dynamics and restoration of yellow pine and oak forests in the southern Appalachian Mountains. Restoration Ecology 15:400–411.

Lashley, M. A., M. C. Chitwood, A. Prince, M. B. Elfelt, E. L. Kilburg, C. S. DePerno, and C. E. Moorman. 2014. Subtle effects of a managed fire regime: a case study in the longleaf pine ecosystem. Ecological Indicators 38:212–217.

Lauvaux, C. A., C. N. Skinner, and A. H. Taylor. 2016. High severity fire and mixed conifer forest-chaparral dynamics in the southern Cascade Range, USA. Forest Ecology and Management 363:74–85.

Levin, S. A., and R. T. Paine. 1974. Disturbance, patch formation, and community structure. Proceedings of the National Academy of Sciences 71:2744–2747.

Little, S. 1946. The effects of forest fires on the stand history of New Jersey's pine region. Forest Management Paper No. 2. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA. 43p.

Little, S. 1979. Fire and plant succession in the New Jersey Pine Barrens. Pages 297–314 *in* R. T. T. Forman, editor. Pine Barrens: Ecosystem and Landscape. Academic Press, New York.

Little, S., and E. B. Moore. 1949. The ecological role of prescribed burns in the pine-oak forests of southern New Jersey. Ecology 30:223–233.

Loudermilk, E. L., R. M. Scheller, P. J. Weisberg, and A. Kretchun. 2017. Bending the carbon curve: fire management for carbon resilience under climate change. Landscape Ecology 32:1461–1472.

Marschall, J. M., M. C. Stambaugh, B. C. Jones, R. P. Guyette, P. H. Brose, and D. C. Dey. 2016. Fire regimes of remnant pitch pine communities in the Ridge and Valley region of central Pennsylvania, USA. Forests 7:1–16.

Matlack, G. R. 2013. Reassessment of the use of fire as a management tool in deciduous forests of eastern North America. Conservation Biology 27:916–926.

McEwan, R. W., T. F. Hutchinson, R. P. Long, D. R. Ford, and B. C. McCarthy. 2007. Temporal and spatial patterns in fire occurrence during the establishment of mixed-oak forests in eastern North America. Journal of Vegetation Science 18:655–664.

McGee, G. G., D. J. Leopold, and R. D. Nyland. 1995. Understory response to springtime prescribed fire in two New York transition oak forests. Forest Ecology and Management 76:149–168.

Noonan-Wright, E. K., N. M. Vaillant, and A. L. Reiner. 2014. The effectiveness and limitations of fuel modeling using the Fire and Fuels Extension to the Forest Vegetation Simulator. Forest Science 60:231–240.

Nowacki, G. J., and M. D. Abrams. 2008. The demise of fire and "mesophication" of forests in the eastern United States. BioScience 58:123–138.

Olson, M. G. 2011. Tree regeneration in oak–pine stands with and without prescribed fire in the New Jersey Pine Barrens: management implications. Northern Journal of Applied Forestry 28:47–49.

Perera, A. H., and W. Cui. 2010. Emulating natural disturbances as a forest management goal: lessons from fire regime simulations. Forest Ecology and Management 259:1328–1337.

PlantMaps. https://www.plantmaps.com.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Rebain, S. A. 2010. The Fire and Fuels Extension to the Forest Vegetation Simulator: Updated model documentation. Internal Rep. U.S. Department of Agriculture, Forest Service, Forest Management Service Center, Fort Collins, CO. 403p. (Revised: March 23, 2015)

Royse, J., M. A. Arthur, A. Schörgendorfer, and D. L. Loftis. 2010. Establishment and growth of oak (*Quercus alba*, *Quercus prinus*) seedlings in burned and fire-excluded upland forests on the Cumberland Plateau. Forest Ecology and Management 260:502–510.

Ryan, K. C., E. E. Knapp, and J. M. Varner. 2013. Prescribed fire in North American forests and woodlands: history, current practice, and challenges. Frontiers in Ecology and the Environment 11:e15–e24.

Schaffhauser, A., T. Curt, and T. Tatoni. 2008. The resilience ability of vegetation after different fire recurrences in Provence. WIT Transactions on Ecology and the Environment 119:297–310.

Scheller, R. M., S. Van Tuyl, K. Clark, N. G. Hayden, J. Hom, and D. J. Mladenoff. 2008. Simulation of forest change in the New Jersey Pine Barrens under current and pre-colonial conditions. Forest Ecology and Management 255:1489–1500.

Scheller, R. M., S. Van Tuyl, K. L. Clark, J. Hom, and I. La Puma. 2011. Carbon sequestration in the New Jersey Pine Barrens under different scenarios of fire management. Ecosystems 14:987–1004.

Schwenk, W. S., T. M. Donovan, W. S. Keeton, and J. S. Nunery. 2012. Carbon storage, timber production, and biodiversity: comparing ecosystem services with multi-criteria decision analysis. Ecological Applications 22:1612–1627.

Scott, J. H., and R. E. Burgan. 2005. Standard fire behavior fuel models: a comprehensive set for use with Rothermel's surface fire spread model. Gen. Tech. Rep. RMRS-GTR-153. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO. 72 p.

Seidl, R., W. Rammer, and T. A. Spies. 2014. Disturbance legacies increase the resilience of forest ecosystem structure, composition, and functioning. Ecological Applications 24:2063–2077.

Seidl, R., T. A. Spies, D. L. Peterson, S. L. Stephens, and J. A. Hicke. 2016. Searching for resilience: addressing the impacts of changing disturbance regimes on forest ecosystem services. Journal of Applied Ecology 53:120–129.

Seli, R. C., A. A. Ager, N. L. Crookston, M. A. Finney, B. Bahro, J. K. Agee, and C. W. McHugh. 2007. Incorporating landscape fuel treatment modeling into the Forest Vegetation Simulator. Pages 27–39 *in* R. N. Havis and N. L. Crookston, editors. Third Forest Vegetation Simulator Conference. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Shive, K. L., P. Z. Fulé, C. H. Sieg, B. A. Strom, and M. E. Hunter. 2014. Managing burned landscapes: evaluating future management strategies for resilient forests under a warming climate. International Journal of Wildland Fire 23:915–928.

Signell, S. A., M. D. Abrams, J. C. Hovis, and S. W. Henry. 2005. Impact of multiple fires on stand structure and tree regeneration in central Appalachian oak forests. Forest Ecology and Management 218:146–158.

Somes, H. A., and G. R. Moorhead. 1950. Prescribed burning does not reduce yield from oak-pine stands of southern New Jersey. Station Paper No. 36. U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA. 19p.

Stambaugh, M. C., J. M. Marschall, E. R. Abadir, B. C. Jones, P. H. Brose, D. C. Dey, and R. P. Guyette. 2018. Wave of fire: an anthropogenic signal in historical fire regimes across central Pennsylvania, USA. Ecosphere 9:e02222.

Stambaugh, M. C., J. M. Marschall, E. R. Abadir, B. C. Jones, P. H. Brose, D. C. Dey, and R. P. Guyette. 2019. Successful hard pine regeneration and survival through repeated burning: an applied historical ecology approach. Forest Ecology and Management 437:246–252.

Stambaugh, M. C., J. M. Varner, R. F. Noss, D. C. Dey, N. L. Christensen, R. F. Baldwin, R. P. Guyette, B. B. Hanberry, C. A. Harper, S. G. Lindblom, and T. A. Waldrop. 2015. Clarifying the role of fire in the deciduous forests of eastern North America: reply to Matlack. Conservation Biology 29:942–946.

Swetnam, T. W., C. D. Allen, and J. L. Betancourt. 1999. Applied historical ecology: using the past to manage for the future. Ecological Applications 9:1189–1206.

Turner, M. G. 2010. Disturbance and landscape dynamics in a changing world. Ecology 91:2833–2849.

USDA Forest Service. 2018. FIA DataMart: FIADB_1.7.0.01. Last updated March 14. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA. https://apps.fs.usda.gov/fia/datamart/datamart.html (accessed March 26, 2018).

Vaillant, N. M., A. L. Reiner, and E. K. Noonan-Wright. 2013. Prescribed fire effects on field-derived and simulated forest carbon stocks over time. Forest Ecology and Management 310:711–719.

Vankat, J. L. 1979. The Natural Vegetation of North America: An Introduction. Wiley.

Varner, J. M., M. A. Arthur, S. L. Clark, D. C. Dey, J. L. Hart, and C. J. Schweitzer. 2016. Fire in eastern North American oak ecosystems: filling the gaps. Fire Ecology 12:1–6.

Vickers, L. A., W. H. McWilliams, B. O. Knapp, A. W. D'Amato, M. R. Saunders, S. R. Shifley, J. M. Kabrick, D. C. Dey, D. R. Larsen, and J. A. Westfall. 2019. Using a tree seedling mortality budget as an indicator of landscape-scale forest regeneration security. Ecological Indicators 96:718–727.

Vose, J. M., and K. J. Elliott. 2016. Oak, fire, and global change in the eastern USA: What might the future hold? Fire Ecology 12:160–179.

Wacker, P. O. 1979. Human exploitation of the New Jersey Pine Barrens before 1900. Pages 3–23 *in* R. T. T. Forman, editor. Pine Barrens: Ecosystem and Landscape. Academic Press, New York.

Wright, H. E. 1974. Landscape development, forest fires, and wilderness management. Science 186:487–495.

APPENDIX A – Data Collection Protocols

Appendix Figure 1. Data collection protocol corresponding to the Pennsylvania Department of Conservation and Natural Resources (DCNR) Bureau of Forestry Continuous Forest Inventory (CFI). *Source: Commonwealth of Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry – Inventory Manual of Procedure for the 2003 State Forest Plan – Inventory of Biological Resources (Phase 3), June, 2003 (Revised March 9, 2006).*

III. PLOT LEVEL DATA

The collected data includes both qualitative and quantitative measurements that describe stand age, forest health, disturbance, landform, topographic position, site attributes and general vegetative structure of the forest type in which the plot is located. Data are recorded from the center of the $1/5^{th}$ acre plot. Some of these items are to be specifically attributed to the area inside the plot while others are to include the surrounding stand in which the plot is located. If the plot is being remeasured and is now part of a silvicultural treatment, visibly a clearcut or seed tree cut, see the section **What to do When a Plot has Been Cut** on page 15.

Item 1. **Ecological Region**

Record the appropriate code for the ecological region in which the plot is located. See codes list in Appendix B.

Item 2. **State Forest District Number**

Record the district number in which the plot is located.

Item 3. **Plot Number**

New plots will be numbered consecutively by ecological region. The plot number will be a 5-digit integer with the following format: EE###. Where EE is the 2 digit ecological region number and ### is a 3 digit plot number beginning with 001 for the first plot of each ecological unit.

This number should not be changed on remeasured plots.

Item 4. **Date of Measurement**

Record the month, day, and year the fieldwork is completed (e.g. 06/30/2002).

Item 5. **Crew Identification**

Enter your crew name.

Item 6. **Plot Measurement Sequence Number**

Enter a 1 for new plots.

Increment the previous occasion number by 1 for remeasured plots.

Item 7. **Stand Age**

Determine stand age from three borings of representatives of the “main stand” i.e., dominant and codominant growing stock trees on or near the plot location. In stands having more than one age class, classify the stand by the age class comprising 50 percent or more of the stocking. If no age class comprises 50 percent or more of the stocking, classify the stand as mixed age.

CODE	AGE CLASS	CODE	AGE CLASS
02	1 - 20 years	14	121 - 140 years
04	21 - 40 years	16	141 - 160 years
06	41 - 60 years	18	161 - 180 years
08	61 - 80 years	50	mixed ages

10	81 - 100 years
12	101 - 120 years

Item 8. **<u>Stand Structure</u>**

Determine which code describes the basic form of <u>the trees in the stand</u> in which the plot resides.

<u>CODE & DESCRIPTION</u>

1. <u>Single-storied</u>: stands characterized by an even canopy of uniform height with close competition between trees. The smaller trees are usually members of the stand that were stressed or overtopped and have fallen behind their associates. Regeneration and/or tall relics from a previous stand may be present. Most of the trees in the stand are within the height class of the average stand height.

2. <u>Two-storied</u>: stands composed of two relatively even but distinct canopy layers, such as a mature overstory with an understory sapling layer, possibly from seed tree or shelterwood operations, or an overstory of tall conifers with an understory of low hardwoods. Neither canopy is necessarily continuous or closed, but both canopy levels tend to be uniformly distributed across the stand. Each canopy level must cover at least 25 percent of the stand.

3. <u>Multi-storied:</u> stands generally containing trees from every size group on a continuum from seedlings to mature trees and are characterized by a broken or uneven canopy layer. Usually the largest number of trees is in the smaller diameter classes. Consider any stand with three or more structural layers as multi-storied if each of the three or major layers covers at least 25 percent of the stand.

4. <u>Mosaic:</u> stands contain at least two distinct size classes each of which covers at least 25 percent of the stand; however, these classes are not uniformly distributed but are grouped in small repeating aggregations, or occur in stringers less than 120 feet wide, throughout the stand. Each size class aggregation is too small to be recognized and mapped as an individual stand; the aggregations may not be single-storied.

Item 9. **<u>Percent Slope</u>.**

Record the percent slope of the terrain at the plot center. In order to avoid microsite conditions, the slope should be taken over a span of at least 100 feet across the 1/5th acre plot. The slope measurement should be taken in the same direction as the aspect for the point. Record actual percent slope as a two-digit integer value except: record 00 when the slope is less than 5%.

Item 10. **<u>Aspect</u>**

Aspect is the exposure for the land surfaces that are not horizontal. It is the direction towards which the slope faces. Determine and record the aspect of the terrain at plot center. To avoid microsite conditions, a distance of 100 feet, across the 1/5th acre plot, is the minimum span over which aspect should be determined. The compass sighting should be downhill in the same direction as the slope of the terrain. Use a three-digit integer to record aspect to the nearest degree except: record 000 when there is no aspect (slope of terrain is less than 5% and record 360 for a north aspect.

Item 11. <u>Terrain Position</u>

Terrain Position is the location of the plot center along the slope profile. Select the terrain position that best relates the 1/5th acre plot to the slope profile. To avoid microsite conditions, a distance of 100 feet is the minimum span to consider.

Code	Terrain Position
1	Top of Slope (convex)
2	Upper Slope (convex)
3	Mid-slope (uniform angle)
4	Bench (slope deviation)
5	Lower Slope (concave)
6	Bottomland (horizontal)
7	Flatland (areas not part of or related to the slope)

See Figure 1 on page 27, Terrain Position and Slope Profile, for definitions.

Item 12. <u>Physiographic Class</u>

Landform, topographic position, and soil generally determine physiographic class. As a rule of thumb, look out over 100 feet from the 1/5th acre plot center to determine physiographic class and always use your best judgment when assessing the surrounding area.

Xeric Sites that are normally low or deficient in moisture available to support vigorous tree growth. These areas may receive adequate precipitation, but experience a rapid loss of available moisture due to runoff, percolation, evaporation, etc.

11 <u>Dry Tops</u> - Ridge tops with thin rock outcrops and considerable exposure to sun and wind.

12 <u>Dry Slopes</u> - Slopes with thin rock outcrops and considerable exposure to sun and wind. Includes most steep slopes with a southern or western exposure.

13 <u>Deep Sands</u> - Sites with a deep, sandy surface subject to rapid loss of moisture following precipitation. Typical examples include sand hills, sites along the beach and shores of lakes and streams, and many deserts.

19 <u>Other Xeric</u> - All dry physiographic sites not described above.

Mesic Sites that have moderate but adequate moisture available to support vigorous tree growth except for periods of extended drought. These sites may be subjected to occasional flooding during periods of heavy or extended precipitation.

21 Flatwoods - Flat or fairly level sites outside flood plains. Excludes deep sands and wet, swampy sites.

22 Rolling Uplands - Hills and gently rolling, undulating terrain and associated small streams. Excludes deep sands, all hydric sites, and streams with associated flood plains.

23 Moist Slopes and Coves - Moist slopes and coves with relatively deep, fertile soils. Often these sites have a northern or eastern exposure and are partially shielded from wind and sun. Includes moist mountaintops and saddles.

24 Narrow Flood Plains / Bottomlands - Flood plains and bottomlands, less than ¼-mile in width, along rivers and streams. These sites are normally well drained but are subjected to occasional flooding during periods of heavy or extended precipitation. Includes associated levees, benches, and terraces within a ¼-mile limit. Excludes swamps, sloughs, and bogs.

25 Broad Flood Plains / Bottomlands - Flood plains and bottomlands, ¼-mile or wider in width, along rivers and streams. These sites are normally well drained but are subjected to occasional flooding during periods of heavy or extended precipitation. Includes associated levees, benches, and terraces. Excludes swamps, sloughs, and bogs with year-round water problems.

29 Other Mesic - All moderately moist physiographic sites not described above.

Hydric Sites that generally have a year-round abundance or over-abundance of moisture. Hydric sites are very wet sites where excess water seriously limits both growth and species occurrence.

31 Swamps / Bogs - Low, wet, flat forested areas usually quite extensive that are flooded for long periods of time except during periods of extreme drought. Excludes cypress ponds and small drains.

32 Small Drains - Narrow, stream-like, wet strands of forestland often without a well-defined stream channel. These areas are poorly drained or flooded throughout most of the year and drain the adjacent higher ground.

34 Beaver ponds

39 Other hydric - All other hydric physiographic sites.

Item 13. Carvell-Perkey Site Class

This method of site classification was taken from Carvell and Perkey (1997). Five site classes, or productivity classes are recognized based on aspect and slope position. A color figure of the topographic representation of aspect and slope position by site class is located in Appendix H. Use that figure along with your determination of percent slope, aspect, terrain position, and physiographic class to select one of the following site class codes.

Site Class Code	Site Class	Aspect & Slope Position
1	Hydric / moist mesic	Lower-third, NE facing slopes; Bottomlands
2	Mesic	Middle-third, NE facing slopes; Lower-third, NW & SE facing slopes
3	Dry mesic	Upper-third, NE facing slopes; Middle-third, NW & SE facing slopes; Lower-third, SW facing slopes
4	Dry	Upper-third, NW & SE facing slopes; Middle-third, SW facing slopes
5	Xeric	Upper-third, SW facing slopes; Ridgetops

Item 14. Forest Community Classification

For **new plots** record the management map values for:

15a forest community type
15b site class
15c size/stocking class

Use the current type, site, size /stocking class designations (see Phase I of Inventory Manual of Procedure, 1997).

For **remeasured plots** this field will contain information from the previous sampling occasion. The only field that may need to be changed is 15c, the size/stocking class.

Item 15. Past Treatment

Record any apparent silvicultural treatment that has been applied to the stand during the past 15-year period for new plots and the past 5-year period for remeasured plots.

Code	Treatment	Code	Treatment
0	Haul roads	7	Seed Tree
1	Clear-cut	8	Thinning
2	Improvement	9	Right-of-way
3	Seed tree removal	A	Salvage treatment(s)

4	Shelterwood removal	N	Natural disturbance
5	Selection	X	No treatment
6	Shelterwood	O	Other explain in remarks

If natural disturbance (N), describe in plot remarks field. A list of these codes are available on board the data collector by pressing the F2 key when the cursor is in the past treatment field.

Item 16. Deer Impact

Estimate the amount of browsing pressure that deer are likely to exert on regeneration. Deer impact is a function of the deer population and the amount of available food sources within the acre surrounding the sample point.

Code & Description

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

Item 17. Forest Health Rating

Characterize the health of multiple resource, commercial stands greater than 40 years of age. This rating applies to the stand in which the plot resides. To apply this rating correctly six stand factors must be considered; 1) the condition of tree crowns, 2) overstory mortality, 3) the confirmed occurrence of seedling, saplings, poles, and large trees, 4) the occurrence of site suitable species, 5) the presence/absence of exotic/invasive species, and 6) the presence/absence of environmental damage.

Code Description

5. Very Healthy

a) Crown conditions are good throughout the stand and only minor dieback and dead branches are noticeable.
b) Overstory mortality is less than 1% and dead trees are scattered and are of a variety of ages.
c) Seedlings, saplings, poles, and large trees are all present (except if the stand is a young plantation or recently regenerated stand.
d) A variety of species suitable to the site are present, except n a young plantation.
e) No exotic or invasive species appear to present.
f) No environmentally damage or significant damage causing agents are evident.

4. Healthy

a) Some thin crowns or dieback and/or branch mortality is noticeable.
OR
b) Overstory mortality is more than 1% but less than 20%

OR

c) Seedlings and sapling stages are not fully represented.
OR

d) Variety of suitable species not present (except in young plantations).
OR

e) Some exotic or invasive species are present that might impact the stand.
OR

f) Some environmentally caused damage or noticeable causing agents are present.

3. Moderately Healthy
Classify here if any two of category 4 factors are true

2. Moderately Unhealthy

a) Thin crowns or significant dieback and/or branch mortality are evident.
OR

b) Overstory mortality is more than 20% but less than 50%.
OR

c) Regeneration is rare or not present.
OR

d) Unsuitable species for the site or lack of diversity is apparent (except for younh plantations).
OR

e) Exotic or invasive species are impacting the stand.
OR

f) Environmentally caused damage or damage causing agents have impacted the stand.

1. Unhealthy
Classify here if any two of the category 2 factors are true.

0. Not Applicable
Stand is <40 years of age or not a multiple resource, commercial stand.

Item 18. **<u>Disturbance1</u>**

Record the code corresponding to the presence of the following disturbances. Disturbance can indicate positive or negative effects. The area affected by any natural or human-caused disturbance must be at least one acre in size. Record up to three different disturbances from the most important to lesser important as best as can be determined. Record only on forested plots. The disturbance must have occurred in the last five years.

Some of the disturbance codes below require ”any visible evidence” others require “significant threshold”. Significant threshold implies:

1. Mortality and/or damage to 25 percent of individual trees, serious enough to meet minimum threshold requirements, and

2. 25% of all trees in the stand are impacted.

Code		Meaning
00		None – No observable disturbance
10		Insects – Significant threshold damage from insects.
20		Disease - Significant threshold damage from disease.
30		Weather - Significant threshold damage from weather other than the following.
	31	Ice - Significant threshold damage from ice
	32	Wind - Significant threshold damage from wind (includes hurricane and tornado).
	33	Flooding - Significant threshold damage from weather induced flooding.
	34	Drought - Significant threshold damage from drought.
40		Fire – Any visible evidence of crown and ground fire, either prescribed or natural.
	41	Ground fire – Any visible evidence of ground fire.
	42	Crown fire – Any visible evidence of crown fire.
50		Domestic animal – Any evidence of domestic livestock.
60		Wild animal - Significant threshold damage from wild animals other than the following:
	61	Beaver - Significant threshold damage from beaver includes flooding.
	62	Porcupine - Significant threshold damage from porcupines
	63	Deer – Deer Impact (see item 16) is high or very high.
70		Human - Significant threshold damage from human-caused damage (e.g. ATV)
80		Other natural - Significant threshold natural damage not described by the above codes (describe it in the remarks field).

Item 19. **Disturbance2**

If stand has experienced more than one disturbance, record the second disturbance here.

Item 20. **Disturbance3**

If stand has experienced more than two disturbances, record the third disturbance here.

Item 21. **Low Evergreen Cover**

Based on the one-fifth acre plot, record coverage class in low, woody evergreen cover with a one-digit code. Low evergreen cover is 1-10 ft. in height and includes such species as mountain laurel and rhododendron or conifers with live limbs touching or close to the ground.

CODE	% COVERAGE
0	0
1	1 - 10
2	11 - 50
3	51 - 90

4	91 - l00

Item 22. **High Evergreen Cover**

Based on the one-fifth acre plot, record coverage class in high, woody evergreen cover with a one-digit code. High evergreen cover is defined as live coniferous trees greater than 10 ft. in height and providing aerial cover.

CODE	% COVERAGE
0	0
1	1 - 10
2	11 - 50
3	51 - 90
4	91 - l00

Item 23. **Grasses & Sedges**

Based on the one-fifth acre plot, record coverage class in grass-like herbaceous vegetation. Grasses can be defined as low (< 3 ft.) grass-like species such as grasses, sedges and rushes.

CODE	% COVERAGE
0	0
1	1 - 10
2	11 - 50
3	51 - 90
4	91 - l00

Item 24. **Forbs**

Based on the one-fifth acre plot, record coverage class in non-grasslike herbaceous vegetation. Forbs are any herbaceous vegetation (< 3-ft.) that is not considered grass-like or ferns.

CODE	% COVERAGE
0	0
1	1 - 10
2	11 - 50
3	51 - 90
4	91 - l00

Item 25. **Ferns**

Based on the one-fifth acre plot, record coverage class in ferns. Ferns are herbaceous non-flowering plants do not include sweetfern

CODE	% COVERAGE
0	0
1	1 - 10
2	11 - 50
3	51 - 90
4	91 - l00

Item 26. **Deciduous Shrubs**

Based on the one-fifth acre plot, record coverage class in low, woody deciduous trees or shrubs. Low deciduous shrubs include tree and shrub species < 15 ft. in height.

CODE	% COVERAGE
0	0
1	1 - 10
2	11 - 50
3	51 - 90
4	91 - l00

Item 27. **Coarse Woody Debris**

The field generates a random number that determines the direction of the woody debris transect line.

0 = 0°

1 = 72°

2 = 144°

3 = 216°

4 = 288°

Item 28. **Remarks**

Record any remarks on the data recorder.

Record any other herbaceous plants and shrubs not present on the mil acre plots that might be of diagnostic value.

V. OVERSTORY DATA - 1/5th acre plot

Trees at least 4.5 inches in diameter and 4.5 feet in length are sampled within the 1/5th acre plot (52.7 foot radius). Tally trees are defined as all live and standing dead trees encountered when the plot is first established, and all trees that grow into the plot thereafter. Trees are alive if they have any living parts (leaves, buds, cambium) at or above the point of diameter measurement. Trees that have been temporarily defoliated are still alive. Once tallied, dead trees over 4.5 inches in diameter are tracked until they fall down and have disintegrated, no evidence remaining.

The current 2003-2007 cycle is the first cycle that Tree Condition (Item 10) will be recorded. This code now permits trees to be tracked from standing live through standing dead, down dead, and down dead decayed. When establishing new plots only live and standing dead trees with a tree condition of 1 through 5 should be tallied. Valid dead tally trees on previously established plots arise from two circumstances. The previous tree history was either a survivor or ingrowth and is now dead or the previous tree history was dead. If the first case is true any of the five dead condition codes (4,5,6,7,8) may apply. If the second case is true codes 4, 5, and 6 are most likely. A new tree history code of 40 (dead tree, standing or down but still present) is appropriate in either case except if tree condition 6 was chosen. If the dead down tree (tree condition 6) is in advanced state of decay then a new tree history of 41, instead of 40, will indicate that the dead tree will no longer be tracked in future inventories.

Working around dead trees is a safety hazard - crews should exercise extreme caution. Trees that are deemed unsafe to measure should be noted as such and left alone.

Broken portions of trees that are completely separated from their base are not treated as separate trees. Whether live or dead, standing trees do not have to be self-supporting. They may be supported by other trees. High stumps (trees that have been cut) do not qualify as standing dead trees. To qualify as a standing dead tally tree, dead trees must be upright, at least 4.5 feet tall and be at least 4.5 inches in diameter.

Trees with a diameter at least 1.0 inch but less than 4.5 inches are termed mid canopy trees and are sampled within the 1/20th acre subplot (see section VI).

Item 1. Ecological Region

Record the appropriate ecological region in which this plot is located. This code will automatically be repeated on each new record by the data collection program.

Item 2. State Forest District Number

Record the district number in which the plot is located. This code will automatically be repeated on each new record by the data collection program.

Item 3. Plot Number

Record the same plot number as that of the 1/5th acre plot, item 3 of Plot Level Data (page 17).

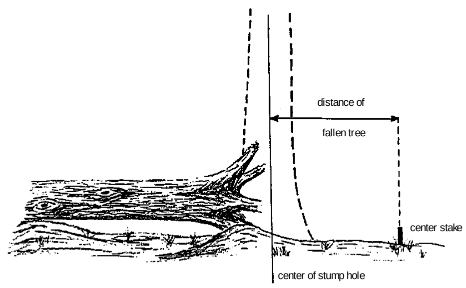
Item 4. Tree Number

New plots:

Record a unique five-digit number to permanently identify each tree on the 1/5th acre plot. A tree is determined to be "in" or "out" of the plot radius (52.7 feet) by measuring the horizontal distance from plot center to the pith of the tree at the base.

A leaning tree is determined to be "in" or "out" of the plot radius by measuring the horizontal distance from plot center, to the center of the tree at the base. The direction that the tree leans is of no consequence.

For a down and wind-thrown tree measure the horizontal distance to the spot where the center of the tree would have been if the tree was still standing; i.e., measure the distance to the center of the stump, or ground cavity.



Begin measurement starting with the first tree to the right of 0 degree azimuth and proceed clockwise to the other trees working outwards from plot center to the plot edge. On new plots trees will be numbered by hundreds - for example, tree no. 1 will be 00100; tree number 2 will be 00200; and tree number 13 will be 01300, and so forth (note it is not necessary to enter the leading zeros on the data-collector). See page 48 item 19 for off plot site tree numbering.

Remeasured plots:
For remeasured trees this number will be displayed on the data collector. Ingrowth trees will be recorded by choosing a unassigned number between the two previously measured trees that it occurs. For example, an ingrowth tree occurring between tree numbers 01200 and 01300 would be assigned a number between 01201 and 01299. The exact number chosen should depend upon which of the previously measured trees is closest to the ingrowth tree. Also try to take into account other mid canopy-sized trees that may later become ingrowth trees. When using a data collector it will be necessary to use the copy, paste, and clear commands to insert a blank ingrowth tree record between the two existing tree records.

Item 5. Species

Record as a two or three-digit code using the standard species codes shown in the Appendix I. Use codes 17 for unknown dead conifers and 99 for unknown dead hardwoods when the exact species cannot be determined.
For remeasured plots this number will be displayed on data collector.

Items 6.1 to 6.5 Previous Tree Measurements

For remeasured plots only: the following measurements will be displayed on the data collector to help locate individual trees.

DBH, Tree History,
Pole timber height in number of 8 foot bolts to 4.0" top if previously pole,
Or
Saw timber height in number of 16-foot logs if previously sawtimber.
Percent Board Foot cull if tree was previously a saw timber tree.

Item 7. **Tree History**

Tree history describes the status of a tree during this inventory as compared to its status during the previous inventory. This is the key variable used to differentiate components of change between inventories. A list of tree histories used in previous inventories can be found in Appendix C.

On New Plots enter 00 for all live trees and 40 for all dead standing trees.
On Remeasured Plots assign a two-digit code for:

- Every tree that was tallied as a live tree at the last inventory if it had a DBH of 4.5 inches or greater.
- Every live tree with current DBH of 4.5 inches or greater that is being tallied for the first time during this inventory.
- Standing dead tree that is alive, but not large enough (4.5 inches DBH) to be tallied at the last survey, but which grew to 4.5 inches DBH or greater and died since the last inventory. These are dead ingrowth.
- Standing snag that was dead at the last occasion but are still standing. **Do not mistake a snag for dead ingrowth**.

Both for numbering purposes and for tree history, follow the trees consecutively in the original tally and record tree history as the plot is measured.

Survivors

Live, previously measured tree, or a tree that was a missed tree at the last occasion.

10 Same live tree -- was in before, is in now

12 Tree was missed at last survey -- should have been tallied but wasn't, is now tallied.

Tree History 15 and 16 apply to two or more stems that were fused from the base and that had a combined diameter measurement at 4.5 feet. Tree History 15 reconciles the old combined/fused stem. Tree History 16 accounts for stems (two or more) that are the result of the new diameter rules for fused trees.

15* Multiple stemmed tree -- the product of two (possibly more) previously measured trees **of the same species** that had grown together and the diameter was measured at 4.5 feet. These fused stems were treated as one tree. This code recondciles the previous tree only. (Used only in conjunction with code 16).

16* Multiple stemmed tree – one of two, or more, trees **of the same species** that were treated as one tree, but are now tallied as individual stems and the diameter measured at 4.5 feet. Accounts for the new stems from code 15 created by the new "Special DBH Situation" rule 8. (Used only in conjunction with code 15).

Tree History 17 and 18 apply to stems that fork above 4.5 feet and the diameter was measured at 4.5 feet or below where there was normal stem form. Tree History 17 reconciles the old single stem. Tree History 18 accounts for the new stems (two or more) that are the result of the new diameter rules for forked trees and the use of pith separation.

17* Multiple forked tree – the product of two (possibly more) stems that forked above 4.5 ft and were treated as one tree (used only in conjunction with code 18).

18* Multiple forked tree – one of two, or more, stems that the diameter measurement is now taken 3.5 ft above the point of pith separation (used only in conjunction with code 17).

19 Tree that is alive, but was incorrectly tallied as dead at the last occasion (limited to a tree with a **previous** tree class of 5 or 6).

*** Histories 15, 16, 17, and 18 may include dead trees.**

<u>Ingrowth</u> Tree that is correctly tallied for the first time,

20 Live tree, not previously measured.

21 Live or dead tree, that was tallied before but should not have been, and is a tally tree now.

24 Dead tree or snag, that was too small to tally before but has grown to tally size and died since the previous inventory, is a tally tree now.

25 Dead tree, should have been tallied, was missed, has since died, and is now tallied.

<u>Removals</u> Previously tallied tree that:
has been harvested, killed or presumed to have been harvested during a cultural operation (logging, land clearing, TSI work)

30 The location where the tree is, or was, is still forested land, the tree has been killed, it can be standing or down.

31 The location where the tree was is still forested, the tree has been removed (usually a stump will be present).

<u>Mortality</u> Previously tallied tree that has died since the last inventory.

40 Dead tree --standing or down-- tree is still present; when DBH measurement is not possible, or current DBH is smaller than the previous DBH, use previous DBH for current.

41 Dead, down, disintegrated, no evidence remaining; previously measured tree that has died, is down and is in advanced stages of decay or any previously measured tree that cannot be accounted for.

Other Trees

50 Tree that had a recorded horizontal distance of 52.0 feet or less, that now has a horizontal distance greater than 52.0 feet.

99 Off plot site trees.

Item 8. Diameter

Diameters are measured at breast height (DBH). Trees at least 4.5 inchs DBH and larger are measured. In order to accurately remeasure DBH at the same point on the tree bole on successive visits the point of measurement must be marked with a scribe or paint. See Appendix J, Using The Diameter Tape, for instructions on the proper methods of measuring DBH. When marking trees for the first time, measure the diameter after the mark is in place. Use caution to avoid damaging trees with scribes.

- Do not penetrate the cambium when using a bark scribe
- Do not scribe species vulnerable to introduction of pathogens such as aspen, americian chestnut, american elm.
- Do not scribe thin bark trees such as beech.

New trees: The diameter mark is located one-inch below where the diameter is taken, on the side of the tree facing the 1/5th acre plot center. If using a bark scribe or paint marker the mark should be horizontal and approximately two-inches long. Check for irregularities before making diameter marks. (See "*Specieal DBH Situations*" beginning on page 38.)

Remeasured trees: When remeasuring the diameter of a tree tallied at a previous visit, always take the measurement at the location marked by a previous crew unless it is not physically possible (e.g. tree partially buried), *or the previous location is more than 12 inches beyond where the diameter should be measured according to current protocols.* Assign a Diameter Check (item 6) code of 2 whenever the point of measurement is moved.

When reconciling dead trees and snags, if the current diameter is less than the previous diameter, record the previous diameter as the current diameter.

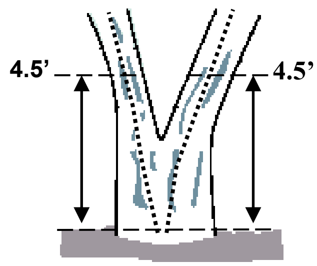
DBH: Unless one of the "*Special DBH Situations*" described on the following pages occurs, measure DBH at 4.5 feet above ground line on the uphill side of the tree. Record a 3-digit number for DBH, **rounding down to the last 1/10 inch**. Example: a 9.18" diameter tree would be recorded 091; a 22.43" tree as 224, etc.

Special DBH Situations:

1) **Forked tree:** In order to qualify as a fork, the stem in question must be at least 1/3 the diameter of the main stem and must branch out from the main stem at an angle of 45° or less. **Forks originate at the point on the bole where the piths intersect**. Forked trees are handled differently depending on whether the fork originates below 1.0 ft, between 1.0 and 4.5 ft, or above 4.5 ft.

- Trees forked below 1.0 ft. Trees forked in this region are treated as distinctly separate trees (Figure 2). DBH is measured for each stem at 4.5 ft above the ground. When stems originate from pith intersections below 1 ft, it is possible for some stems to be within the limiting distance of the 1/5th acre plot and others to be beyond the limiting distance. If stems originating from forks that occur below 1.0 ft and fork again between 1.0 and 4.5 ft, the DBH of each fork is measured at a point 3.5 ft above the pith intersection (Figure 13-B).

Figure 2. Forked below 1.0 ft

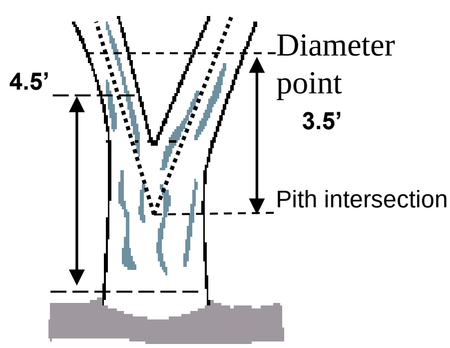


- Trees forked between 1.0 ft and 4.5 ft. Trees forked in this region are also counted as separate trees (Figure 3). The DBH of each fork is measured at a point 3.5 ft above the pith intersection. When forks originate from pith intersections between 1.0 and 4.5 ft, the limiting distance is the same for all forks--they are either all on, or all off the plot.

  Multiple forks are possible if they all originate from approximately the same point on the main stem. In such cases, measure DBH on all stems at 3.5 ft above the common pith intersection (Figure 13 F).

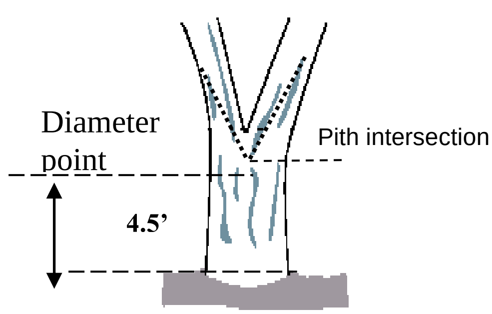
  Once a stem is tallied as a fork that originated from a pith intersection between 1.0 and 4.5 ft, do not recognize any additional forks that may occur on that stem. Measure the diameter of such stems at the base of the second fork as shown in Figure 13-E (i.e., do not move the point of diameter the entire 3.5 ft above the first fork).

Figure 3.
Forked between 1.0-4.5 ft



- (Figure 4). If a fork occurs at or immediately above 4.5 ft, measure diameter below the fork just beneath any swelling that would inflate DBH.

Figure 4. One tree



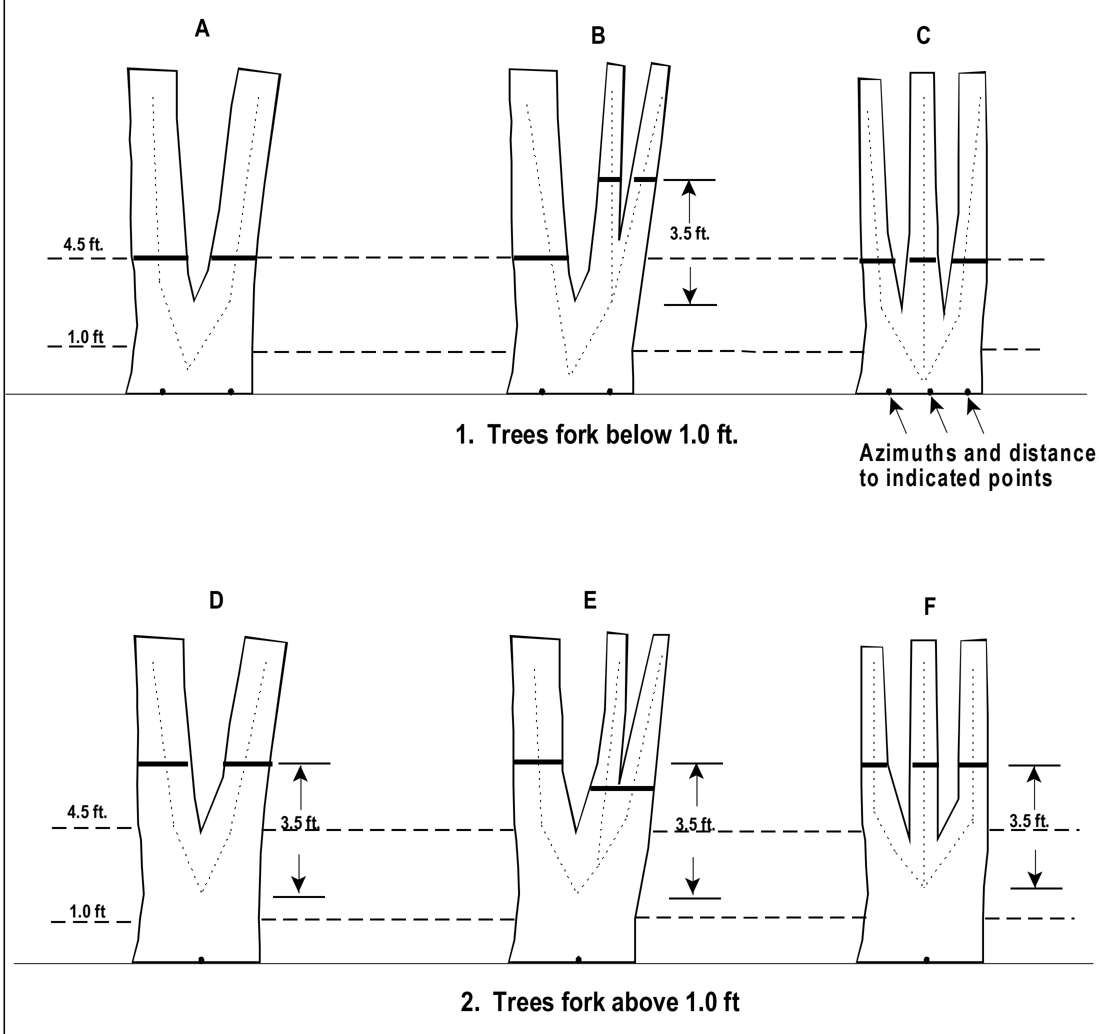


Figure 13. Summary of where to measure DBH, distance, and azimuth on forked trees.

2) **<u>Stump Sprouts</u>:** Stump sprouts originate between ground level and 4.5 ft on the boles of trees that have died or been cut. Stump sprouts are handled the same as forked trees, with the exception that stump sprouts are not required to be 1/3 the diameter of the dead bole. Stump sprouts originating below 1.0 ft are measured at 4.5 ft from ground line. Stump sprouts originating between 1.0 ft and 4.5 ft are measured at 3.5 ft above their point of occurrence.

3) **<u>Tree with butt-swell or bottleneck</u>**: Measure these trees 1.5 ft above the end of the swell or bottleneck if the swell or bottleneck extends 3.0 ft or more above the ground (Figure 5)

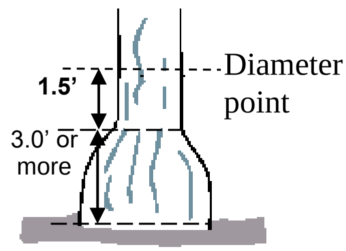


Figure 5. Bottleneck tree

4) **<u>Tree with irregularities at DBH:</u>** On trees with swellings (Figure 6), bumps, depressions, and branches (Figure 7) at DBH, diameter will be measured immediately above the irregularity at the place it ceases to affect normal stem form.

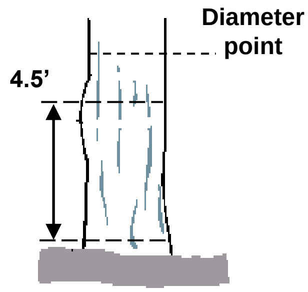


Figure 6. Tree with swelling

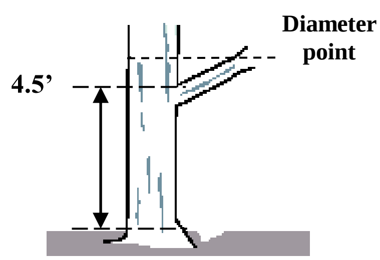


Figure 7. Tree with branch

5) **<u>Tree on slope:</u>** Measure diameter at 4.5 ft from the ground along the bole on the uphill side of the tree (Figure 8).

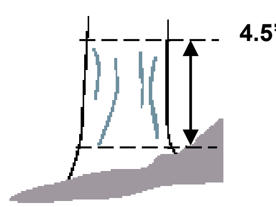


Figure 8. Tree on a slope

6) **Leaning tree:** Measure diameter at 4.5 ft from the ground along the bole. The 4.5 ft distance is measured along the underside face of the bole (Figure 9).

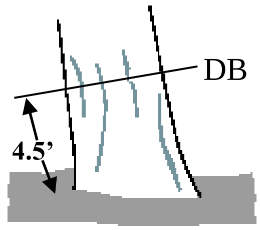


Figure 9. Leaning tree

7) **Independent trees that grow together:** If two or more independent stems have grown together at or above the point of DBH, continue to treat them as separate trees. Estimate the diameter of each, set the "Diameter Check" code to 1, and explain the situation in the notes.

8) **Missing wood or bark.** Do not reconstruct the DBH of a tree that is missing wood or bark or at the point of measurement. Record the diameter, to the nearest 0.1, of the wood and bark that is still attached to the tree (Figure 10). If a tree has a localized abnormality (gouge, depression, etc.) at the point of point of DBH, apply the procedure described for trees with irregularities at DBH (Figure 5).

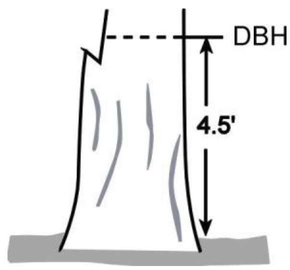


Figure 10. Tree with broken stem

9) **Live wind-thrown tree:** Measure from the top of the root collar along the length to 4.5 ft (Figure 11).

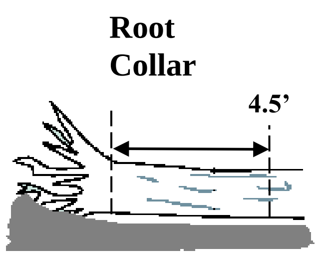


Figure 11. Tree on the ground

10) Down live tree wih tree-form branches growing vertical from main bole. When a down live tree, touching the ground, has vertical (<45° from vertical) tree-like branches coming off the main bole, first determine whether or not the pith of the main bole (averaged along the first log of the tree) is above or below the duff layer.

- If the pith of the main bole is above the duff layer, use the same forking rules specified for a forked tree, and take all measurements accordingly (Figure 12).

  - ➢ If the pith intersection of the main down bole and vertical tree-like branch occurs below 4.5 ft from the stump along the main bole, treat that branch as a separate tree, and measure DBH 3.5 ft above the pith intersection for both the main bole and the tree-like branch.

  - ➢ If the intersection between the main down bole and the tree-like branch occurs beyond the 4.5 ft point from the stump along the main bole, treat that branch as part of the main down bole.

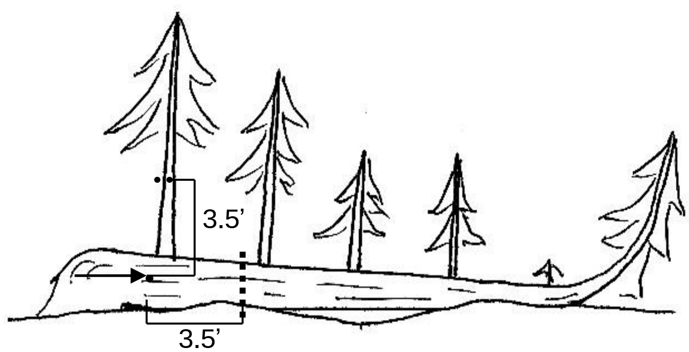


Figure 12. Down tree above duff

- If the pith of main tree bole is below the duff layer, ignore the main bole, and treat each tree-like branch as a separate tree; take DBH and length measurements from the ground, not necessarily from the top of the down bole (Figure 13). However, if the top of the main tree bole curves out of the ground towards a vertical angle, treat that portion of that top as an individual tree originating where the pith leaves the duff layer.

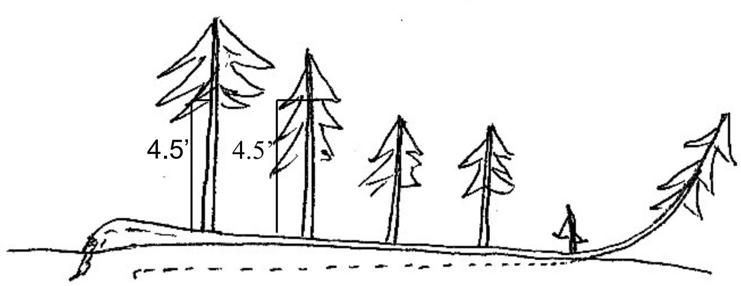


Figure13. Down tree below duff

Item 9. <u>Diameter Check</u>

Record the code to identify any irregularities in diameter measurement positions (e.g., abnormal swellings, diseases, damage, new measurement positions, etc.) that may affect the use of this tree in diameter growth/change analyses.

0 Diameter measured accurately
1 Diameter estimated
2 Diameter measured at different location than previous measurement (remeasurement trees only)

NOTE: If both codes 1 and 2 apply, use code 2.

Item 10. <u>Tree Condition Class</u>

Record one of the following condition class codes for all trees 4.5 inch DBH and larger. Broken tops must be significant enough to introduce rot into the main stem.

CODE	DESCRIPTION	COMMENTS
1	Live tree, live intact top	
2	Live tree, broken top	
3	Live tree, intact dead top	Tops may merely be defoliated – use with caution.
4	Dead tree, intact top	Before recording as dead, use a scribe to check the cambium layer for moisture.
5	Dead tree, broken top	Before recording as dead, use a scribe to check the cambium layer for moisture
6	Dead tree, down	Do not tally if advanced decay is present and wood is punky.
7	Snag, intact top	
8	Snag, broken top	
9	Removals	

Dead trees - are trees that have recently died (within the last several years); but still retain many branches (including some small branches and possibly some fine twigs); and have bark that is generally tight and hard to remove from the tree.

Snags - are dead trees, or what remains of a dead tree, that is at least 4.5 feet tall and is missing most of its bark. This category includes trees covered with bark that is very loose. This bark can usually be removed, often times in big strips, with very little effort, <u>snags are not recently dead trees.</u> Most often they will have been dead for several years - sometimes, for more than a decade.

The selection of a tree condition code will determine which remaining data fields should be measured or skipped. The following table details which data fields should be measured or skipped depending upon tree contition. The remarks field is always available for comments. Site trees should only be trees with a condition code of 1 unless the plot and has been impacted by severe environmental damage; then condition code 2 or 3 is possible.

CODE	FIELDS MEASURED AND SKIPPED
1	Complete tree history, DBH, DBH check, tree posture, total length, skip actual length, and continue completing all remaining fields.
2	Complete tree history, DBH, DBH check, tree posture, total length, actual length, and all remaining fields.
3	Complete tree history, DBH, DBH check, tree posture, total length, skip actual length, and continue completing all remaining fields.
4	Complete tree history, DBH, DBH check, tree posture, total length, skip next five fields (actual length, sawlog length, cull percentage, height to live crown and crown class), complete cavities, skip defoliation.
5	Complete tree history, DBH, DBH check, tree posture, total length, actual length, skip next four fields (sawlog length, cull percentage, height to live crown and crown class), complete cavities, skip defoliation.
6	Complete tree history, DBH, DBH check, tree posture, total length, skip next seven fields (actual length, sawlog length, cull percentage, height to live crown, crown class, cavities, and defoliation).
7	Complete tree history, DBH, DBH check, tree posture, total length, skip next five fields (actual length, sawlog length, cull percentage, height to live crown and crown class), complete cavities, skip defoliation.
8	Complete tree history, DBH, DBH check, tree posture, total length, actual length, skip next four fields (sawlog length, cull percentage, height to live crown and crown class), complete cavities, skip defoliation.
9	Complete tree history skip to remarks

Item 11. Tree Posture

Record the code that describes the degree leaning of the tree. A tree supported by other trees or by it's own branches is considered standing or leaning.

0 Standing (less than 45° of lean from vertical)
1 Leaning (more than 45° degrees of lean but not touching the ground.)
2 Down (some part of the bole touching the ground).

Item 12. Total Tree Height (Total Length)

Record the Total Length of the tree, to the nearest 1.0 ft, from ground level to the tip of the apical meristem (tree condition 1). For a tree growing on a slope, measure on the uphill side of the tree. If the tree has a broken or missing top (Tree Condition 2, 5 and 8), estimate what the total length would be if there were no missing or broken top. A forked tree is treated the same as an unforked tree.

Item 13. **<u>Actual Length</u>**

For a tree with a broken or missing top (Tree Condition 2, 5, and 8), record the Actual Length of the tree to the nearest foot from ground level to the highest remaining portion of the tree still present and attached to the bole. Use the length to the break for Actual Length until a new leader qualifies as the new top for Total Length; until that occurs, continue to record Actual Length to the break. **If the top is intact (Tree Condition 1, 3, 4, and 7), this variable may be omitted**. Forked trees should be treated the same as un-forked trees.

NOTE: Trees with previously broken tops are considered recovered (i.e., actual length = total length) when a new leader is 1/3 the diameter of the broken top at the point where the top was broken (not where the new leader originates from the trunk).

Item 14. **<u>Merchantable Height (SawLog Length)</u>**

Record Sawlog Length to the last whole foot of all sawtimber-sized trees. The measurement should extend from a 1 ft stump to (in order of priorities):

1. The point, where no physical 1/2 log, whether or not merchantable, can be produced because of excessive limbs, forks, or crooks. Sawlog Length should not extend above this point unless at least one 1/2 log, 8 ft or longer, is present. **(A 1/2 log is a section at least 8 ft long, not containing a fork, sufficiently straight enough to yield at least an 8 ft board.)**

2. Minimum top sawlog diameter:

   a. 8" DIB (diameter inside bark) for hardwoods

   b. 6" DIB for softwoods

3. On broken-off trees, to the point of the break.

When a tree forks into two or more sawlog-sized sections, measure the section with the largest diameter immediately above the fork regardless of its condition or whether the other fork may yield more Sawlog Length. Sawlog Length, <u>*in general*</u>, should terminate at the second fork in hardwood trees.

If the sawtimber-sized tree does not contain at least one 12 ft or two non-contiguous 8 ft logs, record 00 for sawlog length.

Sawlog Length when measured with a laser will be to the nearest foot. The next two fields on the data collector will convert Sawlog Length to the appropriate number of logs and 4 foot sections as aid for estimating Cull Percentage (item 15).

Item 15. **Cull Percentage**

Record the percent of volume within the sawlog portion, from the one-foot stump to the merchantable height, which cannot be recovered for use as lumber because of rot, sweep, crook, or other defect. Cull volume is expressed as a percent of total tree volume within the sawlog remaining below merchantable height (item 14). Percent bd. ft. cull includes the entire volume of logs that do not meet minimum log grade requirements (Log Grade 5). Enter 00 for a sawlog tree with no cull.

Sound cull (sweep, crook, excessive limb size, forks, seams, cracks, etc.) is visible and can be estimated from the percent bd. ft. volume by 4-foot sections or from sweep tables (see Appendix E for Board Foot Volume Cull Tables). Deductions for sweep can be made on the basis of 8-foot logs. Cull as small as 1/4 of a 4-foot section should be recorded. Most rotten cull is associated with indicators of defect such as cankers, conks, swollen knots, or other visibly important abnormalities.

Item 16. **Height to Live Crown**

Use the laser to measure a height from the base of the tree to the base of the live crown. Some care is needed in defining the base of the live crown consistently among individuals. A suggested definition is the "lowest group or whorl of live branches in at least three quadrants, exclusive of epicormic branches and branch groups or whorls not continuous with the main crown." Irregular and one-sided crowns must be ocularly *adjusted* to estimate the corresponding position of the base of a normally formed crown of the same volume. Use figure 14 below as a guide. Ignore the percentages listed below each tree. Focus instead on the position of the lower dotted line that is the base of the live crown.

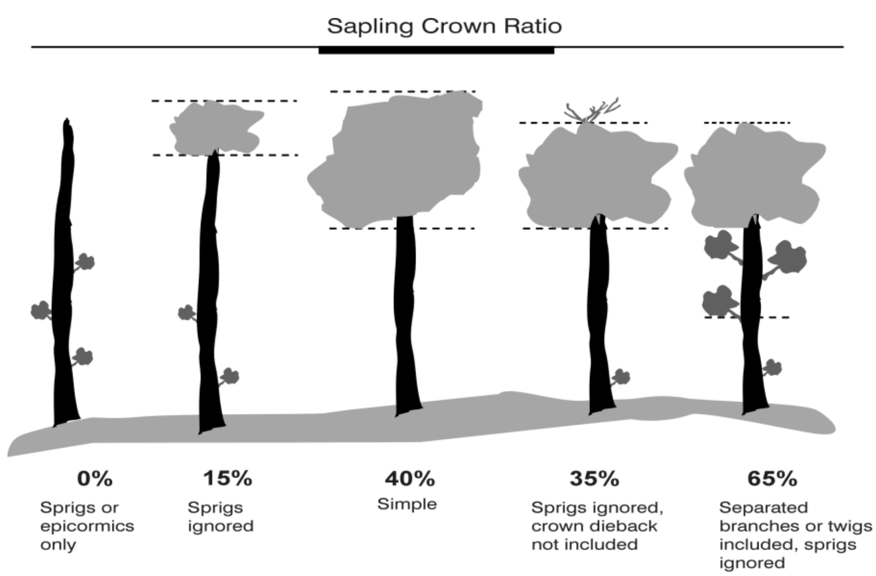


Figure 14

Item 17. **Crown Class**

Record a one-digit code to show the crown class for trees 4.5" DBH and larger, as follows:

Code	**Crown Class**
1	OPEN GROWN Trees with crowns that have received full light from above and from all sides throughout most of the life of the tree, particularly during its early development period. Their forms or crown shapes have not been and are not likely to be influenced by other trees.
2	DOMINANT. Trees with crown extending above the general level of the crown cover and receiving full light from above and partly from the sides, larger than the average trees in the stand, and with crowns well developed, but possibly somewhat crowded on the sides.
3	CODOMINANT. Trees with crowns forming the general level of the crown canopy and receiving full light from above, but comparatively little from the sides - usually with medium-sized crowns more or less crowded on the sides. (In stagnated stands, includes trees with small-sized crowns crowded on the sides.)
4	INTERMEDIATE. Trees shorter than those in the two preceding classes, but with crowns either below or extending into the crown cover formed by codominant and dominant trees, receiving little direct light from above and probably crowded on the sides.
5	OVERTOPPED. (Suppressed) trees with crowns entirely below the general level of the crown cover, receiving no direct light either from above or from the sides.

A list of these codes is available on board the data collector by pressing the F2 key when the cursor is in the crown class field.

In multiple-age stands with understory trees of younger age classes, crown classification is often difficult. As a general rule, the crown class for each tree should be judged in the context of its immediate environment; that is, those trees affecting it or being affected by it in terms of crown competition. For example, the intermediate and overtopped crown classes are intended to include only trees seriously affected by direct competition from adjacent trees.

As another example: A dominant tree is one that generally stands head and shoulders above all other trees in its vicinity. However, there may be a young, vigorous tree nearby, but not overtopped by a dominant tree. This smaller tree may be considerably shorter than the dominant, but still be receiving full light from above and partly from the sides. In its own immediate environment, it is dominant and should be recorded as such. Only understory trees immediately adjacent to the overstory tree will be assigned subordinate crown classes.

Wind-thrown trees, if still alive, are to be classified in the context of their immediate environment as described above.

Item 18. Cavities

The tree contains a cavity suitable for use by wildlife. Trees can be alive or dead, but must be standing. Record the presence of one or more cavities by entering a Y (for yes) in this field. The default value for the field is N for no cavities.

A list of these codes is available on board the data collector by pressing the F2 key when the cursor is in the cavity field.

Item 19. Defoliation

Trees with 1% to 60% of defoliation will probably refoliate. An excess of 60% defoliation implies that these trees are not likely to refoliate. Defoliation in this context refers to that caused by insect, disease, or climate. No cause needs to be assessed.

Code	Defoliation
0	No Defoliation
1	1% to 60%
2	Greater than 60%

A list of these codes is available on board the data collector by pressing the F2 key when the cursor is in the defoliation field.

Item 20. Remarks

Use for notes on individual trees. There is space available for 100 characters.

Item 21. Site Trees

This field will designate which trees have been chosen for site trees. The codes are listed below.

Code	Description
N	Not a site tree (default value)
Y	A site tree on the 1/5 plot
O	A site tree off the fifth acre plot

If a site tree is not contained in the 1/5th acre, the azimuth and distance to the tree should be recorded as (e.g. AZ 180.1 degrees DIST 63.5 ft.) in the remark field. The last highest three consecutive tree numbers will be reserved for off plot trees: e.g. numbers 99999, 99998, and 99997. These numbers should be assigned in reverse order, 99999 being first.

VI. MID-CANOPY DATA - 1/20th acre plot

Trees with a diameter >=1.0 but less than 4.5 inches in diameter are sampled on a 1/20th acre circular plot (radius 26.3 ft). The center point for this plot is the same as that of the 1/5th acre plot. Tally trees are defined as all live trees encountered when the1/20th acre plot is established, as well as all seedlings that grow into the 1/20th acre plot thereafter. They are included in the tally until they grow to 4.5 inches, at which time they are tallied in the 1/5th acre overstory plot. This plot data will assure that the stand diameter distribution will not be truncated at an abnormally high diameter limit.

Item 1. Ecological Region

Record the appropriate ecological region in which this plot is located. This code will automatically be repeated on each new record by the data collection program.

Item 2. State Forest District Number

Record the district number in which the plot is located. This code will automatically be repeated on each new record by the data collection program.

Item 3. Plot Number

Record the same plot number as that of the 1/5th acre plot, item 3 of Plot Level Data (page 17). This number will automatically be repeated on each new record by the data collection program.

Item 4. Item Counter

This field is an automatic counter that will incremented by the data collector. It can be reset to 1 for each plot.

Item 5. Species

Record a two-digit species code using the standard species shown in the Appendix I. A list of these species is available on board the data collector by pressing the F2 key when the cursor is in the species field.

Item 6. DBH (Diameter at Breast Height)

Record a 2-digit code for diameter rounding down to the last 1/10 inch. Example: a 2.18" diameter tree would be recorded as 29; a 1.92 tree as 19, etc. Use a diameter tape or plastic caliper.

Item 7. Total Tree Height

Measure and record total tree height from the base of the tree to the top of the crown. It may be necessary to hold an object such as a clipboard against narrow stems in order to facilitate taking the first distance shot with the laser.

Item 8. Origin

Code Description

1 Single seedling or root sucker
2 stump sprout
3 clump - e.g. beech brush, striped maple, scrub oak

Item 9. <u>Crown Class</u>

Record a one-digit code to show the crown class for trees 4.5" DBH and larger, as follows:

Code	**Crown Class**
1	OPEN GROWN
2	DOMINANT
3	CODOMINANT
4	INTERMEDIATE
5	OVERTOPPED

See item 14 in the Over-story Tree Sampling section for the definitions for crown class an how to apply them.

Item 10. <u>Defoliation</u>

Trees with 1% to 60% of defoliation will probably refoliate. An excess of 60% defoliation implies that these trees are not likely to refoliate. Defoliation in this context refers to that caused by insect, disease, or climate. No cause needs to be assessed.

Code	Defoliation
0	No Defoliation
1	1% to 60%
2	Greater than 60%

A list of these codes is available on board the data collector by pressing the F2 key when the cursor is in the defoliation field.

VII. GROUND FLORA DATA - 1/000th acre plot

Ground flora composition and abundance will be sampled using five mil-acre plots (radius of 3.72 feet). They will be located 60 feet from the 1/5th acre plot center along azimuths of 0°, 72°, 144°, 216°, and 288°. Ground flora consists of herbaceous plants, tree seedlings, and tree saplings.

The abundance of herbaceous plants and tree seedlings will be estimated in terms of the percent of the area of the sample plot occupied by each species. Ocular estimates of abundance have been chosen as the most effective and expedient means of quantification. Extensive research into developing optimized scales for measuring coverage has found scales that are logarithmic, or have finer levels of resolution in the lower cover classes, are most effective for capturing ecologically important information. For this the inventory the Domin-Krajina cover-abundance scale for forest communities will be used to quantify herbaceous plants and tree seedlings. This method is useful in forest communities where differences in species abundance among more rare species are often quite noticeable. It has been applied successfully to many forest communities in British Columbia (Krajina 1969) and also in Nigeria (Kershaw 1968). See Appendix H for a color flow chart of this scale. A tabular version is listed below (Item 9).

Tree saplings greater than or equal to one foot in height and less than one inch in diameter will qualify as regeneration. These will be counted and recorded in item 9. Regeneration species codes should begin with the letter **R** plant type prefix. Tree species less than one foot in height will not be counted as regeneration but their abundance will be estimated as percent cover and their species codes should begin the the letter **T** prefix. See item 8 for species code descriptions.

Ground flora plots have a vertical as well as horizontal profile (item 7). Percent cover and regeneration counts are to be recorded in two predetermined height intervals. These two vegetative layers, along with the midcanopy and overstory plots, will capture a more complete description of all the vegetation present.

Item 1. **Ecological Region**

Record the appropriate ecological region in which this plot is located. This code will automatically be repeated on each new record by the data collection program.

Item 2. **State Forest District Number**

Record the district number in which the plot is located. This code will automatically be repeated on each new record by the data collection program.

Item 3. **Plot Number**

Record the same plot number as that of the 1/5th acre plot, item 3 of Plot Level Data (page 17). This number will automatically be repeated on each new record by the data collection program

Item 4. **Mil-Acre Plot Identification**

Record the code that represents the azimuth direction from the 1/5th acre plot center to the mil-acre plot. This code will automatically be repeated on each new record by the data collection program.

Code	Description
N	0° North Plot
A	72°

B	144°
C	216°
D	288°

Item 5. Disturbance Code

Record the degree of disturbance to the vegetation (trampling etc.) of each mil acre plot. This code will automatically be repeated on each new record by the data collection program.

Code	Description
1	none/slight 0-10% of plot disturbed
2	moderate > 10-50%
3	heavy > 50%

Item 6. Observation Counter

This field is a automatic counter that is automatically incremented by the data collector. It can be reset to 1 for each plot.

Item 7. Height Strata

Record as a one-digit code. Use for regeneration and herbaceous species. The same species may be recorded in each height strata.

Code	Definition	Stratum Height
1	Ground/bryophyte/low herb layer	0 to 2 feet
2	High herb/low shrub layer	>2 to 6 feet

Item 8. Species

Record as a four-character species code. The format for the code is A###, where the prefix A is an alpha character for the plant type and ### a three digit number suffix to identify individuals in each type.

Plant Type Prefix	Plant Type	Examples	Special species codes		
			Identified in field but not on plant list. Record name in remarks and take a sample.	Unknown speciman of a specific plant type. Take a sample.	Specimen cannot be identified even with a sample. Record percent cover.
F	Fern cover	F006	F000	FUNK	FUID
G	Grass/sedge cover	G100	G000	GUNK	GUID
R	Regeneration counts	R032	R000	RUNK	RIUD
S	Shrub cover	S090	S000	SUNK	SIUD
T	Tree cover	T032	T000	TUNK	TUID
V	Vine cover	V010	V000	VUNK	VUID
W	Forb cover	W300	W000	WUNK	WUID
X	Microhabitat	X002	-	-	-`

	cover				

When the "**R**" plant type is chosen the cursor will jump to item 10 (tree regeneration count), otherwise it will default to item 8 (cover class). The ground flora species list, shown in Appendix I, is the same list that appears on the field data collectors. This list will be updated and expanded as new species are identified in the process of the inventory shifting among the ecological units.

Item 9. **Cover Class**

Record the appropriate cover class rating for each species encountered on the plot.

Code	Cover % of the Species	Number of Plants in each Species
10	100	any number
9	>75, but <100	any number
8	50 to 75	any number
7	33 to 50	any number
6	25 to 33	any number
5	10 to 25	any number
4	5 to 10	any number
3	1 to 5	Scattered
2	<1	Very Scattered
1	2 or 3 plants	Seldom
+	1 plant	Solitary

Item 10. **Tree Regeneration Count**

Record the number of trees by species that are less than one inch DBH and greater than one foot in total height. If the regeneration stem is less than two feet high record a 1 in the height strata field; if tie stem is greater than two feet enter a 2 in the strata height field.

Item 11. **Sample**

This is a Yes/No field with No set as default. **If a new species is found that is not on the plant list or if the species cannot be identified in the field a sample should be bagged and photographed for later identification.** Each specimen should be collected off plot and marked with the 1/5th acre plot number and the mil-acre plot code. At end of the field day these samples should be placed in the crew plant press. These specimens will be returned to Penn Nursery on a weekly basis for identification. When a specimen is taken this data field should set to Yes.

Item 12. **Remarks:** There is space available for 100 characters.

Appendix Figure 2. Data collection protocol corresponding to the Pennsylvania Game Commission Continuous Forest Inventory (CFI). *Source: Commonwealth of Pennsylvania Game Commission – Manual of Procedure for the Continuous Forest Inventory of Forest Wildlife Habitat Resources, 3rd edition January 2013.*

III. PLOT LEVEL DATA – *PLT01*

Data are recorded from the center of the 1/5th acre plot. Some of these items are specifically attributed to the area inside the plot while others include the acres that surround the plot, referred to in this document as the "stand" where the plot resides. The italicized type after each item is how that item appears on the screen of Allegro Juniper in the data collection program.

Item 1. Ecological Region – *EcoUnit* - the appropriate code for the ecological region in which the plot is located. See codes list in Appendix B.

Item 2. State Game Lands Number – *SGL* - the SGL number in which the plot is located.

Item 3. Plot Number - *Plot#* - New plots are numbered consecutively by ecological region. The plot number is a 5-digit integer with the following format: EE###. Where EE is the 2-digit ecological region number and ### is a 3-digit plot number beginning with 001 for the first plot of each ecological unit. This number does not change on remeasured plots.

Item 4. Date of Measurement – *Date* - the year, month and day the fieldwork is completed. Ex. 2007/03/25.

Item 5. Crew Identification – *Crew*- Enter your crew name, ALPHA or BRAVO.

Item 6. Plot Measurement Sequence Number - *Measure #* - Enter a 1 for new plots; increment the previous occasion number by one for remeasured plots.

Item 7. Type of Plot - *Type of Plot*- Enter "N" if the plot is new or "R" if the plot is being remeasured.

Item 8. *Stand Age* - If the plot is New then determine stand age from three borings of representatives of the "main stand" i.e., dominant and codominant growing stock trees on or near the plot location. In stands having more than one age class, classify the stand by the age class comprising 50% or more of the stocking. If no age class comprises 50% or more of the stocking, classify the stand as mixed age.

CODE	AGE CLASS	CODE	AGE CLASS
02	1 - 20 years	12	101 - 120 years
04	21 - 40 years	14	121 - 140 years
06	41 - 60 years	16	141 - 160 years
08	61 - 80 years	18	161 – 180 years
10	81 - 100 years	50	mixed ages

Item 9. *Stand Structure* - Determine the structure of the trees in the stand in which the plot resides.

1. Single-storied: characterized by an even canopy of uniform height with close competition between trees. Smaller trees are usually members of the stand that were stressed or overtopped and have fallen behind their associates. Regeneration and/or leave trees from a previous stand may be present. Most of the trees in the stand are within the height class of the average stand height.

2. Two-storied: composed of two relatively even but distinct canopy layers, such as a mature overstory with an understory sapling layer, possibly from seed tree or shelterwood operations, or an overstory of tall conifers with an understory of low hardwoods. Neither canopy is necessarily continuous or closed, but both canopy levels tend to be uniformly distributed across the stand. Each canopy level must cover at least 25 percent of the stand.

3. Multi-storied: Generally containing trees from every size group on a continuum from seedlings to mature trees and are characterized by a broken or uneven canopy layer. Usually the largest number of trees is in the smaller diameter classes. Consider any stand with three or more structural layers as multi-storied if each of the major layers covers at least 25 percent of the stand.

4. Mosaic: Contain at least two distinct size classes, each of which covers at least 25 percent of the stand. However, these classes are not uniformly distributed but are grouped in small repeating aggregations, or occur in stringers less than 120 feet wide, throughout the stand. Each size class aggregation is too small to be recognized as an individual stand; the aggregations may not be single-storied.

Item 10.Percent Slope – *Slope* - the percent slope of the terrain at the Plot Center. In order to avoid micro site conditions, measure slope over a span of at least 100 feet across the 1/5th acre plot in the same direction as the aspect for the plot. Record actual percent slope as a 2-digit value except record 00 when the slope is less than 5%.

Item 11. Aspect – *Aspect* - Aspect is the direction that the slope faces. Determine the aspect of the terrain at Plot Center. To avoid micro site conditions, a distance of 100 feet, across the 1/5th acre plot is the minimum span over which aspect is determined. The compass sighting is downhill in the same direction as the slope of the terrain. Use a 3-digit value to record aspect to the nearest degree except record 000 when there is no aspect (slope is less than 5%).

Item 12. Terrain Position – *Terrain Pos* - Terrain Position is the location of the Plot Center along the slope profile. To avoid micro site conditions, a distance of 100 feet, across the 1/5th acre plot is the minimum span over which aspect is determined. Codes 4, 6, and 7 are the only valid codes for plots with an aspect of 000 (slope less than 5%). Bottomlands are associated with drainages, flatlands are not.

CODE	**TERRAIN POSITION**
1	Top of Slope - convex
2	Upper Slope – convex region at upper edge of slope.
3	Mid-slope - uniform angle fairly straight region.
4	Bench - slope deviation, area of level land with slope above and below.
5	Lower Slope - concave region at the lower edge of slope.
6	Bottomland - horizontal region in low-lying areas, which may be subject to occasional flooding.
7	Flatland - regions not part of or related to slope; may have minimal elevation changes, i.e. less than 5%.

Slope Position Diagram

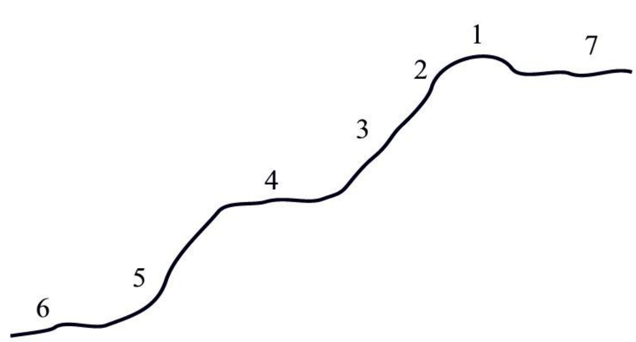


Figure 2 - Terrain Position and Slope Profile

Item 13. Physiographic Class – *Physgrphc* - Landform, topographic position, and soil determine physiographic class. Look out over 100 feet from the 1/5th acre Plot Center to determine physiographic class and use your best judgment when assessing the surrounding area.

Xeric - Sites that are normally low or deficient in moisture available to support vigorous tree growth. These areas may receive adequate precipitation, but experience a rapid loss of available moisture due to runoff, percolation, evaporation, etc.
11 - Dry Tops - Ridge tops with thin rock outcrops and considerable exposure to sun and wind.
12 - Dry Slopes - Slopes with thin rock outcrops and considerable exposure to sun and wind. Includes most steep slopes with a southern or western exposure.
13 - Deep Sands - Sites with a deep, sandy surface subject to rapid loss of moisture following precipitation. Typical examples include sand hills, sites along the beach and shores of lakes and streams, and many deserts.
19 - Other Xeric - All dry physiographic sites not described above.

Mesic - Sites that have moderate but adequate moisture available to support vigorous tree growth except for periods of extended drought. These sites may be subjected to occasional flooding during periods of heavy or extended precipitation.
21 - Flatwoods - Fairly level sites outside flood plains. Excludes deep sands and wet, swampy sites.
22 - Rolling Uplands - Hills and gently rolling, undulating terrain and associated small streams. Excludes deep sands, all hydric sites, and streams with associated flood plains.
23 - Moist Slopes and Coves - Moist slopes and coves with relatively deep, fertile soils. Often these sites have a northern or eastern exposure and are partially shielded from wind and sun. Includes moist mountaintops and saddles.
24 - Narrow Flood Plains / Bottomlands - Flood plains and bottomlands, less than ¼-mile in width, along rivers and streams. These sites are normally well drained but are subjected to occasional flooding during periods of heavy or extended precipitation. Includes associated levees, benches, and terraces within a ¼-mile limit. Excludes swamps, sloughs, and bogs.
25 - Broad Flood Plains / Bottomlands - Flood plains and bottomlands, ¼-mile or wider in width, along rivers and streams. These sites are normally well drained but are subjected to occasional flooding during periods of heavy or extended precipitation. Includes associated levees, benches, and terraces. Excludes swamps, sloughs, and bogs with year-round water problems.
29 - Other Mesic - All moderately moist physiographic sites not described above.

Hydric - Sites that generally have a year-round abundance or over-abundance of moisture. Hydric sites are very wet sites where excess water seriously limits both growth and species occurrence.
31 - Swamps / Bogs - Low, wet, flat forested areas usually quite extensive that are flooded for long periods of time except during periods of extreme drought. Excludes cypress ponds and small drains.
32 - Small Drains - Narrow, stream-like, wet strands of forestland often without a well-defined stream channel. These areas are poorly drained or flooded throughout most of the year and drain the adjacent higher ground.
34 - Beaver ponds
39 - Other hydric - All other hydric physiographic sites.

Item 14. *Carvell-Perkey Site Class* – Classify the acre where the plot resides using the 5 productivity classes based on aspect and slope position. A color figure of the topographic representation of aspect and slope position by site class is located in Appendix M. Use that figure along with your determination of percent slope, aspect, terrain position, and physiographic class to select one of the following site class codes.

Code	Site Class	Aspect & Slope Position
1	Hydric / moist mesic	Lower 1/3, NE facing slopes; Bottomlands
2	Mesic	Middle 1/3, NE facing slopes; Lower 1/3, NW & SE facing slopes
3	Dry mesic	Upper 1/3, NE facing slopes; Middle 1/3, NW & SE facing slopes; Lower 1/3, SW facing slopes
4	Dry	Upper-third, NW & SE facing slopes; Middle-third, SW facing slopes
5	Xeric	Upper-third, SW facing slopes; Ridgetops

Item 15. Forest Community Classification – *Cur For Type* - Classify the acre where the plot resides using the current type, site, size /stocking class designations (see MANUAL OF PROCEDURE FOR STATE GAME LANDS COVER TYPING).

15a Forest Community Type
15b Site Class - *Site*
15c Size/Stocking Class - *Size*

Item 16. *Past Treatment* - the silvicultural treatment that has been applied to the plot during the past 15-year period. If natural disturbance (N), describe in plot remarks field.

CODE	TREATMENT	CODE	TREATMENT
0	Haul roads	7	Seed Tree
1	Clear-cut	8	Thinning
2	Improvement	9	Right-of-way
3	Seed tree removal	A	Salvage treatment(s)
4	Shelterwood removal	N	Natural disturbance
5	Selection	X	No treatment
6	Shelterwood	O	Other explain in remarks

Item 17. *Deer Impact* - Estimate the amount of browsing pressure that deer are likely to exert on regeneration. Deer impact is a function of deer population and amount of available food in the area where the plot resides. Estimates of food availability are subjective. Evidence of low food availability include: a distinct browse line; substantial numbers of browsed stems; large areas dominated by browse-resistant/less-preferred species; extensive unbroken forest with little cultivated cropland within 1 mile of the stand; a prevalence of pole-sized and unthinned sawtimber stands and a limited area in regenerating clearcuts within a mile of the stand; limited diversity of plant species in the understory or in regenerating harvest cuts; and limited presence of woodland flowering plants.

Evidence of high deer food availability is the opposite of that described above: a lush understory and vigorous regeneration of a wide variety of species, including preferred browse species; abundant woodland flowers; a preponderance of recent harvest cuts and thinned sawtimber stands within a 1 mile radius; and cultivated cropland nearby.

CODE & DESCRIPTION

1. Very Low: Sample location is inside a well-maintained deer exclosure.
2. Low: Desirable regeneration common, widespread, of varying heights and accompanied by a diverse herbaceous plant community. Ferns, grasses and other unpalatable/browse-resistant plant species present but not common.
3. Medium: Desirable regeneration present but heights are uniformly low. Browse evidence is widespread. Ferns, grasses and other unpalatable/browse-resistant plant species common.
4. High: Desirable regeneration lacking, small; no stump sprouts. Few herbaceous plants; widespread unpalatable browse resistant plants, often browsed. Indistinct browse line.
5. Very High: Desirable regeneration absent or nearly so; no stump sprouts. Only the hardiest browse-resistant and unpalatable plant species present. Distinct browse line.

Item 18. *Forest Health* Rating - Characterize the health of the stand where the plot resides. Six stand factors are considered:

1. The condition of tree crowns
2. Overstory mortality
3. The confirmed occurrence of seedling, saplings, poles, and large trees
4. The occurrence of site suitable species
5. The presence/absence of exotic/invasive species
6. The presence/absence of environmental damage

CODE	DESCRIPTION
5. Very Healthy – Choose if all 6 statements below are TRUE	
a)	Crown conditions are good throughout the stand and only minor dieback and dead branches are noticeable.
b)	Overstory mortality is less than 1% and dead trees are scattered and are of a variety of ages.
c)	Seedlings, saplings, poles, & large trees all present (except if the stand is a young plantation or recently regenerated stand.
d)	A variety of species suitable to the site are present, except n a young plantation.
e)	No exotic or invasive species appear to present.
f)	No environmentally damage or significant damage causing agents are evident.
4. Healthy – Choose if ONLY ONE of the statements below are TRUE	
a)	Some thin crowns or dieback and/or branch mortality is noticeable.
b)	Overstory mortality is more than 1% but less than 20%.
c)	Seedlings and sapling stages are not fully represented.
d)	Variety of suitable species not present (except in young plantations).
e)	Some exotic or invasive species are present that might impact the stand.
f)	Some environmentally caused damage or noticeable causing agents are present.
3. Moderately Healthy – Choose if ONLY TWO of the statements below are TRUE	
a)	Some thin crowns or dieback and/or branch mortality is noticeable.
b)	Overstory mortality is more than 1% but less than 20%.
c)	Seedlings and sapling stages are not fully represented.
d)	Variety of suitable species not present (except in young plantations).
e)	Some exotic or invasive species are present that might impact the stand.
f)	Some environmentally caused damage or noticeable causing agents are present.
2. Moderately Unhealthy - Choose if ONLY ONE of the statements below are TRUE	
a)	Thin crowns or significant dieback and/or branch mortality are evident.
b)	Overstory mortality is more than 20% but less than 50%.
c)	Regeneration is rare or not present.
d)	Unsuitable species for site or lack of diversity is apparent (except for young plantations).
e)	Exotic or invasive species are impacting the stand.
f)	Environmentally caused damage or damage causing agents have impacted the stand.
1.	**Unhealthy - Choose if at least TWO of the statements below are TRUE**.
a)	Thin crowns or significant dieback and/or branch mortality are evident.
b)	Overstory mortality is more than 20% but less than 50%.
c)	Regeneration is rare or not present.
d)	Unsuitable species for site or lack of diversity is apparent (except for young plantations).
e)	Exotic or invasive species are impacting the stand.
f)	Environmentally caused damage or damage causing agents have impacted the stand.

Item 19. *Disturbance – D1* – use the code corresponding to the listed disturbances. The area affected by natural or human-caused disturbance must be ≥ 1 acre in size, and occurred in the last 5 years. For insect/disease disturbances if a sign is evident or a symptom is present that is directly linked to a disease/insect then note the agent in the Remarks section, *Item 29*. Record up to 3 different disturbances from most to least important as best determined. Some of the disturbance codes below require “any visible evidence” others require “significant threshold” implying mortality and/or damage to 25% of all trees in the stand.

CODE & DESCRIPTION

00 - None – No observable disturbance
10 - Insect – Significant threshold damage from insects.
20 - Disease - Significant threshold damage from disease.
30 - Weather - Significant threshold damage from weather other than the following:
- **31 -** Ice - Significant threshold damage from ice
- **32 -** Wind - Significant threshold damage from wind (includes hurricane and tornado).
- **33 -** Flooding - Significant threshold damage from weather induced flooding.
- **34 -** Drought - Significant threshold damage from drought.

40 - Fire – Any visible evidence of crown and ground fire, either prescribed or natural.
- **41 - G**round fire – Any visible evidence of ground fire.
- **42 -** Crown fire – Any visible evidence of crown fire.
- **43 -** Loss of humus/duff
- **44 -** Erosion due to fire

50 - Domestic animal – Any evidence of domestic livestock.
60 - Wild animal - Significant threshold damage from wild animals other than the following:
- **61 -** Beaver - Significant threshold damage from beaver includes flooding.
- **62 - P**orcupine - Significant threshold damage from porcupines
- **63 -** Deer – Deer Impact (see item 16) is high or very high.

70 - Human - Significant threshold damage from human-caused damage (e.g. ATV).
- **71 -** Past timber harvest
- **72 -** Heavy equipment.
- **73 -** Piles slash/stumps

80 - Other natural - Significant threshold natural damage not described by the above codes. (describe in Remarks).

Item 20. Disturbance2 –*D2* - If stand has experienced more than 1 disturbance, record the 2nd disturbance.

Item 21. Disturbance3 – *D3* - If stand has experienced more than 2 disturbances, record the 3rd disturbance.

Items 22 through 27 below are all based upon the 1/5 acre plot and all use the following code:

CODE	% COVERAGE
0	0
1	1 - 10
2	11 - 50
3	51 - 90
4	91 - l00

Item 22. Low Evergreen Cover –*LEVGR* - coverage class in low, woody evergreen cover using a 1-digit code. Low evergreen cover is 1-10 ft. in height and includes such species as mountain laurel, rhododendron, *Gaultheria procumbens* or conifers with live limbs touching or close to the ground.

Item 23. High Evergreen Cover – *HEVGR* - coverage class in high, woody evergreen cover with a1-digit code. High evergreen cover is defined as live coniferous trees >10 ft. in height and providing aerial cover.

Item 24. Grasses & Sedges – *GRASS* - coverage class in grass-like herbaceous vegetation. Grasses are defined as low (< 3 ft.) grass-like species such as grasses, sedges and rushes.

Item 25. Forbs – *FORBS* - coverage class in non-grasslike herbaceous vegetation. Forbs are any herbaceous vegetation (< 3-ft.) that is not considered grass-like or ferns.

Item 26. Ferns – *FERNS* - coverage class in ferns. Ferns and fern allies are non-flowering, herbaceous plants.

Item 27. Deciduous Shrubs – *DECID* - coverage class in low, woody deciduous trees or shrubs. Low deciduous shrubs include tree and shrub species < 15 ft. in height.

Item 28. Coarse Woody Debris – *CWD_AZMTH* - Press F2 on the Juniper for the field to generate a random number that determines the direction of the woody debris transect line.

0 = 0°   1 = 72°   2 = 144°   3 = 216°   4 = 288°

Item 29. Remarks – *REMARK* – any remarks on the data recorder that further explain the codes used above.

1) Record the Operational Zone within brackets in which the plot exists using the Operational Zone Classifications as detailed in the MANUAL OF PROCEDURE FOR STATE GAME LANDS COVER TYPING.

[M] Multiple opportunity operation zone
[B] Aesthetic/buffer operation zone
[L] Limited opportunity operation zone
[S] Special resources operation zone
[H] Anthropogenic operation zone
[E] Easement/lease operation zone

2) Provide details on a specific disease or insect damage from Disturbance 1, 2 or 3.

3) Use this field for any hazards on plot such as rattlesnakes, poison ivy or criminal activity.

V. OVERSTORY DATA - 1/5th acre plot – *PLT02N & PLT02R*

Trees ≥4.5” DBH and 4.5 feet in length are sampled within the 1/5th acre plot (52.7 ft. radius). Tally trees are all live and standing dead trees encountered when the plot is first established, and all trees that grow into the plot thereafter. Trees are alive if they have any living parts (leaves, buds, cambium) at or above the point of diameter measurement. Trees that have been temporarily defoliated are still alive. Once tallied, dead trees ≥ 4.5” DBH are tracked until they fall down and have disintegrated, with no evidence remaining.

Tally all standing trees when establishing new plots. Valid dead tally trees on previously established plots arise from two circumstances. The previous tree history was either a survivor or an ingrowth and is now dead or the previous tree history was dead. If the first case is true, condition codes 4 and 5 may apply. If the second case is true, codes 7 and 8 are most likely. Use of tree history code 40 (dead tree, standing or down but still present) is appropriate in either case except if tree condition 6 was chosen. If the dead down tree (condition 6) is in advanced state of decay then a new tree history of 41, instead of 40, indicates that the dead tree will no longer be tracked in future inventories. Working around dead trees is a safety hazard - crews need to exercise extreme caution. Make a remark in Item 21 for trees that are unsafe to measure and leave them alone.

Broken portions of trees that are completely separated from their base are not treated as separate trees. Whether live or dead, standing trees do not have to be self-supporting. They may be supported by other trees. High stumps (trees that have been cut) do not qualify as standing dead trees. To qualify as a standing dead tally tree, dead trees must be upright, ≥4.5 ft. tall and be ≥4.5” DBH.

Item 1. Ecological Region – *EcoUnit*- the ecological region where the plot is located.

Item 2. State Game Lands Number – *SGL#* - the Game Lands number where the plot is located.

Item 3. Plot Number – *Plot#* - use the same plot number recorded in the PL**OT LEVEL** DATA, Item 3.

Item 4. Tree Number – *Tree#*

New plots – PLT02N

Record a unique 3 to 5-digit number to permanently identify each tree on the 1/5th acre plot. Begin measurement starting with the first tree to the right of 0° azimuth and proceed clockwise to the other trees working outwards from Plot Center to the plot edge. On new plots trees are numbered by hundreds, ex. tree #1=0100; tree #2=0200 etc. It is not necessary to paint zeros on the overstory trees.

A tree is determined to be "in" or "out" of the plot radius (52.7 feet) by measuring the horizontal distance from Plot Center to the pith of the tree at its base. For a leaning tree, the direction that the tree leans is of no consequence. For a down and wind-thrown tree measure the horizontal distance to the spot where the center of the tree would have been if the tree was still standing; i.e., measure the distance to the center of the stump, or ground cavity. Down trees are only measured if they were tallied in the previous cycle. See Fig. 4.

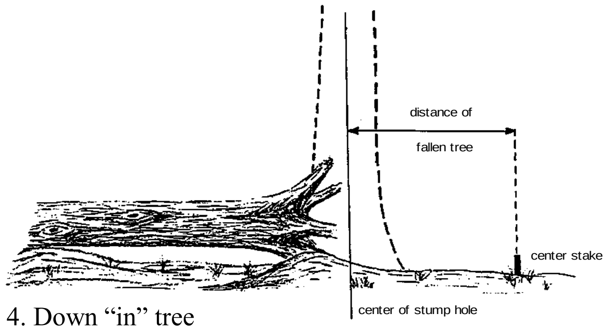


Figure 4. Down "in" tree

Remeasured plots – PLT02R

For remeasured trees, this number is displayed on the data collector. Record ingrowth tree numbers by choosing an unassigned number between the two previously measured tree numbers. An ingrowth tree between tree 1200 & 1300 is assigned a number between 1201 and 1299. Ingrowth trees before the first tree, 100, are initially numbered in increments of 10 and then on further remeasurements in 1's. The exact number chosen depends upon which of the previously measured trees is closest to the ingrowth tree. Take into account mid-canopy trees that may later become ingrowth trees. When using a data collector it is necessary to use the Edit pull down by hitting Escape, then arrow over to Edit. Use the Copy and Paste commands for as many records you need for all new ingrowth trees between existing "in" trees (F5 and F6 are very helpful for moving back and forth between records).

Plots Highly Impacted by Disturbance – PLT02R

The goal is to track every overstory tree throughout multiple CFI cycles until it disintegrates or is removed. When a plot is highly impacted by disturbance, it may be difficult to achieve this aim. Using the **PLT02R** overstory data on the recorder, attempt to identify as many overstory trees from the previous cycle as possible and re-number them. Number ingrowth with a previously unassigned number as above. Populate the fields for the trees that have been removed or cut and left assuming no change has occurred to diameters, heights, or conditions. <u>If it is impossible to differentiate one residual tree from another or if no overstory trees remain, then renumber the overstory as if the plot was new</u>. Number the first tree to the right of 0° azimuth as #100 and then proceed clockwise to the other trees working outwards from Plot Center to the plot edge. Residual trees that cannot be differentiated have a Tree History 11, of a Survivor.

Item 5. Species – *Species*- a 2-digit code using the species codes shown in Appendix O. Use code 17 for unknown <u>dead conifers</u> and 99 for unknown <u>dead hardwoods</u> when the exact species cannot be determined. For remeasured plots, this number is displayed on the data collector.

Items 6.1 to 6.5 Previous Tree Measurements – *PHIST, PDBH, PTOTHGT, PMHGT, P%CULL*

<u>For remeasured plots,</u> Tree History, DBH and Total Height previous measurements are displayed on the data collector to help locate individual trees. Fields for Merchantable Height and % Cull contain data if the tree viewed was previously saw timber.

Item 7. Tree Condition Class – *Tree Cond* - the codes from the table below when selected determine which remaining data fields are measured or skipped. For every Condition Class record the complete tree history, DBH, DBH check, tree posture and total length. On new plots, site trees should only have a condition code of 1 unless the plot is impacted by severe environmental damage; then condition codes 2 or 3 are possible. Do not tally a tree with Condition 6, dead/down, if advanced decay is present and wood is punky. For dead standing trees, Conditions 4 & 5, scribe the tree to check the cambium layer for moisture. Broken tops must be significant enough to

introduce rot into the main stem. See Appendix A, the Glossary, for more complete definitions of dead trees and snags.

CODE	DESCRIPTION	FIELDS SKIPPED
1	Live tree, live intact top	actual length
2	Live tree, broken top	
3	Live tree, intact dead top	actual length
4	Dead tree, intact top	actual length, sawlog length, cull percentage, height to live crown, crown class
5	Dead tree, broken top	sawlog length, cull percentage, height to live crown, crown class, defoliation
6	Dead tree, down	actual length, sawlog length, cull percentage, height to live crown, crown class, cavities, defoliation
7	Snag, intact top	actual length, sawlog length, cull percentage, height to live crown, crown class, defoliation
8	Snag, broken top	sawlog length, cull percentage, height to live crown, crown class, defoliation
9	Removals	complete tree history skip to remarks

Item 8. Tree History – *Tree Hist* - Describes the status of a tree during this inventory as compared to its status during the previous inventory.

On New Plots enter 00 for all live trees and 40 for all dead standing trees.

On Remeasured Plots assign a two-digit code for:

- Every tree that was tallied as a live tree in the last cycle if it was ≥4.5” DBH.
- Every live tree ≥4.5” DBH that is being tallied for the first time.
- Standing dead trees that are alive, but were not large enough (≥4.5” DBH) to be tallied in the last survey, but which grew to ≥4.5” DBH and died since the last cycle. This tree is dead ingrowth.
- Standing snags that were dead at the last occasion but are still standing.

Survivors (re-measure plots only)

Live, previously measured tree, or a tree that was missed in the last cycle.

10 - Same live tree - was in before, is in now

11 - Suspected to be measured in the last cycle, but tree cannot be positively linked to a tree number from the previous cycle. Used on highly disturbed plots.

12- Tree was missed at last survey; it should have been tallied but was not, is now tallied.

Histories 15, 16, 17, and 18 may include dead trees. Tree History 15 and 16 apply to two or more stems that were fused from the base and that had a combined diameter measurement at 4.5 feet. Tree History 15 reconciles the old combined/fused stem. Tree History 16 accounts for stems (two or more) that are the result of the new diameter rules for fused trees.

15 - Multiple stemmed tree -- the product of two (possibly more) previously measured trees **of the same species** that had grown together and the diameter was measured at 4.5 feet. These fused stems were treated as one tree. This code reconciles the previous tree only. Used only with code 16.

16 - Multiple stemmed tree - one of two or more trees **of the same species** that were treated as one tree, but are now tallied as individual stems and the diameter measured at 4.5 feet. Accounts for the new stems from code 15 created by the new “Special DBH Situation” rule 7. Used only with code 15.

Tree History 17 and 18 apply to stems that fork above 4.5 feet and the diameter was measured at 4.5 feet or below where there was normal stem form. Tree History 17 reconciles the old single stem. Tree History 18 accounts for the new stems (two or more) that are the result of the new diameter rules for forked trees and the use of pith separation.

17 - Multiple forked tree – the product of two (possibly more) stems that forked above 4.5 ft and were treated as one tree. Used only in conjunction with code 18.

18 - Multiple forked tree – one of two, or more, stems that the diameter measurement is now taken 3.5 ft above the point of pith separation. Used only in conjunction with code 17.

19 - Tree that is alive, but was incorrectly tallied as dead at the last occasion (limited to a tree with a **previous** tree class of 5 or 6).

Ingrowth (re-measure plots only) Tree that is correctly tallied for the first time,

20 - Live tree, not previously measured.

21 - Live or dead tree that was tallied before but should not have been, and is a tally tree now.

24 - Dead tree or snag, that was too small to tally before but has grown to tally size and died since the previous inventory, is a tally tree now.

25 - Dead tree, should have been tallied, was missed, has since died, and is now tallied.

Removals (re-measure plots only) Previously tallied tree that has been harvested, killed or presumed to have been harvested during a cultural operation (logging, land clearing, TSI work)

30 - The location where the tree is, or was, is still forested land, the tree has been killed, it can be standing or down.

31 - The location where the tree was, remains forested, the tree has been removed, usually a stump will be present.

Mortality Previously tallied tree that has died since the last inventory.

40 - Dead tree --standing or down-- tree is still present; when DBH measurement is not possible, or current DBH is smaller than the previous DBH, use previous DBH for current measurement.

41 - Dead, down, disintegrated, no evidence remaining; previously measured tree that has died, is down and is in advanced stages of decay or any previously measured tree that cannot be accounted for.

Other Trees
50 - Tree that had a recorded horizontal distance of ≤52.7 ft., that now has a horizontal distance >52.7 ft.

90 - Off plot site trees.

Item 9. Diameter – *DBH* - Unless one of the *Special DBH Situations* described on the following pages occurs, measure DBH at 4.5 ft. above ground line on the uphill side of the tree. Record a 2 or 3-digit number rounding down to the last 1/10 inch. Ex. Record a 9.18" diameter tree as 91. To accurately remeasure DBH the point of measurement must be marked with a scribe or paint. When marking trees for the first time, measure the diameter after the mark is in place. Do not penetrate the cambium when using a bark scribe; and do not scribe thin barked trees or trees that are vulnerable to introduction of pathogens such as American chestnut or elm.

New trees: The diameter mark is located 1" below where the diameter is taken, on the side of the tree facing the 1/5th ac. Plot Center. The mark is made horizontal and approximately 2" long. Check for irregularities before making diameter marks. See *Special DBH Situations* beginning on the next page.

Remeasured trees: When remeasuring the diameter of a tree tallied at a previous visit, always take the measurement at the location marked by a previous crew unless it is not physically possible (e.g. tree partially buried), or the previous location is more than 12 inches beyond where the diameter should be measured according to current protocols. Assign a Diameter Check (Item 10) code of 2 whenever the point of measurement is moved. When reconciling dead trees and snags, if the current diameter is less than the previous diameter, record the previous diameter as the current diameter.

Special DBH Situations

1) Forked tree: To qualify as a fork, the stem in question must be at least 1/3 the diameter of the main stem and must branch out from the main stem at an angle of 45° or less. Forks originate at the point on the bole where the piths intersect. Forked trees are handled differently depending on whether the fork originates below 1 ft, between 1 & 4.5 ft, or above 4.5 ft.

a) Trees forked below 1.0 ft. are treated as distinctly separate trees (Fig. 5). Measure DBH for each stem 4.5 ft above the ground. When stems originate from pith intersections below 1 ft, it is possible for some stems to be within the limiting distance of the 1/5th acre plot and others to be beyond the limiting distance. If stems originating from forks that occur below 1 ft. and fork again between 1& 4.5ft, the DBH of each fork is measured at a point 3.5 ft. above the pith intersection (Fig. 8-B).

b) Trees forked between 1 & 4.5 ft. are also counted as separate trees (Fig. 6). Measure the DBH of each fork at a point 3.5 ft. above the pith intersection. When forks originate from pith intersections between 1 & 4.5 ft, the limiting distance is the same for all forks, they are either all on, or all off the plot. Multiple forks are possible if they all originate from approximately the same point on the main stem. In such cases, measure DBH on all stems at 3.5 ft above the common pith intersection (Fig. 8-F). Once a stem is tallied as a fork that originated from a pith intersection between 1 & 4.5 ft, do not recognize any additional forks that may occur on that stem. Measure the diameter of such stems at the base of the second fork as shown in Fig. 8-E (i.e., do not move the point of diameter the entire 3.5 ft above the first fork).

c) Trees forked above 4.5 ft. are measured below the fork just beneath any swelling that would inflate DBH. (Fig. 7)

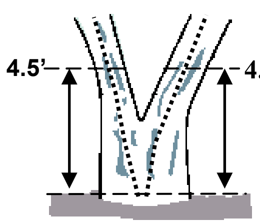


Figure 5. Forked below 1 ft.

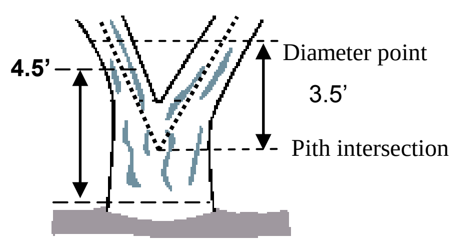


Figure 6. Forked between 1 & 4.5 ft

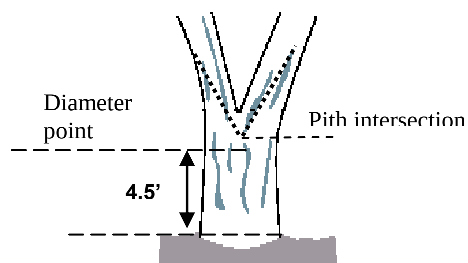


Figure 7. One tree

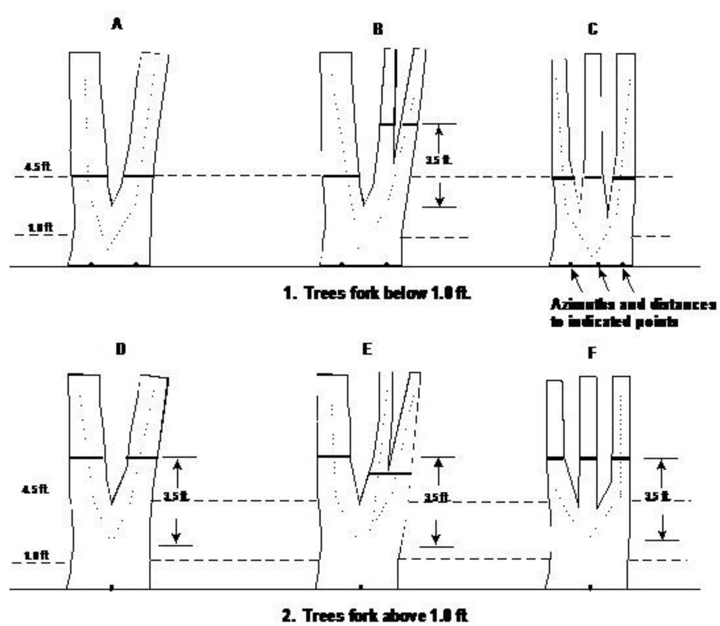


Figure 8. Summary of where to measure DBH, distance & azimuth on forked trees

2) Stump Sprouts originate between ground level and 4.5 ft. on the boles of trees that have died or are cut. Stump sprouts are handled the same as forked trees, with the exception that stump sprouts are not required to be 1/3 the diameter of the dead bole. Stump sprouts originating below 1 ft. are measured at 4.5 ft. from ground line. Stump sprouts originating between 1 & 4.5 ft. are measured at 3.5 ft. above their point of occurrence.

3) Trees with butt-swells or bottlenecks are measured 1.5 ft. above the end of the swell or bottleneck if the swell or bottleneck extends 3 ft. or more above the ground (Fig. 9)

4) Trees with irregularities at DBH swellings (Fig. 10); bumps, depressions, and branches (Fig. 11) the diameter is measured immediately above the irregularity at the place it ceases to affect normal stem form.

5) Trees on a slope are measured at 4.5 ft. on the uphill side of the tree (Fig. 12).

6) Leaning trees are measured at 4.5 ft. from the ground along the bole. The 4.5 ft distance is measured along the underside face of the bole (Fig. 13).

7) Independent trees that grow together at or above the point of DBH, are separate trees. Estimate the diameter of each, set the "Diameter Check" code to 1.

8) Missing wood or bark is not reconstructed at the point of measurement. Record the diameter, to the nearest 1/10 in., of the wood and bark that is still attached to the tree (Fig. 14). If a tree has a localized abnormality (gouge, depression, etc.) at the point of point of DBH, apply the procedure described for trees with irregularities at DBH (Fig. 8).

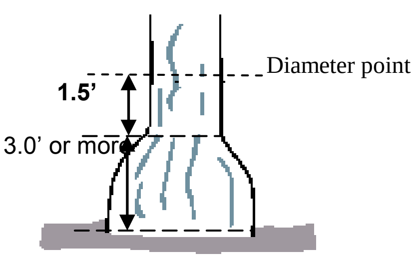


Figure 9. Tree with bottleneck

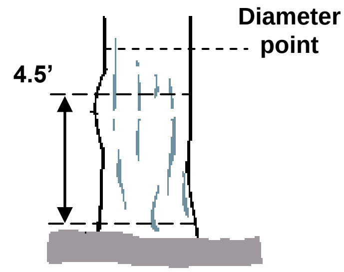


Figure 10. Tree with swelling

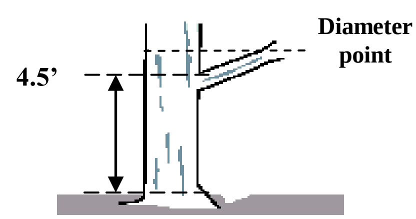


Figure 11. Tree with branch

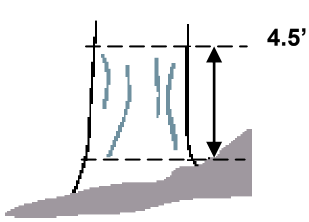


Figure 12. Tree on a slope

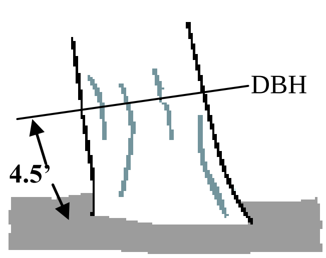


Figure 13. Leaning tree

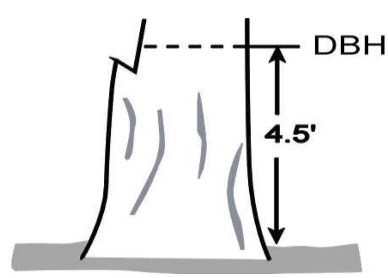


Figure 14. Tree with broken stem

9) Live wind-thrown trees are measured from the top of the root collar along the length to 4.5 ft. (Fig. 15).

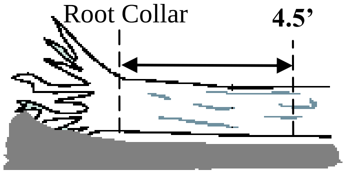


Figure 15. Tree on the ground

10) Down live trees with tree-form branches growing vertical from main boles touch the ground, and have tree-like branches coming off the main bole <45° from vertical. First, determine whether the pith of the main bole, averaged along the first log of the tree, is above or below the duff layer.
a) If the pith of the main bole is above the duff layer, use the same forking rules specified for a forked tree, and take all measurements accordingly (Fig. 16).
b) If the pith intersection of the main down bole and vertical tree-like branch occurs below 4.5 ft. from the stump along the main bole, treat that branch as a separate tree, and measure DBH 3.5 ft. above the pith intersection for both the main bole and the tree-like branch.
c) If the intersection between the main down bole and the tree-like branch occurs beyond the 4.5 ft point from the stump along the main bole, treat that branch as part of the main down bole.
d) If the pith of main tree bole is below the duff layer, ignore the main bole, and treat each tree-like branch as a separate tree; take DBH and length measurements from the ground, not necessarily from the top of the down bole (Fig. 17). However, if the top of the main tree bole curves out of the ground towards a vertical angle, treat that portion of that top as an individual tree originating where the pith leaves the duff layer.

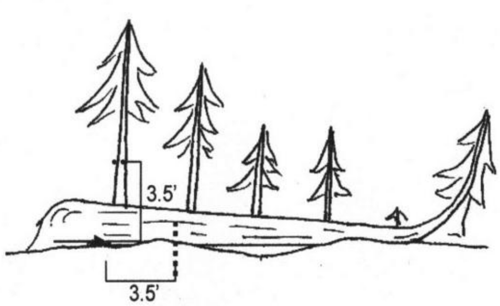


Figure 16. Down tree above duff

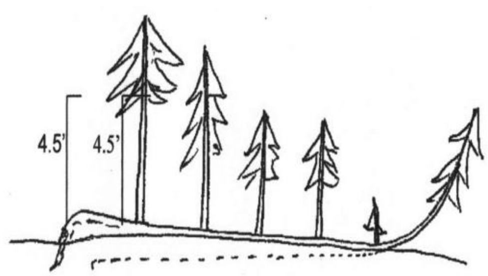


Figure 17. Down tree below duff

Item 10. Diameter Check – *DBH Check* - identify any irregularities in diameter measurement positions (e.g., abnormal swellings, diseases, damage, new measurement positions, etc.) that affect the use of this tree in diameter growth/change analyses.

CODE & DESCRIPTION

0 Diameter measured accurately
1 Diameter estimated
2 Diameter measured at different location than previous measurement (remeasurement trees only)

NOTE: If both codes 1 and 2 apply, use code 2.

Item 11. Tree Posture – *Tree Pstr* - Describes the degree leaning of the tree. A tree supported by other trees or by its own branches is considered standing or leaning.

CODE & DESCRIPTION

0 Standing (less than 45° of lean from vertical)
1 Leaning (more than 45° degrees of lean but not touching the ground.)
2 Down (some part of the bole touching the ground).

Item 12. Total Tree Height (Total Length) - *Total Height* - the Total Length of the tree, to the nearest foot, from ground level to the top of the tree. If the tree is growing on a slope, measure it on the uphill side of the tree. If the tree has a broken or missing top (Tree Conditions 2, 5 and 8), estimate what the total length would be if there were no missing or broken top. A forked tree is treated the same as an unforked tree.

Item 13. Actual Length – *Actual Hgt* - For trees with broken or missing tops (Tree Conditions 2, 5, and 8), record the Actual Length of the tree to the nearest foot from ground level to the highest remaining portion of the tree still present and attached to the bole. Use the length to the break for Actual Length until a new leader qualifies as the new top for Total Length; until this occurs, continue to record Actual Length to the break. If the top is intact (Tree Condition 1, 3, 4, and 7), this variable is omitted. Forked trees should be treated the same as un-forked trees. NOTE: Trees with previously broken tops are considered recovered (i.e., actual length = total length) when a new leader is 1/3 the diameter of the broken top at the point where the top was broken, not where the new leader originates from the trunk.

Item 14. Merchantable Height (Saw Log Length) - *Merch Height* - Sawlog Length to the last whole foot of all sawtimber-sized trees. When a tree forks into two or more sawlog-sized sections, measure the section with the largest diameter immediately above the fork regardless of its condition or whether the other fork may yield more Sawlog Length. Sawlog Length generally terminates at the second fork in hardwood trees. If the sawtimber-sized tree does not contain at least one 12 ft. or two non-contiguous 8 ft. logs, record 00 for sawlog length. In order of priority, the measurement extends from a 1 ft. stump to:

1) The point, where no physical 1/2 log, whether or not merchantable, can be produced because of excessive limbs, forks, or crooks. Sawlog Length should not extend above this point unless at least one 1/2 log, 8 ft or longer, is present. A 1/2 log is a section at least 8 ft long, not containing a fork, sufficiently straight enough to yield at least an 8 ft. board.

2) Minimum top sawlog diameter

a) 8" DIB (diameter inside bark) for hardwoods

b) 6" DIB for softwoods

3) On broken-off tops, to the point of the break.

Item 15. Height to Live Crown – *Live Crown Hgt* - Use the laser to measure a height from the base of the tree to the base of the live crown. A suggested definition is the "lowest group or whorl of live branches in at least three quadrants, exclusive of epicormic branches and branch groups or whorls not continuous with the main crown." Irregular and one-sided crowns must be ocularly adjusted to estimate the corresponding position of the base of a normally formed crown of the same volume. Use Fig. 18 below as a guide. Focus on the position of the lower dotted line that is the base of the live crown.

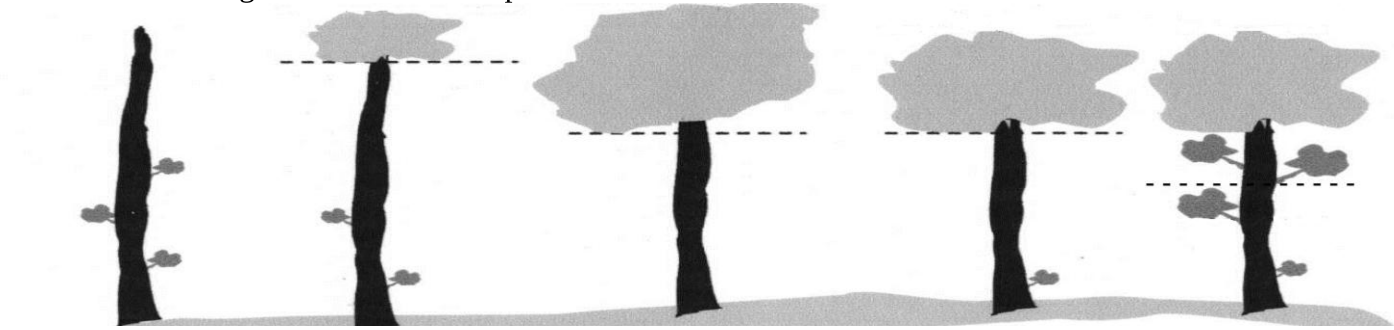


Figure 18. Live Crown Guide

Item 16. 4 Foot Sections - *4 Ft Sections* - If a tree has a Merchantable Height (Item 14) then press F2 on the data recorder to automatically populate this field. If a tree does not have a Merchantable Height than skip this field rather than populating it.

Item 17. Cull Percentage - *% Low Cull* - The percent of volume within the sawlog portion, from the 1 ft. stump to the merchantable height, which cannot be recovered for use as lumber because of rot, sweep, crook, or other defect. Percent bd. ft. cull includes the entire volume of logs that do not meet minimum log grade requirements (Log Grade 5). Enter 00 for a sawlog tree with no cull.

Sound cull (sweep, crook, excessive limb size, forks, seams, cracks, etc.) is visible and can be estimated from the percent bd. ft. volume by 4-ft. sections or from sweep tables (see Appendices I and J for Board Foot Volume Cull Tables). Record deductions for sweep based on 8-ft. logs. Record cull as small as 1/4 of a 4-ft. section. Most rotten cull is associated with indicators of defect such as cankers, conks, swollen knots, or other visibly important abnormalities.

Item 18. Crown Class - *Crown Class* - Crown class for each tree is judged in the context of its immediate environment; that is, trees affecting it or being affected by it in terms of crown competition. Intermediate and overtopped crown classes include trees seriously affected by direct competition from adjacent trees. Example: A dominant tree stands head and shoulders above all other trees in its vicinity; however, there may be a vigorous tree nearby, but not overtopped by a dominant tree. This smaller tree may be shorter than the dominant, but still be receiving full light from above and partly from the sides. In its own immediate environment, it is dominant and is recorded as such. Only understory trees immediately adjacent to the overstory tree will be assigned subordinate crown classes. Record a 1-digit code to show the crown class as follows:

CODE & CROWN CLASS

1 - OPEN GROWN - Trees with crowns that receive full light from above and from all sides throughout the life of the tree, particularly during its early development period. Tree form or crown shape has not been and is not likely to be influenced by other trees.

2 - DOMINANT - Trees with crowns extending above the general level of the crown cover and receiving full light from above and partly from the sides, larger than the average trees in the stand, and with well developed crowns, but possibly somewhat crowded on the sides.

3 - CODOMINANT - Trees with crowns forming the general level of the crown canopy and receiving full light from above, but comparatively little from the sides - usually with medium-sized crowns more or less crowded on the sides. In stagnated stands, this includes trees with small-sized crowns crowded on the sides.

4 - INTERMEDIATE - Trees shorter than those in the two preceding classes, but with crowns either below or extending into the crown cover formed by codominant and dominant trees, receiving little direct light from above and probably crowded on the sides.

5 - OVERTOPPED - Suppressed trees with crowns entirely below the general level of the crown cover, receiving no direct light either from above or from the sides.

Item 19. Cavities – *Cavity* – Does the tree contain a cavity suitable for use by wildlife? Mice and house wrens can use holes as small as 1 ¼ inches in diameter. Trees can be alive or dead, but must be standing. Record the presence of one or more cavities by entering a “Y” for yes in this field. The default value for the field is “N” for no cavities. Make a note in Remarks, Item 21, if there is evidence a cavity is currently being utilized and if known, what kind of animal is using it.

Item 20. Defoliation - *Defoliation* - Trees with 1- 60% defoliation will probably refoliate. An excess of 60% defoliation implies that the tree is not likely to refoliate. Defoliation in this context refers to that caused by insect, disease, or climate. If a cause can be assessed, make a note in Remarks, Item 21.

CODE	DEFOLIATION
0	No Defoliation
1	1% to 60%
2	Greater than 60%

Item 21. Remarks – *Remarks* - Use for notes on individual trees. There is space available for 100 characters.

Item 22. Site Trees – *Site Tree* - Designates which trees are selected for site trees. If a site tree is not contained in the 1/5th acre, the azimuth and distance to the tree from the Plot Center is recorded (e.g. AZ 180 DIST 63.5) in the remark field. The last highest three consecutive tree numbers are reserved for off plot trees: e.g. numbers 99999, 99998, and 99997. These numbers are assigned in reverse order, 99999 being first.

CODE & DESCRIPTION	
N	Not a site tree (default value)
Y	A site tree on the 1/5 plot
O	A site tree off the fifth acre plot

VI. MID-CANOPY DATA - 1/20th acre plot - *PLT03*

Trees with a diameter ≥1 in. but <4.5 inches in diameter are sampled within the 1/20th acre circular plot (radius 26.3 ft). The center point for this plot is the same as that of the 1/5th acre plot. Tally trees are all live trees encountered when the1/20th acre plot is established, as well as all seedlings that grow into the 1/20th acre plot thereafter. Saplings are included in the tally until they grow to 4.5 inches and become ingrowth trees in the 1/5th acre overstory plot.

Item 1. Ecological Region – *EcoRegion* - The appropriate ecological region where the plot is located.

Item 2. State Game Lands Number – *SGL#* - The Game Lands number where the plot is located.

Item 3. Plot Number – *Plot* Number – same # as in Section III **PLOT LEVEL** DATA Item 3 on page 11.

Item 4. Item Counter – *Tree #* - automatic counter that is incremented by the data collector. Reset this number to "1" for each plot.

Item 5. Species – *Species* – A 2-digit species code using the standard species shown in the Appendix O.

Item 6. Diameter at Breast Height – *DBH* - a 2-digit code for diameter rounding down to the last 1/10 inch. Ex. a 2.18" diameter tree is recorded as 21; a 1.92" tree as 19, etc. Use the average of at least two measurements with a plastic caliper or use a small diameter tape to preserve the loggers tape from becoming pigtailed. Refer to the Special DBH Situation section above for guidance on multi-stemmed mid-canopy trees.

Item 7. Total Tree Height – *Total Height* - total height from the base of the tree to the top of the crown. Trees that are bent or leaning are virtually "stood up" to get their true height. Hold the reflective target against narrow stems in order to facilitate taking the first distance shot with the laser.

Item 8. Origin - *Origin*

CODE & DESCRIPTION	
1	single seedling or root sucker
2	stump sprout
3	clump - e.g. beech brush, striped maple, scrub oak

Item 9. Crown Class – *Crown Class* – A 1-digit code for crown class. See Item 18 in Section IV OVERSTORY DATA for definitions of crown class an how to apply them.

CODE & CROWN CLASS	
1	OPEN GROWN
2	DOMINANT
3	CODOMINANT
4	INTERMEDIATE
5	OVERTOPPED

Item 10. Defoliation – *Defoliation* – see Item 20 in Section IV OVERSTORY DATA.

CODE	**DEFOLIATION**
0	No Defoliation
1	1% to 60%
2	Greater than 60%

VII. GROUND FLORA DATA - 1/1000th acre plot – *PLT04*

Ground flora composition and abundance are sampled on five mil-acre plots (radius of 3.72 feet) located 60 feet from the 1/5th acre Plot Center along azimuths of 0°, 72°, 144°, 216°, and 288°. Ground flora consists of herbaceous plants, tree seedlings, and tree saplings. The abundance of herbaceous plants and tree seedlings are estimated in terms of the percent of the area of the sample plot occupied by each species. Ocular estimates of abundance are the most effective and expedient means of quantification. Items are quantified by what is visible and not what is covered; for example, moss growing on rocks is quantified but the rock below the moss is not; only the portion of the rock that is visible is quantified.

Tree saplings ≥ 1ft. in height and < 1 inch in diameter qualify as regeneration and are counted and recorded in Item 10. Regeneration species codes begin with the letter **R** plant type prefix. Tree species < 1 ft. in height are not counted as regeneration but their abundance is estimated as percent cover; their species codes begin the letter **T** prefix. See Item 8 for species code descriptions.

Ground flora plots have a vertical as well as a horizontal profile (Item 7). Percent cover and regeneration counts are recorded in two predetermined height intervals. These two vegetative layers, along with the midcanopy and overstory plots, capture a more complete description of all the vegetation present. A third stratum in this cycle captures vegetation that does not originate on the mil-acre (rooted within) but contributes to percent cover of the mil-acre.

Item 1. Ecological Region – *EcoRegion* - The appropriate ecological region where the plot is located.

Item 2. State Game Lands Number – *SGL#* - The Game Lands number where the plot is located.

Item 3. Plot Number – *Plot* Number – same # as in Section III **PLOT LEVEL** DATA Item 3 on page 11.

Item 4. Mil-Acre Plot Identification – *SubPlot* - the azimuth direction from the 1/5th acre Plot Center to the mil-acre plot. This code is automatically repeated on each new record by the data collection program and needs to be changed when moving to another mil-acre plot location.

N = 0° A = 72° B = 144° C = 216° D = 288°

Item 5. Disturbance Code – *Disturbance* - the degree of disturbance to the vegetation (trampling etc.) of each mil acre plot.

CODE	DESCRIPTION
1	none/slight 0-10% of plot disturbed
2	moderate > 10-50%
3	heavy > 50%

Item 6. Observation Counter – *Item #* - a counter that is automatically incremented by the data collector. Reset this field to 1 for each mil-acre plot.

Item 7. Height Strata – *Height Stratum* - a 1-digit code used to describe the height of all items recorded. The same item may be recorded in each height strata. This field retains the previous item #'s entry and needs to be changed when individual item's stratum's change.

CODE	DEFINITION	HEIGHT	EXAMPLES
1	Ground/bryophyte/low herb layer	0 to 2 feet	all **X**'s, **T**'s<1ft, **R**'s≥1ft & <1in DBH
2	High herb/low shrub layer	>2 to 6 feet	**R**'s≥2ft & <1in DBH
3	Parts of plants originating outside that reach into the mil-acre	0 to 6 feet	**T**'s reaching into mil-acre

Item 8. Species – *Species* - a 4-character species code. The format is A###, where the prefix A is an alpha character for the plant type and ### is a 3-digit number suffix to identify individuals in each type. When the "**R**" plant type is chosen the cursor will jump to Item 10 Tree Regeneration Count, otherwise it will default to Item 8 Cover Class.

PLANT TYPE PREFIX	PLANT TYPE	EXAMPLES	SPECIAL SPECIES CODES		
			IDENTIFIED IN FIELD BUT NOT ON LIST – RECORD NAME IN REMARKS	UNKNOWN SPECIMEN OF A SPECIFIC PLANT TYPE - TAKE A SAMPLE	SPECIMEN CANNOT BE IDENTIFIED EVEN FROM A SAMPLE
F	fern cover	F006	F000	FUNK	FUID
G	grass/sedge cover	G100	G000	GUNK	GUID
R	regeneration counts	R032	R000	RUNK	RIUD
S	shrub cover	S090	S000	SUNK	SIUD
T	tree cover	T032	T000	TUNK	TUID
V	vine cover	V010	V000	VUNK	VUID
W	forb cover	W300	W000	WUNK	WUID
X	microhabitat cover	X002	-	-	-

Item 9. Cover Class – *Cover percent* - the cover class rating for each species encountered on the plot.

CODE	**COVER % OF SPECIES**	**# PLANTS IN EACH SPECIES**
10	100	any number
9	>75, but <100	any number
8	50 to 75	any number
7	33 to 50	any number
6	25 to 33	any number
5	10 to 25	any number
4	5 to 10	any number
3	1 to 5	Scattered
2	<1	Very Scattered
1	2 or 3 plants	Seldom
+	1 plant	Solitary

Item 10. Tree Regeneration Count – *Stem Count* - the number of trees by species that are < 1 in. DBH and >1ft. in total height. If the regeneration stem is < 2 ft. high, record a 1 in the height strata field. If the stem is >2 ft. enter a 2 in the strata height field. Unlike other stratum 2 items, regeneration is not limited at 6 ft., but by 1 inch in DBH; there is no maximum height for stratum 2 stem count regeneration.

Item 11. Sample – *Sample* - Yes/No field with No set as default. If the species cannot be identified in the field, a sample is taken for later identification. Each specimen is collected off plot and marked with the plot number and the mil-acre plot code. After leaving the plot these samples are placed in the crew plant press. These specimens are returned to FIA Head Quarters at Howard Nursery on a weekly basis for identification.

Item 12. Remarks – *Remarks* – Space is available for 100 characters.

Appendix Figure 3. Data collection protocol corresponding to the Pennsylvania Game Commission pre- and post-burn forest monitoring research. *Source: Pennsylvania Game Commission – Prescribed Fire Monitoring Protocol.*

Pennsylvania Game Commission - Prescribed Fire Monitoring Protocol

Collection periods are defined as follows:

- **Pre-burn** – data is collected mid-May to mid-August preceding the prescribed fire. For example, burns scheduled for April 2014 have pre-burn data collection between May and August of 2013. Burns scheduled for September 2014 have pre-burn data collection between May and August 2014. Ideally, pre-burn data is collected in the above timeframe; however, prescribed fires are occasionally postponed. If pre-burn data will be more than two years old by the time the unit is burned, then it is recommended to recollect data to reflect the most accurate pre-burn condition. Detailed description starts on page 1.

- **Post-burn0** – data collection occurs within several weeks after the prescribed fire; the earlier the better so that post-burn fuel conditions can be more accurately measured. Detailed description starts on page 9.

- **Post-burn1** – data collected one year after prescribed fire and within two calendar weeks of the pre-burn data collection date. This should help minimize phenological differences between pre- and post-burn measurements. Detailed description starts on page 11.

- **Post-burn5** – data collected five years after prescribed fire and within two weeks of the calendar year of the pre burn data collection date. Detailed description starts on page 11.

Pre-burn Data Collection

Sample intensity, location, and rejection criteria for pre-burn plots should be done in consultation with the prescribed fire monitoring coordinator. The number of desired plots per burn unit will generally be no less than twenty, and will be higher for burn units larger than 100 acres. Adequate sample sizes are influenced by specific management objectives and the cover types present within the burn unit. Clearer sample size guidelines will continue to emerge as more post-burn data becomes available to assess the objective variables that focus on vegetative change.

Sometimes a fire line around the burn unit perimeter has not been established when the pre-burn assessments are conducted. If this is the case, then the fire monitoring coordinator may choose to keep plot locations approximately 200 feet away from GIS-delineated burn unit boundaries. This will minimize the chance that pre-burn monitoring plots end up outside of the actual burn unit.

1. Plot Location Sheet – Use a new plot location sheet for each individual burn unit; this expedites data entry and subsequent analysis.

a. Site (SGL/Unit) – Record the site name as indicated on the map provided to you.

b. Crew – Record the full names of the crewmembers taking the measurements. The note taker's name should appear first in the sequence.

c. Page – Record the page number sequentially. When the final plot for the unit is finished fill in the blank that details how many pages total there are.

d. Plot # – Record the number for the plot.

e. Date – Record the date.

f. Latitude and Longitude – Overwrite the proposed location of the plot on the GPS by taking a new marker/waypoint on the GPS in decimal degrees, WGS 1984 format. Record this exact location on the data sheet in the same decimal degree, WGS 1984 format.

g. Forest Type/Site/Size – Record the forest type, site and size for the principal plot area; an area that extends to more or less the surrounding acre around the plot center. If the surrounding stand around the principal plot area is a different forest type, site or size, you should indicate this in the comments section; but be sure to record on the data

1

sheet the type/site/size of the principal plot area as described here. It is important to designate individual plot forest types for analysis. See the document, "Terrestrial & Palustrine Plant Communities of Pennsylvania" by Jean Fike, Pennsylvania Natural Diversity Inventory, PA Department of Conservation and Natural Resources 1999 or the "Manual of Procedure for State Game Land Cover Typing" for descriptions of forest types and definitions of site, size and stocking.

h.Deer impact – Record the deer impact using the key at the bottom of the page. This is the same methodology utilized when collecting SILVAH data.

i. Aspect – Determine the topography over the plot and record the appropriate aspect in degrees using 360 for due north. Tip: visualize which direction a drop of mercury would roll if placed at plot center.

j. % Slope – Record percent slope in the direction of the aspect using a clinometer. The ground distance over which this is measured is from the one side of the overstory plot to the opposite side, approximately 82 feet.

k. Disturbance Code & Description – Use one or more of the following codes to characterize any disturbance that has occurred on the plot. The area affected by natural or human-caused disturbance must be ≥ 1 acre in size, and occurred in the last 5 years. For insect and disease disturbances, if a sign is evident or a symptom is present that is directly linked to a specific disease or insect then note the agent below the code. Some of the disturbance codes below require "any visible evidence" others require "significant threshold" implying mortality and/or damage to 25% of all trees on the plot.

CODE & DESCRIPTION

- **00** - None – No observable disturbance
- **10** - Insect – Significant threshold damage from insects.
- **20** - Disease - Significant threshold damage from disease.
- **30** - Weather - Significant threshold damage from weather other than the following:
  - **31** - Ice - Significant threshold damage from ice
  - **32** - Wind - Significant threshold damage from wind (includes hurricane and tornado).
  - **33** - Flooding - Significant threshold damage from weather induced flooding.
  - **34** - Drought - Significant threshold damage from drought.
- **40** - Fire – Any visible evidence of crown and ground fire, either prescribed or natural.
  - **41** - Ground fire – Any visible evidence of ground fire.
  - **42** - Crown fire – Any visible evidence of crown fire.
  - **43** - Loss of humus/duff due to fire
  - **44** - Erosion due to fire
- **50** - Domestic animal – Any evidence of domestic livestock.
- **60** - Wild animal - Significant threshold damage from wild animals other than the following:
  - **61** - Beaver - Significant threshold damage from beaver includes flooding.
  - **62** - Porcupine - Significant threshold damage from porcupines
  - **63** - Deer – Deer Impact (see item 16) is high or very high.
- **70** - Human - Significant threshold damage from human-caused damage (e.g. ATV).
  - **71** - Past timber harvest
  - **72** - Heavy equipment.
  - **73** - Piles slash/stumps
  - **74** - Herbicide treatment
  - **75** – Hydro ax mowing
- **80** - Other natural - Significant threshold natural damage not described by the above codes.

l. Photo numbers/time – The PGC retains ownership of all photos taken. Photos are uploaded to a server in Harrisburg and are available to PGC personnel for use in programs and all forms of media. No crew equipment or refuse should be in any of the photos.

After the overstory trees are numbered and midcanopy trees are lettered, a photo is taken in each of the four cardinal directions with the center of the orange triangle as the focal point of each photo. Using the Olympus Stylus 720, <u>take all photos on ISO automatic setting, without any zoom, white balance automatic, landscape setting</u> and review each photo after it is taken before moving on to the next direction to ensure quality. Carefully unfold and assemble the orange triangle and attach it, point down, level side up to a mil-acre stick. The camera operator stands at plot center and directs the photo pole placer along each azimuth to a distance of 26.3 feet. Push the PVC photo pole holder into the ground as far as it can go up the threaded rod, bottom of the PVC cap flush with the ground if possible. Place the mil-acre stick with triangle attached into the PVC pipe with the flat side perpendicular to plot center. Steady the camera on top of a second mil-acre stick, point the camera at the center of the triangle as the focal point center of each photo. If the triangle is unseen at any azimuth due to more than a third of the photo occupied by one or more tree boles immediately in front of the camera, then direct the photo pole to an incrementally higher azimuth until the triangle is seen, preferably the replacement of the photo pole is on a whole number azimuth. It does not matter if the orange triangle cannot be seen at this distance due to interfering vegetation; the photo taken with the interfering vegetation is a true reflection of the plot's condition. Record the series of photo numbers as displayed on the digital camera that were taken in order N, E, S, and W and note any azimuth deviations on the Plot Location Sheet for the next inventory crew. Also, record the time you took the photo set for each plot.

FIA Office Photo Import Routine
Re-label photo files subsequently in the office. Label photo folders as a combination of the monitoring year (Pre-burn, Postburn0, Postburn1, or Postburn5), PA Game Commission Region, Game Land number and Unit (ex. Pre-burnNC176Unit1 for pre-burn photos taken for the North Central Region on SGL 176, Unit 1). Label individual photos with the plot number, with preceding zeros for digits below 100, and cardinal direction (ex. 001N, 001E, 001S, 001W).

Guidelines for Photos of Plants
When a plant cannot be field identified and is not numerous enough to take a sample, record the plant as a WUNK, SUNK or FUNK on the data sheet and create a descriptive comment for each unknown plant indicating which photo numbers apply to the unknown plant. Take multiple photos of the plant from a variety of angles to best document the specimen. Photos should have these characteristics clearly visible:

1) Flower type - irregular or the number of regular parts
2) Plant leaf arrangement - no leaves, basal leaves, alternate, opposite or whorled
3) Leaf type - none, entire, toothed, lobed, or divided

If the above characteristics cannot be photo documented properly with the camera, they must be added to the comment to aid in office identification. Also, include any unique characteristics such as a description of the sample's smell or the way the stem or leaf surface feels.

m. Reference tree information – Plot stakes should ideally be 12" metal rebar for magnetic relocation. If using a wood stake, label the stake with a permanent maker or paint stick with the plot number proceeded with "Rx" (ex. Rx03). If using metal rebar then label with an aluminum tag if possible. Clear the leaf litter and duff away from the stake; hammer in the stake leaving the top 1" exposed. Select a healthy; outstanding (above average size or unusual species in plot area) reference tree that is proximate to the plot stake. For thin barked species use a paint marker and for thick barked species make a single 4" scribe on the Reference Tree's bole above DBH and on the root flare facing the plot center. As per Plot Location Sheet instructions record in this specific order: 1) the diameter at breast height (DBH) to the tenth of an inch 2) species code of the reference tree 3) distance to the tenth of a foot and 4) bearing **from** the reference tree **to** the plot stake in degrees. *RECORD ALL COMPASS READINGS AS MAGNETIC BEARINGS.*

2. Overstory Trees - Circular plots of 41.37 ft. radius (12.61 m) are the basic sampling unit. Tally trees are all upright; live, dying and standing dead trees ≥4.5 ft. tall and ≥4" DBH encountered when the plot is first established, and all trees that grow into the plot thereafter. Trees are alive if they have any living parts (leaves, buds or cambium) at or above the point of diameter measurement. Trees that have been temporarily defoliated are still alive. Broken portions of trees completely separated from their base are not separate trees. Whether live or dead, standing trees do not have to be self-supporting; other trees may support them. High stumps (cut trees) do not qualify as standing dead trees unless they are 4.5 feet in height or higher and have a measurable point at DBH. Track standing dead trees until they fall down. Use caution when working around dead trees. If necessary, estimate measurements for hazard trees from a safe distance and indicate this in the comments section.

a. Site (SGL/Unit), b. Crew, c. Plot Number, d. Page – Record as for the **Plot Location Sheet**

e. No. - Record a unique sequential number that identifies each tree on the plot. Write this number both on the data sheet and physically on the tree itself with a lumber crayon or paint marker. Begin measurement starting with the first tree to the right of 0° azimuth and proceed clockwise to the other trees working outwards from Plot Center to the plot edge. A tree is determined to be "in" or "out" of the plot radius (41.37 feet) by measuring the horizontal distance from Plot Center to the pith of the tree at its base. For a leaning tree, the direction that the tree leans is of no consequence.

f. Sp. - Record the species of the tree using the PGC FIA species codes. Refer to the last pages of this protocol for species coding.

g. DBH – Diameter at Breast Height. Measure the diameter of the tree 4.5 ft. above the ground on the high side to the nearest tenth inch rounding down. For specific examples of where to measure diameters in unusual situations, refer to the ***Special DBH Situations*** in the "Manual of Procedure for the Continuous Forest Inventory of Forest Wildlife Habitat Resources" (PGC CFI, 2013).

h. Status – Record the status of the tree as either **L** for live, **DY** for dying, or **SD** for standing dead.

i. Comments - Record any comments about insect, disease, or other evident damage to individual trees.

ITEMS "J" THROUGH "M" BELOW ARE FOR POST-BURN0 ASSESSMENTS ONLY:
j. Status – not recorded at this time
k. Bark Scorch – not recorded at this time
l. Crown Begin/End– not recorded at this time
m. Comments– not recorded at this time

3. Sapling Data – Sapling plots have a radius of 13.2 feet (4 m). Measure and record only live trees that are ≥4.5 feet tall and are <4" at DBH.

a. Page, b. Site (SGL/Unit), c. Plot #, d. Crew, e. Date – Record as for the **Plot Location Sheet**

f. Species – Record each species of only live saplings found within a plot on a separate line by DBH class.

g. DBH Class –Saplings of each species are dot tallied and classified by one of three DBH classes. A key to DBH Classes is at the bottom of the Sapling Data Sheet.

h. Tally – Use this space to dot tally saplings of each species/DBH class combination.

i. Total – Record the total of the dot tally in this box.

4. Ground Flora/Regeneration – There are four Ground Flora/Regeneration sub-plots each located 45 ft. (13.72 m) from plot center, one at each of the following azimuths: 45°, 135°, 225°, and 315°. Use a new sheet for each sub-plot. Tree regeneration less than one inch in diameter, shrubs, ferns, forbs, vines, grasses and micro-habitat variables are all sampled on a 4.1 ft. radius circular sub-plot (r = 1.26 m). The size and azimuths of these sub-plots is a standard because they are permanent and measurements are repeated in one and five-year intervals. Note any deviation so subsequent measurements can be repeated.

If a sub-plot location does not provide good baseline data to measure diversity or species richness and quantity, it is relocated. This may occur when large rocks take up 50% or more of the sub-plot; permanent water is present such as a creek beds or ponds; or a forest road, a well-worn trail or other system is on the sub-plot that has compacted soils. Do not relocate sub-plots however for skid trails or vernal ponds because these are temporary. When an obstruction is present move the individual sub-plot in +15° increments until it is completely out of the impacted area. Write the new azimuth on the data sheet in the sub-plot section.

Record the following information for all vegetation rooted within the plot as well as percentage cover for plants (other than regeneration) that have their origin outside the sub-plot.

a. Page, **b. Site (SGL/Unit)**, **c. Plot #**, – Record as for the **Plot Location Sheet**

d. Sub-plot – Circle the azimuth on which you are currently recording data; write in the azimuth if the sub-plot is relocated.

e. Crew, f. Date – Record as for the **Plot Location Sheet**

g. Spp. of Dominant Tree (>5" DBH originating on sub-plot) – If present, record the FIA species code of a dominant tree located in any portion of the sub-plot. If no tree >5" DBH is present, then draw a line through this space to indicate that it was not accidentally skipped.

h. **Canopy Cover percentage** - This measurement is to capture tree canopy cover percentage 6 feet and above the ground level. Use either the supplied Cover Estimator or a densiometer to measure and record Canopy Cover percentage. Record how the measurement is taken; either estimate or densiometer. Use the densiometer according to manufacturers' instructions; with its bottom at DBH. For consistency a suggested way of doing this is to level the densiometer on top of the staff that the PGC's Forest Inventory and Analysis Section uses for field measurements. If understory brush is a part of the densiometer's reading then have your partner pull the vegetation aside without breaking the vegetation to get a better measurement.

All Species and Regeneration Species Columns
Shrub, fern, forb, vine, grass and micro-habitat data are recorded in the **All Species** columns which includes variables for **Species, Cover Class, Live Cover Class** and **Average Height**. Do not record **Regen Source, Regen Height Class** or **Regen Count** for non-tree variables. Record every **All Species** and **Regeneration Species** variable for qualifying tree species. When a tree species does not qualify as Regeneration (it is < 2" high) do not record **Regen Source**, **Regen Height Class** or **Regen Count**; however, still record the variables **Cover Class**, **Live Cover Class** and **Average Height**.

All Species
i. Species – Record every species found in the Sub Plot on a separate line by FIA species code *always beginning by documenting % cover of mineral soil, X003*. If a regeneration species is growing on the Sub Plot from more than one **Regen Source** and/or is in multiple **Regen Height Classes** then each variance has its own line on the data sheet. **Except stump sprouts** which are recorded based upon the average height of the 3 highest sprouts for a group of sprouts from one source. Create a record for each **Regen Source** and **Height Class** as its own separate line item with its own **Cover Class**, **Live Cover Class**, **Average Height**, and **Regen Count**.

j. Cover Class - Ocularly estimate and record the total cover percent of both live and dead plant material that each species' crown occupies in the Sub Plot being measured. Percentage classes' descriptions are in a key on the data sheet. If a species is dead but identifiable, record it here but not in **Live Cover Class**.

k. Live Cover Class - Ocularly estimate and record the cover percent of only live plant material that each species' crown occupies in the Sub Plot being measured.

l. Average Height - Measure in inches the average height of each separate **Cover Class** of species.

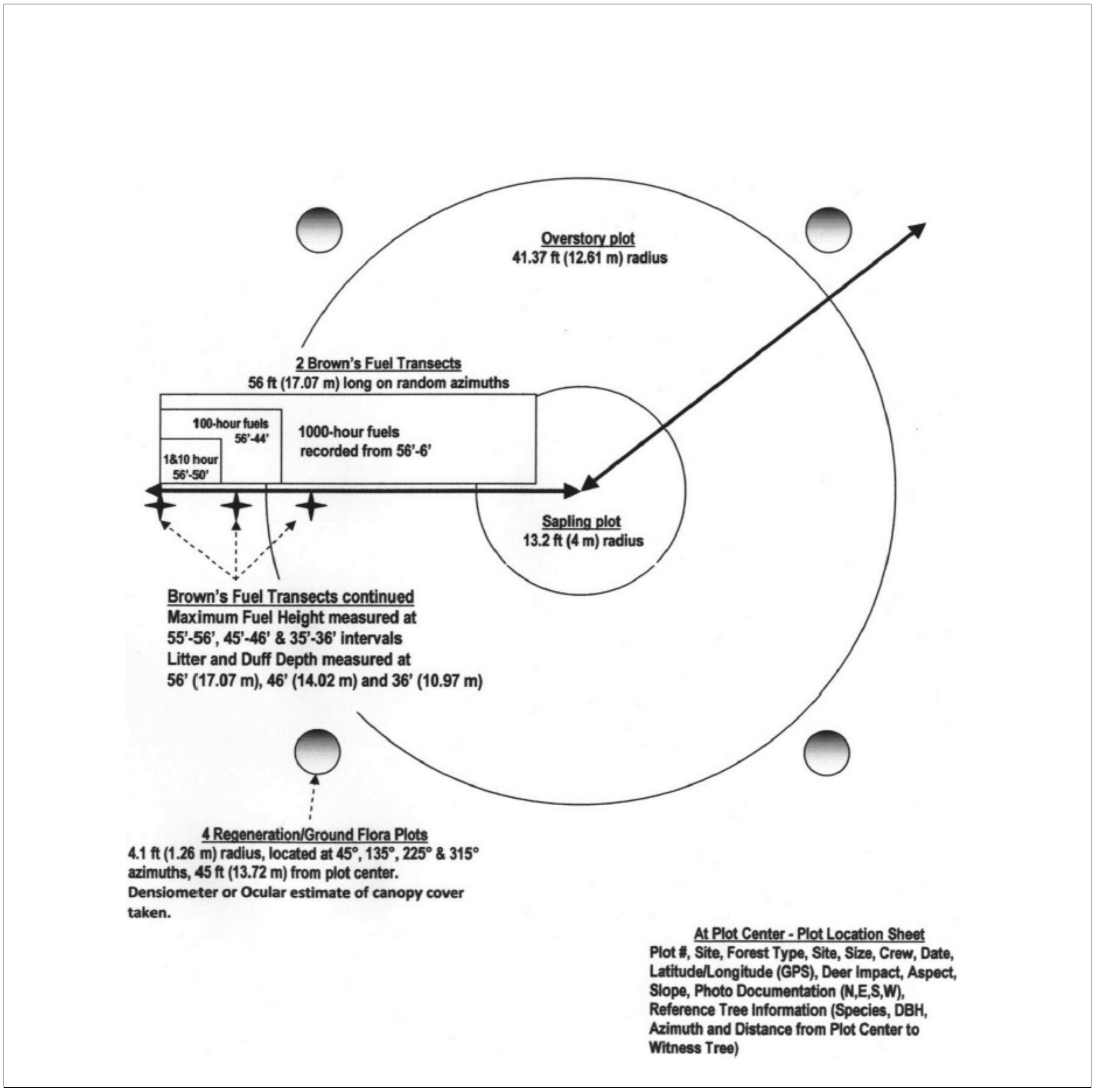
Regeneration Species
Qualification definitions are described on the data sheet for tree regeneration counts of oak, hickory and walnut based upon both height and root collar specifications. Qualification definitions of pine species counts are described on the data sheet by height and whorl variables. SILVAH uses similar restrictions for regeneration counts. Count tree regeneration based on the conditions listed in the key on the data sheet. For **Regeneration Source** check if a tree's origin is from a **(1) stump sprout** [count only the 3 most dominant sprouts on stumps ≥2" and use an average height]; **(2) other seedling** [from seed and not competitive]; **(3) competitive** [root collar diameter (RCD) is >0.75"]; **(4) established** [RCD is <0.75" but >0.25", or the seedling is 0.5'-3' tall]; or **(5) new oak** [RCD is <0.25 and is <0.5'

tall]. Record the **Regen Source** in all circumstances for qualifying regeneration; this is a key variable when weighing the chances of having successful regeneration.

m. Regen Source – Use information above and the key on the data sheet to record the **Regen Source** of all tree species. A list of tree species codes with "T" and "R" is in the "Manual of Procedure for the Continuous Forest Inventory of Forest Wildlife Habitat Resources" and at the end of this document. Give an "R" prefix and fill in data for **Regeneration Source**, **Regeneration Height Class** and **Regeneration Count** to tree seedlings that qualify as regeneration. If a tree seedling does not qualify as regeneration, give a "T" prefix and it does not get a **Regeneration Source**, **Regeneration Height Class** or **Regen Count** but instead it is given a **Species**, **Cover Class**, **Live Cover Class** and **Average Height**. Do not count shrubs, such as scrub oak, *Quercus ilicifolia*, as regeneration.

n. Regen Height Class – Use the key on the data sheet to classify the height class of the stem(s) counted as regeneration for each species.

o. Regen Count – Record the total count of tree species in each **Height Class/Regeneration Source** combination on the Ground Flora plot.



Overstory plot
41.37 ft (12.61 m) radius
2 Brown's Fuel Transects
56 ft (17.07 m) long on random azimuths
100-hour fuels
56'-44'
1000-hour fuels
recorded from 56'-6'
1&10 hour
56'-50'
Sapling plot
13.2 ft (4 m) radius
Brown's Fuel Transects continued
Maximum Fuel Height measured at
55'-56', 45'-46' & 35'-36' intervals
Litter and Duff Depth measured at
56' (17.07 m), 46' (14.02 m) and 36' (10.97 m)
4 Regeneration/Ground Flora Plots
4.1 ft (1.26 m) radius, located at 45°, 135°, 225° & 315°
azimuths, 45 ft (13.72 m) from plot center.
Densiometer or Ocular estimate of canopy cover
taken.
At Plot Center - Plot Location Sheet
Plot #, Site, Forest Type, Site, Size, Crew, Date,
Latitude/Longitude (GPS), Deer Impact, Aspect,
Slope, Photo Documentation (N,E,S,W),
Reference Tree Information (Species, DBH,
Azimuth and Distance from Plot Center to
Witness Tree)

Appendix Figure 4. Data collection protocol corresponding to the Pennsylvania Game Commission pre- and post-burn forest monitoring research conducted in State Game Land 176 Unit 2. *Source: SGL 176 Prescribed Burn Inventory – 2009 Pre-burn Inventory, August 2009.*

Methods

The data collection protocols followed for this inventory were based on the *Handbook for Inventorying Surface Fuels and Biomass in the Interior West* (Brown et al. 1982) and the *Sampling Protocols for Simulated Effects of Fuel Treatments on Fire Behavior and Viewsheds in Inner WUI Forest of Yosemite National Park* (Taylor 2008). Data on forest ground flora, tree regeneration, midcanopy, overstory and downed woody fuel loading were collected on each plot. The plot sampling diagram is found in Figure 3.

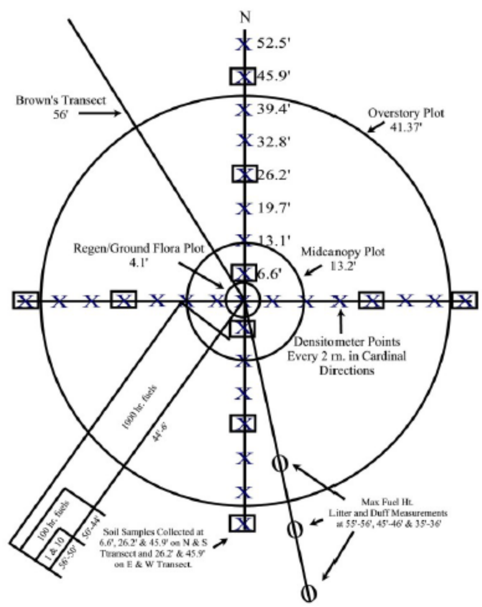


Figure 3. Plot diagram.

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Permanent inventory plots were established, monumented and inventoried using a stratified random sampling design. Twelve plots were located in the mixed oak forest type and two in the aspen forest type. A total of 14 inventory plots were established and inventoried (Figure 4).

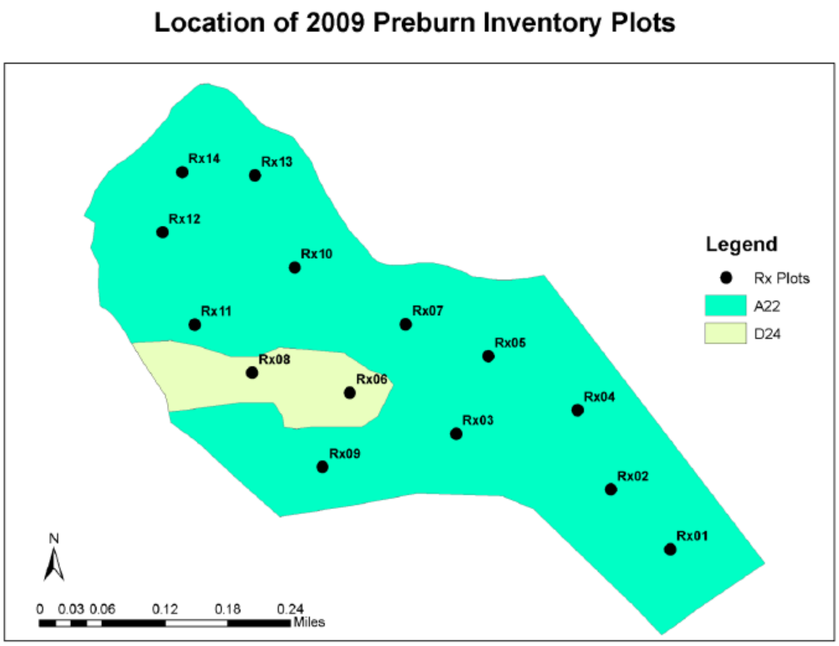

Figure 4. Plot distribution in 2009 prescribed fire treatment unit.

Plot Monumentation

Each plot center was permanently marked and documented. A 10 inch wooden stake was marked with the plot number and driven into the ground to mark plot center. A GPS point was taken and one witness tree was recorded and scribed with two slashes at eye level and stump level. This will enable relocating the plot for post-burn and subsequent re-inventories.

General Plot Description

At each plot, general plot information was recorded. Information on the measurement date, inventory crew, percent slope and aspect were recorded. In addition, a digital photo in each cardinal direction from six feet behind plot center was taken.

Regeneration/Ground Flora

Regeneration and ground flora were sampled on one 4.13 ft. radius plot originating from plot center. Data on species, cover class, live cover class, average height and regeneration counts were collected. Cover classes were based on the following scale:

< 1%
1 – 5%
5 – 25%
25 – 50%
50 – 75%
75 – 100%

Regeneration counts were taken for all tree species greater than six inches in height and less than one inch in diameter.

Midcanopy

Sapling stem counts were sampled on a 13.2 ft. radius plot originating from plot center. Sapling stem counts were made for live and dead stems. Saplings are defined as trees that are greater than 4.5 ft. tall and less than 3.95 inches in diameter at DBH. Tree species, live or dead and DBH class were recorded. DBH classes are as follows:

< 1.3 in.
1.3 – 2.4 in.
2.41 – 3.9 in.

Overstory

Tree stem counts were sampled on a 41.13 ft. radius plot originating from plot center. Overstory trees are defined as trees that are greater than 4.5 ft. tall and greater than 4.0 inches in diameter at DBH. Tree species, status, DBH, crown class, total tree height, live crown height, height to lowest live branch and height to lowest dead branch were recorded. Tree status includes Live, Standing Dead and Down Dead. Crown classes are Dominant, Codominant, Intermediate and Suppressed (Avery and Burkhart 1994).

Appendix Figure 5. Data collection protocol corresponding to the New Jersey Forest Service state forest inventory. *Source: Request for Proposal 16-X-24150 – For: State Forest Inventory, NJDEP, December 24, 2015.*

3.5 NJSFS MINIMUM PLOT LEVEL DATA SPECIFICATIONS FOR STATE FOREST INVENTORY

3.5.1 PLOT DESIGN OVERVIEW

The Contractor shall utilize variable radius point sampling plots with centered nested, fixed radius sub plots for collecting advanced regeneration and groundcover data. These plots shall be recorded for compatibility with the Northeast Decision Model 2 (NED-2) software and can be recorded using (Northeast Decision Model lite (NEDLite) or compatible data collection software (US Forest Service). The Contractor shall provide deliverables in digital format; however, data does not have to be collected with digital data collectors.

3.5.1 PLOT DYNAMICS

The Contractor shall meet the following requirements for the measuring, recording, and reporting of plot dynamics:

a. Plot name;

   1. Plot naming protocol shall be as follows: X Y Z, where X is an abbreviation of the forest type, Y is an abbreviation of the state forests or natural areas, and Z is a number designating plot number. Example: OAKWAR001 would be the first plot in the oak forest type measured in Wharton State Forest;

b. Date recorded;

c. Aspect (North, Northeast, East, Southeast, South, Southwest, West, Northwest); shall be recorded in the NED-2 user code 3 field for the first tree recorded in each plot on non-cored plots, or with the cored tree for cored plots;

d. Slope (measured to the nearest five percent [5%]); shall be recorded in the NED-2 user code 4 field for the first tree recorded in each plot on non-cored plots, or with the cored tree for cored plots;

e. GPS Point of plot center (see Section 3.6, for requirements);

f. Stand photo at least two (2) megapixel from plot center facing north at eye level (with no personnel in the photos);

g. For each plot at least one (1) witness tree shall be scribed, with azimuth, distance, and species recorded in the plot comments section. Witness trees shall be scribed using a tree

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scribe to carve a mark on the tree's bark and flagging to identify the tree from any angle. Scribing should not cut into living tissue of the tree, only the outer bark. Azimuth, distance, and species shall be recorded in NED-2 deliverables in the plot comments for an additional locator tree, but scribing this additional tree is not required. Tree paint is not an acceptable method; and

h. Plot center shall be indicated using a wooden dowel or comparable biodegradable substitute left onsite after a plot is completed.

3.5.2 OVERSTORY

The Contractor shall meet the following requirements for the measuring of overstory:

a. Variable plot radius shall be determined using a Basal Area Factor (BAF) of ten (10) ft^2/acre. In cases of extreme density, such as Atlantic white-cedar stands, a BAF of 30 is acceptable. The Contractor shall use the same BAF throughout a single forest type.

b. Overstory trees (trees ≥ four inches [4"] DBH) that fall within the plot shall have the following data collected:

   1. Species (Augmented NED-2 species list will be provided by NJSFS);
   2. DBH (rounding down to the nearest inch);
   3. Tree count;
   4. Living/Dead;
   5. Tree crown class (i.e. Dominant, Codominant, Intermediate, Suppressed);
   6. Total height (nearest five [5] ft.);
   7. Merchantable height (nearest five [5] ft.); and
   8. Tree product class;
      i. Veneer – a log meeting the quality and size requirements for veneer in the professional opinion of the Contractor;
      ii. Sawtimber – twelve inches (12") minimum DBH to eight inch (8") diameter top;
      iii. Pulpwood – four inches (4") minimum DBH to four inch (4") diameter top;
      iv. Pole – a log smaller than sawtimber but of sufficient quality to meet specifications for poles in the professional opinion of the Contractor;
      v. Firewood - four inches (4") minimum DBH to four inch (4") diameter top, not suitable for pulp;
      vi. Cull; and
      vii. Snag.

c. Tree core data shall be taken on 50% of the plots in each associated forest type (with a minimum of one (1) per forest type) from either a dominant or co-dominant tree of a representative species measuring:

   1. Total tree age (# of years) recorded in the NED-2 user code 1 field;

   2. Radial growth for the last ten (10) years (measured from inside of bark to the nearest 10th of an inch) recorded in the NED-2 user code 2 field; and

   3. All cored trees shall be designated using the "visually interesting" status in NED-2.

d. If a plot produces zero (0) trees in overstory, the Contractor must clearly indicate the plot is a zero (0) plot within the month/final report as well as the user comment column in NED-2.

3.5.3 UNDERSTORY

The Contractor shall meet the following requirements for the measuring of understory:

a. Advanced regeneration (< four inches [4"] DBH + at least 4.5 feet tall) shall be counted on a 1/50th acre (16.7 ft. radius) nested subplot by species.

3.5.4 GROUNDCOVER

The State's intentions of collecting groundcover data are to assess competition for tree regeneration, note the extent of invasive species, and enable the Natural Heritage Program to prioritize habitats for future botanical surveys using site indicator species. The Contractor's data shall make note of what is visible at the time of visit. Contractors are not expected to re-visit sample locations unless quality control issues arise as per the Section 3.8 of the RFP.

The Contractor shall measure groundcover data using a 1/500 acre (5.3 ft. radius) nested subplot and recorded as a percent cover of each species, including observations taller than 4.5 feet that occur within or hang over plot, in the following categories:

a. Ferns (by species from list provided by NJSFS);

b. Herbaceous plants (by species from list provided by NJSFS);

c. Moss (cushion vs. sphagnum);

d. Woody Vine (by species from list provided by NJSFS);

e. Shrubs (by species from list provided by NJSFS);

f. Lichens (by form: Furticose, Foliose, Crustose);

g. Exotics/invasives (by species from list provided by NJSFS); and

h. Tree Seedlings shorter than 4.5 feet in height (count by species in addition to estimated % cover).

Appendix Figure 6. Forest Inventory and Analysis (FIA) Fact Sheets showing the data collection protocol corresponding to the U.S. Forest Service FIA Program. *Source: FIA Fact Sheet Series, 2/3/05*.

Forest Inventory and Analysis
Sampling and Plot Design

FIA Fact Sheet Series

Overview. The FIA Program collects, analyzes, and reports information on the status, trends, and condition of America's forests: how much forest exists, where it exists, who owns it, and how it is changing, as well as how the trees and other forest vegetation are growing and how much has died or has been removed in recent years.

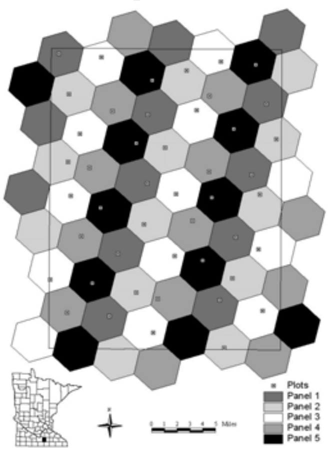
The components and characteristics of the FIA Program that relate to sampling and plot design include:

* Coverage - A single inventory program to include all forested lands in the US, regardless of ownership or availability for forest harvesting. The new program includes all forest land in all 50 States plus all of the territories and possessions of the US. It covers all public and private forest land such as reserved areas, wilderness, National Parks, defense installations, and National Forests.

* Sampling Intensity - The new program includes the measurement of a fixed proportion of the plots in each State, each year, known as annual inventory. Each portion of the plots is known as a panel. The legislative mandate requires measurement of 20% of the plots in each State, each year, to be achieved through a federal-state partnership. Plans have also been developed for less intensive sampling levels of 15% per year and 10% per year. We have agreed that the base federal program to be implemented in all states will include sampling levels of 15% per year in the eastern US and 10% per year in the western US.

* Precision - The plot intensity assumes that enough plots are measured to satisfy precision standards for area and volume estimates, which are consistent with historical levels. Individual States may choose to increase the sample intensity by installing additional plots, at their own expense, in order to increase the precision. However, one of the advantages of the proposed annual inventory system is that it will provide maximum flexibility to States to engage in such intensifications.

* National Sampling Design - A nationally uniform cell grid has been super-imposed over our existing set of sample locations, in order to provide a uniform basis for determining the annual set of measurement plots.



Phase 2 hexagons from Waseca Co. Minnesota and the selected Phase 2 plots for each cell by panel.

This system will eliminate existing discrepancies in the sample intensity between States and regions, and will provide a standard frame for integrating FIA and for linking the program's other data sources such as satellite imagery, spatial models, and other surveys.

* Core Variables - The FIA program includes a national set of core measurements (including some forest health variables collected on a subset of the plots), collected on a standard field plot.

* Data Collection - All field data collectors, regardless of whether they are Federal, State, or contractor receive standardized training and pass a certification test before collecting data.

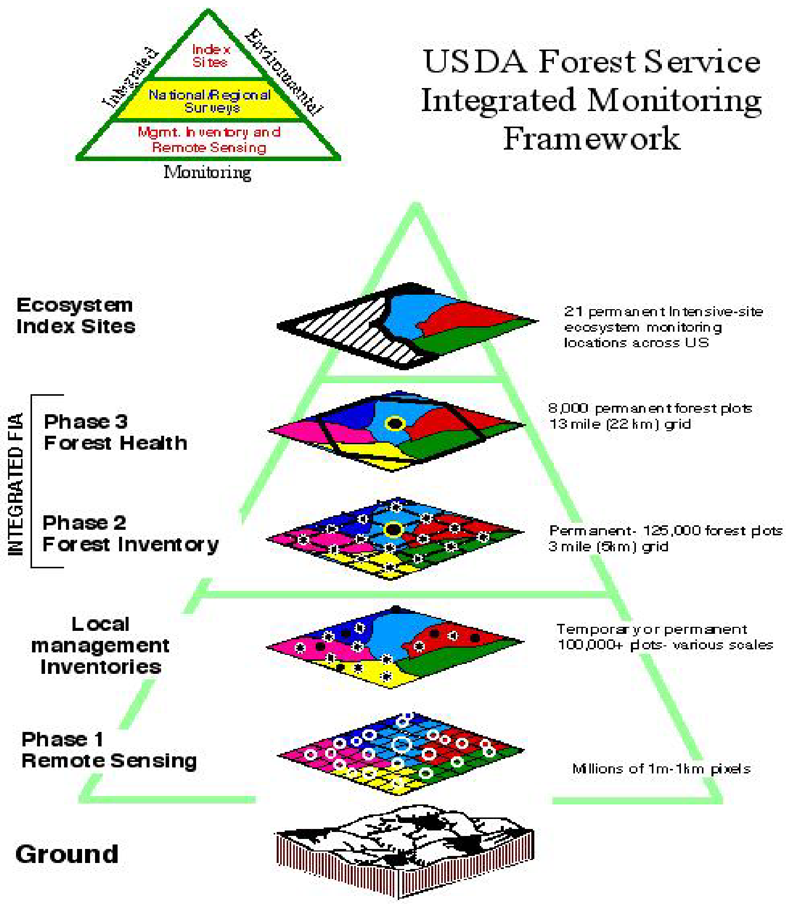
* Quality Assurance (QA) - The present QA program includes training for data collectors, documentation of methods, checks of data quality, peer review of analysis products, and continuous feedback to ensure that the system improves over time.

Forest Inventory and Analysis. In response to legislative direction , the USDA Forest Service significantly enhanced FIA by changing from a periodic survey to an annual survey, by increasing our capacity to analyze and publish data, and by merging the FIA and the FHM sampling designs. The wide array of data collected on the Nations' forested ecosystems are used by a diverse set of customers for many purposes.

The enhanced FIA program consists of three phases or tiers.

* Phase 1 - Phase 1 is the aspect of data collection related to remotely sensed data in the form of aerial photographs, digital orthoquads, and satellite imagery. This accomplishes two tasks, intial plot measurement via remotely sensed data and stratification. This activity is accomplished in the office. A Phase 1 "photo point" is characterized as forest or nonforest. A subset of the photo points are selected for field data collection (Phase 2).

* Phase 2 – This component consists of one field sample site for every 6,000 acres. Field crews collect data on forest type, site attributes, tree species, tree size, and overall tree condition on accessible forest land.



* Phase 3 – This component consists of a subset of Phase 2 sample plots that are measured for a broader suite of forest health attributes. There is approximately one Phase 3 plot for every 16 Phase 2 plots; or one Phase 3 plot for every 96,000 acres. These attributes include tree crown conditions, lichen community composition, understory vegetation, down woody debris, and soil attributes. Soil samples are sent to a laboratory for chemical analysis. Finally, an associated sample scheme exists to detect and monitor ozone injury on forest vegetation.

Plot Layout. An FIA plot consists of a cluster of four circular subplots spaced out in a fixed pattern. The plot is designed to provide a sampling frame for all P2 and P3 measurements.

Most tree measurements are taken within the subplots. Seedlings, saplings and other vegetation are measured on the microplots. Annular plots are used for tree measurements that require collecting a physical sample. This allows the subplots to remain unaltered by sample collection.

Subplots are never reconfigured or moved; a plot may straddle more than one 'condition class' such as two different forest types or a forest and a meadow. A condition class is defined as a specific combination of attributes such as land use, forest type, stand age, and other attributes which collectively describe a homogeneous area. Every plot exists in at least one condition class, and may include more than one. If multiple condition classes occur on a plot, each condition class is described separately.

Forested condition classes are further classified by the following groups reserved status, owner group, forest type, stand size class, regeneration status, and tree density. If any of these attributes changes within a plot, then an additional condition class is defined and described. The rest of the variables within the condition class level data are used to describe the condition class in more detail, but **changes in these auxiliary variables are not used to define an additional condition class**.

Fact Sheet Author: Bill Burkman

For more information about the FIA Program:

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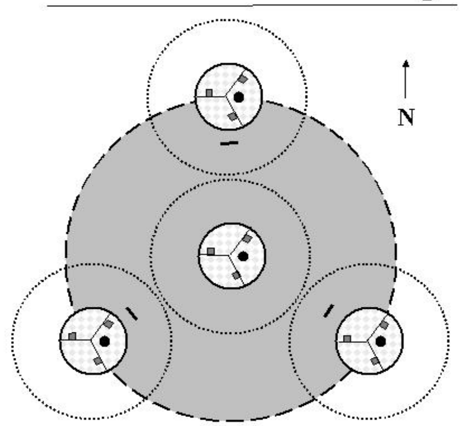
- Visit our national FIA website: http://www.fia.fs.fed.us

Phase 2/Phase 3 Plot Design



Subplot	24.0 ft (7.32 m) radius
Microplot	6.8 ft (2.07 m) radius
Annular plot	58.9 ft (17.95 m) radius
Lichens plot	120.0 ft (36.60 m) radius
Vegetation plot	1.0 m² area
Soil Sampling	(point sample)
Down Woody Debris	24.0 ft (7.32 m) transects

Forest Inventory & Analysis

Phase 2 and Phase 3: Ground Measurements

FIA Fact Sheet Series

The FIA program has recently made a number of changes including: transitioning from periodic surveys to annual surveys, increasing our capacity to analyze and publish data, and merging the FIA and FHM plots into a single three-tiered (or phased) FIA system.

Phase 1 is the traditional aerial photography and/or remote sensing activity used to characterize the acreage of forest and non-forest land in the US. Phase 2 are the traditional FIA ground plots that focus on forest and tree information as it relates to timber but not exclusively. Phase 3 are the ground plots previously installed and measured by the FHM program, and are a subset of the phase 2 plots. It is on phase 3 plots that information relating to forest health is collected.

The National Core Field Guide for P2 and P3 is used by all FIA units to describe how to collect a core set of forest inventory and forest health data. In addition, each FIA unit collects additional variables at the regional level to meet their regional and local needs. The National Core Data Elements are consistent across all of the US.

For a copy of the current National Core Field Guide please visit the National FIA web page. (Note: see webpage address at the end of this document.)

Data Collection. Data are collected by permanent or temporary Federal employees; State employees through cooperative agreements; or non-government sources (universities, private contractors, etc.) via contract. The FIA units have experience with all of these options. Each field unit develops staffing plans that provide for flexibility to take advantage of local conditions. All field data collectors receive standardized training and must pass a certification test before collecting data.

Quality Assurance. The present Quality Assurance (QA) program, includes documentation of methods, training for data collectors, checks of data quality, peer review of analysis products, and continuous feedback to ensure that the system improves over time. Field crews enter measurements into portable data recorders (PDRs) in the field. The PDR software includes a high level of real-time error checking as data are entered. QA data and analyses will be included in publications and made available.

Core Variables. The annual inventory program includes a nationally consistent set of core measurements, collected on a standard field plot, with data managed, processed, analyzed, and reported uniformly. The set includes ecological variables not previously collected consistently in all regions. Because a nationally consistent set of core variables is needed to respond to legislative mandates and address customer information needs across scales, field units use the national definitions and measurement protocols established for the core variables on all forest land.

Phase 2. Phase 2 is the field data collection activity that occurs on the standard FIA plot grid (1 plot per 6,000 acres). Forested plots are installed and measured regardless of intended use or any restrictive management policy. It is on these field locations that the majority of data collection activities occurs. Plots are installed across all ownership groups. Public and private owners awareness of the program and granting access to the forest land is essential to the success of the program. To protect the privacy of a participating landowner, the exact plot location coordinates are kept confidential.

Maps, aerial photographs/imagery, and GPS units are utilized to properly install the ground plots. The information on the photo is used to establish a starting point (SP). The SP is a easily recognizable monument that can seen on the photo and/or found by using land use patterns. The crew then navigates to the plot center (PC) either by this information or via the use of a GPS instrument. Once the crew has traversed along the azimuth and distance to PC from the SP, the crew will examine the photo and verify that they are actually at PC and GPS readings are recorded. All of this information is useful for future FIA field crews to re-locate the plot. Any additional information that future crews need in collecting the data is also included in the general plot notes.

On all our forested field plots, we gather quantitative and qualitative measurements that describe

- Tree diameter, length, damage, amount of rotten or missing wood, and tree quality.
- Tree regeneration.
- Site quality information.
- Stocking.
- General land use.
- General stand characteristics such as forest type, stand age, and disturbance.
- Changes in land use and general stand characteristics.
- Estimates of growth mortality, and removals.

Change estimates are determined by comparing data from the same plot at two different measurement time periods, usually 5 to 10 years.

Phase 3. On a subset of the Phase 2 plots (one Phase 3 plot per 16 Phase 2 plots), we collect a more extensive set of data. These measures relate to forest ecosystem function, condition, and health. Due to the seasonality associated with some of these measurements, the Phase 3 data are generally collected during a three-month window – June, July, and August. The current measurements on the Phase 3 subset of plots can be grouped into the following categories:

- Crown Conditions – generally good crown conditions are signs of vigorous trees and poor crown conditions are symptoms of trees under stress.
- Soil Condition – soil erosion and compaction are measured and soil samples are collected for analysis of physical and chemical properties including estimates of site fertility.
- Lichen Communities – lichen species richness and abundance are measured on the plot. The presence or absence of certain lichen species indicates air quality, climate changes, and ecosystem biodiversity.
- Vegetation Diversity and Structure – the composition of vegetation (species and growth forms), abundance, and spatial arrangement in the forest are measured to determine such things as vegetative diversity, presence and abundance of . exotic and introduced plant species, fuel loading, wildlife habitat suitability, and carbon cycling.
- Down Woody Debris – measurements of the amount of coarse and fine wood on the ground can estimate carbon storage, soil erosion potential, fire fuel loading and, combined with the vegetation structure data, wildlife habitat.
- Ozone bioindicator data – certain plant species are sensitive to ozone exposure. On a separate grid, ozone sensitive species are evaluated for the presence of ozone injury during the late summer.

Plot Layout. An FIA plot consists of a cluster of four circular subplots spaced out in a fixed pattern. The plot is designed to provide a sampling location for all P2 and P3 measurements.

Subplots are never reconfigured or moved; a plot may straddle more than one 'condition class' such as two different forest types or a forest and a meadow. A condition class is defined as a specific combination of environmental attributes such as land use, forest type, stand age, and other attributes which collectively describe a homogeneous area. Every plot exists in at least one condition class, and may include more than one. If multiple condition classes occur on a plot, each condition class is described separately.

Forested condition classes are further subdivided by the following groups (listed in order of priority): reserved status, owner group, forest type, stand size class, regeneration status, and tree density. If any of these attributes changes within a plot, then an additional condition class is defined and described. The rest of the variables within the condition class level data are used to describe the condition class in more detail, but changes in these auxiliary variables are not used to define an additional condition class.

Fact Sheet Author: Bill Burkman

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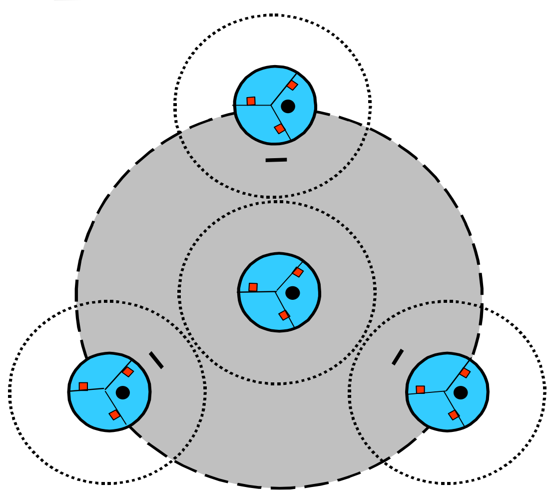
Phase 2/Phase 3 Plot Design



(symbol)	**Subplot**	**24.0 ft (7.32 m) radius**
(symbol)	**Microplot**	**6.8 ft (2.07 m) radius**
(symbol)	**Annular plot**	**58.9 ft (17.95 m) radius**
(symbol)	**Lichens plot**	**120.0 ft (36.60 m) radius**
(symbol)	**Vegetation plot**	**1.0 m² area**
—	**Soil Sampling**	**(point sample)**
—	**Down Woody Debris**	**24 ft (7.32 m) transects**

Forest Inventory and Analysis
Sampling Hexagons

FIA Fact Sheet Series

Background. Federal legislation passed in 1998 (Agricultural Research, Extension, and Education Reform Act of 1998 – PL 105-185), required major changes to the FIA program. A primary driving force behind this change was user requests to minimize differences in inventory techniques and therefore maximize the ability to compare and contrast the forest resources in different places or in different time periods. One of the more fundamental changes mandated by the legislation was to conduct annual inventories in each State. The target for Eastern states is to complete 20% of their entire inventory each year while Western states are to complete 10% of their entire inventory each year. Inventory cycles for Alaska, Hawaii, and other island areas will be tailored to their needs.

A consistent, regular, spatial and temporal distribution of sampled locations across the U.S. is one part of the strategy developed to meet this objective. This fact sheet describes the approach used to locate field plots in the lower 48 states of the U. S. near a regularly spaced array of points and also assign them to a specific measurement year.

The FHM Experience. The FHM (Forest Health Monitoring) program used hexagons of equal area to establish monitoring plots systematically across the landscape and regularly spaced in time (Scott *et al*. 1993). The hexagons completely covered the conterminous 48 states, were assigned to one of four inter-penetrating groups (called panels), and included one and only one location to be sampled on the ground. The field locations within hexagons assigned to a given panel were visited once every four years. Thus, this method distributes field locations regularly in both time and space (figure 1).

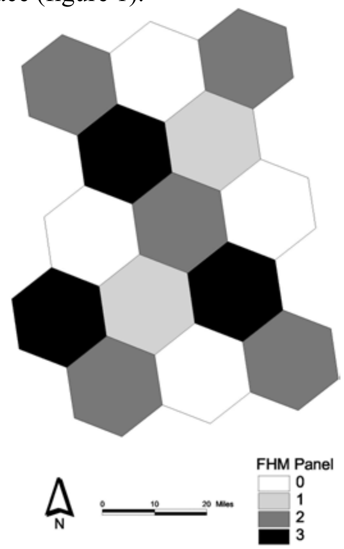


Figure 1. Original FHM hexagons.

The FIA Hexagons. The FHM hexagons served as the basis for the FIA hexagons. A 27 factor increase in the FHM sampling intensity, resulted in hexagons that encompassed 5937.2 acres. Selecting one plot for each hexagon made the sampling intensity close to the 1 field plot per 6000 acres estimated to meet mandated national sampling precision (M. H. Hansen 1998, personal communication). Temporal regularity was incorporated by systematically assigning each hexagon to one of 5 inter-penetrating panels (figure 2). Plots located in eastern panel 1 hexagons were to be measured in 1999. Half the western panel 1 hexagons were to be measured in 1999 (called subpanel 1) and the other half in 2004 (subpanel 2). Panel 2 was to be measured in 2000 (for subpanel 1 in the west or 2005 for subpanel 2). The same pattern is repeated for panel 3, 4, and 5. Once the five or ten-year cycle is complete, the sequence would start again.

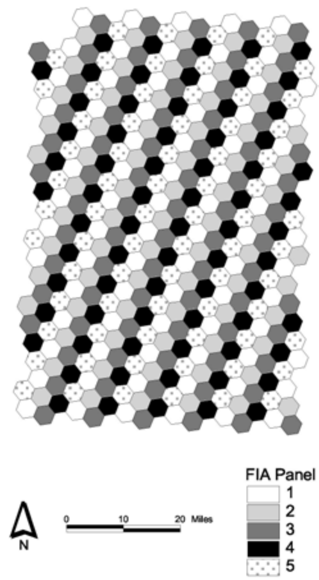


Figure 2. Original FIA hexagons.

Various attributes for each hexagon have been stored. These include a unique identifier, the latitude and longitude of its center, the state and county in which its center is located, the panel assigned to the hexagon, and if the hexagon is also a P3 hexagon (see below).

Plot locations. A variety of grids and methods had been employed by FIA to locate field plots. For the annual inventory, the actual field location selected for each hexagon followed these rules:

1. If an FHM plot existed within the hexagon, it was selected (to satisfy the national objective to integrate the samples and maintain existing FHM plots);
2. If no FHM plot existed in the hexagon, then an existing FIA plot within the hexagon and closest to the center of the hexagon was selected (to satisfy the national objective to maintain existing FIA plots

and select them without bias);
3. If the hexagon did not contain an existing FHM or FIA plot, then a new location near the center of the hexagon was chosen.

Panel Adjustments. The regular temporal order for collecting FIA data enhances the ability to analyze change. Rule 1, from above, redistributed FHM plots temporally from their originally assigned measurement sequence to the sequence based on the panel associated with their FIA hexagons. The redistribution also reduced the number of FHM plots measured each year by 20%. A further reduction in the number of plots measured annually was caused by the elimination of FHM overlap plots; i.e. plots measured in consecutive years. To compensate for the reduction in annually measured FHM plots, a new set of locations (a 67% increase) were created. This maintained the original locations plus added new locations for the fifth panel and the loss of overlap plots (William D. Smith, 1999, personal communication).

The negative impact to the FHM program caused by using the FIA panel sequence would be significant. Therefore, the original panel assigned to those FIA hexagons with existing FHM plots was changed to match the original FHM panel (Brand et al. 2000). The resulting spatial and temporal irregularity (figure 3) was deemed an acceptable tradeoff for maintaining FHM temporal continuity.

The final FIA sampling hexagons (figure 4) are 5937.2-acres in area, each containing one plot for the base National program. About 1 out of every 16 hexagons is designated as the FHM (now called a phase 3 or P3) hexagon. For plots located within the P3 hexagon, P3 measurements in addition to standard P2 (phase 2) are collected (Burkman 2002 FIA Fact Sheet: "Sampling and Plot Design" for additional information on P2/P3 measurements).

Figure 3. Comparison of original FHM hexagons (large ones) with the FIA hexagons designated as P3 hexagons (small ones).

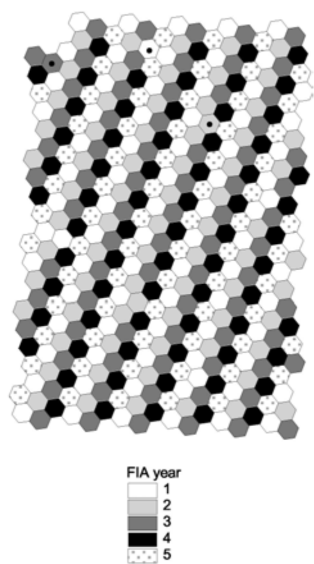


Figure 4. The final FIA hexagons. Note that the hexagons with the dots are examples of hexagons with reassigned panels to accommodate the original FHM panel.

References:
Brand, G.J., Nelson, M.D., Wendt, D.G., and Nimerfro, K.K. 2000. The hexagon/panel system for selecting FIA plots under an annual inventory. In Proceedings of the first annual forest inventory and analysis symposium, (R.E. McRoberts, G.A. Reams, P.C. Van Deusen, Eds.), Gen. Tech. Rep. NC-213 U.S. Department of agriculture, Forest Service, North Central Research Station, St. Paul, MN, pp. 8-13.

Scott, C.T., Cassell, D.L., and Hazard, J.W. 1993. Sampling design of the U.S. National Forest Health Monitoring Program. In Proceedings of the Ilvessalo symposium on national forest inventories, 1992 August 17-21, Helsinki, Finland, Res. Pap. 444, Finish Forest Research Instituted, pp 150-157.

Fact Sheet Author: Gary Brand

For more information about the FIA Program:
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- See our "FIA Contacts" Fact Sheet

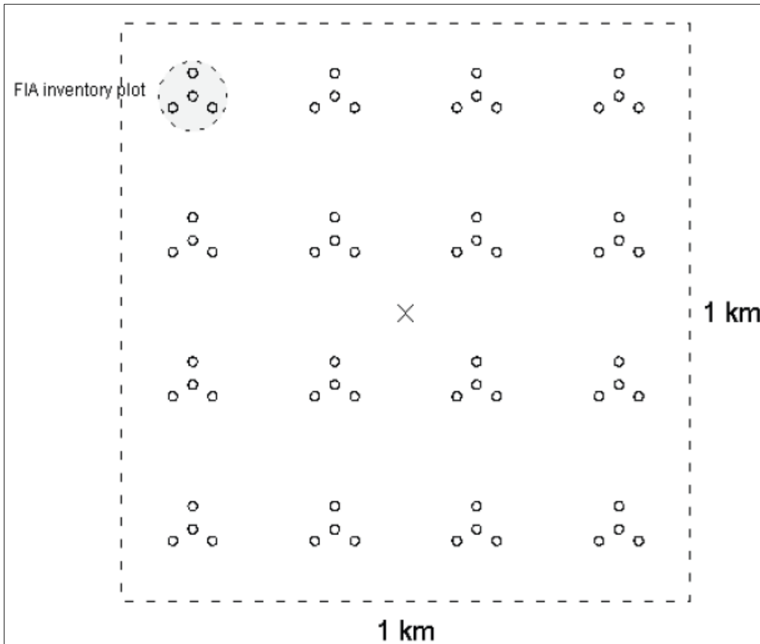

Figure 2—A landscape-scale sampling design using 16 FIA inventory plots. The exact number and configuration of sample plot locations were determined by variability of the landscape and number of sampling strata. The X at the center represents a flux or meteorological tower.

Appendix Figure 7. FIA inventory plots were used in the U.S. North American Carbon Program landscape-scale carbon monitoring sampling design. *Source: Database for Landscape-Scale Carbon Monitoring Sites, September 2013.*

APPENDIX B – Tree Survival Rates

Appendix Table 1. Seedling height classes and corresponding reliability indices (RI), which were used to estimate seedling survival rates. *Source: Vickers et al. 2019.*

Seedling Height (m)	RI
≤ 0.3	0.054
0.6	0.195
0.9	0.395
1.2	0.395
1.5-2.7	0.745
≥ 3.0	1.0

Appendix Table 2. Tree species types and corresponding estimated large tree survival rates. *Source: Vickers et al. 2019.*

Tree Species Type	Estimated Survival (%)
Pines	98.8
Oaks (Mixed with Pines)	98.8
Oaks (Mixed with Other Hardwoods)	98.5
Hickories	98.5
Other Hardwoods	98.0

APPENDIX C – Supplemental Tables

Appendix Table 3. Projected changes in relative BA for pines (*Pinus* spp.), oaks (*Quercus* spp.), and other species and total BA values (m^2 ha^{-1}) over 60 years, and standard deviation among experimental replicates, for each forest class with different fire regime treatments. Values for forest groups are based upon weighted means among the constituent stands. *Table 3* in *ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx.*

Appendix Table 4. Top four most dominant species in terms of BA, corresponding BA proportions relative to total stand BA, total stand BA (m^2 ha^{-1}), and standard deviation among experimental replicates at initial inventory, year 30, and year 60 for each stand, with different fire regime treatments. In cases where the identified species differed within any of the four positions among the replicates, the greater-identified species, i.e. identified in two of the three replicates, was selected; in the very rare instance when each replicate projected a different species, species were selected to avoid overlap with the other species present within the set. *Table 4* in *ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx.*

Appendix Table 5. Top four most abundant species in terms of density, corresponding density proportions relative to total stand density, total stand density (trees ha^{-1}), and standard deviation among experimental replicates at initial inventory, year 30, and year 60 for each stand, with different fire regime treatments. In cases where the identified species differed within any of the four positions among the replicates, the greater-identified species, i.e. identified in two of the three replicates, was selected; in the very rare instance when each replicate projected a different species, species were selected to avoid overlap with the other species present within the set. *Table 5* in *ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx.*

Appendix Table 6. Projected changes in total density values (trees ha^{-1}) over 60 years, and standard deviation among experimental replicates, for each forest class with different fire regime treatments. Values for forest groups are based upon weighted means among the constituent stands. *Table 6* in *ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx.*

Appendix Table 7. Projected changes in quadratic mean diameter (QMD) for pines (*Pinus* spp.), oaks (*Quercus* spp.), and all species combined over 60 years, and standard deviation among experimental replicates, for each forest class with different fire regime treatments. Values for forest groups are based upon weighted means among the constituent stands. *Table 7* in *ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx.*

Appendix Table 8. Projected changes in relative BA for pines (*Pinus* spp.), oaks (*Quercus* spp.), and other species and total BA values (m^2 ha^{-1}) over 60 years, and standard deviation among experimental replicates, for each stand with different fire regime treatments. *Table 8* in *ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx.*

Appendix Table 9. Projected changes in quadratic mean diameter (QMD) for pines (*Pinus* spp.), oaks (*Quercus* spp.), and all species combined over 60 years, and standard deviation among experimental replicates, for each stand with different fire regime treatments. *Table 9* in *ZhaoAnthony_MastersThesis_APPENDIX_C.xlsx.*