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Arizona's Forest Resources, 2001–2014

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Abstract

This report presents a summary of the most recent inventory of Arizona's forests based on field data collected between 2001 and 2014. The report includes descriptive highlights and tables of forest and timberland area, numbers of trees, biomass, volume, growth, mortality, and removals. Most sections and tables are organized by forest type or forest-type group, species group, diameter class, or owner group. The report also describes the inventory's design, inventory terminology, and data reliability. Results show that Arizona's forest land covers 18.6 million acres. Forty-one percent (7.7 million acres) of this forest land is administered by the USDA Forest Service, and another 39 percent (7.3 million acres) is privately owned. The State's most abundant forest type is pinyon/juniper woodland, which covers more than 7.3 million acres. Pinyon/juniper woodlands, combined with juniper woodland, cover over 11 million acres, or almost 60 percent of Arizona's forest land area. Common pinyon is the most abundant tree species by number of trees, and ponderosa pine is the most abundant by volume and biomass. Arizona's forests contain 14.5 billion cubic feet of net volume in trees 5.0 inches diameter and larger. Gross growth of all live trees 5.0 inches diameter and larger averaged 184 million cubic feet per year. Average annual mortality totaled 238 million cubic feet per year, and net growth was –53.6 million cubic feet per year, or about a 0.37 percent reduction of the State's total wood volume.

Keywords: Arizona, forest inventory, field data, trees, biomass, volume, growth, mortality, removals

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Report Highlights

Forest Area

- There are an estimated 18.6 million acres of forestland in Arizona, about 25 percent of the State's total land area. Almost 91 percent (16.9 million acres) of the forest land is unreserved, meaning that it is available to be managed for production of various forest resources. Almost 18 percent (3.0 million acres) of the unreserved forest land is classified as timberland, meaning that the land has the capability of producing greater than 20 cubic feet per acre per year of wood volume.
- Arizona's most common forest-type group is pinyon/juniper, which covers 11.1 million acres or almost 60 percent of the State's forest land. The woodlands hardwoods group is the second most abundant, making up 3.6 million acres (19.5 percent) of the State's forest land.
- Arizona's largest owner of forest land is the USDA Forest Service's National Forest System, which manages about 7.7 million acres (41.3 percent) of forest land. Collectively, privately owned forest land totals 7.3 million acres (39.3 percent) of Arizona's total forest land area, second only to National Forest System lands.

Numbers of Trees Volume, and Biomass

- Arizona has an estimated 4.0 billion live trees 1 inch in diameter or larger and over 75 million dead trees 5 inches in diameter or larger. Over 68 percent of live trees are softwood species, and 35 percent of live softwoods are under 5 inches in diameter.
- The net volume of all live trees on Arizona's forest land totals 14.6 billion cubic feet, 7.7 billion cubic feet of which (53 percent) is located on lands managed by the U.S. Forest Service. Privately owned forests contain 36.4 percent of the State's total live volume. The western woodland softwoods forest-type group contains almost 42 percent of the State's live tree volume, followed by the ponderosa pine group, with over 30 percent.

Forest Growth and Mortality

- Gross growth of wood volume is over 181 million cubic feet per year, but annual mortality is nearly 238 million, resulting in a negative net growth (reduction in live tree volume) of nearly 54 million cubic feet per year on forest land in Arizona. As a percentage of total live volume —0.37 percent per year— this results in a relatively small change in the live-tree inventory.

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Introduction

This report contains highlights of the status of Arizona's forest resources, with discussions of pertinent issues based on the first 14 years of inventory under the Forest Inventory and Analysis (FIA) annual system (Gillespie 1999). In 1998, the Agricultural Research Extension and Education Reform Act (also known as the Farm Bill) mandated that inventories would be conducted throughout United States' forests on an annual basis. This annual system integrates FIA and Forest Health Monitoring (FHM) sampling designs resulting in the mapped-plot design, which includes a nationally consistent plot configuration with four fixed-radius subplots; a systematic national sampling design consisting of one plot in each approximately 6,000-acre hexagon; annual measurement of a proportion of permanent plots; data or data summaries within 6 months after yearly sampling is completed; and a State summary report after 5 years. The inventory strategy for the western United States involves measurement of 10 systematic samples, or subpanels, where one subpanel is completed each year and all subpanels are measured over a 10-year period. Each subpanel is pre-assigned to be surveyed during a specific calendar year, which is referred to as the inventory year (see Appendix A for standard FIA terminology). The year in which each plot was actually surveyed is recorded as its measurement year. Annual inventory summaries are updated each spring to include the most recent subpanels of data. These data are usually available to the public within 6 months of the close-out of the previous field season. Data may be downloaded in table form or queried using a variety of online tools (http://fia.fs.fed.us/tools-data/default.asp).

Arizona's Annual Forest Inventory

Interior West Forest Inventory and Analysis (IWFIA) implemented the new annual inventory strategy in Arizona in 2001, shortly after conclusion of the 1999 periodic inventory (see next section). At the time annual inventory was started, the IWFIA program used criteria of 5 percent projected canopy cover or 40 trees per acre (including seedlings and saplings) as part of the definition of forest land. About the time that the first report on Arizona's forest resources, based on annual inventory, was scheduled to begin (mid-2006), the Forest Service Washington Office Director for Science Policy Planning, Inventory, and Information directed a change in the FIA definition of forest for inventory purposes. There were two parts to the justification of this change: (1) crown cover was more consistent with international definitions of forest land; most international definitions use some minimum measure of crown or canopy cover in the forest land definition; and (2) FIA was expanding the national inventory to include areas not traditionally viewed as forest land. Several pilot projects underway at the time highlighted the need to define and categorize areas not traditionally viewed as forest land, and crown cover was considered superior as a measure of tree stocking in making these classifications. The new forest definition used a minimum projected canopy cover of

10 percent, which includes standing dead trees and trees recently removed from the stand.

The directive also included a requirement that the new definition be applied retroactively. Plots measured previously that didn't meet the new forest definition were to be excluded from the inventory of forest land and re-classified as nonforest. However, there was no set of variables in the FIA database that could be used to definitively assess whether a plot that was measured using a minimum of 5 percent cover would still meet the new forest definition of 10 percent cover. Moreover, there was no nationally consistent approach to qualifying land as forest; although the IWFIA program used a cover-based definition, the three other regional FIA programs used different approaches—for example, based on local stocking equations. As a result, the directive only started the process of moving toward a national, cover-based definition with a 10 percent minimum.

In response to this situation, the IWFIA program implemented two actions. First, for the upcoming (2007) field season, three temporary variables were added to the inventory—live tree canopy cover percent, live and dead/missing canopy cover percent, and number of seedlings per acre. These variables were assessed not on the plot footprint, but on the 1-acre area that encompassed the plot. Second, each of the plots measured in Arizona from 2001–2006 was assessed, using a variety of methods, as to whether they met the 10 percent cover definition. This approach was called "plot filtering" and is described in detail in the 2000–2005 report on Utah's forests (DeBlander et al. 2010, Appendix A). That report was nearly completed using the 5 percent cover definition and was modified in accordance with the revised definition, whereas the Arizona report was delayed until the new definition and related procedures were fully implemented.

The new, nationally consistent forest definition was implemented in 2011, with version 5.0 of the IWFIA field manual (http://www.fs.fed.us/rm/ogden/data-collection/pdf/iwfia_p2_50.pdf). As a result of the filtering approach and the addition of temporary variables, the first 10 years of annual data (2001–2010) for Arizona included a combination of plots that were classified as forest based on filtering, and plots that were classified as forest using variables that eventually were added to version 5.0 of the field manual. Because Arizona has a large area of marginally forested land, this meant that many forest/nonforest calls from 2001–2006 were considered tentative, pending remeasurement visits to those plots during 2011–2016. However, using a combination of the temporary canopy cover variables and the application of the new definition and procedures since 2011, the majority of previously tentative forest/nonforest determinations have now been verified and the results are reflected in this report.

The inventory years covered in this report are 2001 through 2014. Because this span of subpanels includes 4 years of remeasurement, only the most recent 10 subpanels (2005–2014) are used to produce current inventory estimates, such as are presented in the Appendix B tables. Data from the first 4 inventory years are used for other analyses, such as trends in certain variables since the beginning of annual inventory.

Previous Inventories of Arizona's Forests

Prior to implementation of the annual forest inventory, Arizona's forest attributes were estimated from periodic inventories. Periodic inventories in most States generally used data collected over a span of 2 to 5 years, which were then grouped into a single "inventory year." This process was done periodically (hence the name), with an interval between inventories of 10 to 15 years. There were three periodic inventories in Arizona, dated 1966 (Spencer 1966); 1985 (Conner et al. 1990) and 1999 (O'Brien 2002).

The 1966 periodic inventory report (Spencer 1966) was the most comprehensive assessment of Arizona's forests at the time. Some statistics on Arizona's forests were published earlier within national reports (USDA FS 1958, 1965), but the underlying data were not comprehensive for the State. The 1966 inventory was based on a combination of airphoto analysis and ground verification. The 1985 periodic inventory was conducted with support from several cooperators, including the Forestry Division of the Arizona State Land Department, the Bureau of Land Management, and the Bureau of Indian Affairs (Conner et al. 1990). Two national forests collected data for the inventory, and the U.S. Forest Service Southwestern Region supplied data for other national forests. The Bureau of Indian Affairs supplied data for part of the Fort Apache Indian Reservation. Data collection in the remaining areas of the State was done by the FIA staff (then known as Forest Survey) with the assistance of State, Federal, and Tribal cooperators. The 1999 periodic inventory report was based on data collected on 2,763 plots (O'Brien 2002), some of which were carry-over plots from the 1985 inventory. Most plots used a mapped-plot design similar to that used in the current annual inventory.

Data from new inventories are often compared with data from earlier inventories to quantify forest trends. However, for the comparisons to be valid, the procedures used in the inventories must be compatible. Procedures for past inventories of Arizona are different enough from present procedures that direct comparisons of summary results are not recommended. However, it is possible to compare individual plots that were measured during both inventories. The plot design used during the 1999 periodic inventory was very similar to the annual inventory's plot design. Therefore, plots on forest land that were sampled during both inventories can be compared to evaluate changes in attributes such as per-acre estimates of live volume, mortality, growth, and biomass. Details on this approach, as well as comparison of selected characteristics between Arizona's 1999 periodic inventory and annual inventory, have been published (Goeking 2015). A more detailed description of the differences between the periodic and annual forest inventories of Arizona, as well as results of plot-to-plot comparisons of periodic and annual inventory data, can be found in this report in the "Comparisons Between Arizona's Periodic and Annual Forest Inventories" chapter.

Accessing Arizona's Forest Inventory Data

FIA data are publicly available from the national FIA website at http://fia.fs.fed.us. This site includes data downloads; online tools that allow users to perform custom queries; and documentation of FIA's field inventory protocols, database structure, and publications. Plot data may be downloaded in table form or summarized using a variety of online tools (http://fia.fs.fed.us/tools-data/default.asp).

The national FIA database contains data from the 1985 periodic inventory (Conner et al. 1990) and the 1999 periodic inventory (O'Brien 2002), as well as annual forest inventory data, which are updated each year as additional measurements are collected. Data collected as part of the annual inventory are assigned an inventory year that corresponds to the year in which the plot was scheduled for measurement within a 10-year remeasurement cycle, although measurement year can differ from inventory. This can occur, for example, when a plot is inaccessible during its scheduled year because of active fires in the vicinity. For assistance with finding information on this site or with performing custom analyses, data users are encouraged to contact one of the members of the Analysis Team of the Interior West FIA Program who are listed as authors at the beginning of this report.

Overview of Standard and Supplemental Tables

Forest Inventory and Analysis produces a set of standard tables that incorporates most of the core FIA program, using both Phase 2 and Phase 3 data. Appendix B presents tables B1–B37, which summarize annual forest inventory data collected in Arizona between 2005 and 2014 in terms of traditional FIA attributes. These tables encompass statistics for land area, numbers of trees, wood volume, biomass (oven-dry weight), growth, mortality, and sampling errors. Table B1 is the only table that includes all land cover types, and it summarizes the proportions of sample plots that were recorded as forest, nonforest, and nonsampled (e.g., due to inaccessibility). All other tables exclude nonforest land and therefore include only accessible forest land or timberland (see Appendix A for definitions). Table B37 shows sampling errors for area, volume, net growth, and mortality at the 67 percent confidence level.

This report also contains supplemental tables within the body of the report. To avoid confusion between supplemental tables found in individual report chapters and the standard FIA tables found in Appendix B, supplemental tables in the body of this report are labeled consecutively as they appear, beginning with table 1. The standard tables located in Appendix B will be referred to with the appendix letter followed by the table number (e.g., table B1).

Inventory Methods

This chapter briefly describes five key aspects of the FIA program. The first four sections describe configuration of field plots, the national sample design, the three-phase inventory system, and sources of error, which are consistent among all States. The last section describes FIA's quality assurance program and presents the results of quality assessments for the current forest inventory of Arizona.

Plot Configuration

The national FIA plot design consists of four 24-foot radius subplots configured as a central subplot and three peripheral subplots (USDA FS 2011; see fig. 1). Centers of the peripheral subplots are located at distances of 120 feet and at azimuths of 0 degrees, 120 degrees, and 240 degrees from the center of the central subplot. A circle passing through the centers of the peripheral subplots encompasses about one acre. Each standing tree with a diameter at breast height (d.b.h.) for timber trees, or a diameter at root collar (d.r.c.) for woodland trees, of 5 inches or larger is measured on these subplots. Each subplot contains a 6.8-foot radius microplot with its center located 12 feet east of the subplot center on which each tree with a d.b.h./d.r.c. from 1 inch to 4.9-inches is also measured.

To enable division of the forest into various domains of interest for analysis, it is important that the tree data recorded on these plots are properly associated with stand-level data. In addition to the tree data recorded on FIA plots, data are also gathered about the condition class in which the trees are located. A condition

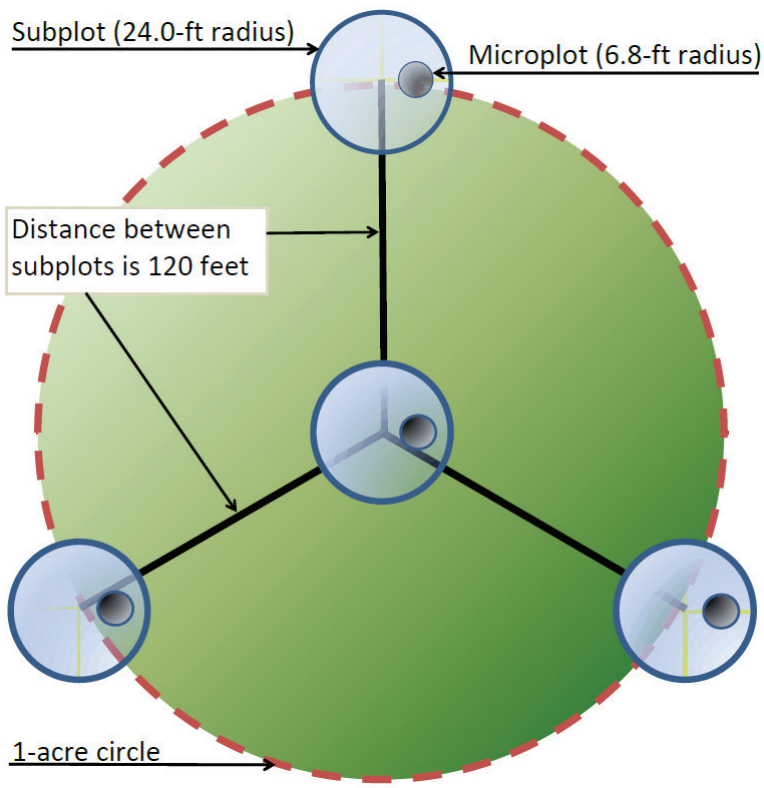

Figure 1—Plot configuration used by the Forest Inventory and Analysis program. Each plot consists of four subplots with a 24-foot radius. The three outer subplots are located 120 feet from the central subplot's center at azimuths of 0, 120, and 240 degrees. Microplots with radii of 6.8 feet are located on each subplot, with centers located 12 feet from the subplot center at an azimuth of 90 degrees.

class (or condition) is the combination of discrete landscape and forest attributes that define and describe the area associated with a plot. The six variables that define distinct condition classes are forest type, stand origin, stand size, ownership group, reserved status, and stand density (Bechtold and Patterson 2005). In some cases, the plot footprint spans two or more conditions if there is a distinct change in any of these six variables. For example, the four subplots on a plot may intersect both forest and nonforest areas, the plot may include distinct stands differentiated by forest type and/or stand size, or the plot may straddle an ownership boundary. All three of these examples would result in more than one condition per plot. Field crews assign numbers to condition classes in the order they are encountered on a plot. Each tree is assigned the number of the condition class in which it stands to enable partitioning of tree data into meaningful categories for analysis.

Sample Design

Based on historic national standards, a sampling intensity of approximately one plot per 6,000 acres is necessary to satisfy national FIA precision guidelines for area and volume. Therefore, FIA divided the area of the United States into nonoverlapping, 5,937-acre hexagons and established one plot in each hexagon using procedures designed to preserve existing plot locations from previous inventories. These sample plots, designated as the Federal base sample, were divided into five spatially interpenetrating panels and 10 subpanels, where each panel consists of two subpanels. In the eastern United States, two subpanels are measured each year such that the inventory cycle is on a 5-year rotation, while in the western United States, including Arizona, one subpanel is measured each year and inventory cycles are completed on a 10-year rotation (Gillespie 1999). For estimation purposes, the measurement of each subpanel of plots can be considered an independent, equal probability sample of all lands in a State, or all plots can be combined to represent the State.

Three-phase Inventory

FIA conducts inventories in three phases. In Phase 1, remote sensing data are digitally analyzed to stratify each State into homogeneous groups such as forest and nonforest areas. In Phase 2, a permanent network of ground plots is first examined using digital imagery, and then forested plots are visited in the field and traditional inventory variables such as forest type and tree diameter are measured. In Phase 3, additional variables associated with forest and ecosystem health are measured on a subset of Phase 2 plots.

Phase 1

Phase 1 uses remote sensing data to delineate homogeneous areas, or strata, throughout the entire State. The purpose of this delineation is to reduce the variance of FIA estimates through post-sampling stratification of field data. The initial Phase 1 strata map consisted of forest, nonforest, and census water strata (see

Appendix A for definitions), which were delineated at a spatial resolution of 250 meters using a combination of 2004 MODIS satellite imagery, other geospatial datasets, and plot-based calibration data (Blackard et al. 2008).

In most Interior West States, post-sampling stratification is based solely on forest and nonforest strata under the assumption that any nonresponse plots occur randomly across the plot grid. Non-response plots are defined as plot locations that cannot be sampled by a field crew. These situations typically occur when landowners or managers do not grant permission for field crews to access plot locations on their lands, although some plots are not sampled due to hazardous conditions that may be permanent in nature, such as sheer cliffs, or temporary hazards, such as current wildfires or active logging operations. Only 4.8 percent of the plots in Arizona were nonresponse (table B1), including 3.5 percent that were classed as access denied.

FIA produces estimates at the scale of individual States, which can then be aggregated into regional estimates, as well as at smaller scales within each State. Within-State population estimates are constructed at two scales: survey units that are comprised of groups of counties, and smaller estimation units that represent individual counties. Arizona consists of two survey units and 15 estimation units denoted as *g*, each containing ng ground plots. The area of each estimation unit is divided into strata of known size using the State's stratification map (fig. 2), which divides the total area of the estimation unit into 250-meter pixels and assigns each pixel to one of *H* strata. Each stratum, h, within an estimation unit, g, then contains nhg ground plots where the Phase 2 attributes of interest are observed.

To illustrate, the area estimator for forest land within an estimation unit in Arizona is defined as:

$$\hat{A}_g = A_{Tg} \sum_{h=1}^{H} W_{hg} \frac{\sum_{i=1}^{n_{hg}} y_{ihg}}{n_{hg}}$$

where:

$\hat{A}g$ = total forest area (acres) for estimation unit *g*

A_{Tg} = total land area (acres) in estimation unit *g*

H = number of strata

W_{hg} = proportion of Phase 1 pixels in estimation unit *g* that occur in stratum *h*

Y_{ihg} = forest land condition proportion on Phase 2 plot *i* in stratum *h* in estimation unit *g*

n_{hg} = total number of Phase 2 plots in stratum *h* in estimation unit *g*

Phase 2

Phase 2 pertains to FIA's network of permanent plot locations, where each plot is assigned spatial coordinates and represents approximately 6,000 acres. To

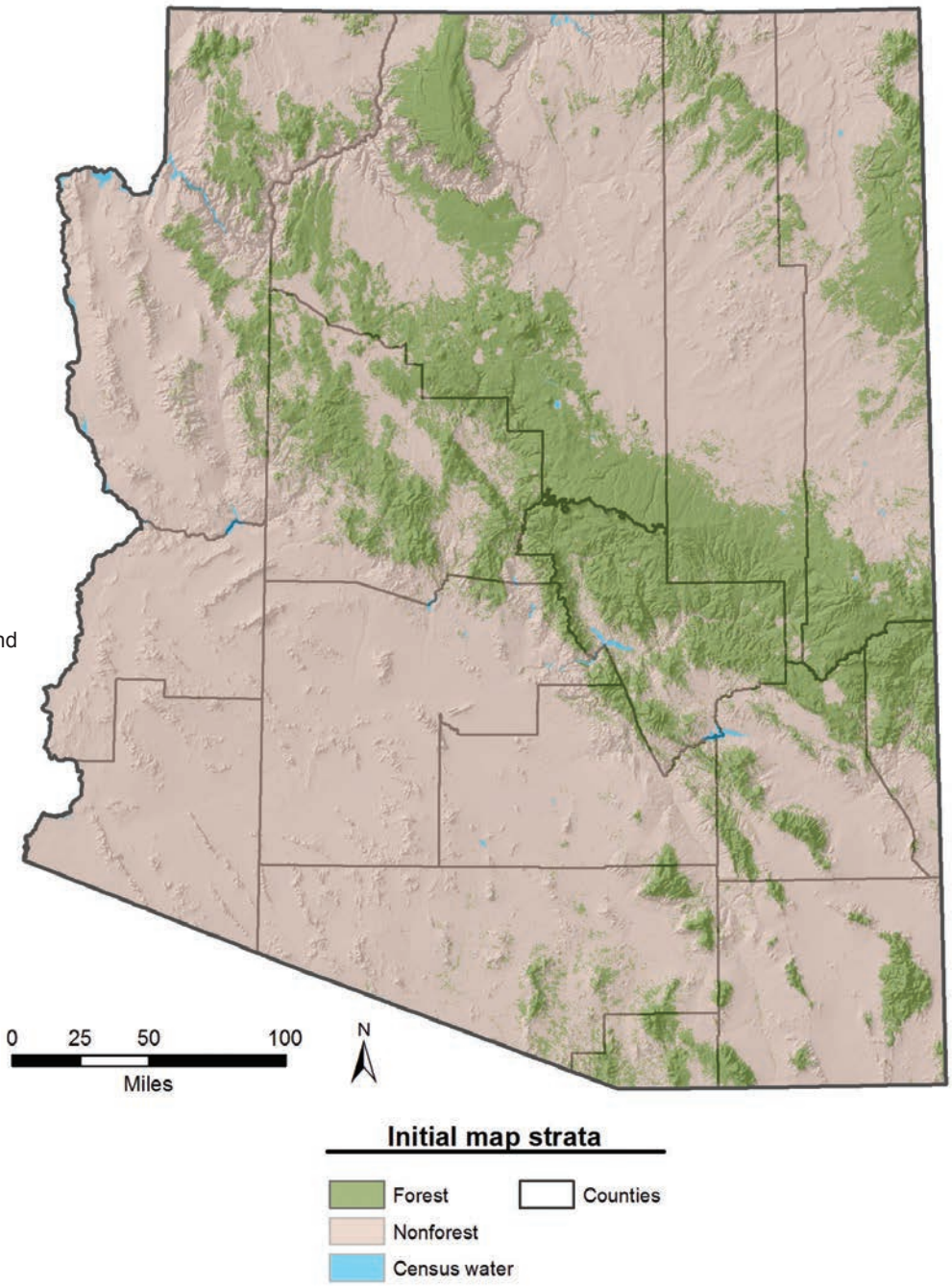

Figure 2—The strata used for post-stratification of Arizona's forest inventory, 2005–2014; background shows shaded relief and county boundaries.

minimize inventory costs, plots that are obviously and entirely nonforest are not designated for field sampling, and these plots are recorded as nonforest. A human interpreter examines each plot location using digital imagery from the National Agriculture Imagery Program and distinguishes plots that potentially contain forest or wooded land from those that do not intersect any forest or wooded land. This process is known as prefield interpretation, and it was historically considered part of Phase 1 because both prefield interpretation and Phase 1 relied on remote sensing data. However, Phase 1 delineation of forest and nonforest strata occurs independently of current prefield interpretation of the Phase 2 grid. Therefore, prefield data collection is considered part of Phase 2 and not part of Phase 1.

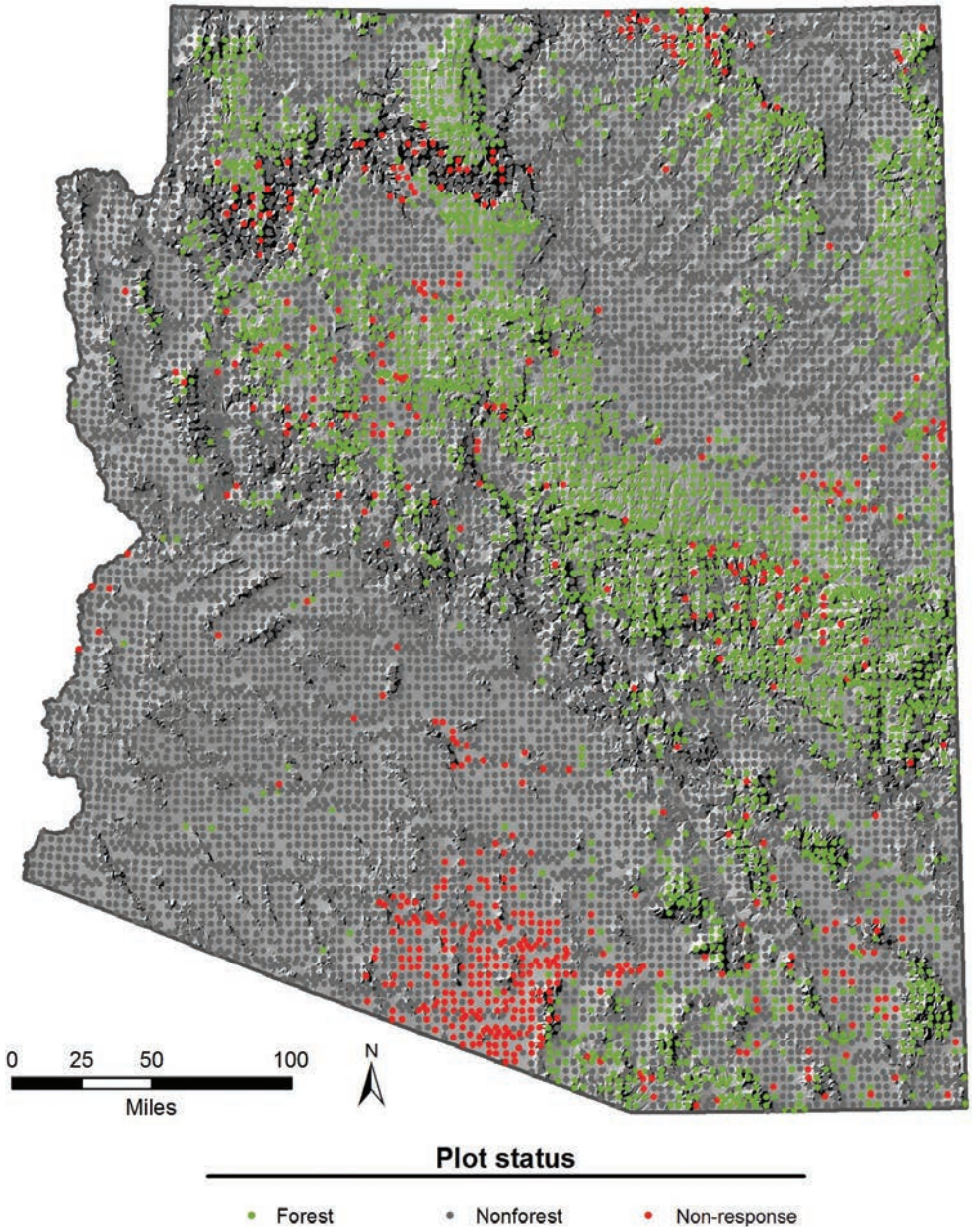

Figure 3—Plot status of the 12,274 Phase 2 plots in Arizona's annual forest inventory, 2005–2014. (Note: Plot locations are approximate; some plots on private land were randomly swapped.)

The status of each plot in the Phase 2 grid is eventually assigned as accessible forest land, nonforest land, or non-repsonse (fig. 3). Plots that were not designated for field sampling by prefield interpreters are automatically recorded as nonforest plots. For plots that are designated for field sampling, field crews record the plot status as accessible forest land if (a) they can physically visit the plot location, and (b) the plot satisfies FIA's definition of forest land (see Appendix A). Some field plots are recorded as nonforest because the field crew determines that they do not meet FIA's definition of forest land. A field plot may be recorded as non-response if a field crew cannot safely measure the plot or if they cannot obtain permission to access the plot location. Before visiting privately owned plot locations, FIA crews identify each plot's ownership status by consulting county land records and then seek permission from private landowners to

measure plots on their lands. Information about individual landowners and the existence of FIA plots on their property is considered confidential and is never shared outside the FIA program, regardless of whether permission to access the plot location is granted. Table B1 shows the total percentage of Phase 2 plot areas that represent forest, nonforest, and non-response conditions. Note that figure 3 and table B1 are the only portions of this report that include summaries of non-response plots; all other summaries of forest and nonforest are based on sampled plots, and estimates have been adjusted to account for missing observations at non-response plots as described by Goeking and Patterson (2013).

Field crews record a wide variety of data on plot locations that contain accessible forest land. Crews locate the geographic center of the plot using geographic positioning system (GPS) receivers and then establish markers to facilitate relocation of the plot for future remeasurement. They record condition-level variables that include land use, forest type, stand origin, stand-size class, stand age, site productivity class, forest disturbance history, silvicultural treatment, slope, aspect, and physiographic class. Some of these area attributes are measured or observed (e.g., regeneration status), some are assigned by definition (e.g., ownership group), and some are computed from tree data (e.g., percent stocking). For each tree on the plot, field crews record a variety of attributes including species, live/dead status, diameter, height, crown ratio, crown class, damage, and decay status. The field procedures used in Arizona's forest inventory are described in detail in the FIA field guide (USDA FS 2011). Data analysts apply statistical models using field measurements to calculate additional variables such as volume and biomass for individual trees, as well as volume, biomass, growth, mortality, and number of trees per unit area.

Phase 3

The third phase of the enhanced FIA program focuses on forest and ecosystem health. The Phase 3 sample consists of a 1/16 subset of the Phase 2 plots, which equates to one Phase 3 plot for approximately every 96 thousand acres. All the measurements collected on Phase 2 plots are collected on Phase 3 plots, plus an extended suite of ecological data (forest health indicators) pertaining to soil samples, down woody materials, lichen communities, tree crowns, and understory vegetation structure. Phase 3 measurements are obtained by field crews during the growing season. The original Phase 3 approach is being superseded in the IWFIA States by a shift toward expanding some protocols to all Phase 2 plots. Down wood materials, vegetation structure, and tree crown data are all collected on Phase 2 plots at the same intensity as all other data but with slightly different sampling designs than the Phase 3 versions. Soil data collection has been expanded beyond the original Phase 3 plots and will eventually cover the entire set of Phase 2 plots. The remaining indicators are being implemented only as special studies at this time.

Sources of Error

Sampling error

The process of sampling (selecting a random subset of a population and calculating estimates from this subset) causes estimates to contain error they would not have if every member of the population had been observed and included in the estimate. The 2005–2014 FIA inventory of Arizona is based on a sample of 12,274 plots systematically located across the State. The total area of Arizona is 73.1 million acres, so the sampling rate is approximately one plot for every 5,953 acres.

The statistical estimation procedures used to provide the estimates of the population totals presented in this report are described in detail in Bechtold and Patterson (2005). Along with every estimate is an associated sampling error that is typically expressed as a percentage of the estimated value, but it can also be expressed in the same units as the estimate or as a confidence interval (the estimated value plus or minus the sampling error). This sampling error is the primary measure of the reliability of an estimate. An approximate 67 percent confidence interval constructed from the sampling error can be interpreted to mean that under hypothetical repeated sampling, approximately 67 percent of the confidence intervals calculated from the individual repeat samples would include the true population parameter if it were computed from a 100-percent inventory. The sampling errors for State-level estimates are presented in table B37.

Because sampling error increases as the sample size decreases, users should aggregate data categories as much as possible. Sampling errors obtained from data aggregation are only approximations of reliability because homogeneity of variances is assumed. Users may compute statistical confidence for subdivisions of the reported data using the formula below:

$$SE_{\mathrm{s}} = SE_{\mathrm{t}} \frac{\sqrt{X_t}}{\sqrt{X_s}}$$

SE_s = sampling error for subdivision of State total.
SE_t = sampling error for State total.
X_s = sum of values for the variable of interest (area, volume, biomass, etc.) for subdivision of State total.
X_t = sum of values (area, volume, biomass, etc.) for State total.

Measurement error

Measurement errors are associated with the methods and instruments used to observe and record the sample attributes. On FIA plots, attributes such as the diameter and height of a tree are measured with specialized instruments; other attributes, such as species and crown class, are observed without the aid of an instrument. On a typical FIA plot, 30 to 70 trees are observed with 15 to 20 attributes recorded on each tree. In addition, many attributes that describe the plot and conditions on the plot are observed. Errors in any of these observations affect the quality

of the estimates. If a measurement is biased—such as tree diameters consistently taken at a height other than 4.5 feet from the ground—then the estimates that use this observation (e.g., calculated volume) will reflect this bias. Even if measurements are unbiased, high levels of random error in the measurements will add to the total random error of the estimation process. To ensure that FIA observations meet the highest standards possible, a quality assurance program, described below, is integrated throughout all FIA data collection efforts.

Prediction error

Prediction errors are associated with using mathematical models (such as volume models) to provide information about attributes of interest based on sample attributes. Area, number of trees, volume, biomass, growth, removals, and mortality are the primary attributes of interest presented in this report. FIA estimates of area and number of trees are based on direct observations and do not involve the use of prediction models; however, estimates of volume, biomass, growth, and mortality use model-based predictions in the estimation process and are thus subject to prediction errors.

Quality Assurance

FIA employs a Quality Assurance (QA) program to ensure the quality of all collected data. The QA program provides a framework to assure the production of complete, accurate, and unbiased forest information of known quality. There are two primary facets of FIA's QA program: quality control and quality assessment.

FIA's quality control process is carried out using data quality inspectors, who assess individual field crews and then provide timely feedback to improve the crews' performance. This is accomplished by means of hot checks and cold checks. During a hot check, an inspector accompanies a field crew to a plot and provides immediate feedback on the quality of their measurements. Cold checks occur when an inspector visits a recently completed plot, typically in possession of the original crew's data but without the crew present, and then verifies each measurement and provides the crew an overall score as well as feedback on measurements that did not meet FIA specifications. On average, hot checks are done on 2 percent of all field-sampled plots and cold checks are done on 5 percent of field-sampled plots.

Quality assessment is the second facet of FIA's QA program, and this process quantifies the overall precision of field measurements by comparing two independent measurements of the same plot. The independent measurements are collected by means of blind checks, where a regular field crew collects measurements and then a second crew collects a second set of measurements, without knowledge of or access to the first crew's measurements (Pollard et al. 2006). Thus, these paired observations provide a means of assessing repeatability of FIA's field measurements.

Quality control and quality assessment both require a data quality standard that defines the target level of precision for field measurements. FIA has specific Measurement Quality Objectives (MQOs) that enumerate data quality standards for individual field-measured variables. These data quality objectives were developed

from knowledge of measurement processes in forestry and forest ecology as well as the requirements of the FIA program. MQOs for each variable consist of a measurement tolerance and a compliance standard. Measurement tolerances define the acceptable range of variability between two independent observations, and compliance standards define the target percentage of observations that should be within the measurement tolerance when recorded by two independent observers. The practicality of these MQOs, as well as the measurement uncertainty associated with a given field measurement, can be tested by comparing the results of quality assessments using blind check data.

Quality assessment data for Arizona's current inventory were collected between 2010 and 2014. The results of the QA analysis for this period are presented in tables 1 and 2. Table 1 describes tolerances for condition-level variables, and table 2 describes tree-level variables. Each variable and its associated measurement tolerance are followed by the percentage of total paired records that fall within one, two, three, and four times the tolerance. The last four columns show the number of observations that fell outside the tolerance. For example, table 1 shows that there were 62 paired records, representing 62 conditions that were measured independently by two field crews, for the variable "Disturbance 1." About 89 percent of those records fell within the tolerance of having no errors. The percentage of observations that fall within the 1X tolerance level is referred to as the observed compliance rate, which can be compared to the compliance standard for each variable's MQO to determine that variable's performance. Compliance standards and measurement tolerances for FIA's field measurements are listed within the field manual (USDA FS 2011).

The information in tables 1 and 2 shows variables with varying degrees of repeatability. For example, one condition-level regional variable that appears to be fairly repeatable is "percent crown cover." At the 1X tolerance level, its observed compliance rate was about 98 percent. This represents that 98 percent of 56 paired observations were within plus or minus 10 percent of each other. In contrast, the compliance rate for "Habitat Type 1," which has no tolerance variability, was only 55 percent. This low compliance rate warrants further investigation into the potential repeatability issues associated with evaluating habitat type, which can provide insight into successional status when combined with existing vegetation (such as tree numbers, size class, and species by habitat types or series). Habitat types are represented as a categorical value, and it is likely that the compliance rate for habitat types would be higher if we could consider habitat type groups (or groups of types that are very similar) in our quality assurance analysis.

The tree measurements that have the biggest influence on estimates of forest volume are tree species, tree diameter, and tree height. As shown in table 2, the compliance rate for the variable "Species" was 87 percent. The diameter variables "d.b.h." and "d.r.c." represent the respective diameters of timber and woodland tree species (see appendices C and D). Whereas timber species are measured at breast height (4.5 feet above ground level), woodland species are measured near ground level at root collar. The 1X compliance rate was 91 percent for d.b.h.,

Table 1—Results of quality assessment for condition-level variables from 71 conditions in Arizona, 2010–2014. Variables that did not have any non-null values recorded on any QA plots are not shown; these include regeneration species as well as secondary and tertiary disturbances and treatments.

Variable	Tolerance	Percentage of data within tolerance				Number of times data exceeded tolerance				Number of records
		@1x	@2x	@3x	@4x	@1x	@2x	@3x	@4x	
National core variables										
Condition status	No tolerance	98.6				1				71
Reserve status	No tolerance	98.6				1				71
Owner group	No tolerance	100.0				0				71
Forest type (type)	No tolerance	82.3				11				62
Stand size	No tolerance	83.9				10				62
Regeneration status	No tolerance	100.0				0				62
Tree density	No tolerance	100.0				0				62
Owner industrial status	No tolerance	100.0				0				19
Disturbance 1	No tolerance	88.7				7				62
Disturbance Year 1	±1 yr	66.7	66.7	66.7	100.0	2	2	2	0	6
Treatment 1	No tolerance	100.0				0				62
Treatment year 1	±1 yr	100.0				0				1
Physiographic class	No tolerance	48.4				32				62
Regional variables										
Percent crown cover	±10 %	98.2	100.0			1	0			56
Percent bare ground	±10 %	74.2	88.7	91.9	95.2	16	7	5	3	62
Habitat type 1	No tolerance	54.8				28				62
Habitat type 2	No tolerance	53.2				29				62

Table 2—Results of quality assessment for tree-level variables from 1,066 trees in Arizona, 2010–2014.

Variable	Tolerance	Percentage of data within tolerance				Number of times data exceeded tolerance				Number of records
		@1x	@2x	@3x	@4x	@1x	@2x	@3x	@4x	
National core variables										
Diameter (d.b.h.)	±0.1 /20 in.	91.2	97.2	97.6	98.0	22	7	6	5	249
Diameter (d.r.c. using IW MQO)	±0.2 in*#stems	88.2	95.3	97.7	98.9	96	38	19	9	815
Azimuth	±10 °	98.8	99.2	99.3	99.4	13	8	7	6	1066
Horizontal distance	±0.2 /1.0 ft	94.4	97.1	98.3	98.9	60	31	18	12	1066
Species	No tolerance	86.5				144				1066
Tree status	No tolerance	99.8				2				1066
Rotten/missing cull	±10 %	94.9	98.5	99.4	99.8	51	15	6	2	993
Total length	±10 %	83.6	96.9	98.6	99.4	175	33	15	6	1066
Actual length	±10 %	84.2	97.0	98.4	99.6	111	21	11	3	703
Compacted crown ratio	±10 %	100.0				0				968
Uncompacted crown ratio (P3)	±10 %	82.5	94.4	97.7	98.6	157	50	21	13	897
Decay class	±1 class	100.0				0				96
Cause of Death	No tolerance	54.4				26				57
Mortality year	±2 yr	71.9	86.0	98.2	100.0	16	8	1	0	57
Condition class	No tolerance	100.0				0				1066
Regional Variables										
Mistletoe	±1 class	97.5	98.6	99.2	99.3	24	14	8	7	968
Number of Stems	±1 stem	96.1	98.8	99.4	99.5	32	10	5	4	815
Percent missing top	±10 %	97.3	97.3	97.3	97.3	27	27	27	27	993
Sound dead	±10 %	41.5	41.5	41.5	41.5	581	581	581	581	993
Form defect	±10 %	59.8	59.8	59.8	59.8	49	49	49	49	122
Current tree class	No tolerance	98.5				16				1066
Tree age	±5 %	80.2	83.0	86.8	89.6	42	36	28	22	212
Horiz dist-timberland	±0.2 /1.0 ft	98.0	98.4	98.8	98.8	5	4	3	3	250
Horiz dist-woodland	±0.2 /1.0 ft	93.3	96.7	98.2	98.9	55	27	15	9	816

which has a 0.1-inch tolerance, and 88 percent for d.r.c., which has a 0.2-inch per stem tolerance to allow for larger tolerances on multi-stemmed trees. Tree height is represented by the variables "total length" and "actual length." Both variables have a tolerance level of ±10 percent of the observed length, and compliance rates at the 1X level were about 84 percent for both variables. "Sound dead," which indicates the percentage of the tree's volume that is estimated as cull due to sound dead wood, was the least repeatable tree-level variable, with a 1X compliance rate of only 42 percent.

When a variable's compliance rate falls below the compliance standard, it indicates that one of three things should occur to address the shortfall. First, more intensive crew training may be required. Second, a variable's MQO may need to be adjusted accordingly to better reflect the realistic expectation of quality for that variable. Third, the variable could be eliminated from FIA's field protocols. As a result, MQOs are used not only to assess the reliability of FIA measurements and their ability to meet current standards, but also to identify areas of improvement of data collection protocols and training. This ongoing process improves repeatability or may even lead to elimination of variables that prove to be unrepeatable.

Overview of Arizona's Forests

This chapter summarizes the current status of Arizona's forests in terms of traditional forest attributes such as forest ownership, forest type, stand age, numbers of trees, volume, biomass, growth, mortality, removals, and stand density index. Nearly all attributes are based directly on FIA measurements, except where noted in individual sections.

Ecoregion Provinces of Arizona

Although Arizona is well-known as a "desert" State because of its iconic saguaro cactus stands and spectacularly exposed geology, the State contains a wide variety of forests and woodlands. About 25.5 percent of the surface area of the State is covered by forest. The distribution of forest types is strongly controlled by an interaction of climate and soils (Pearson 1931). In fact, the obvious zonation of vegetation types in the San Francisco Peaks and vicinity led to the development of the life zone concept by Merriam in 1889 (Merriam 1898; Merriam and Steineger 1890; see Colorado Plateau Semi-Desert Province below). Precipitation ranges from about 4 to over 28 inches annually across the State (Greening 1941), but it is the interaction of precipitation and evaporation—ultimately controlling available soil moisture—that truly determines potential vegetation (Pearson 1931; Zon 1941). For example, 15 inches of precipitation is sufficient to support ponderosa pine forests in Montana, but 20 or more inches are necessary to offset the higher evaporation potential in Arizona and New Mexico (Pearson 1931; Zon 1941). Some forests and woodlands actually experience negative soil moisture balances at times (Pearson 1931).

Because of these limitations, Arizona's forests are largely confined to the Mogollon Rim portion of the Colorado Plateau, the Kaibab Plateau, and the Chuksa Mountains. Isolated pockets of forest land are also found in the Madrean Archipelago, or "Sky Islands," that are found in the southeastern section of the State. In all cases, the high-elevation forest types are surrounded by wide bands of woodland types and other wooded land. These bands are, in turn, surrounded by large expanses of nonforest. The abundance of these transition zones makes it possible to observe some or all of Merriam's life zones (Merriam and Steineger 1890) by driving short distances at many different locations throughout the State. This feature of Arizona's forests makes their diversity as important as their extent. Many aspects of this diversity are discussed in this report.

The multitude of factors that influence forest conditions often occur across political and ownership boundaries. Forest scientists and land managers must assess and manage for these issues regardless of such boundaries. Ecological units provide an alternative spatial framework for assessing and managing forest resources because they characterize areas of similar vegetation, climate, soils, hydrologic processes, disturbance regimes, topography, geology, and other processes such as nutrient cycling and plant community succession (Cleland et al. 1997). Each ecological unit is therefore similar with regard to natural processes and probable responses to management activities (Bailey 1983). Ecoregions in the United States are hierarchically subdivided, in descending order of size, into domains, divisions, provinces, sections, and subsections. Provinces are defined largely by vegetation patterns and are therefore the most relevant units for describing forest lands.

FIA uses the modifications to Bailey (1995) of Cleland et al. (2007) to assign plots to ecological provinces, sections, and subsections. Arizona spans four ecological provinces (fig. 4): the Chihuahuan Semi-Desert (321); American Semi-Desert and Desert Province (322); the Colorado Plateau Semi-Desert (313); and the Arizona-New Mexico Mountains Semi-Desert–Open Woodland–Coniferous Forest–Alpine Meadow (M313). All four provinces contain some amount of forest land, although the composition and extent vary widely.

The Chihuahuan Semi-Desert Province (321) covers southeastern Arizona and extends through southern New Mexico and west Texas. The province is primarily desert, with long, hot summers and short winters that have brief periods below freezing. Spring and summer are very dry, but local, sometimes heavy rains start in July and extend through October. The province covers 13.2 percent of Arizona (9.7 million acres) and is 28.3 percent forested (2.7 million acres). Mesquite woodland accounts for about 45 percent of forested land, followed by evergreen oak woodland (27.2 percent) and pinyon/juniper woodland (10.4 percent).

The American Semi-Desert and Desert Province (322) covers southwestern Arizona, southeastern California, and southern Nevada. Like the Chihuahuan province, summers are long and hot, and winters are moderate. Precipitation is not regular anywhere in the province; rain falling in winter is usually widespread and gentle, whereas summer rain comes in the form of localized thunderstorms. The

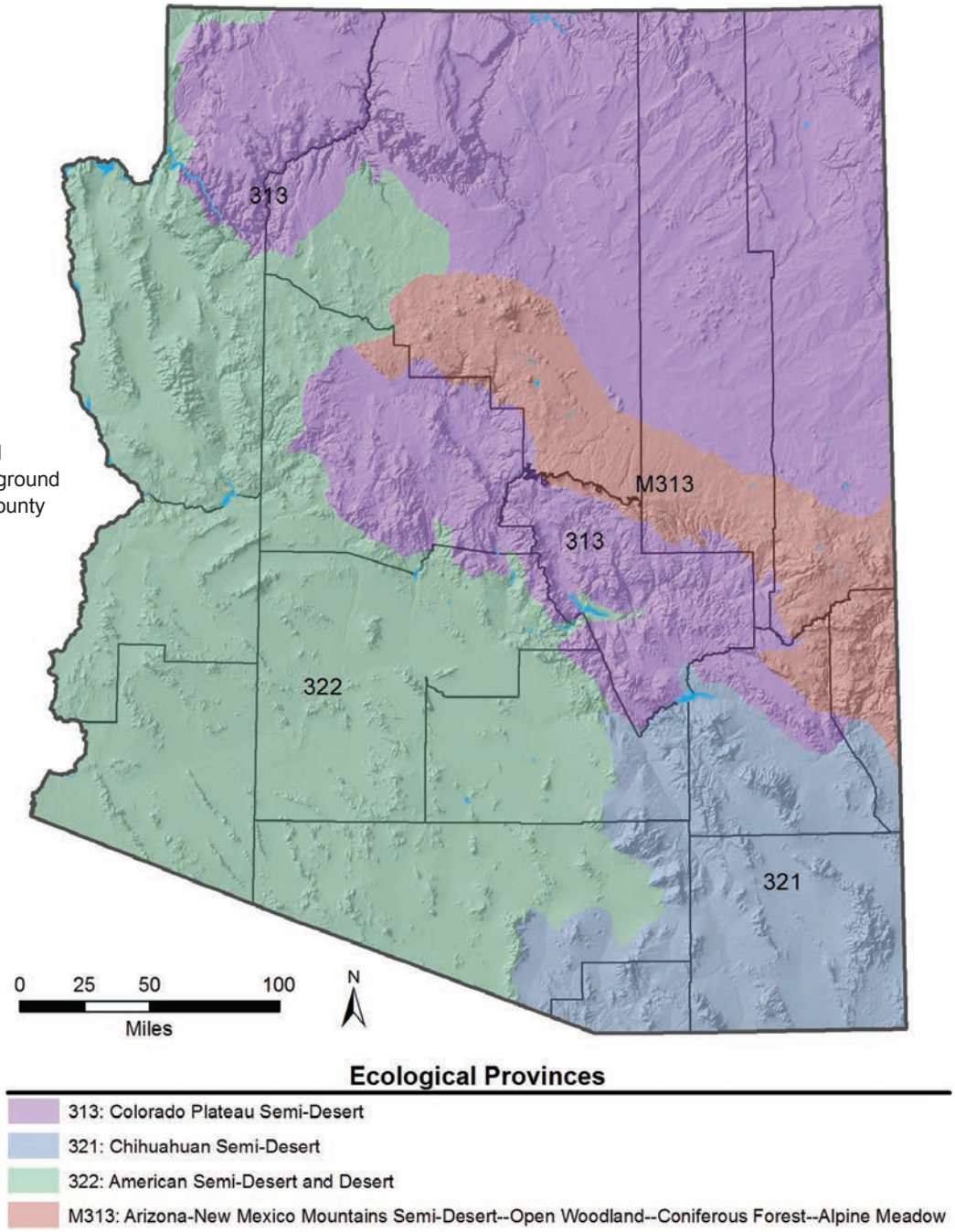

Figure 4—The four ecological provinces in Arizona; background shows shaded relief and county boundaries.

province covers 37.9 percent of Arizona (27.7 million acres), but forest cover is only 6.4 percent (1.8 million acres). Pinyon/juniper woodland is most common, accounting for 41.2 percent of the forested land, followed by juniper woodland (37.7 percent) and mesquite woodland (13.9 percent).

The Colorado Plateau Semi-Desert Province (313) covers the Colorado River Plateau regions of Arizona, Colorado, New Mexico, and Utah. The province is intersected in some areas by the Arizona-New Mexico Mountains Semi-Desert–Open Woodland–Coniferous Forest–Alpine Meadow (M313; see below), which represents the highest portions of the plateau, including several mountain ranges.

Plateau areas are relatively high elevation (5,000–7,000 ft), so winters are relatively cold, but temperatures in canyon bottoms can be more moderate. Summers are characterized by hot days and cool nights, with wide daily temperature fluctuations. Precipitation varies with elevation, with lower areas averaging less than 10 inches annually. By comparison, the highest elevations of the San Francisco Peaks, near Flagstaff, average 35 to 40 inches annually. The wide range of climate found in the province, such as the variation found from the bottom of the Grand Canyon to the top of the San Francisco Peaks (which is actually in the adjacent, related province; see below), led to development of the life zone concept (Merriam and Steineger 1890). The province covers 40 percent of Arizona (29.2 million acres), and is 31 percent forested (9.1 million acres). There is relatively high forest diversity, with 18 forest types represented. However, of the forested land, 55.5 percent is the pinyon/juniper type, 22.6 percent is juniper woodland, and 5.4 percent is evergreen woodland oak. Ponderosa pine is the non-woodland type with the highest portion of area, with 6.6 percent.

The Arizona-New Mexico Mountains Semi-Desert–Open Woodland–Coniferous Forest–Alpine Meadow (M313) covers parts of Arizona and New Mexico. As implied by the lengthy name, the province is very diverse and characterized by high relief. In general, the province encompasses the highest plateaus and mountains (elevation >7,000 ft) within the Colorado Plateau Semi-Desert Province (313), although some of the province includes elevations as low as 4,500 feet. Climate varies with elevation; precipitation ranges between 10 and 35 inches annually and arrives mostly as snow in the high mountains. Late spring is relatively dry, with moisture deficits relieved by summer thunderstorms. The province covers 8.8 percent of Arizona (6.4 million acres), but is 78.0 percent forested (5.0 million acres). The province contains the largest variety of forests in Arizona, with 19 forest types represented. This is the only province in which a timber forest type (ponderosa pine) is the most common, covering 35.4 percent (1.8 million acres) of the forested area. However, the total area of woodland types (52.7 percent, or 2.7 million acres) is still greater than the total acres of timber forest types (2.2 million acres, or 43.1 percent). As is the case elsewhere in the State, the most common woodland types are pinyon/juniper woodland, with 26.1 of the forested area, and juniper woodland, with 15.3 percent.

Forest Land Classification

FIA uses a nationally consistent standard for defining different categories of forest land based on reserved status and productivity. These categories were originally developed for the purpose of separating forest land deemed suitable for timber production from forest land that was either not suitable or unavailable for timber harvesting activity, which includes woodland forest types. The first division of forest land is unreserved forest land and reserved forest land. Unreserved forest land is considered available for harvesting activity where wood volume can be removed for wood products. Reserved forest land is considered unavailable for any type of wood utilization management practice through administrative proclamation or legislation.

Both unreserved and reserved forest lands are further divided based on productivity. Unreserved forest land is subdivided into timberland and unproductive forests. Timberland is defined as unreserved forest land capable of producing 20 cubic feet of wood per acre per year of trees designated as a timber species. Unproductive forests, because of a combination of species' characteristics and site conditions, are not capable of producing 20 cubic feet of wood per acre per year of trees designated as a timber species (see Appendix A). Reserved forest land is also divided into productive and nonproductive forests. Some characteristics that contribute to productivity can be visibly obvious, such as the presence or absence of non-commercial species, rocky substrates, steep slopes, and high elevation. While these distinctions may be important for understanding reserved area management concerns (e.g., their effect on visitor experience), wood production capability on reserved forest land is useful only as a potential indicator of non-timber values. For example, higher-productivity reserved lands will tend to produce higher fuel loads than lower-productivity lands.

The State of Arizona encompasses 73.1 million acres of land area, of which 18.6 million acres (25.5 percent) are estimated to be forest land by FIA. Unreserved forest land accounts for 90.9 percent of the forest land in Arizona and totals 16.9 million acres (table B2). Timberland constitutes almost 18 percent (3.0 million acres) of Arizona's unreserved forest land, and the remaining 82 percent (13.9 million acres) is classified as unproductive forest land. Reserved forests account for over 9 percent (1.7 million acres) of total forest land, with most of that area being unproductive forests.

Forest Land Ownership

Federal agencies manage more forest land in Arizona than any other land ownership or management group (table B2). Arizona's largest manager of forest land is the USDA Forest Service's National Forest System (NFS), which manages about 7.7 million acres of forest land. This represents over 10 percent of Arizona's total land area and 41.3 percent of its forest land area. NFS lands in Arizona consist of six different national forests. More than 91 percent, or 7.0 million acres, of the forest land managed by NFS is classified as unreserved forest land. About 28 percent, or 2.2 million acres, of unreserved forest land managed by NFS is further classified as unreserved timberland, while the remaining 72 percent is classified as unproductive (table B2). The net volume of live trees (table B12), as well as the average annual tree mortality (table B25), is higher on NFS lands than any other owner class.

Other public agencies managing large portions of Arizona's forest land include the State of Arizona, with 8.7 percent of forest land (1.6 million acres), and the Bureau of Land Management (BLM), with 7.6 percent (1.4 million acres). The Departments of Defense and Energy (DOD/DOE), the National Park Service (NPS), the U.S. Fish and Wildlife Service (FWS), and other Federal ownerships account for only 2.8 percent of forest land, or just over 524 thousand acres. All of

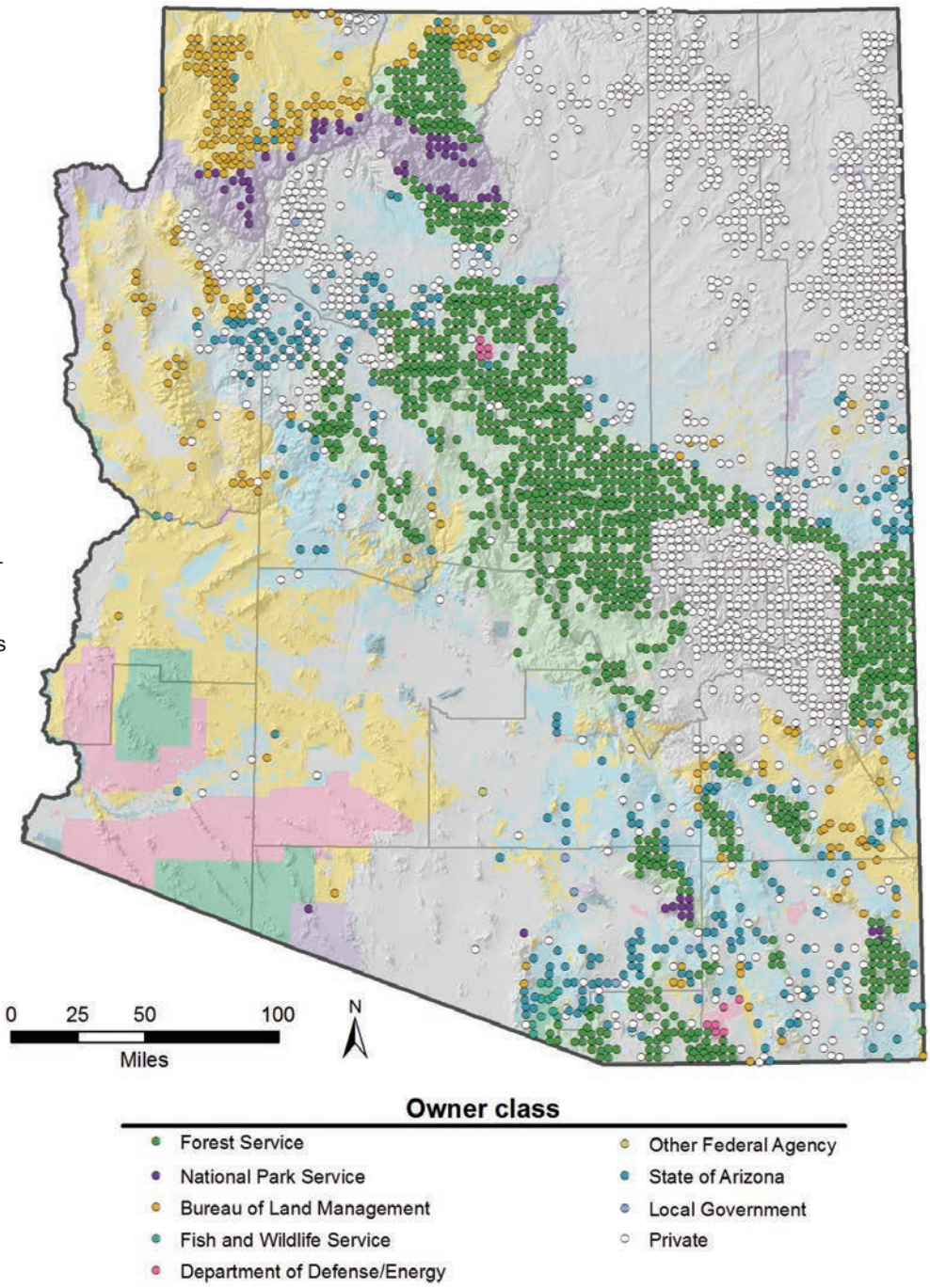

Figure 5—Distribution and percentage of inventory plots on forest land by owner class, Arizona, 2005–2014. (Note: Plot locations are approximate; some plots on private land were randomly swapped.)

Arizona's State-managed forest land is classified as unreserved, but nearly all of it is classified as unproductive forest.

Privately owned forest land totals 7.3 million acres, or 39.3 percent of the State's total forest land area, second only to national forest land (fig. 5). Arizona's diverse array of private landowners consists of private individuals/families, corporations, tribes, and non-governmental organizations such as private associations or conservation groups. Although conservation easements can cover substantial portions of private land, all private forest land is categorized as unreserved. About 766 thousand acres, or 10.5 percent of all private forest land, are classified

as timberland while 6.5 million acres are classified as unproductive forest land. Average annual net growth is higher overall on private lands than any other owner class (table B21).

Forest Types and Forest-Type Groups

Forest type is a classification of forest land based on the species forming a plurality of living trees growing in a particular forest. Forest type names may be based on a single species or groups of species. Forest types are an important measure of diversity, structure, and successional stage. The distribution of forest types across the landscape is determined by factors such as climate, soil, elevation, aspect, and disturbance history. The loss or gain of a particular forest type over time can help assess the impact of major disturbances related to fire, weather, climate, insects, disease, and human-caused disturbances such as timber harvesting or ecosystem restoration.

Forest types are aggregated into forest-type groups to simplify interpretation of large-scale forest trends. Arizona's forests are classified into 10 forest-type groups that are further divided into 21 distinct forest types, all of which are described in Appendix C. Some forest-type groups contain only one forest type, while other forest-type groups include several individual forest types. An example of a forest-type group with multiple forest types is the pinyon/juniper forest-type group, which consists of the Rocky Mountain juniper forest type, the pinyon/juniper forest type, and the juniper woodland forest type. The distribution of forest types as well as individual tree species may vary among ecological provinces. Figure 6 shows the area occupied by each forest-type group in Arizona. Figures 7–10 illustrate the spatial distribution of inventory plots in the most common forest-type groups and the forest types within those groups.

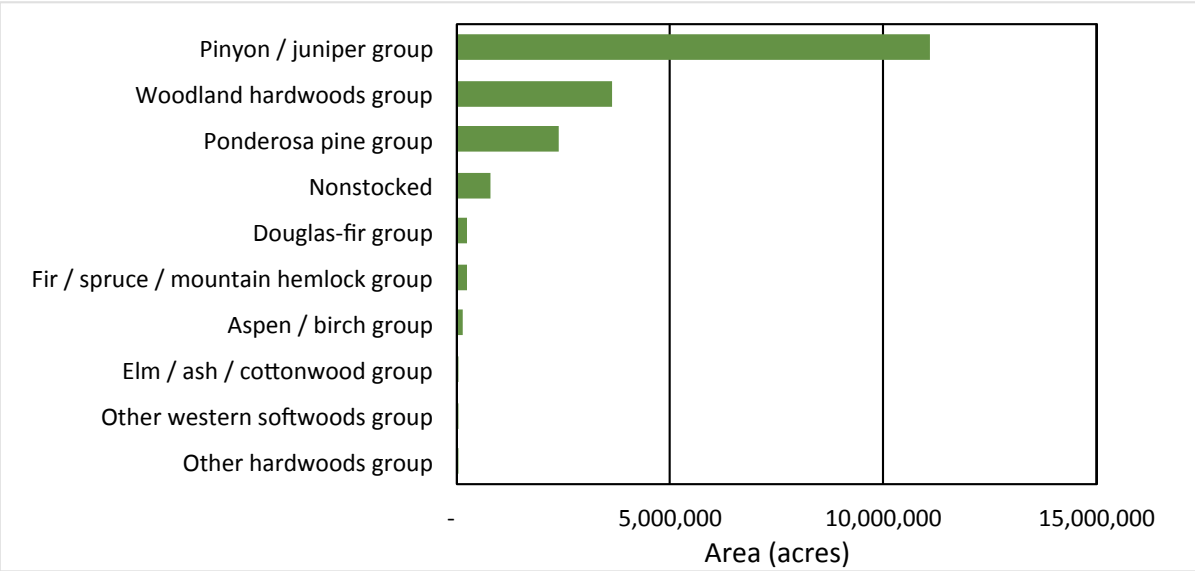

Figure 6—Area of land by forest-type group, Arizona, 2005–2014. See Appendix C for forest types and tree species included in each group.

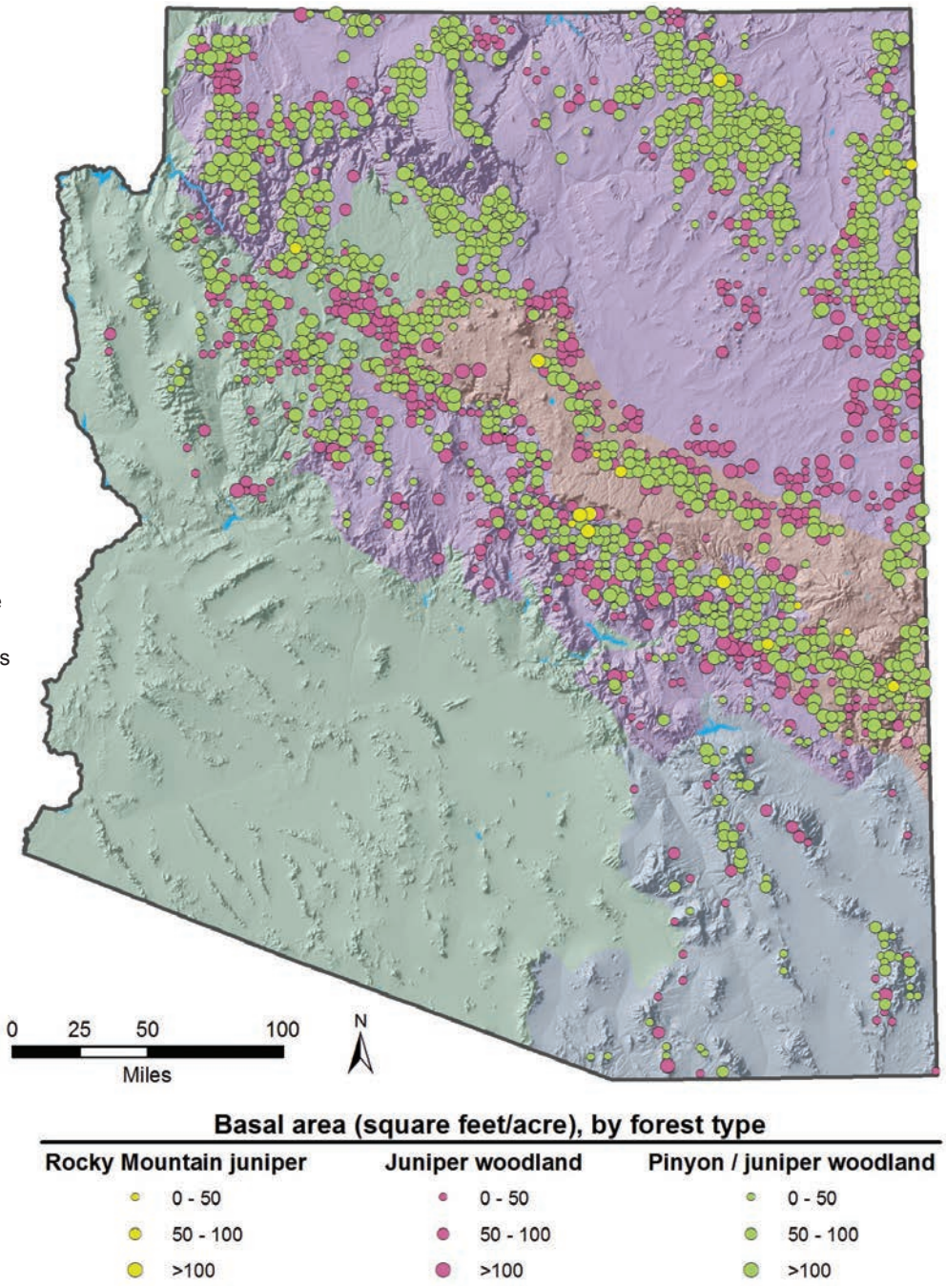

Figure 7—Distribution of inventory plots in the pinyon/juniper forest-type group, by forest type and basal area class, Arizona, 2005–2014. (Note: Plot locations are approximate; some plots on private land were randomly swapped.)

Arizona's most abundant forest-type group is the pinyon/juniper group, which covers more than 11.1 million acres and accounts for 59.6 percent of forest land in the State (table B3). Within this forest-type group, the pinyon/juniper forest type is most abundant (7.3 million acres), followed by the juniper woodlands forest type (3.6 million acres). Arizona's second most abundant forest-type group is the woodland hardwoods group, which comprises 3.6 million acres and 19.5 percent of the State's forest land. The most abundant forest types in this group includes the mesquite forest type (1.6 million acres), the evergreen oak woodland forest type (1.5 million acres), and the deciduous oak woodland forest type (0.5 million acres).

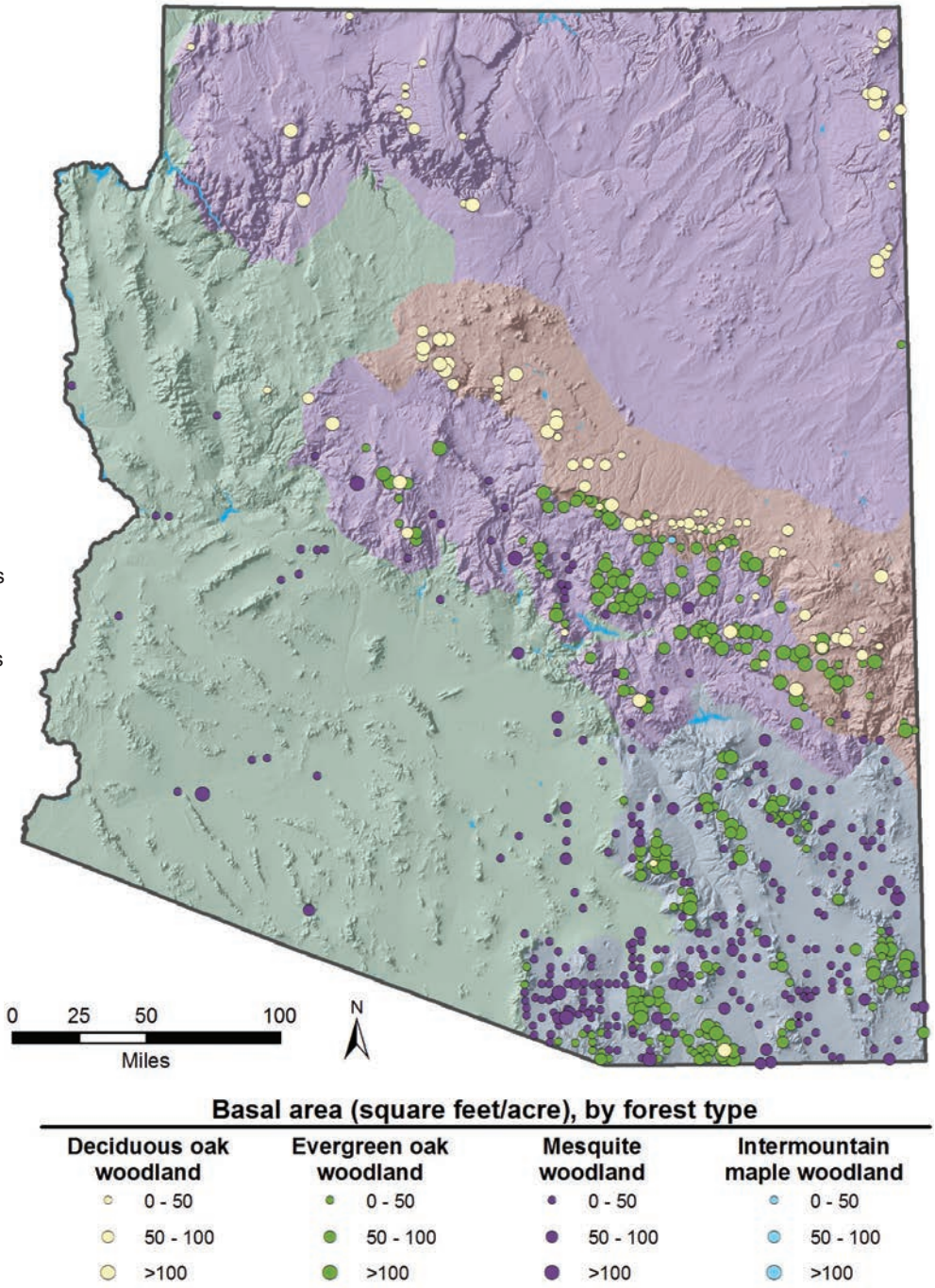

Figure 8—Distribution of inventory plots in the woodland hardwoods forest-type group, by forest type and basal area class, Arizona, 2005–2014. (Note: Plot locations are approximate; some plots on private land were randomly swapped.)

The ponderosa pine forest-type group is Arizona's third most abundant group, covering 2.4 million acres and 13 percent of the State's forest land. The remaining forest-type groups covering at least 1 percent of forest land are nonstocked forests (768 thousand acres), the Douglas-fir forest-type group (229 thousand acres), and the fir/spruce/mountain hemlock group (221 thousand acres). Note that although mountain hemlock is part of the group name, the species does not naturally occur in Arizona (see Appendices C and D). Although the aspen/birch group, which is

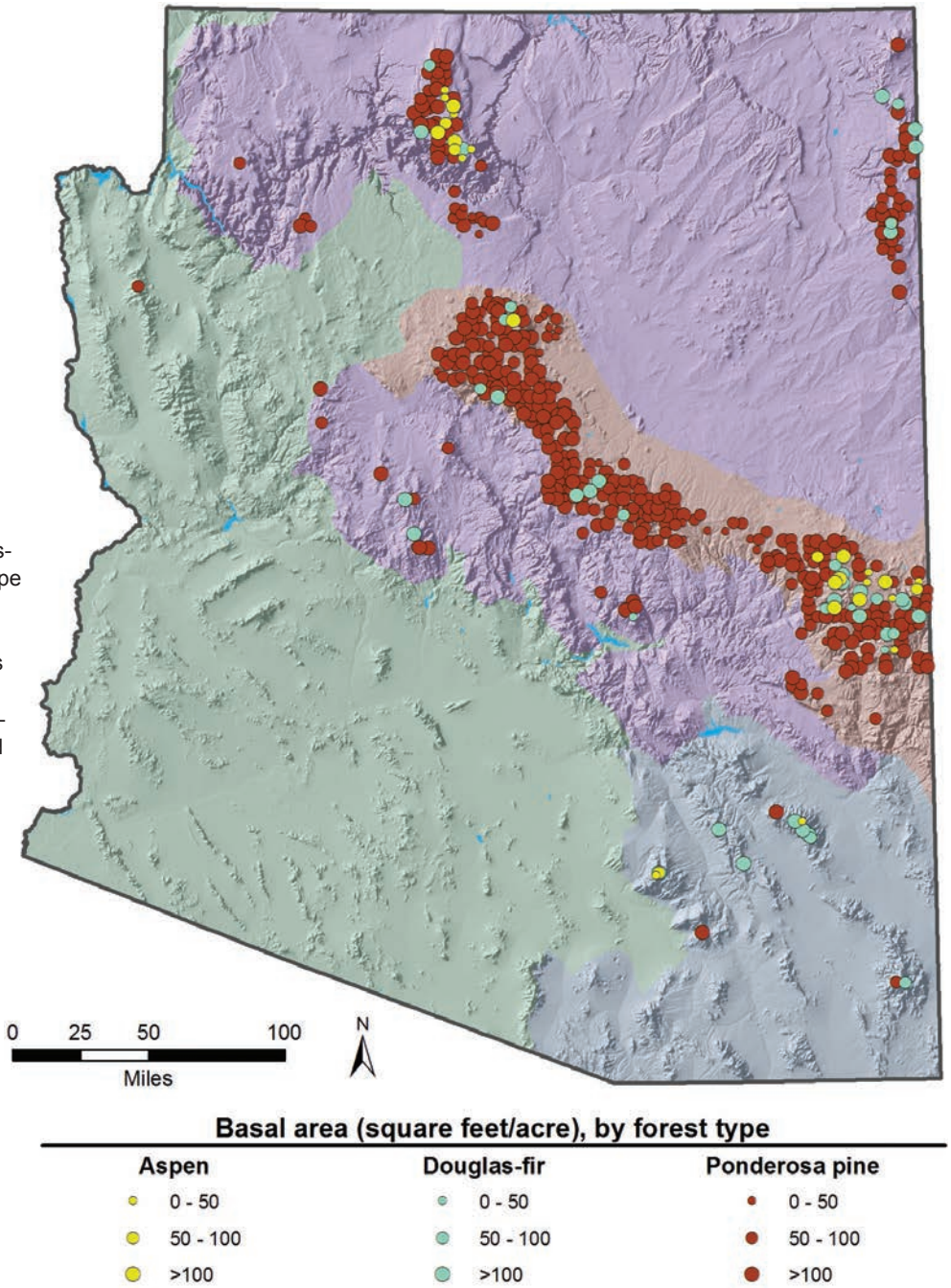

Figure 9—Distribution of inventory plots in the aspen/birch, Douglas-fir, and Ponderosa pine forest-type groups, by forest type and basal area class, Arizona, 2005–2014. Each of these forest-type groups contains only one forest type. (Note: Plot locations are approximate; some plots on private land were randomly swapped.)

entirely the aspen forest type, occupies only 0.8 percent of forest land (153 thousand acres), aspen is a prominent feature on many more acres, where it occurs as a minority stocking in other forest types (see section on *Aspen Status and Trends*).

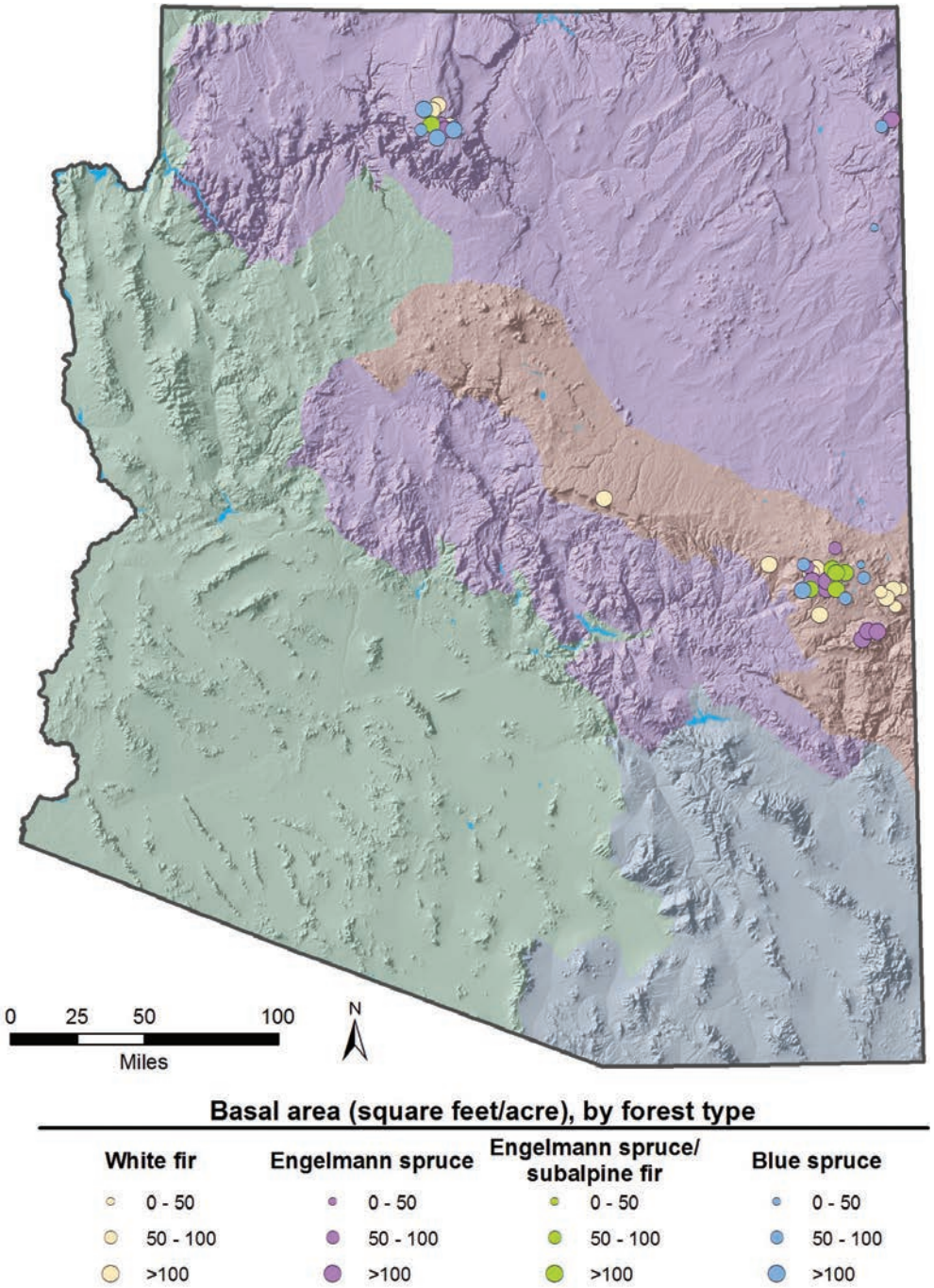

Figure 10—Distribution of inventory plots in the fir/spruce/mountain hemlock forest-type group, by forest type and basal area class, Arizona, 2005–2014. (Note: Plot locations are approximate; some plots on private land were randomly swapped.)

Stand Age

The age structure of forest land provides insight into prospective shifts in stand structure and composition over time. On every FIA plot that samples forest land and includes suitable trees for increment core extraction, stand age is estimated based on the average age of only those trees that fall within the calculated stand-size category. For example, suppose an FIA plot sampled a softwood forest type where about 30 percent of the live trees were in the large diameter stand-size class (trees at least 9.0 inches d.b.h. and larger) and 70 percent were in the medium diameter size class (trees between 5.0 and 9.0 inches d.b.h.). The stand would be classified as a medium diameter stand-size class, and therefore only the medium size trees would be used in determining stand age.

There are limitations to collecting data for stand age computation. Repeatable measurements of increment cores are difficult to collect from certain tree species, particularly woodland species or those that may be very long-lived. Stand age may not accurately depict the age structure of uneven-aged stands, which encompasses multiple age classes. Stand ages are difficult to accurately determine for stands that are predominated by small diameter tree species such as Gambel oak trees. Stand ages are not assigned to nonstocked conditions, which are stands that contain less than 10 percent stocking of live trees because of disturbance.

Table B6 shows the area of forest land, by age class and forest-type group, with 20-year intervals representing stand-age classes. Nearly half of Arizona's forest land, or 9.0 million acres, is between 60 and 140 years of age, and nearly two-thirds are between 60 and 180 years old. There are approximately equal areas of forest in the 81–100 year and the 101–120 year class, which are the two largest 20-year classes with about 2.7 million acres each. Forests younger than 60 years cover about 2.8 million acres (15 percent), while forests older than 180 years cover 3.5 million acres (18.5 percent). Only 8.8 percent of Arizona's forest land, or 1.6 million acres, is in stands less than 20 years of age; this includes nonstocked stands, for which age is not computed, and is set to zero. The high abundance of middle-aged forests (80–120 years) in comparison to young forests (0–20 years) suggests that disturbance is lagging behind the rate needed to rejuvenate the population and early seral habitats may be lacking.

There is a considerable difference in stand age distribution among the major forest-type groups in the State (fig. 11). Half of the six most abundant forest-type groups—Douglas-fir, fir/Spruce/Mountain Hemlock, and ponderosa pine groups—have more forest land area in the 81–120 year age classes than any other class. The pinyon/juniper forest-type group has the most even distribution among age classes, with seven of the 20-year classes accounting for about 73 percent of area. The 201+ year age class has the largest area of any class, but this is expected given the longevity of pinyons and junipers, coupled with the fact that the age class is open-ended. The Douglas-fir, fir/spruce/mountain hemlock, and ponderosa pine forest-type groups all have a very small proportion of forest land area that is younger than 60 years (0 percent, 0.4 percent, and 5.8 percent, respectively). Compared to these

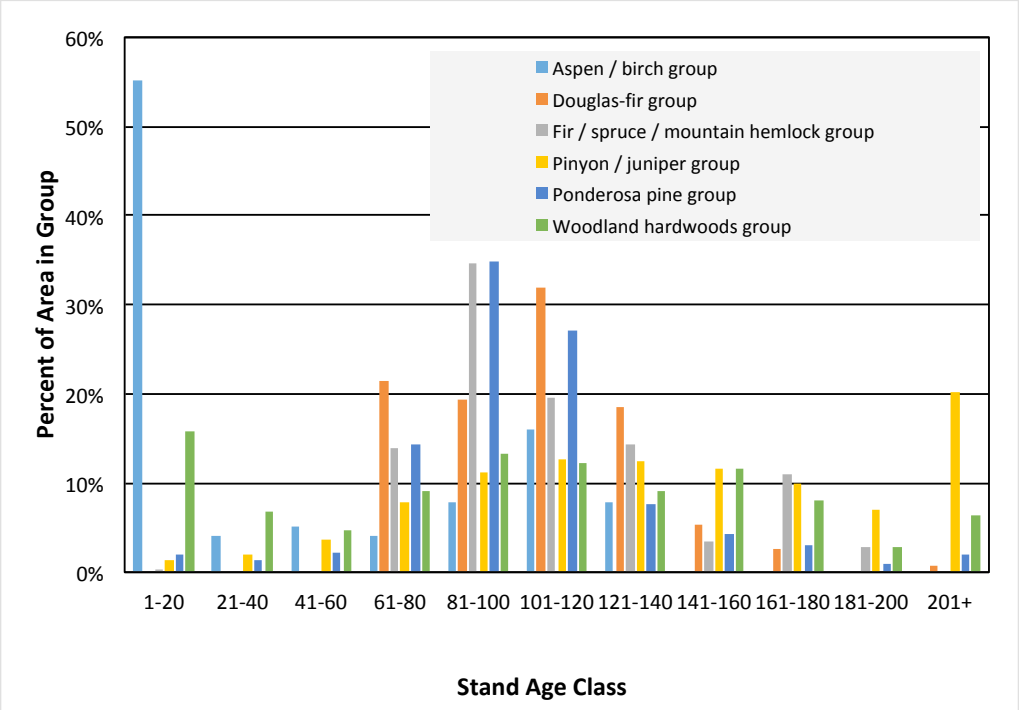

Figure 11—Distribution of forest land by stand age class for major forest-type groups, Arizona, 2005–2014.

coniferous forest-type groups, aspen forests have a much higher percentage of area that is younger than 60 years (64 percent). More than 55 percent of aspen forest type area is less than 20 years old. A very small percentage of aspen stands are older than 120 years (7.8 percent). After the aspen type, the woodland hardwoods group has the next greatest proportion of its area in young stands, with 15.8 percent younger than 20 years; the majority of acreage is irregularly distributed among all of the other age classes.

Number of Trees

Estimates of the numbers of trees are beneficial to a variety of silvicultural, forest health, and habitat management applications. These estimates are typically combined with information about the size and species of the trees to provide meaningful summaries of forest dynamics and stand structure. Younger forest stands usually consist of large numbers of small-diameter trees, whereas older forest stands contain small numbers of large-diameter trees. FIA classifies individual tree species into species groups and categorizes each species and species group as either softwood or hardwood (Appendix D).

Arizona contains an estimated 4.0 billion live trees 1 inch in diameter or larger (table B10) and over 75 million dead trees 5 inches in diameter or larger. Softwood species total 2.8 billion trees or 68.5 percent of the State's live trees. Almost 35 percent of live softwood trees are under 5.0 inches in diameter and 5.8 percent are 15.0 inches and larger in diameter. The western woodland softwoods species group accounts for 69.3 percent (1.9 billion live trees) of the softwood trees (fig. 12). Oneseed juniper and common pinyon are the most abundant tree species in this group, which also includes Pinchot juniper, redberry juniper, alligator

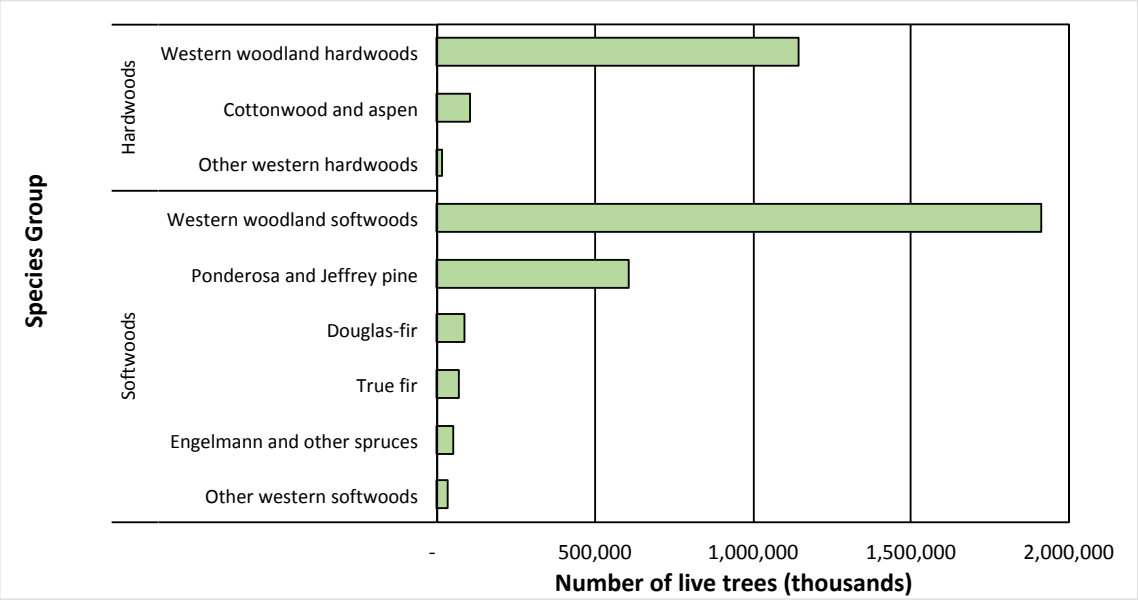

Figure 12—Number of live trees 1.0 inch diameter and larger on forest land, by species group, Arizona, 2005–2014.

juniper, Utah juniper, Rocky Mountain juniper, Mexican pinyon, and Arizona pinyon. The second most abundant softwood group is the ponderosa and Jeffrey pine group with 605 million live trees (22 percent of softwood trees), all of which are ponderosa pines. Each of the other four forest-type groups account for less than 4 percent of live trees.

Hardwood species account for 1.3 billion trees, or 31.5 percent of Arizona's live trees. The western woodland hardwoods group includes the vast majority (90.4 percent) of the live hardwood trees occurring in Arizona, followed by the cottonwood and aspen species group (8.5 percent percent). The hardwood species group also includes Gambel oak, bigtooth maple, honey mesquite, velvet mesquite, Arizona white oak, Emory oak, Mexican blue oak, silverleaf oak, gray oak, and netleaf oak.

Figure 13 shows the number of live trees by diameter class for seven species groups in Arizona. The pattern of many smaller trees compared to larger ones is expected for most species, but it also illustrates the different life histories of various species groups. Most species in the woodland hardwoods species group, which includes several species of oak and mesquite, do not attain large size. A large fraction of trees (69.8 percent) occur in the small diameter classes (less than 5 inches diameter), with just over 6 percent of trees 11.0 inches and greater. In contrast, most timber species groups have more balanced size distributions. Less than half of ponderosa pine and Douglas-fir trees are under 5.0 inches, and approximately 20 percent of trees of each species are 11.0 inches or greater. Spruces, true firs, and poplars (cottonwoods and aspen) have distributions that more closely resemble the woodland species, possibly because of recent disturbance and regeneration. The size distribution of western woodland softwoods, which include pinyons and junipers, more closely resembles that of some timber types. This situation is likely due to the fact that pinyons and junipers are long-lived, reproduce slowly, and self-thin relatively little during stand development.

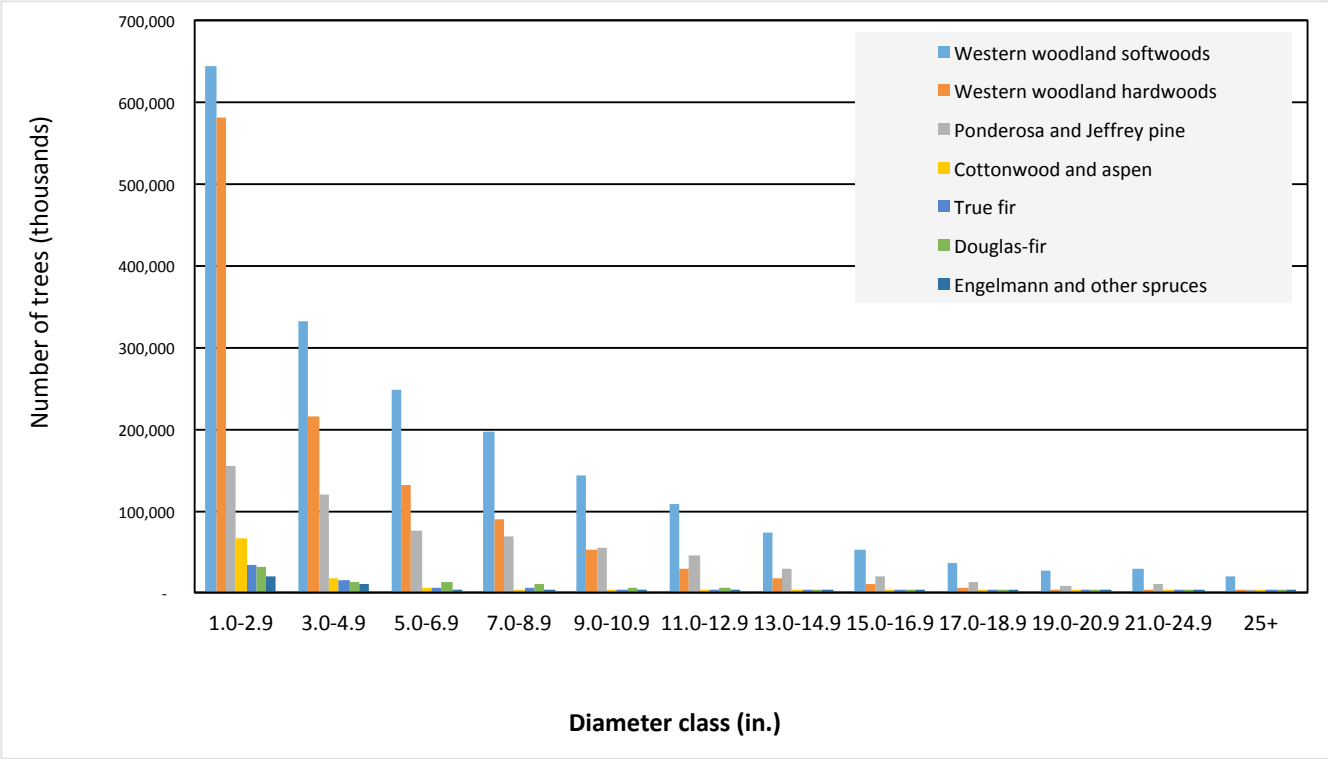

Figure 13—Number of live trees on forest land, by species group and diameter class, Arizona, 2005–2014.

Tree Volume and Biomass

The amount of cubic-foot volume of wood in a forest is important for determining the sustainability of current and future wood utilization. The forest products industry and forest managers are interested in knowing the tree species composition and size distribution, as well as the geographic location and ownership status, of available wood volume. Estimates of gross and net volume include only the merchantable portion or sawlog portion (e.g., cubic-foot or board-foot) of live trees 1.0 inch in diameter and larger. Net volume is computed by deducting rotten, missing, or form defects from gross volume. Net volume is reported below as net volume of all live trees, net volume of growing-stock trees, net volume of sawtimber, and net volume of sawlogs. All of these terms are defined below as well as in Appendix A. Tree biomass estimates are based on gross volumes and describe aboveground tree weight (oven-dry) by various components (merchantable bole and bark, tops and limbs, saplings). This method of estimating tree biomass is referred to as the component ratio method and is described by Woudenberg et al. (2010, Appendix J). Note that FIA's biomass estimates are produced in units of oven-dry weight; estimates of bone-dry weight can be calculated using the following conversion: one bone-dry unit equals 2,400 pounds of oven-dry wood (Morgan et al. 2006).

Tables B12 through B16 show the net volume of all live trees 5.0 inches diameter and larger on Arizona's forest land, by various categories. The net volume of all live trees on Arizona's forest land totals 14.6 billion cubic feet (table B12).

Almost 53 percent of the live volume, or 7.7 billion cubic feet, is located on lands managed by the NFS. Only 6.4 percent of the NFS-managed volume exists on reserved lands and is unavailable for harvest. Privately owned forests contain 36.4 percent of the State's total live volume, or 5.3 billion cubic feet. Lands managed by Federal agencies other than the NFS include 7.4 percent of net volume, or less than 1.1 billion cubic feet. The remainder, about 0.5 billion cubic feet, is on lands managed by State and local government. For all owner classes, unreserved forests have somewhat lower volumes on timberland than on unproductive forest land (6.2 billion vs. 7.1 billion cubic feet), although on NFS lands the volume on unreserved timberland is about 60 percent of the unreserved volume. The total live volume on unreserved timberland is 6.2 billion cubic feet.

Live tree volume can also be reported by forest-type group and tree species group. The pinyon/juniper forest-type group contains more live tree volume than any other forest-type group (table B13). Similarly, the woodland softwoods species group, which includes all of Arizona's pinyon and juniper species, contains more live tree volume than any other species group (tables B14 and B15). The western woodland softwoods include 41.6 percent of the State's live tree volume and 32 percent of the standing dead volume (fig. 14). The ponderosa forest-type group, with 34.3 percent of live volume, and the ponderosa pine species group, with 36 percent of live volume, account for the majority of the remaining volume among forest type- and species-groups. Pinyon and juniper species are not considered to be timber species, so they are not included in the estimates of growing-stock volume and sawtimber volume that are presented below and in tables B17–B20. When the volumes of individual tree species are compared, ponderosa pine has more volume than any other species with 5.3 billion cubic feet Statewide.

The availability of timber volume for harvest is affected by three primary factors: reserved status, productivity, and merchantability. Timberland is defined as unreserved forest land capable of producing in excess of 20 cubic feet per acre

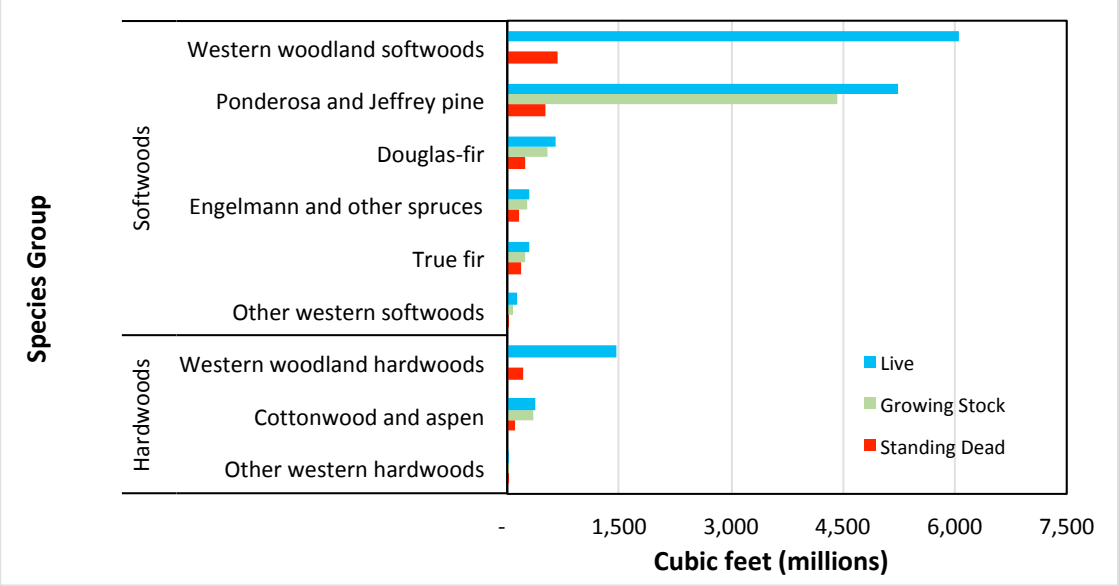

Figure 14—Net cubic-foot volume of trees 5.0 inches diameter or larger on forest land, by species group, Arizona, 2005–2014. (Note that the volume of trees in the "Other western hardwoods" species group is too small to appear on this graph.)

per year of wood at culmination of mean annual increment. Merchantability refers to growing-stock trees, which are at least 5 inches in diameter and contain, or have the potential to produce, an 8-foot sawlog that is reasonably free of defects. Therefore, growing-stock volume on timberland represents the amount of timber that is potentially available for harvest. The net volume of growing-stock trees on timberland in Arizona totals 5.9 billion cubic feet (table B17), or 40.5 percent of the total live volume on forest land.

The distribution of growing-stock volume varies by species or species group and also by owner class (table B18). Across all owner classes, nearly 85 percent of the State's growing-stock volume is composed of two species: ponderosa pine and Douglas-fir. Ponderosa pine constitutes over 75 percent of Arizona's growing-stock volume, or 4.4 billion cubic feet, and Douglas-fir contains 9 percent, or 528 million cubic feet (table B18). The remainder of growing stock is somewhat evenly divided among the species groups true fir (4.1 percent or 241 million cubic feet), Engelmann and other spruces (4.4 percent or 262 million cubic feet), and cottonwood and aspen (5.8 percent or 339 million cubic feet). NFS lands include 4.1 billion cubic feet, or almost 70 percent of the State's growing stock. Almost 1.7 billion cubic feet, or 29 percent of the total growing stock, occur on privately owned lands. Live volume is also reported for sawtimber trees, which are defined as softwood trees 9.0 inches in diameter or larger, or hardwood trees 11.0 inches in diameter or larger (International ¼-inch rule). The net volume of sawtimber trees on timberland totals 28.5 billion board feet (table B19), over 76 percent of which is ponderosa pine.

The total weight of oven-dry aboveground biomass on Arizona's forest land is 269 million tons, 60 percent (162 million tons) of which exists on public lands (table B29). Although biomass is typically sold by green weight, the water content of wood is highly variable geographically, seasonally, and even across portions of a single tree. Therefore, live-tree inventory estimates of green biomass may be unreliable or even misleading. In contrast, oven-dry weight does not change due to fluctuations in tree water content.

Volume and biomass can also be expressed in terms of the amount per acre. Table 3 shows live tree volume (in cubic feet per acre) and biomass (in tons per acre) by forest type. The estimates for each forest type include all of the different species that occur within that forest type. Because estimates for forest types with small samples may not be representative, only forest types sampled on at least 20 plots are included in this discussion. The Douglas-fir forest type has the highest per-acre net volume of live trees 5.0 inches diameter and larger, with 2,842 cubic feet per acre, and also has the highest biomass of live trees 1.0 inch diameter and larger with 55.3 dry tons per acre. Not surprisingly, the forest types with the six largest average net volumes and biomasses are all timber types (Engelmann spruce and Engelmann spruce / subalpine fir are combined, because separately they occupy relatively small area). The woodland forest type with the highest per-acre net volume is the Rocky Mountain juniper forest type, with 957 cubic feet. Deciduous oak woodlands contain more biomass per acre (18.4 dry tons per acre)

Table 3—Net volume (cubic feet per acre) of live trees 5.0 inches diameter and larger, and biomass (tons per acre) of live trees 1.0 inches diameter and larger, averaged by common forest types, Arizona, 2005–2014.

Forest type	Forest type area (acres)	Net volume (ft3 per acre)	Biomass (dry tons per acre)
Douglas-fir	228,661	2,842	55.3
White fir	70,663	2,308	42.0
Ponderosa pine	2,411,236	2,066	37.7
Aspen	153,237	1,868	35.0
Engelmann spruce and Engelmann spruce / subalpine fir	96,188	1,888	31.1
Deciduous oak woodland	539,169	846	18.4
Rocky Mountain juniper	94,293	957	16.6
Pinyon / juniper woodland	7,354,124	649	11.6
Evergreen oak woodland	1,456,812	579	11.5
Juniper woodland	3,635,485	408	7.1
Mesquite woodland	1,630,770	165	4.6
Nonstocked	768,390	25	0.5

than other woodland forest types, although Rocky Mountain juniper has higher average volume.

Forest Change Components: Growth, Mortality, and Removals

Forest vigor, sustainability, and timber supply are often assessed by what are referred to as forest change components: growth, mortality, and removals. The relationship among these three change components quantifies the change in tree volume over time. Growth is typically expressed as net annual growth and is defined as the gross, or total, average annual growth in tree volume minus the volume lost through mortality. Mortality is the average annual net volume of trees dying over a given time period due to natural causes and excludes the volume removed through harvesting. Tree mortality often occurs at low and predictable rates due to insects and disease, suppression by overstory trees, or advanced tree age. Occasionally, highly concentrated and localized losses occur due to insect and disease epidemics, wildfire, or severe weather events. Removals represent the net volume of growing-stock trees removed from the inventory by harvesting or other cultural operations (such as timber-stand improvement), by land clearing, or by changes in land use (such as designation as Wilderness or other reserved status).

The three components of forest change—growth, mortality, and removals—are typically analyzed using measurements of the same plot at two points in time. It is possible, however, to also estimate growth and mortality rates based on a single inventory, as described below. In contrast, removals cannot be reliably estimated without having two measurements of the same set of plots, and the Arizona inventory did not begin remeasurement until 2011. Because fewer than half of plots are available for removal estimation, recent removals are still estimated using

information about the amount of wood cut and processed by the forest products industry. Due to this difference in analysis methods, growth and mortality are analyzed and discussed separately from removals.

At this stage of annual inventory in Arizona, the procedures used to estimate tree growth and mortality depended on the remeasurement status of the plot. A remeasured or paired plot refers to a plot that was established during the previous inventory cycle (time 1), and the field crews were able to relocate the plot during the current inventory (time 2) and account for all trees previously measured. In the current inventory (2005–2014), over 38 percent of all plots that sample forest land in Arizona were remeasured, so the same trees were measured at two points in time. For trees that were alive at time 1 and time 2, growth is calculated based on the change in volume over the time interval between plot visits. The time interval between remeasured plot visits in Arizona varied between 4 and 11 years with an average interval of about 10 years. Mortality volume is based on the volume of any tree that qualifies as a mortality tree over the time interval between plot visits. A tree is classified as mortality if it was alive at time 1 but dead at time 2. A new plot is a plot established for the first time where there was no previous co-located plot to be remeasured. On new plots, annual growth is estimated from a sample of increment core measurements based on the previous 10 years of radial growth. Mortality is estimated from trees that died in the 5 years prior to the year of measurement.

The annual estimate of gross growth of all live trees 5.0 inches diameter and greater on forest land in Arizona totaled nearly 184.1 million cubic feet. This is the sum of growth on all survivor and ingrowth trees. Survivor trees are live trees 5.0 inches and larger in diameter at time 1 and still alive at time 2 on remeasured plots, and live trees determined to be 5.0 inches and larger in diameter 10 years prior to the current measurement on new plots. Ingrowth trees are live trees 5.0 inches and larger in diameter that grew over the 5.0-inch threshold between time 1 and time 2 on remeasured plots or during the previous 10 years on new plots. The average annual mortality of trees 5.0 inches and larger in diameter was 237.8 million cubic feet (table B25). The difference between the live tree growth and mortality indicates a net annual growth estimate of –53.6 million cubic feet on forest land in Arizona (see tables B21–B24).

The negative net annual growth of 53.6 million cubic feet of in Arizona signifies an inventory of live trees that is decreasing annually in the absence of trees removed from human-caused activities. The annual decrease appears to be a large number, but in relative terms is small; net annual growth as a percentage of net volume of all live trees 5.0 inches and larger in diameter averages only –0.37 percent per year. However, negative net growth means that high levels of tree mortality are exceeding gains from live tree growth. In figure 15, the map of net annual growth at individual plots shows that plots with large values of net growth, whether positive or negative, tend to be concentrated in particular areas of the State. Areas where plots with high negative net annual growth are clustered represent areas affected by major disturbances such as insect outbreaks and fires.

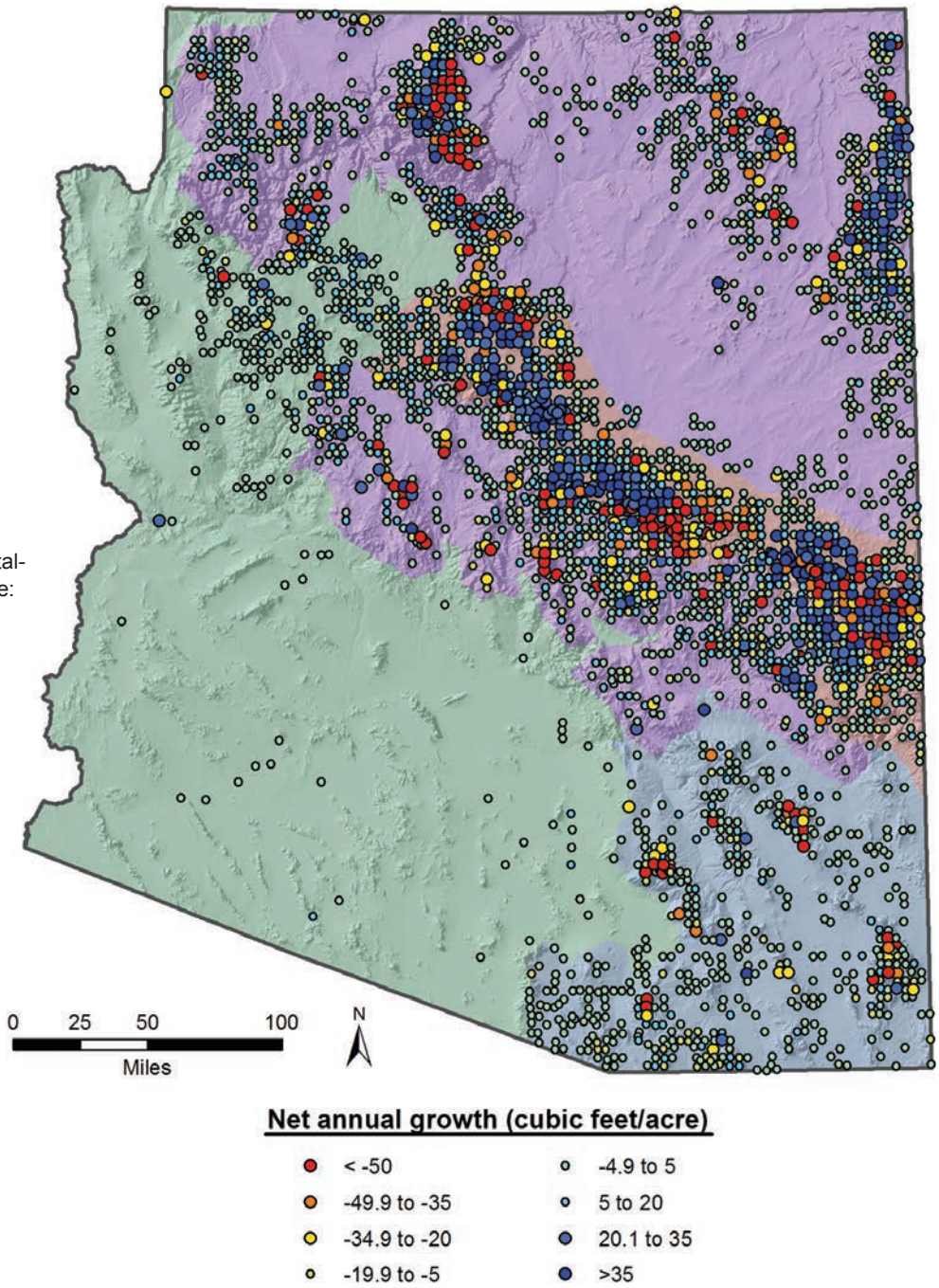

Figure 15—Net annual growth at inventory plots on forest land, Arizona, 2005–2014. Negative values indicate plots where mortality exceeded gross growth. (Note: Plot locations are approximate; some plots on private land were randomly swapped.)

Net growth varies considerably by major owner group. Figure 16 illustrates the relationship between net growth and mortality by owner group in Arizona. Mortality of all trees on forest lands managed by the NFS totaled 161.9 million cubic feet (table B25) compared to –60.7 million cubic feet of net annual growth (table B21). In contrast, net annual growth exceeded mortality on privately owned forests; net growth totaled 5.4 million cubic feet compared to 61.5 million cubic feet of mortality.

Figure 17 illustrates the relationship between net growth and mortality for the 13 major inventory species—those with the greatest total volume—in Arizona. With the exception of ponderosa pine, Utah and oneseed junipers, and velvet

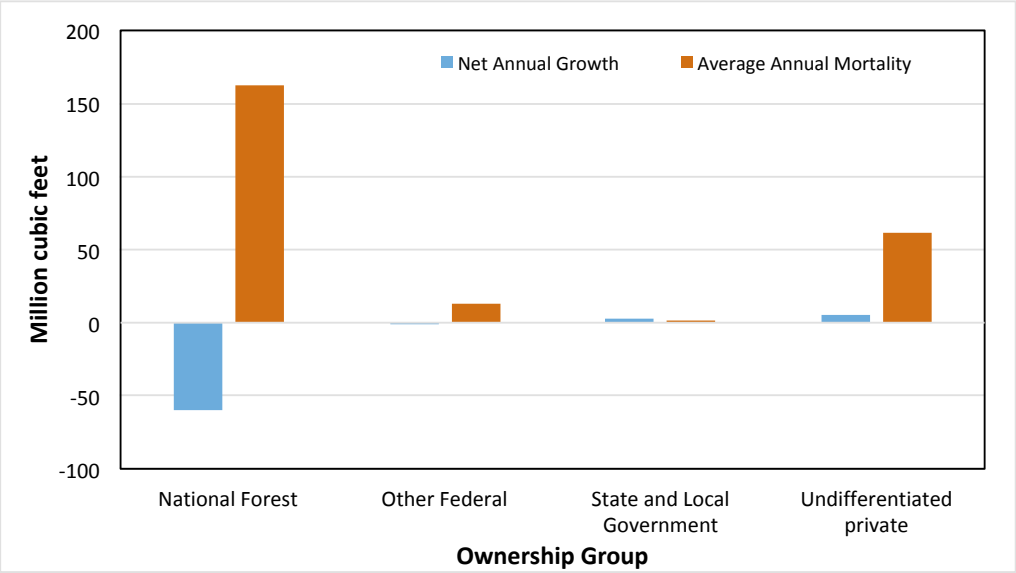

Figure 16—Net annual growth and average annual mortality on forest land by ownership group, Arizona, 2005–2014.

mesquite, annual mortality exceeded growth for all other major species. Douglas-fir, Engelmann spruce, and quaking aspen recorded negative net growth. As a proportion of live volume, velvet mesquite was the highest with 1.1 percent net growth, followed by Utah juniper (0.44 percent), oneseed juniper (0.39 percent), and ponderosa pine (0.19 percent). This is in reverse order of what would be expected in normal periods, because timber species generally grow at higher rates than woodland species. Of the species with negative net growth, the worst loss as a proportion of volume occurred in white fir (–6.2 percent), Engelmann spruce (–3.7 percent), common pinyon (–1.6 percent), and Gambel oak (–1.7 percent).

Since high mortality is the driving force behind the large differences between gross and net growth, further examination of this change component by other resource attributes can help explain the factors behind the high level of tree volume

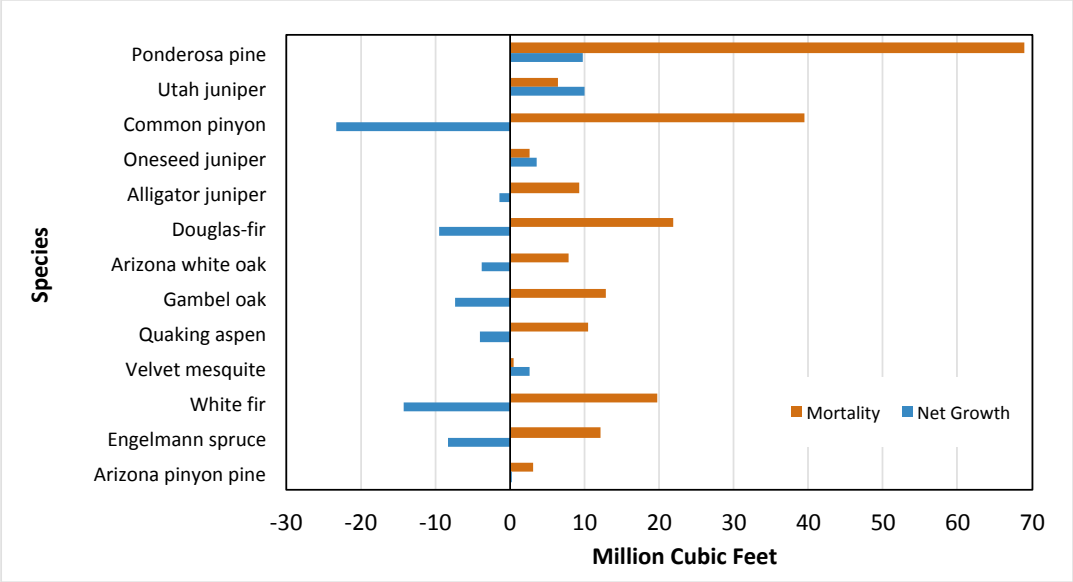

Figure 17—Net annual growth and average annual mortality on forest land for 13 major species, Arizona, 2005–2014.

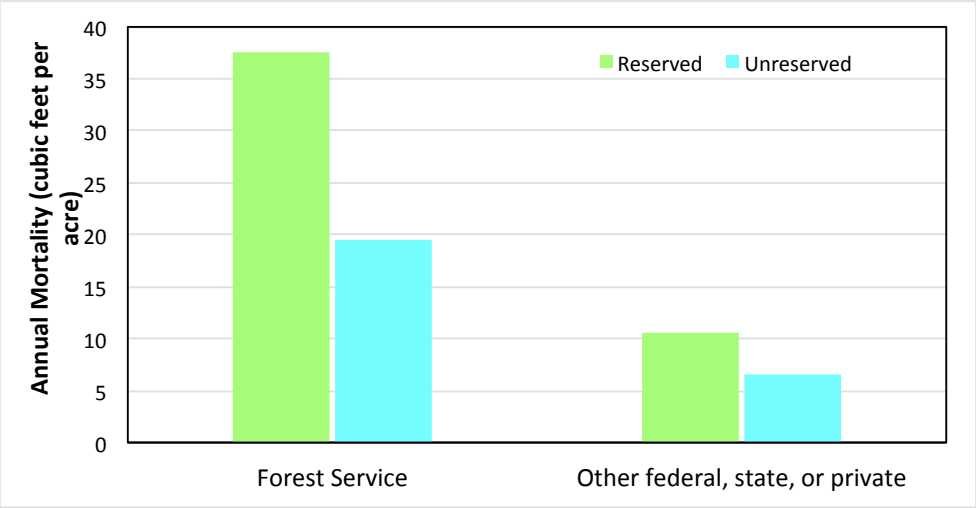

Figure 18—Average annual per-acre mortality on forest land by two major owner categories and reserved status, Arizona, 2005–2014.

estimated to have died in the previous 10 years. Substantial differences were observed in per-acre estimates of mortality between major ownership groups and reserved statuses. Converting the State-level estimates of mortality into per-acre estimates removes the effect of differences in the amount of forest land controlled by different ownership groups. The per-acre estimate of annual mortality volume averages 12.8 cubic feet per year on forest land across all ownerships. Mortality on reserved forest land was appreciably higher than unreserved land, averaging 21.2 cubic feet per acre, compared to 11.9 cubic feet per acre on unreserved forest land. Figure 18 illustrates per-acre estimates of mortality by two major owner categories and reserved status. Reserved lands managed by the NFS recorded the highest average level of per-acre mortality at 37.6 cubic feet, whereas unreserved land controlled by private landowners, other Federal agencies, and State agencies had the lowest at 6.6 cubic feet. Many factors account for this difference, such as the varying ability to manage lands of different reserved status and the different forest type distributions among different combinations of ownership and reserved status.

All trees classified as mortality trees are assigned a cause of death in the field. Drawing conclusions from mortality estimates by cause of death should be done with caution because the actual agent that caused a tree's death may be difficult, if not impossible, to determine. The "other" cause of death category includes trees that have died due to reasons the field crews are unable to determine. Interactions between insects and diseases are complex and make identification of causal agents difficult. Figure 19 illustrates per-acre estimates of mortality by reserved status and cause of death. Substantial differences were noted between reserved and unreserved forest land for mortality caused by insects and fire. Mortality due to fire accounted for the majority (41.5 percent) of total mortality. Insects were the second leading contributor to mortality, accounting for 32.3 percent of total mortality, followed by disease with 11.7 percent.

The leading causes of mortality are typically the same in most Interior West States, although the order of importance of fire and insects changes over time and space. In the neighboring State of New Mexico, insects were found to be the

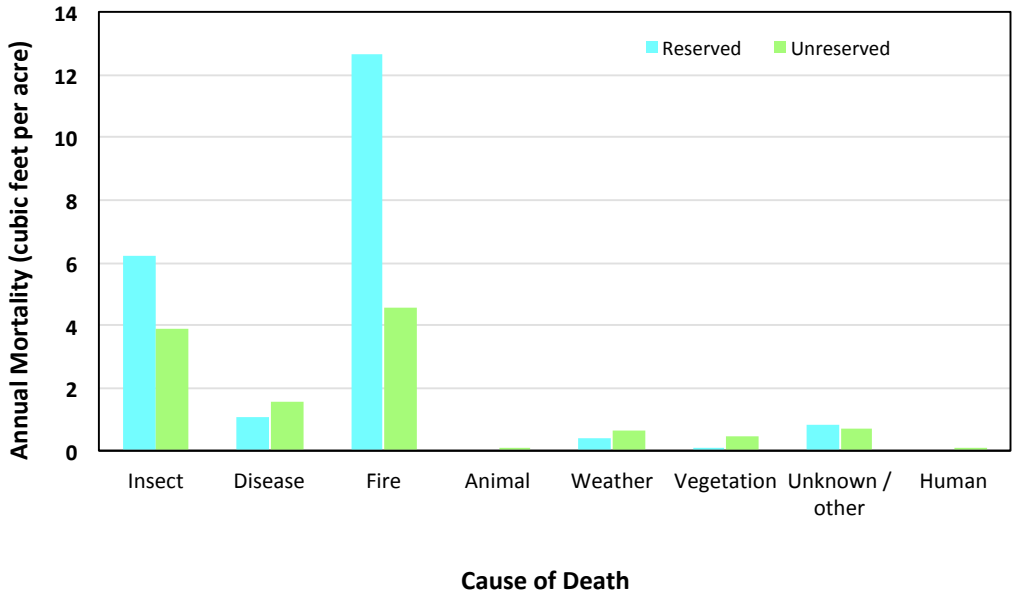

Figure 19—Average annual per-acre mortality on forest land by reserved status and cause of death, Arizona, 2005–2014.

leading cause of mortality in the most recent inventory (Goeking et al. 2014). The reasons behind the differences in levels of tree mortality by owner class and reserved status deserve further investigation. These differences have been observed in other State inventories (Menlove et al. 2012; Witt et al. 2012), which may suggest that reserved NFS lands have a larger share of aging forest stands that are more susceptible to insect and disease. These differences factors will be investigated with additional analysis of stand age, structure, density, species composition, and management regimes.

Stand Density Index (SDI)

Stand density index (Reineke 1933) is a relative measure of stand density, based on quadratic mean diameter of the stand and the number of trees per acre. In the western States, silviculturists often use SDI as one measure of stand structure to meet diverse objectives such as ecological restoration and wildlife habitat (e.g., Lilieholm et al. 1994; Long and Shaw 2005; Shaw and Long 2007; Smith and Long 1987). Originally developed for even-aged stands, SDI can also be applied to uneven-aged stands (Long and Daniel 1990; Shaw 2000). Stand structure can influence the computation of SDI, so the definition of maximum SDI must be compatible with the computation method. SDI was computed for each condition that sampled forest land using the summation method (Shaw 2000), and the SDI percentage was calculated using the maximum SDI for the forest type found on the condition.

Maximum SDI is rarely, if ever, observed in nature at the stand scale because the onset of competition-induced (self-thinning) mortality occurs at about 60 percent of the maximum SDI. Within-stand variability of density results in the average stand density being well below that of the densest patches. A site is considered to be fully occupied at 35 percent of maximum SDI. Below about 25 percent

of maximum SDI, individual trees are considered "free to grow." At these lower densities, individual tree growth is maximized but stand growth is below potential, while at higher densities, individual tree growth is below potential, but stand growth is maximized (Long 1985). There are several reasons why stands may have low SDI. Stands typically have low SDI following major disturbances, such as fire, insect attack, or harvesting. These stands remain in a low-density condition until regeneration fills available growing space. Stands that are over-mature can also have low SDI, because growing space may not be re-occupied as fast as it is released by the mortality of large, old trees. Finally, stands that occur on very thin soils or rocky sites may remain at low density indefinitely, because limitations on physical growing space do not permit full site occupancy.

Because of the length of time that Arizona has been under annual inventory, it is possible to look at changes in stand density over time. For this analysis, conditions measured during the first half of the inventory period (2001–2007) are compared to conditions measured during the second half of the inventory (2008–2014). Each condition-level SDI value was binned at 20-unit intervals, and then the number of conditions in each bin was normalized to account for slightly differing numbers of observations during each 7-year span. After normalization, values from the two periods can be plotted together in each bin for direct comparison (fig. 20).

The general distribution of SDI values is somewhat left-skewed, which is consistent with the fact that Arizona is dominated by dryland forests and woodlands. These forests tend to have a lower capacity for stand density than, for example, the moister forests of the Pacific Northwest or the west side of the Rocky Mountains in northern Idaho and western Montana. Comparison of SDI means and distributions suggests that there had been an overall lowering of stand density since the early 2000s. Mean SDI was 131.8 for conditions measured 2001–2007 and 124.4 for conditions measured 2008–2014, which is a small but statistically significant difference, based on a t-test ($P<0.01$). This difference does not appear to have been caused by the densest of stands being heavily disturbed and changed

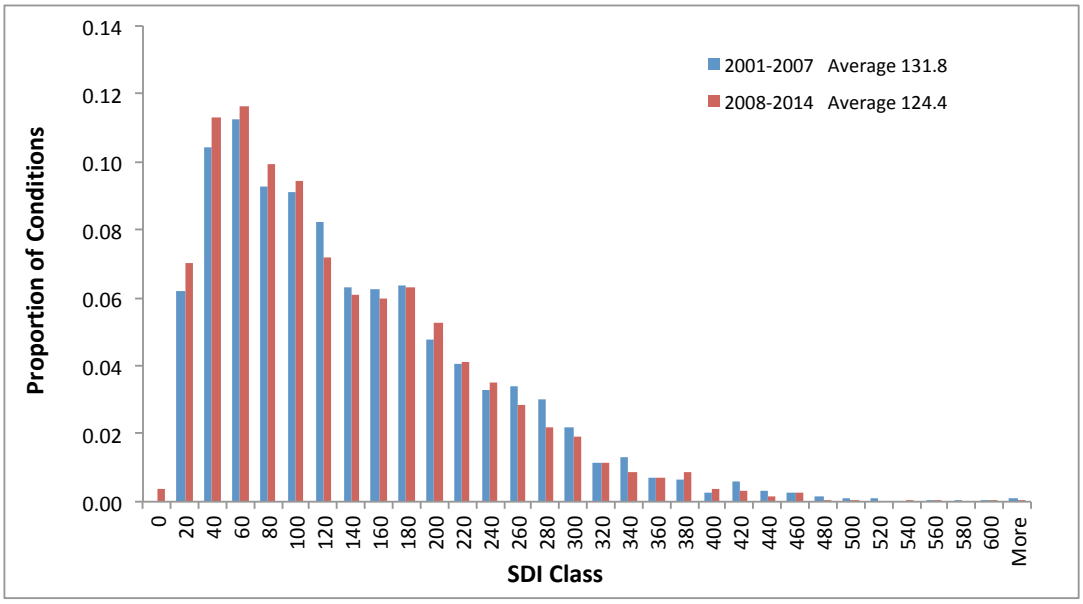

Figure 20—Distribution and average Stand Density Index for the first half and second half of annual inventory in Arizona.

to a much lower-density state; there are very few conditions with SDI = 0. Rather, it appears that conditions previously distributed among the upper two-thirds of the range of SDI have shifted into the lower third.

The overall reduction of stand density is consistent with other results of the inventory. Many species have experienced a period of negative net growth (tables B21–B24), which means that mortality is freeing up growing space faster that the surviving trees on a site can re-occupy that space. It is also consistent with the impacts of fire. Across the Interior West, inventory data has shown that mortality is complete on only about 25 percent of burned conditions, and that less than 10 percent of burned conditions have no regeneration tallied at the time of plot visit (Shaw et al. 2017). The conclusion drawn from this analysis is that while disturbances such as drought, fire, and insects have slightly reduced the overall density of Arizona's forests, the impacts have not been catastrophic at the population scale.

Arizona's Forest Resources

FIA Data as a Habitat Monitoring Tool: The Mexican Spotted Owl as a Case Study

As additional forest attributes such as understory vegetation and down woody material have been added to the Phase 2 protocols, FIA data has become increasingly useful for estimating and monitoring wildlife habitat and tracking changes in its quality and quantity over time. These data can be especially useful in monitoring the changes in habitat of organisms listed under the Endangered Species Act (ESA). Species listed under ESA are afforded certain legal protections, one being a Recovery Plan (Plan) developed by the FWS. The Plan usually outlines a monitoring protocol for assessing the effectiveness of the recovery actions over time. Monitoring is often expensive and logistically cumbersome and might not provide useful information to FWS biologists in a timely fashion. The FIA program can assist with wildlife habitat monitoring, particularly in cases of forest-dwelling species. Inventory data can be useful for estimating habitat over large areas and comparing trends over time with little or no additional costs to the agencies managing the habitat in question. If FIA currently collects data on forest attributes found important to a listed species, estimates of these attributes can be produced quickly. By comparing past and present estimates, FWS staff can develop trends in habitat for a species over large geographic areas in perpetuity.

The Mexican spotted owl (*Strix occidentalis lucida*; "owl") is a resident of the coniferous forests and canyon country of the Southwest, including a large area of Arizona. The owl prefers heavily stocked mixed-confer and pine-oak forests with large diameter trees and a complex understory for nesting and roosting (USFWS 2012). Citing the alteration of its habitat due to timber management practices and the threat of stand-replacing wildlife in its remaining habitat, the owl was listed as threatened under the ESA in 1993, with a Recovery Plan being implemented in 1995. The Plan describes minimum thresholds for forest stand characteristics

known to be important for owl nesting and roosting in mixed-conifer and pine-oak forests. These include the percentage of live basal area (BA) comprised of medium and large diameter trees, the density of large trees, total BA of a stand, and canopy cover. In the following application, we use FIA condition and tree data to identify plots meeting the Plan's definition of the mixed-conifer forest type. In Arizona, mixed-conifer is more common than pine-oak and used by nesting owls more often (USFWS 2012). FIA forest type, habitat type, and the contribution of certain tree species to live basal area were the most important components used to redefine forest types. We then produce estimates of current suitable nesting/roosting habitat in the mixed-conifer forest type of Arizona's Federally administered lands. Area of suitable habitat in mixed-conifer forest on Federal lands from past periodic inventory data (1995–2000) is compared to 2006–2015 estimates to illustrate trend analysis capabilities of FIA data. Area estimates for individual habitat characteristics are presented as well as those for Federal lands that satisfy all habitat characteristics concurrently.

Nearly 275 thousand acres of mixed-conifer forest reside on Federally administered lands in Arizona for the 2015 time series compared to an estimated 278 thousand acres in 2000 (fig. 21). Just over 4 percent of these acres are estimated to meet all of the minimum nesting/roosting requirements outlined in the Plan in both inventories. This indicates that mixed-conifer forest nesting habitat has been maintained through the life of the Recovery Plan. In 2000, 61 percent (170,422 acres) of all mixed-conifer forests met the total basal area requirement, compared to nearly 57 percent (274,860 acres) in 2015. This is the most frequently satisfied habitat component of the owl in mixed-conifer forests in either time period. Basal area from large trees (>18 in. d.b.h.) was the rarest habitat feature found in the 2015 inventory. Nesting habitat in mixed-conifer forests appears to be relatively static over the years between inventories, the largest change being the large increase in stands meeting medium-sized tree basal area contributions. It also appears that forests meeting all criteria concurrently are still a very small percentage of the potential habitat.

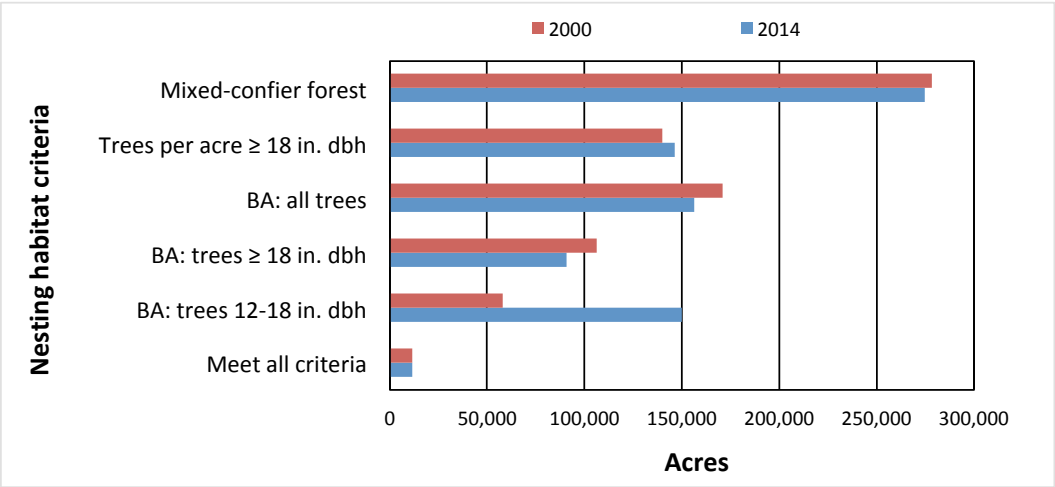

Figure 21—Comparison of mixed-conifer nesting habitat of Mexican spotted owls on federal lands in Arizona between the 2000 and 2015 inventories.

This exercise illustrates the utility of FIA data for future monitoring applications where methodology and temporal distribution of sampling will remain consistent. These estimates can be compared to data collected in the future to assess continuing trends of habitat quality in each forest type. This can help assess the effectiveness of management actions taken to either maintain or increase habitat for the owl over a given period of time. The Interior West FIA plot remeasurement schedule closely approximates the monitoring timeline described in the Plan and allows FIA data to be easily used as a habitat monitoring tool with little additional investment to data collection and monitoring efforts.

Understory Vegetation

The structure and composition of understory vegetation contributes to the diversity, productivity, and habitat structure of forest ecosystems. FIA collects understory vegetation data using two distinct protocols that characterize overall vegetation structure as well as species composition. Under the vegetation structure protocol, field crews record the height class and percent cover that is occupied by each of four plant growth habits: forbs, graminoids, shrubs, and understory trees, which are defined as trees less than 5 inches d.b.h. Under the species composition protocol, height class, growth habit, and percent cover are recorded for plant species that individually occupy at least 3 percent of the ground area. If more than four species occupy more than 3 percent cover, then only the most abundant four species per life form are recorded.

Figure 22 depicts the average percent cover of each plant growth habit for Arizona's 10 most abundant forest types, and nonstocked land. Understory trees cover more area than the other three growth habits on all forest types except for juniper woodlands and nonstocked land. Juniper woodlands have more graminoid

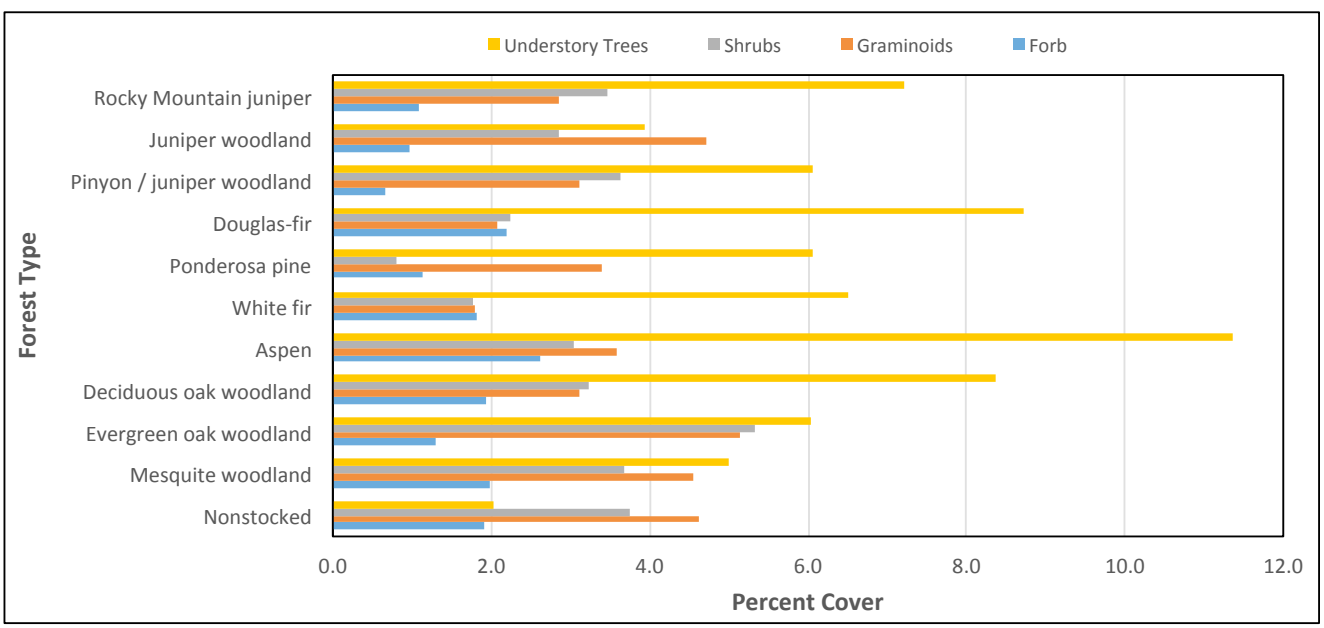

Figure 22—The average percent cover of the four understory vegetation growth habits, by forest type, Arizona, 2005–2014. The 10 most common forest types and nonstocked area are shown.

Table 4—Five most frequently recorded plant species in each understory vegetation growth habit, and average cover where they occur, Arizona, 2005–2014.

Growth habit	Scientific name	Common name	Number of plots	Average cover (percent)
Forb	*Pteridium aquilinum*	western brackenfern	57	7.3
	Erodium cicutarium	redstem stork's bill	25	7.0
	Chenopodium graveolens	fetid goosefoot	20	3.9
	Cordylanthus wrightii	Wright's bird's beak	18	3.9
	Amaranthus palmeri	carelessweed	17	6.6
Gaminoid	*Bouteloua gracilis*	blue grama	863	11.0
	Bouteloua curtipendula	sideoats grama	480	6.1
	Muhlenbergia emersleyi	bullgrass	136	4.6
	Bromus rubens	red brome	104	5.5
	Poa fendleriana	muttongrass	99	4.1
Shrub	*Gutierrezia sarothrae*	broom snakeweed	341	3.2
	Artemisia tridentata	big sagebrush	288	7.9
	Arctostaphylos pungens	pointleaf manzanita	256	9.2
	Cercocarpus montanus	alderleaf mountain mahogany	227	5.0
	Garrya wrightii	Wright's silktassel	184	4.6
Understory tree	*Pinus edulis*	common pinyon	426	3.0
	Quercus gambelii	Gambel oak	316	7.6
	Quercus turbinella	Sonoran scrub oak	280	9.0
	Pinus ponderosa	ponderosa pine	271	5.0
	Prosopis velutina	velvet mesquite	171	6.4

cover than understory tree cover, whereas on nonstocked land both graminoids and shrubs have greater cover. Graminoids and shrubs have about equal cover in most forest types, but shrubs have relatively low cover as compared to graminoids in the ponderosa pine forest type. There were 670 individual plant species recorded on Arizona's forest inventory plots. The five most frequently recorded species within each growth habit are listed in table 4. Blue grama (*Bouteloua gracilis*) was the most frequently encountered species by a large margin and was recorded on nearly a third of all forested plots. On average, blue grama covered 11 percent of all plots where it occurred. Forbs, in general, had relatively low frequencies of occurrence; western brackenfern (*Pteridium aquilinum*) was the most common, but was found on less than 2 percent of plots. It is possible, and perhaps likely, that some forbs are recorded at lower than actual frequencies because the timing of plot visits may not coincide with their emergence. Shrubs, in contrast, are more easily detectable because their woody components are generally visible year-round. Still, the five most common shrubs were only found on 6 to 10 percent of plots. Four of the five most common understory trees were also tally tree species. Only Sonoran scrub oak (*Quercus turbinella*), which is usually found in shrubby form or as small trees, did not represent regeneration of overstory tree species.

Soils on the landscape are the product of five interacting soil forming factors. These are parent material, climate, landscape position (topography), organisms (vegetation, microbes, other soil organisms), and time (Jenny 1994). Many external forces can have a profound influence on forest soil condition and hence forest health. These include agents of change or disturbances to apparent steady-state conditions such as shifts in climate, fire, insect and disease activities, land use activities, and land management actions.

The Soil Indicator of forest health was developed to assess the status and trend of forest soil resources in the United States across all ecoregions, forest types, and land ownership categories. For this report, data were analyzed and are being reported by forest-type groups. This forest type stratification not only reflects the influence of forest vegetation on soil properties, but also the interaction of parent material, climate, landscape position, and time with forest vegetation and soil organisms. Some of the key soil properties in Arizona were graphed by forest-type group, and to place these results in a regional context, these graphs are placed side by side with graphs of regional results. Because the western hardwoods, pinyon/juniper, and ponderosa pine groups occupy extensive areas in Arizona, there are many soil samples from these forest-type groups (35, 96, and 26 plots with soil samples, respectively). The Douglas-fir, aspen, and spruce/fir groups occupy far less area in Arizona so the number of plots sampled for soil are very limited (3, 2, and 2 plots, respectively).

Soil C and N percentages generally increase from drier to wetter forest environments (fig. 23). Generally, soil moisture increases with elevation and latitude (cooler temperatures) and forest types reflect this climatic gradient. When expressed in terms of megagrams of C or N per hectare of forest area, C stocks also generally increase with elevation and latitude (fig. 24).

Aspen forests store more N in the mineral soil than any other forest group in the Interior West (fig. 24, right side). Aspen forests store significantly more N than spruce/fir forests, which often intermingle with aspen. High N levels in aspen forest floor and soils leads to lower C/N ratios than those found in forest floor and soils under spruce/fir. Since low C/N is a good indicator of relative organic matter decomposition rate, nutrient-rich aspen leaves decompose quickly and easily compared to spruce/fir needles.

Soil pH generally decreases with increasing elevation, latitude, and precipitation (fig. 25). The more acidic soils are found in the wetter high-elevation forest types. This is also reflected in higher levels of exchangeable Al in wetter high-elevation forest soils (fig. 25, right side), although this effect is not seen in the Arizona data because of high variability and a very limited sample population. In the Interior West as a whole, much higher levels of Al are found in spruce/fir than aspen soils. Aspen are intolerant of high levels of exchangeable Al. In the Interior West as a whole and to some extent in Arizona, aspen soils store more K than other forest-type groups (fig. 25). High levels of exchangeable Ca are found in the

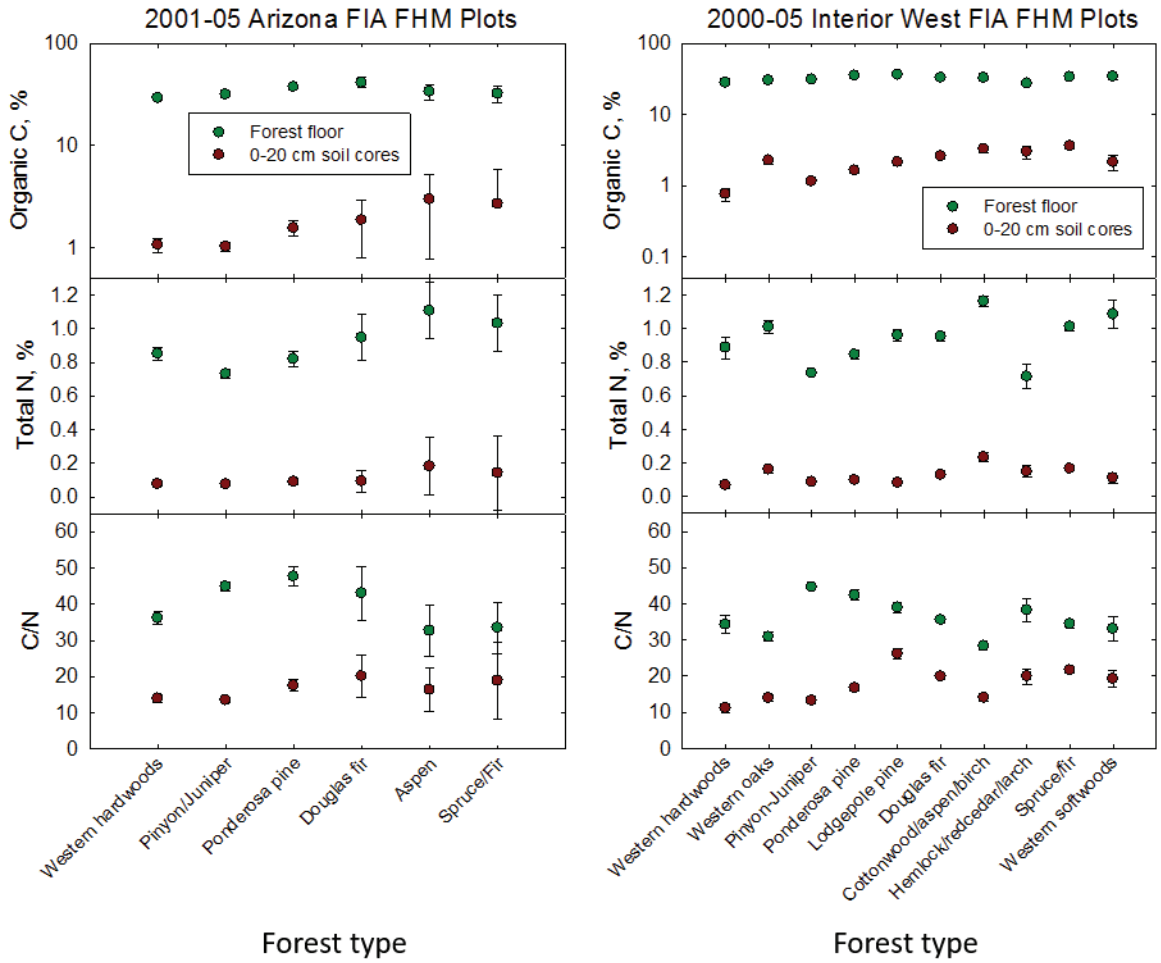

Figure 23—Forest floor and 0–20 cm mineral soil % C, % N, and C/N arranged by forest-type groups in Arizona (left side) and in five Interior West States (Arizona, Colorado, Idaho, Montana, and Utah) (right side). The forest-type groups are arranged left to right in order of increasing latitude, elevation, and precipitation with some overlap among forest types. The western hardwoods group in Arizona includes mesquite woodland, deciduous oak woodland, and evergreen oak woodland. For the Interior West as a whole, the western oak group (deciduous and evergreen oak woodlands) was separated from the other western hardwoods (mesquite and Cercocarpus woodlands). The pinyon/juniper group in Arizona includes Juniper woodland and pinyon/juniper woodland. For the Interior West, this group also includes Rocky Mountain and western juniper types. The spruce/fir group in Arizona includes Engelmann spruce and blue spruce. For the Interior West, this group also includes white fir, grand fir, sub-alpine fir, and mixed Engelmann spruce/subalpine fir. The western softwoods group in the Interior West includes western white pine, foxtail/bristlecone pines, limber pine, and whitebark pine.

calcareous, high-pH soils under western hardwoods including oaks and pinyon/juniper group woodlands (fig. 25).

Western aspen are in decline in Arizona (see *Aspen Status and Trends* section below) and other Interior West States. Causes include fire suppression, overbrowsing by native ungulates and domestic livestock, and forest succession in which aspen are replaced by invading conifers (Bartos and Campbell 1998). Loss of aspen on the landscape can lead to decline or loss of ecosystem benefits provided by aspen. Since aspen soils store large amounts of N and K, and maintain moderate soil pH levels, conifer replacement of aspen can lead to nutrient loses and soil

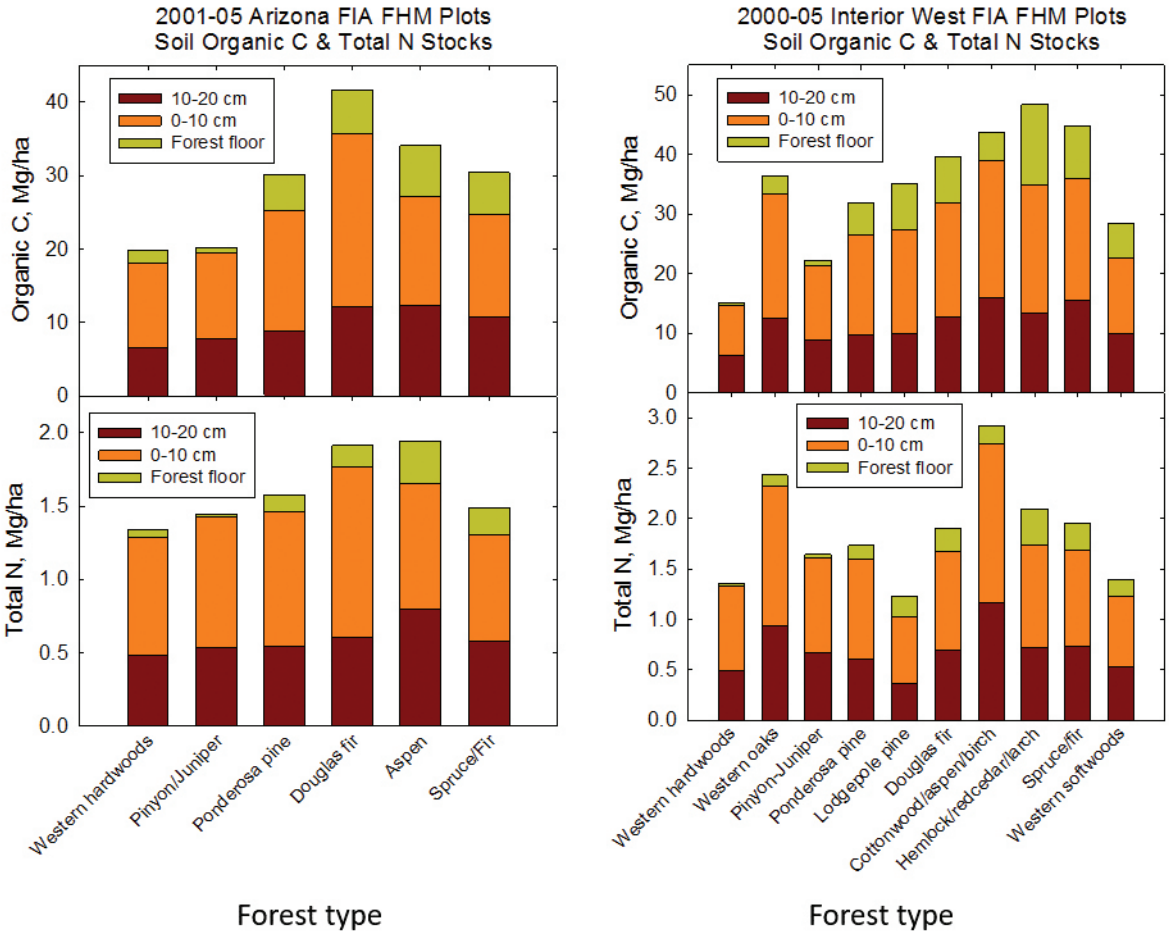

Figure 24—Soil organic carbon (top) and total nitrogen (bottom) stocks (Mg/ha) in the forest floor and 0–10 and 10–20 cm soil layers arranged by forest-type groups in Arizona (left side) and in five Interior West States (Arizona, Colorado, Idaho, Montana, and Utah) (right side).

acidification. If these soil changes are permanent, aspen may be unable to recolonize areas where they formerly thrived.

Down Woody Material

Down woody material (DWM) is an important component of forests that impacts fire behavior, wildlife habitat, and carbon storage and sources. Some examples of DWM are fallen trees, branches, and leaf litter commonly found within forests in various stages of decay. The main components of DWM include fine woody debris (FWD), coarse woody debris (CWD), litter, and duff. FWD comprises the small diameter (up to 2.9-inch) fire-related fuel classes (1-hr, 10-hr, 100-hr moisture equilibration), and CWD comprises the large diameter (3-inch+) 1,000-hr fuels. In 2006, due to the increasing need for more intensive DWM information, IWFIA initiated a DWM inventory in all its annual States. This DWM analysis used data from regional Phase 2 (P2) protocols (USDA FS 2006, 2011) for plots measured between 2006 and 2012.

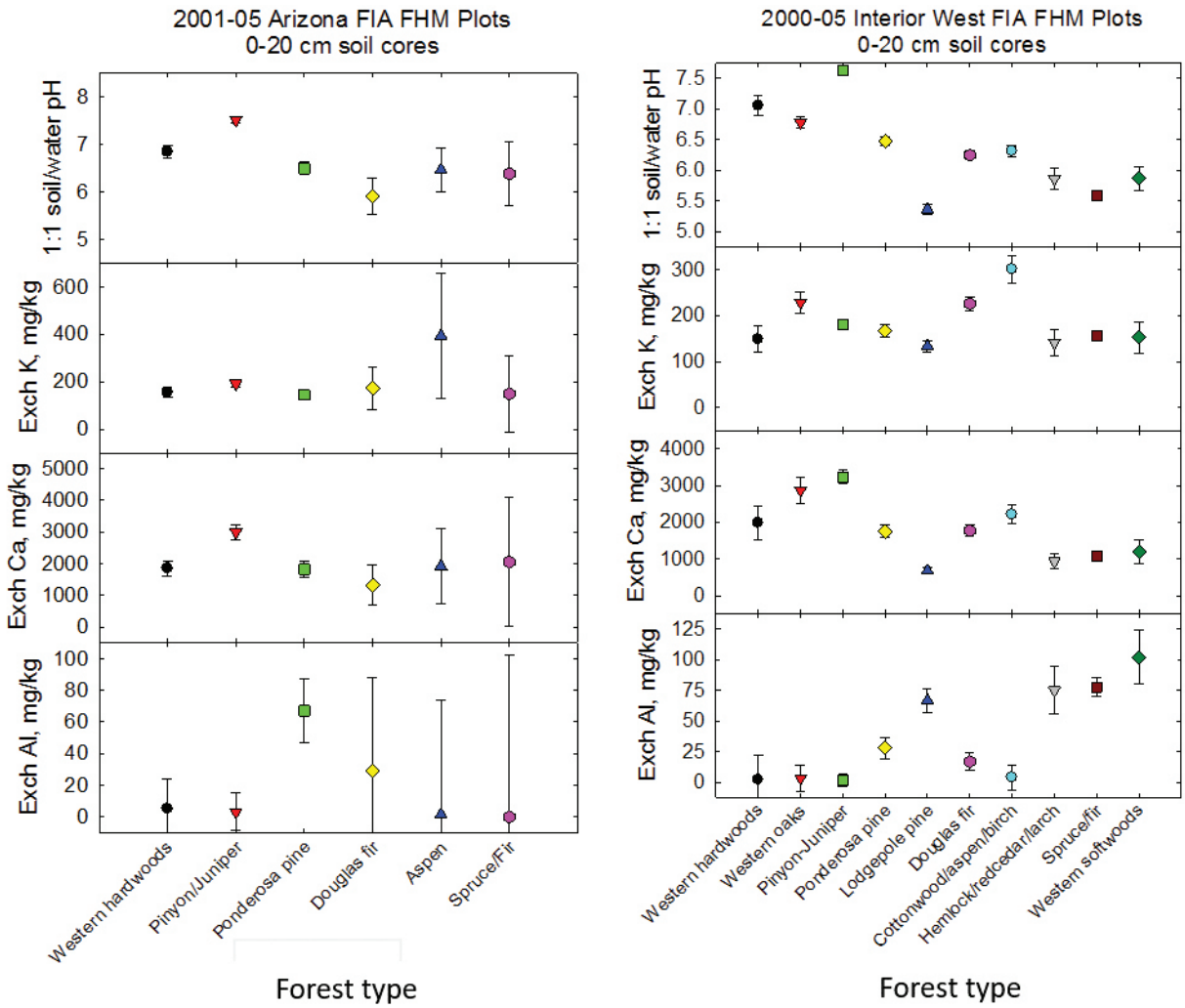

Figure 25—Soil pH and exchangeable potassium, calcium, and aluminum in the 0–20 cm soil layers arranged by forest-type groups in Arizona (left side) and in five Interior West states (Arizona, Colorado, Idaho, Montana, and Utah) (right side).

Figure 26 shows DWM biomass value classes in the State of Arizona, in tons per acre, based on the sum of all six DWM components (CWD, 3 classes of FWD, litter, and duff).

The highest biomass values tend to be found in the higher elevation areas of the State, such as the Kaibab Plateau, the San Francisco Peaks, and White Mountain. This is because higher levels of DWM are generally associated with higher-productivity forest types, and the higher-productivity forest types are generally found where there is higher precipitation (Garbarino et al. 2015). Given that elevation and precipitation are highly correlated in the mountain areas of the West, the pattern emerges clearly.

This can also be shown by plotting DWM biomass averages by forest type and elevation (fig. 27). Note that the woodland types, such as mesquite, juniper, and pinyon/juniper, which occur on dry sites at low elevations, group together with relatively low total DWM biomass values. Aspen and the different spruce-dominated

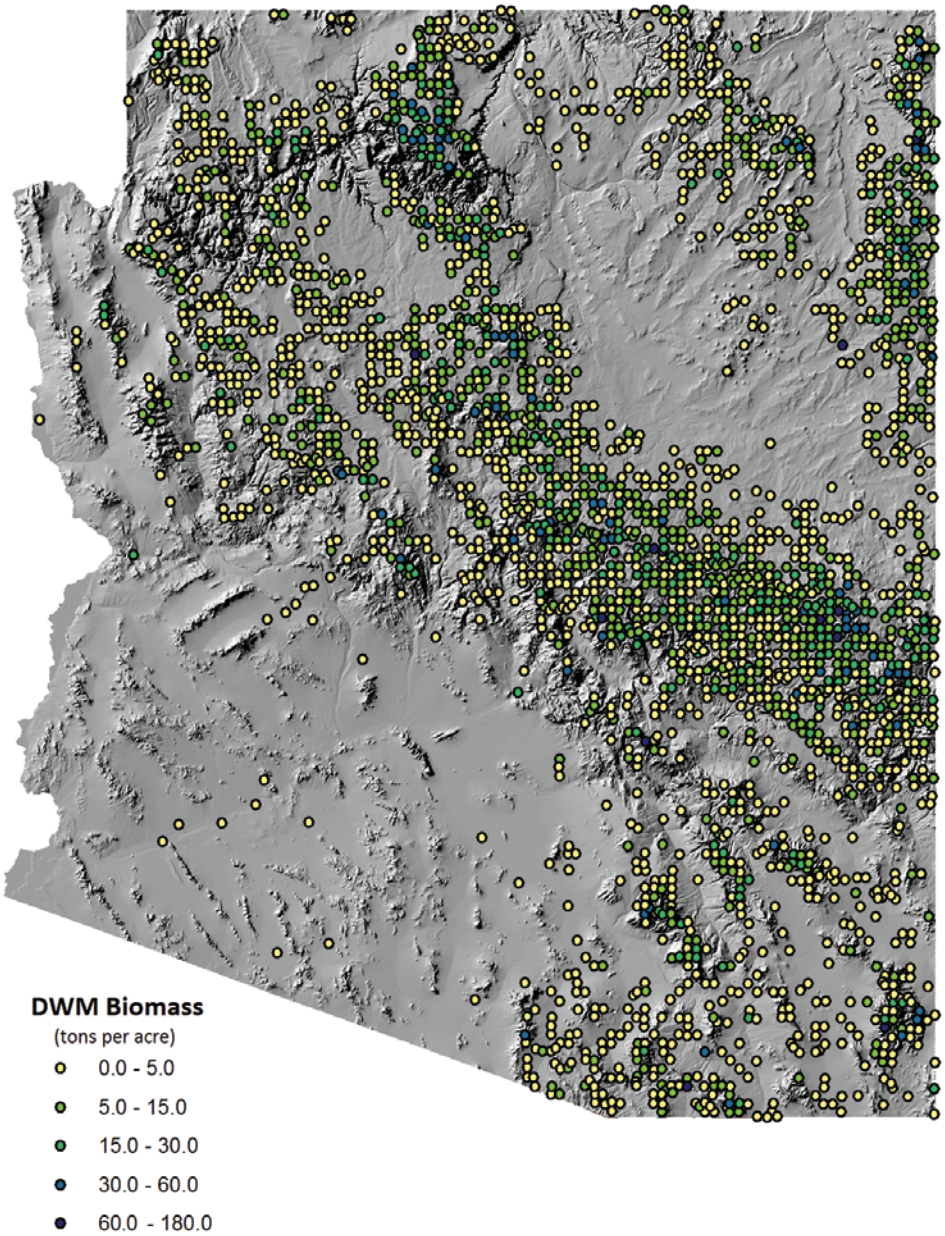

Figure 26—Total biomass (tons per acre) of downed woody material (coarse, fine, litter, and duff components), Arizona, 2006–2014. (Note: Plot locations are approximate; some plots on private land were randomly swapped).

types occur at the opposite end of the scale, both in biomass and elevation. There are a few exceptions to the pattern, such as the cottonwood, cottonwood/willow, and limber pine forest types. Although cottonwood is capable of high growth rates, stands with a large cottonwood component are generally located in riparian areas. While these forest types may produce DWM in proportion to their productivity rates, material on the ground is likely to decay quickly because of the availability of moisture, or even be washed from the stand during periods of high water. The limber pine type is an exception for different reasons. Although limber pine as a species is found in many forest types, sites where limber pine forms its own forest type tend to be rocky or otherwise harsh. Therefore, although moisture is likely to be high because of the elevations at which these stands are found, other limiting factors, like low temperatures and rocky soil, reduce overall productivity and therefore the average amount of DWM found in these stands.

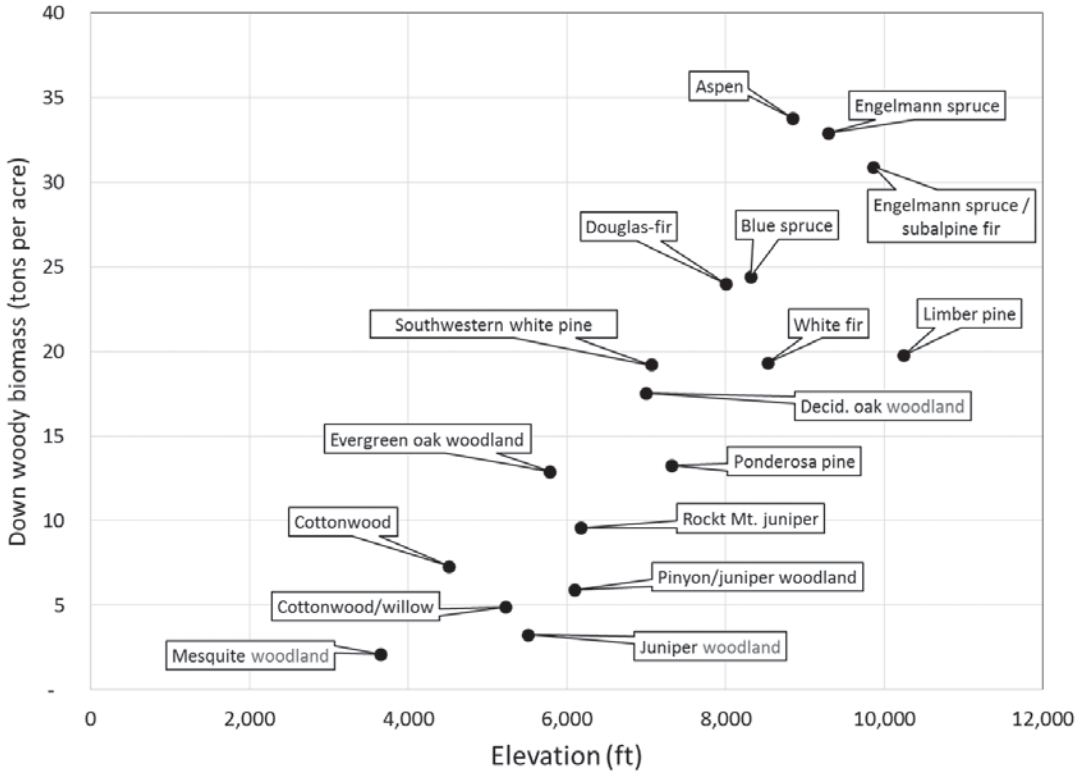

Figure 27—Average down woody material biomass by forest type and elevation.

Remeasurement of DWM started during the 2016 field season, using a nationally consistent approach for Phase 2 plots. As additional data are collected on DWM components, it should be possible to produce trend information for down woody volume, biomass, and carbon, just as for the standing live and dead components of the forest.

Arizona's Primary Wood Products Industry

The Bureau of Business and Economic Research at the University of Montana conducted censuses of Arizona's primary wood products industry for calendar years 1998, 2002, 2007, and 2012 documenting timber use and the condition of the industry (Hayes et al. 2012; Keegan et al. 2001; Morgan et al. 2006; Sorenson et al. 2016). Primary wood products manufacturers are firms that process timber into products such as lumber, house logs, and biomass energy. The secondary industry further processes outputs from the primary industry into other value-added wood products, such as cabinets, doors, or furniture.

Arizona's primary wood products industry consisted of 25 active facilities in 2012 (table 5; fig. 28). The sawmill sector, manufacturing lumber and other sawn products, was the largest sector, operating 14 mills during 2012—six more than operated in 2007. Only two log home and viga producers operated during 2012, while nine other products manufacturers were active.

Table 5—Active Arizona primary wood production facilities, selected years (sources: Hayes et al. 2012; Keegan et al. 2001; McLain 1988; Morgan et al. 2006).

County	Lumber	House logs and vigas	Other products[a]	Pulp and paper	Total
2012 total	14	2	9	0	25
2007 total	8	5	4	0	17
2002 total	11	5	7	0	23
1998 total	6	4	2	1	13
1990 total	14	3	1	1	19
1984 total	20	0	2	1	23

[a] Other products include industrial fuelwood, fuel pellets, biomass energy, posts and poles.

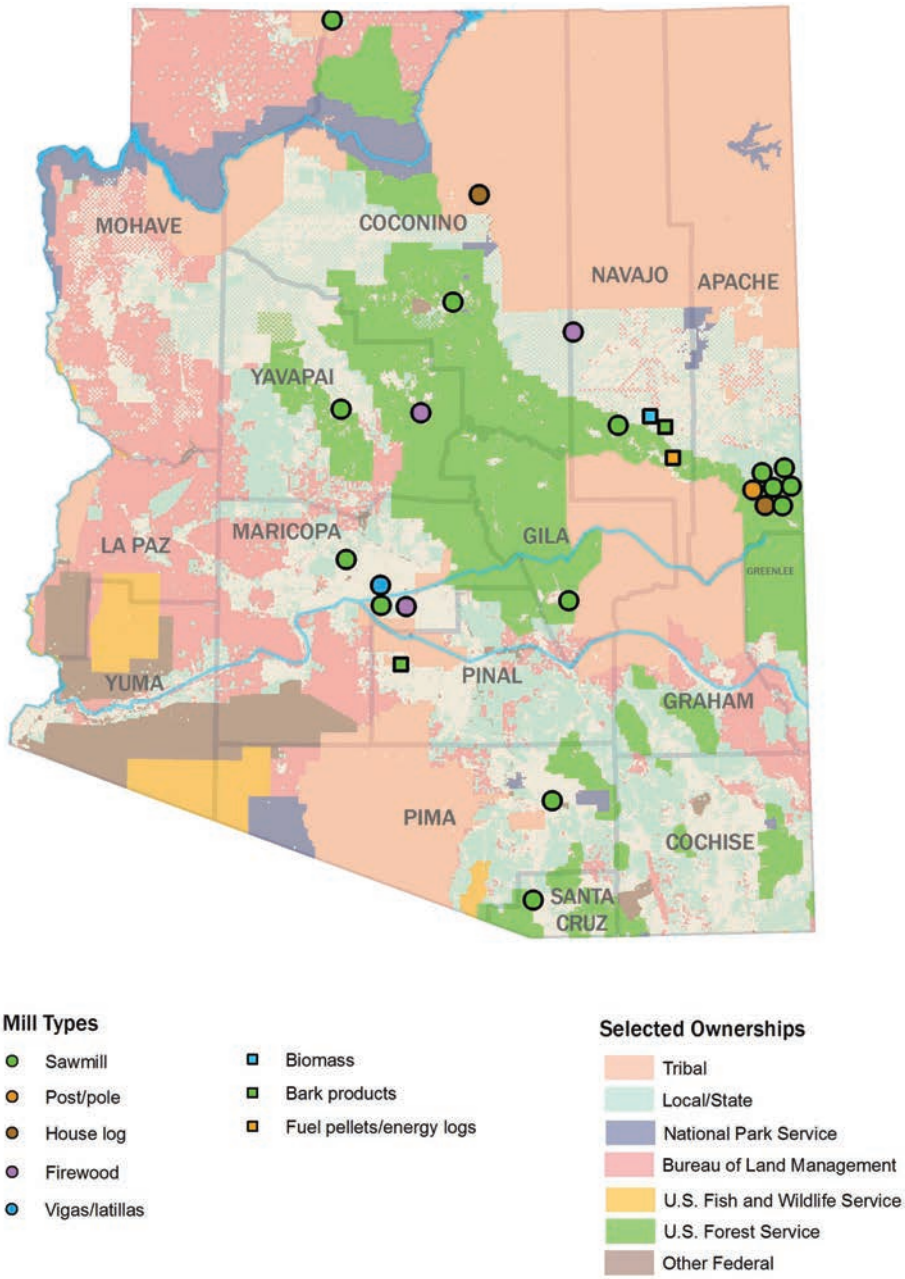

Figure 28—Locations and type of wood processing facilities in Arizona, 2012.

Table 6—Ownership of timber received by Arizona's primary wood products industry, selected years (sources: Hayes et al. 2012; Keegan et al. 2001; Morgan et al. 2006).

	1998		2002		2007		2012	
Ownership class	**MBF Scribner**	**Percentage of total**	**MBF Scribner**	**Percentage of total**	**MBF Scribner**	**Percentage of total**	**MBF Scribner**	**Percentage of total**
Private and tribal timberland	48,102	71.1	58,108	76.3	31,706	60.8	2,623	3.8
Tribal	45,964	68.0	56,150	73.8	4,400	8.4	2,220	3.2
Private	2,138	3.2	1,958	2.6	27,306	52.4	403	0.6
National forests	19,510	28.9	18,006	23.7	20,427	39.2	66,858	96.0
State lands	—	—	—	—	—	—	130	0.2
All owners	67,612	100	76,114	100	52,133	100	69,611	100

Timber processors in Arizona received 69.6 million board feet (MMBF) Scribner of timber in 2012. The vast majority (96 percent) of timber came from national forests. Tribal lands provided 3 percent, and less than 1 percent came from private and State lands combined (table 6). During previous study years, private and Tribal timberland accounted for 60 to 75 percent of the timber received by Arizona mills.

Despite having six more sawmills operating during 2012 than in 2007, total lumber production in Arizona was 49.3 MMBF in 2012 versus 54.9 MMBF in 2007. Average lumber production declined to just 3.5 MMBF per mill in 2012, the lowest level identified since the 1960s (Hayes et al. 2012).

Sales of finished products (excluding mill residue) from Arizona's primary wood products industry increased substantially during 2012 and totaled $83.8 million (table 7). Sawmill sales accounted for 39 percent ($32.4 million) of total sales, while biomass energy, log homes, and other products accounted for 61 percent ($51.4 million). Arizona was the leading overall destination for primary wood products, with in-State sales accounting for almost 71 percent of total sales. The leading destination for lumber was Mexico, and within State was the second leading market area for lumber from Arizona mills. Arizona was also the leading destination for biomass energy, log homes, and other primary products, with nearly 90 percent of sales within State

Arizona timber processors produced almost 68 thousand bone-dry units (BDU) of mill residue in 2012, with 99.9 percent utilized, versus 98.5 percent of

Table 7—Sales value of finished products from Arizona's primary wood products industry, selected years (sources: Hayes and others 2012; Keegan and others 2001; Morgan and others 2006; WWPA various years).

Sector	**1984**	**1990**	**1998**	**2002**	**2007**	**2012**
	Thousands of 2012 dollars					
Sawmills	193,169	158,069	33,452	30,217	22,335	32,403
Log home and other sectors[a]	271	622	2,613	7,853	17,551	51,397
Total[b]	193,440	158,692	36,064	38,070	39,886	83,800

[a] Other sectors include producers of industrial fuelwood, fuel pellets, biomass energy, posts, poles, and vigas.

[b] All sales are reported F.O.B. the manufacturer's plant. Sales of mill residue, mulch, and paper are not included for comparison to previous years.

residue utilized in 2007. Sawmills produced the majority of mill residue, generating 1.07 BDU per MBF of lumber in 2012, compared to 1.22 BDU per MBF of lumber in 2007.

The classification of forest industries used here follows the North American Industry Classification System (NAICS) available online via the U.S. Department of Commerce Census Bureau (USDC CB 2014). The forest industry can be found in four categories: NAICS 113—forestry and logging; NAICS 1153—forestry support activities; NAICS 321—wood product manufacturing; and NAICS 322—paper manufacturing. These categories include employees that work in both the primary and secondary wood products sectors, as defined above.

Based on the four NAICS sectors of the forest industry (113, 1153, 321, and 322), about 6,700 workers were directly employed in the primary and secondary forest products industry in Arizona during 2012 (USDC BEA 2014). This marked a 42 percent decline from 2007 employment in the industry, with most of the loss coming from wood products manufacturing, which declined from over 8,400 jobs in 2007 to about 3,900 in 2012. Just fewer than 800 workers were employed in harvesting and processing timber or in private sector land management (i.e., the primary sector) in 2012, roughly the same level of primary sector employment as in 2007.

Volume removed from forest inventory during the harvesting of timber is referred to as removals. Removals are an important indicator of the sustainability of timber harvest levels. Removals exceeding net growth over an extended period could indicate over-harvesting and decreasing forest inventory. Conversely, growth or mortality greatly exceeding removals could signal a need for increased vegetation management to decrease risks of tree mortality, insect outbreaks, or wildfire.

Removals can come from two sources: growing-stock (portions of live, commercial tree species meeting specified quality or vigor standards) or dead trees and other non-growing stock sources (e.g., tree limbs and tops). The two general types of removals are timber products and logging residue (i.e., volume cut or killed but not utilized). Removals, as reported here, are based on 2002, 2007, and 2012 surveys of Arizona's primary forest products industry (Hayes et al. 2012; Morgan et al. 2006; Sorenson et al. 2016) and the U.S. Energy Information Administration data for residential fuelwood consumption (EIA 2016). More detailed timber products and logging residue data for Arizona and other States are available from FIA's Timber Products Output (TPO) website: https://www.fs.usda.gov/srsfia/php/tpo_2009/tpo_rpa_int1.php.

Total removals in Arizona during 2012 were almost 31.1 million cubic feet (MMCF). Total removals included 28.4 MMCF of timber products, including industrial and residential fuelwood, and 2.6 MMCF of logging residue left in the forest as slash (table 8).

Growing-stock sources accounted for approximately 7.8 MMCF of total removals. Very little (0.1 MMCF) growing-stock volume was unutilized and left in the forest as logging residue, with almost 99 percent of growing-stock removals used

Table 8—Arizona total removals for products and logging residues, selected years.

Product	2002	2007	2012	Annual average
	--------- *million cubic feet* ---------			
Sawlogs	21.648	9.112	7.876	12.9
Composite products	0.421	0.421	—	0.3
Industrial fuelwood	4.143	1.524	9.410	5.0
Post & poles	0.152	—	0.306	0.2
Miscellaneous	0.307	0.242	1.302	0.6
Industrial products	**26.671**	**11.299**	**18.894**	**19.0**
Residential fuelwooda	23.079	31.882	9.520	21.5
Total products	**49.750**	**43.181**	**28.414**	**40.4**
Logging residue	3.707	3.800	2.638	3.4
Total removals	**53.457**	**46.980**	**31.052**	**43.8**

[a] Residential fuelwood is reported by the U.S. Energy Information Administration.

to produce wood products. Ponderosa pine accounted for 86 percent (6.7 MMCF) of growing-stock removals and Douglas-fir accounted for 7 percent (0.5 MMCF). Almost all of the growing-stock removals in Arizona came from public lands, with about 96 percent (7.5 MMCF) originating on national forests, while only 4 percent of the volume came from non-industrial private and Tribal timberlands.

In 2012, removals for all timber products (including industrial fuelwood and residential firewood) totaled 28.4 MMCF accounting for 92 percent of the total removals for the year (table 8). Of the 18.9 MMCF of removals for industrial products, approximately 50 percent came from industrial fuelwood, making it the leading timber product in 2012. Sawlogs accounted for 7.9 MMCF (almost 41 percent) of industrial product removals. Logs for miscellaneous wood products accounted for approximately 7 percent, with logs for posts and poles accounting for the remaining 2 percent of industrial product removals. Approximately 99 percent (18.7 MMCF) of removals for industrial wood products consisted of softwood species. The largest volume of both softwood and hardwood removals was used for industrial fuelwood.

Across Arizona's nearly 3 million acres of timberland, approximately 71 million board feet (MMBF) Scribner, about 18.9 MMCF, of industrial timber products were harvested in 2012. The 2012 industrial harvest was 17.2 MMBF (33 percent) higher than 2007, but only 56 percent of the State's 2002 harvest levels. Dead trees, resulting from wildfires and insect outbreaks, have a dynamic role in Arizona's annual timber harvest level. While dead trees accounted for only 8 percent (4 MMBF) of the harvest in 2007, harvest of dead timber accounted for 70 percent (90 MMBF) of the 2002 harvest and about 56 percent (40 MMBF) of the 2012 harvest (Hayes et al. 2012; Morgan et al. 2006; Sorenson et al. 2016).

Total removals for timber products and logging residue decreased about 42 percent over the past 10 years (table 8), from 53.5 MMCF in 2002 to about 31.1 MMCF in 2012. Total removals decreased approximately 12 percent between 2002 and 2007, and about 34 percent from 2007 to 2012. The EIA reported a dramatic

decrease of 70 percent in residential fuelwood between 2007 and 2012. Removals for industrial products also decreased over the decade, with 2012 approximately 7.7 MMCF (29 percent) lower than in 2002. However, removals for industrial products actually increased between 2007 and 2012 by about 67 percent (7.6 MMCF) after a dramatic decrease from 2002 to 2007.

Removals for sawlogs decreased nearly 64 percent from 2002 to 2012, with the steepest (58 percent) decline occurring from 2002 to 2007. Conversely, industrial fuelwood more than doubled from 2002 to 2012, with an increase of about 5.3 MMCF. Removals for post and poles doubled and other miscellaneous products increased more than four-fold from 2002 to 2012. Logging residue removals increased by about 3 percent from 2002 to 2007, but fell approximately 31 percent from 2007 to 2012. Less volume is being left unused after product harvest activities due to technological advancements in harvesting and milling operations and to notable growth in removals for industrial firewood.

Long-term sustainability of Arizona's timberlands depends upon several interrelated factors: active management of lands available for timber production, the presence of a forest products industry capable of processing harvested timber, and harvest levels that meet societal demands while fostering continual site productivity. To ensure sustainable forests and communities, careful consideration should be given not only to growth, removals, and mortality across Arizona's available timberlands, but also to the forest industry and employees who conduct management activities and utilize timber in Arizona.

Current Issues in Arizona's Forests

Drought-Related Effects on Pinyon/Juniper Woodlands

Collectively, pinyon/juniper and juniper woodlands make up the most common forest type in the American Southwest, covering over 36 million acres in 10 States and extending into Mexico. In Arizona, these types account for 11.1 million acres, or nearly 60 percent of the State's forest land. Within the pinyon/juniper forest-type group, FIA distinguishes three main forest types: pinyon/juniper woodlands, juniper woodlands, and Rocky Mountain juniper woodlands (see Appendix C). The pinyon/juniper forest type is defined by the presence of one or more pinyon species—usually common or singleleaf pinyon—and one or more juniper species; pure stands of pinyon are not considered a separate type by the FIA program. Juniper woodland types are dominated by various juniper species, but other species—exclusive of pinyons—may be present as a minor component. To most laypersons and many managers, the term pinyon/juniper woodland (or P-J, for short) includes all lands dominated by pinyons, junipers, or both. For convenience, in this section the term "pinyon/juniper woodland" refers to all lands covered by this common use of the term and thus includes the juniper and Rocky Mountain juniper forest types as well as the pinyon/juniper forest type.

The IWFIA program operates in Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming; these States include most of the range of pinyon/juniper woodlands in the United States. A drought began across much of the Southwest, including Arizona, about the time that an annual forest inventory was started in the Interior West States. As a result, forest managers and researchers began to notice an increase in the incidence of insects and disease in several forest types, including pinyon/juniper. As the drought progressed, tree mortality appeared to be increasing and there was increasing interest in using FIA data to quantify the effects of drought, insects, and disease on pinyon/juniper woodlands (Shaw et al. 2005). The drought-related mortality episode has provided an opportunity to test the utility of the FIA annual inventory system for quantifying rapid change in pinyon/juniper woodlands over a large geographic area (Shaw 2006).

Since the annual inventory system was implemented in Arizona in 2001, the progression of drought-related mortality was captured as it occurred in the early 2000s. During the first 10 years of annual inventory, all plots visits were treated as "first-time" visits, even though there may have been a previous visit during one or both of the preceding periodic inventories. During first-time visits, trees judged to have died during the 5 years prior to plot visit were considered as mortality trees, and trees judged to have died earlier considered "old dead." Assignment of mortality year for visits up to 5 years post-mortality is known to be relatively reliable because of rapid changes in tree condition (Kearns et al. 2005), but correct assignment becomes increasingly difficult with time. Most mortality trees removed by firewood cutting, blown down, or no longer "on the stump" for other reasons would still be missed by the current inventory, but these situations cover only a small percentage of tally trees. In the case of remeasurement of annual plots, each of the trees from the previous annual visit is accounted for. In this case the assignment of mortality year is less critical, since the status of each tree was known from the previous visit. Because annual inventory was implemented in Arizona before the early 2000s increase in mortality, and the inventory data currently include 40 percent of plots with remeasurements, we consider our estimate of drought-related mortality in Arizona to be a good approximation.

Pinyon mortality from all causes in the Interior West began to increase in 2001 and appears to have peaked between 2005 and 2007 (fig. 29a). Since then, mortality rates have decreased and some states appear to be returning to background mortality rates. However, drought persists in the Southwest, including in Arizona, and fire continues to impact pinyon/juniper woodlands in many areas. Mortality of pinyon in Arizona in the 2000s tended to be somewhat higher than mortality rate of pinyons in all Interior West states combined—peaking at about 15 percent of the total basal area. Among the Four Corners States, Arizona ranks highest in the level of pinyon mortality.

Juniper species have shown to be much more resistant to drought-related mortality than pinyon species. From 2000 to 2003, the mortality rate of juniper species in the Interior West states, from all causes, rose from a very small fraction to about 2 percent and has remained relatively steady since then (fig. 29b).

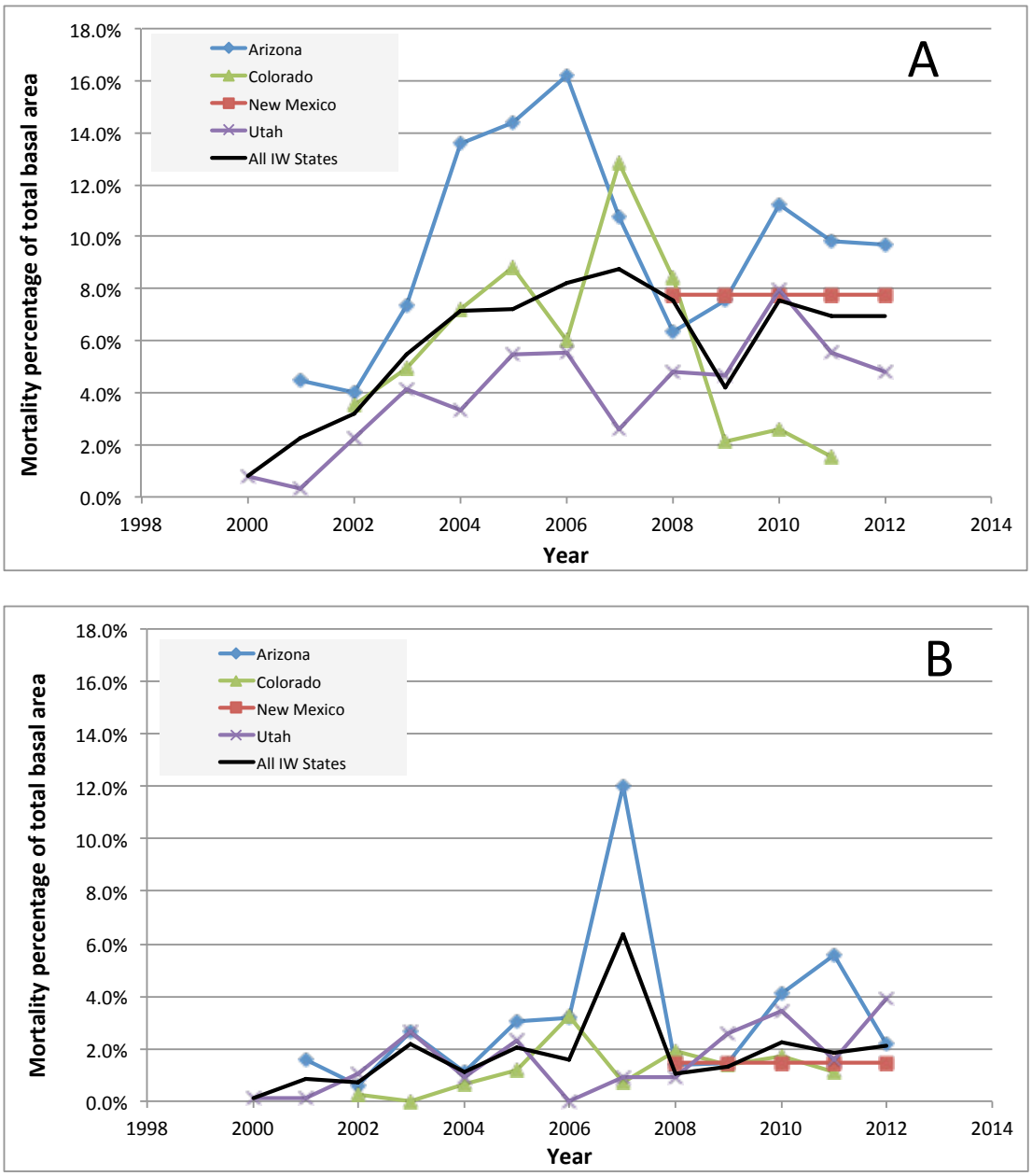

Figure 29—Annual mortality, by measurement year, for pinyon (A) and juniper (B) species in the Interior West States.

The apparent spike in juniper mortality seen in 2007 is largely a result of a large number of "catch-up" plots in Arizona that were located in burned areas. As with the pinyon species, the juniper mortality rate in Arizona appears somewhat higher than the mortality rate for the Interior West as a whole.

The dramatic visual effect of drought-related mortality of pinyon species—dying trees with reddened foliage covering entire landscapes—brought public and media attention to the event. Because there were typically localized hot spots of mortality that were surrounded by large areas of relatively low mortality, it was difficult to obtain unbiased, quantitative estimates of the true extent of mortality. In some cases, mortality estimates were extrapolated from local sites to entire States. For example, one account reported that 90 percent of the pinyon trees in the State of Arizona had been killed (Society of American Foresters 2004). However,

a preliminary analysis of the available data in Arizona, Colorado, and Utah (Shaw et al. 2005) showed that there was clearly an upward trend in mortality but population-level mortality was not nearly as high as initially feared.

Unlike in other states, Arizona pinyon/juniper woodlands have not maintained positive net growth during the past decade (see table B22); recent mortality has exceeded recent growth. However, even though the numeric amount of negative net growth (–8.2 million cubic feet per year) is comparable to the numeric amounts of other species (e.g., Douglas-fir –9.6 million cubic feet, aspen/birch –9.3 million cubic feet), the net change in volume in pinyon/juniper woodlands is very small compared to the live inventory. As a proportion, pinyon/juniper woodlands changed at an average annual rate of only –0.13 percent, as compared, for example, to the Douglas-fir forest-type group (–0.83 percent) and the aspen/birch group (–3.25 percent). Practically speaking, the total live volume of trees in the pinyon/juniper group has remained nearly constant during the past decade in Arizona.

One persistent question about the current episode of drought-related mortality is: "How does the current episode compare with previous drought-related die-offs?" The climatic record shows that similar droughts occurred in the Southwest during the early 1900s and mid-1950s (National Climatic Data Center 1994). Breshears et al. (2005) characterized the recent mortality event as a response to "global-change-type drought" and suggested that recent conditions have been hotter than in the 1950s. Some of the conclusions about the relative magnitude of recent mortality and the mortality of the 1950s are based on the lack of evidence, in the form of remaining dead woody material, from the 1950s. However, despite the perceived long-term persistence of woody material in the arid Southwest, pinyons may decay or physically break down relatively quickly. Although Kearns et al. (2005) found that pinyon snags could persist as long as 25 years, they found that "extremely fragmented" trees were dead for an average of 16.2 years. Because the impacts of the 1950s drought were not well-studied and there is a great deal of uncertainty surrounding the possible surviving evidence of pinyon mortality, the relative magnitude of the two mortality episodes remains uncertain.

The recent drought has undoubtedly impacted the pinyon/juniper resource in Arizona and around the Four Corners States, but the magnitude of impact varies widely between the pinyon and juniper components. Differential mortality among species on the same site has been shown by Mueller et al. (2005), who found mortality of common pinyon to be 6.5 times higher than oneseed juniper mortality during two drought events in northern Arizona. Future mortality rates will likely depend on temperature and precipitation trends. The mortality event of the early 2000s corresponded with a shift of the Palmer Drought Severity Index (PDSI) from positive (wetter) to negative (drier) values, while the decrease in mortality rate corresponded with a temporary shift back to positive values. However, in recent years PDSI has once again become negative. Whether there is a resurgence in mortality or not depends on a number of factors, including what effects the earlier drought-induced thinning of dense stands will have on competition and water relations. The dynamics of this forest type have important implications for carbon

storage, because dead trees have released growing space to the survivors and new regeneration. Although there has been a short-term loss in living biomass, there may be a long-term increase in carbon storage while dead wood persists and new growth accumulates. It will be possible to determine the actual trends as FIA continues to monitor these woodlands into the future.

Expansion of Pinyon/Juniper Woodlands

The pinyon/juniper forest-type group in Arizona consists of three forest types, pinyon/juniper woodland, juniper woodland, and Rocky Mountain juniper, and is the most common group in Arizona, covering 11.1 million acres, or nearly 60 percent of the forest land (Appendix B, tables B3–B7). In addition, 52 percent of the nonstocked area was identified by field crews as formerly and/or potentially stocked by pinyon/juniper group forest types. In total, over 12.5 million acres are either now, were recently, or will soon be pinyon/juniper forest-type groups, or 62 percent of the forest. The dominant species are Utah juniper, oneseed juniper, alligator juniper, redberry juniper, Rocky Mountain juniper, California juniper, common or two-needle pinyon, singleleaf pinyon, Arizona pinyon pine, border pinyon, and Mexican pinyon pine.

There has been concern that since Euro-American settlement of the West, pinyons and junipers have been expanding their ranges dramatically, encroaching on and degrading grasslands and shrublands. This expansion has been well documented in many parts of the pinyon/juniper range (Burkhardt and Tisdale 1976; Tausch and Hood 2007). Generally, expansion has been attributed to direct or indirect alterations of pre-settlement fire regimes. These fire regimes are theorized to be of three general types (Baker and Shinneman 2004; Romme et al. 2009):

1. Low intensity, frequent fires that tend to "thin from below." These would occur in pinyon/juniper stands where the understory is dominated by grasses and forbs, and the tree density should be comparatively low. This type is most common in the extreme Southwest United States. and northern Mexico. It would be expected in parts of Arizona.
2. Less frequent, high intensity stand-replacing fires. This regime occurs in pinyon/juniper stands where the understory is dominated by shrubs, notably sagebrush. This type is common in the Great Basin, but it only occurs in northern Arizona. Elsewhere in Arizona, the shrub component is commonly shrub oaks, *Arctostaphylos* spp. (manzanita) or *Garrya* spp. (silktassel).
3. Very rare, mostly localized fires that occur under only the most extreme conditions and that may only burn small areas. These are pinyon/juniper stands with rocky substrates or cryptobiotic crusts that support little, if any, understory. The topography is often rugged with features such as cliffs and bare bedrock, which prevent or inhibit the spread of fires. This type is documented on the Colorado Plateau (Romme et al. 2003), so would be expected in northern Arizona.

Inventory data were used to evaluate the age, structure, and potential status of pinyon/juniper stands. The age chosen to represent pre-settlement stands was 150 years. The first estimate was stand age, but since this is based on the age of the trees in the dominant size class rather than the oldest trees in the stand, the maximum ages were also evaluated, along with the proportion of trees over 150 years old. Since tree and stand ages are determined from a few live trees on a plot, the presence of very large dead trees (14.5 inches diameter) and dead basal branches (12.4 inches diameter) were evaluated as evidence that the stand was in existence at least 150 years ago. More recently disturbed stands, with few or no live trees, were classified as disturbed. Understory cover and layering, along with tree cover, were evaluated to characterize fire regimes (Scott and Burgan 2005) and estimate fine fuel loading (Caratti 2006).

About 1.1 percent of the pinyon- and juniper-dominated land in Arizona has been recently disturbed. Of the remaining, about 54 percent, or 6.6 million acres, was classified as older than 150 years. The remaining 46 percent, 5.8 million acres, was characterized as having established within the last 150 years. Pinyon and juniper occur in the northern and eastern parts of Arizona, in foothills, and in high plateaus, mostly at elevations between 4,000 and 8,000 feet. Younger stands were more common at lower elevations, and older stands were more common at higher elevations (fig. 30). Also, younger stands tended to be more prevalent in the

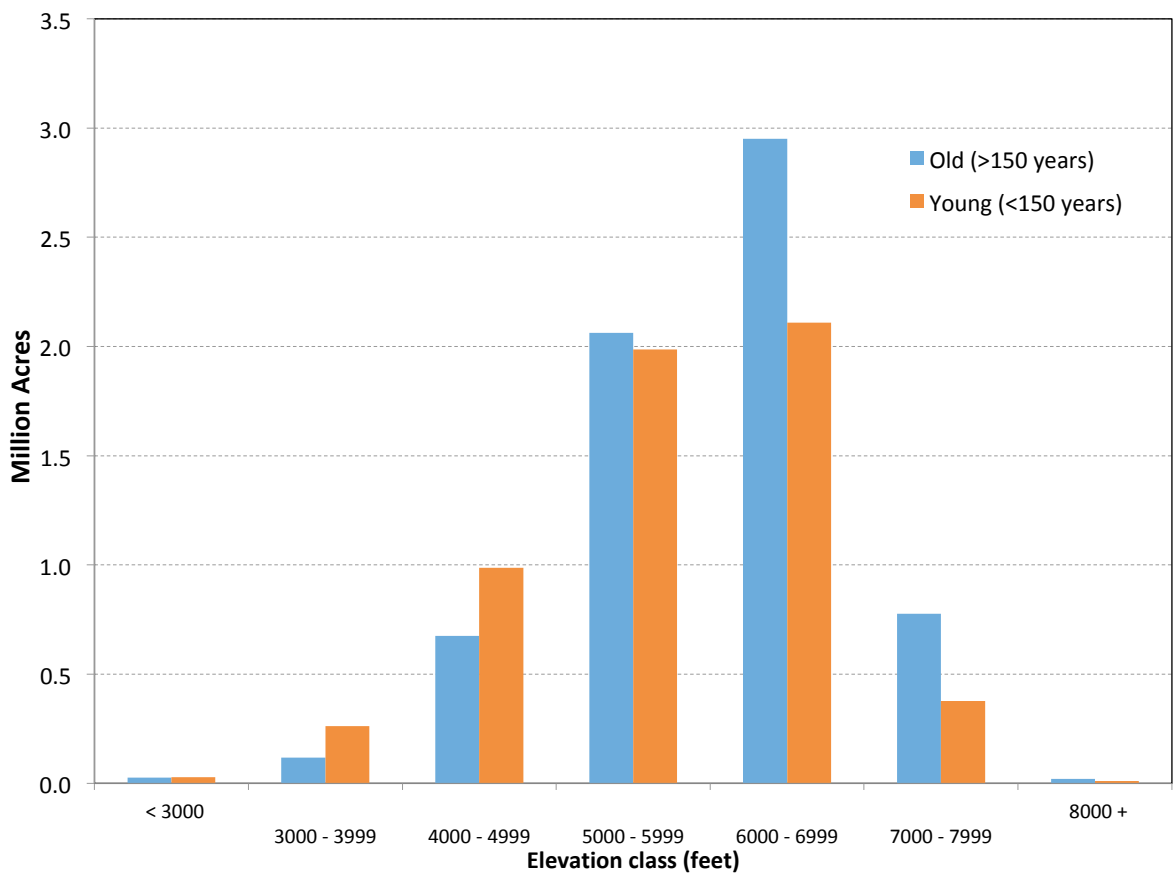

Figure 30—Pinyon/juniper woodlands by age and elevation class.

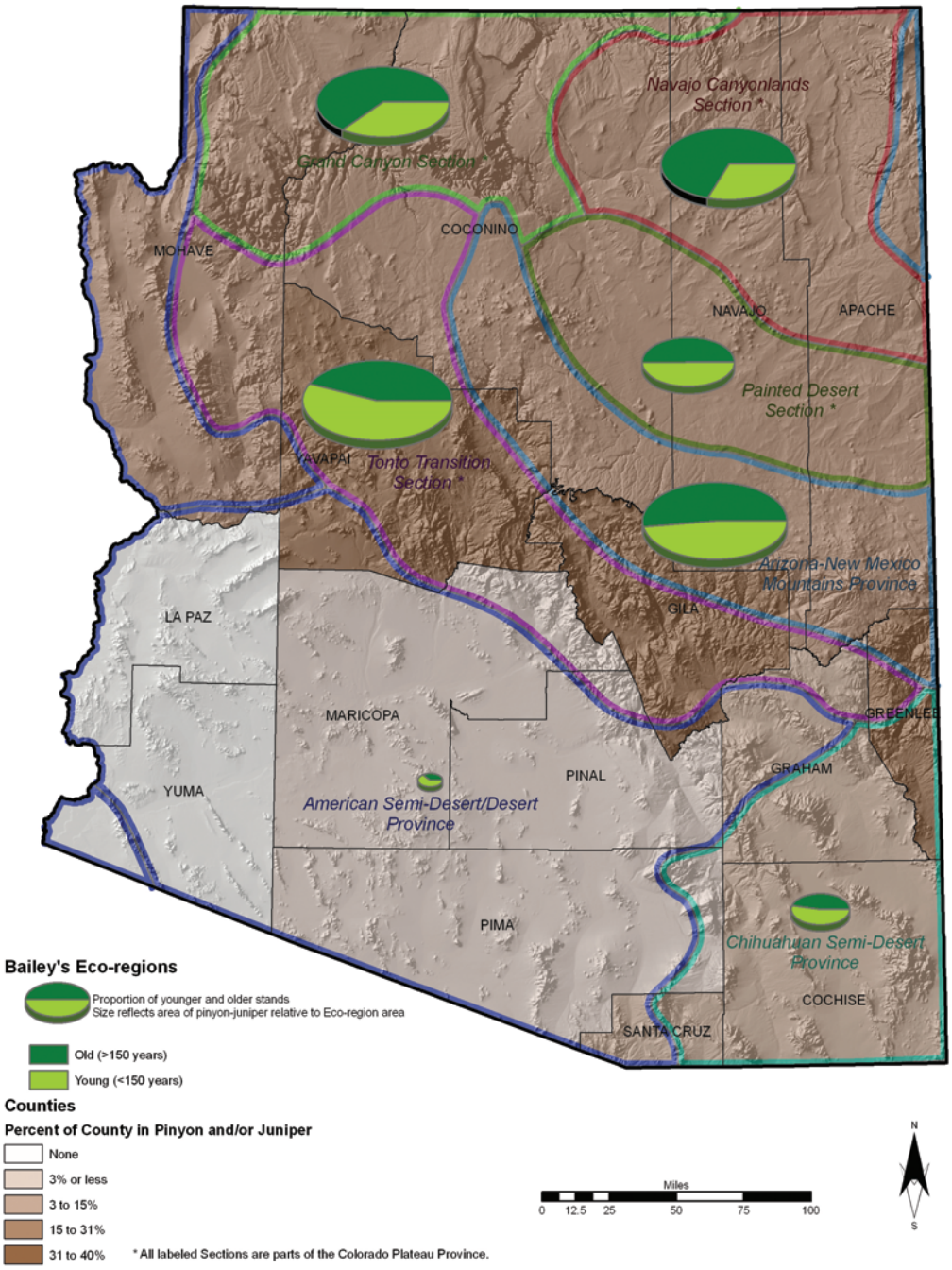

Figure 31—Pinyon area and stand age classification by ecoregion.

southwestern parts of the range, while the older stands occurred more frequently in the northern part of the State (fig. 31).

In terms of fire regime and fuel loading, a larger proportion of the older stands were found to have very low fuel loadings, indicating a low probability of severe fire. Fifty-three percent of older stands had very low fuel loadings, while 44 percent of younger stands did. A higher percentage of younger stands had understories dominated by shrubs, grass, or shrub-grass mixtures (31 percent) than did older stands (17 percent). Fourteen percent of both younger and older stands were not assigned a fire classification, primarily due to the uncertain effects of having over 10 percent of their live tree basal area in species other than pinyons and junipers.

The spatial distribution of Arizona's pinyon- and juniper-dominated stands can be addressed using ecoregions (Bailey 1995), using a combination of ecoregion provinces and sections (fig. 31). The highest proportions of stands older than 150 years occur in the northern part of the State, in the Navajo Canyonlands and Grand Canyon sections of the Colorado Plateau province. This distribution, combined with the finding that a greater proportion of older stands than younger stands have very sparse understories, supports the expectation that the third fire regime, characterized by very rare, localized fires, is operating in this area. This situation results in most pinyon/juniper stands having existed in similar densities, structures, and age classes as they are currently found for hundreds, if not thousands, of years (Romme et al. 2003).

Pinyon- and juniper-dominated stands younger than 150 years are more prevalent toward the Southwest, in the Tonto Transition section of the Colorado Plateau province, and the Chihuahuan Semi-Desert and American Semi-Desert and Desert provinces. The common occurrence of younger stands, along with younger stands having more shrub-dominated understories and lower elevations than older stands, tends to support the expectation that this part of the State is dominated by the second fire regime. In this situation, pinyon and juniper populations are maintained by relatively small areas with fire-resistant properties, similar to those in the third fire regime (Weisberg et al. 2008). In many cases, these areas would tend to be at higher elevations. When conditions favor tree growth, pinyons and junipers expand from these refugia into lower elevation, mostly shrub-dominated areas, where eventually they experience high intensity stand-replacing fires, which halt tree expansion. If the fire frequency is artificially lengthened, trees can increase uninterrupted, displacing shrublands.

Over 10 percent of pinyon and juniper stands were characterized by understories dominated by grasses, or grasses and shrubs. These are stands where the first fire regime would be expected to operate. However, the extent to which these stands actually experience low intensity, "thin from below" fires is not well understood (Romme et al. 2009). Stands younger than 150 years outnumbered older stands two to one in these types.

Some younger pinyon/juniper stands probably represent recovery from severe human-caused disturbances, such as early chaining or harvest for charcoal to support the mining and railroad industries (Romme et al. 2009).

Aspen Status and Trends

Aspen is the widest-ranging species in North America. It is present in all States in the Interior West and occupies a wide elevational range—from 2,000 ft in northern Idaho to 11,700 ft in Colorado. It is also found on a wide range of sites and occurs in 26 of the forest types that occur in the Interior West. The species is intolerant of shade and relatively short-lived, which makes it prone to replacement by conifers through successional change. In the Interior West, it also reproduces infrequently by seeding, relying mostly on root sprouting for reproduction. However, aspen responds well to fire and cutting, and it is able to dominate heavily

disturbed sites for many years following severe disturbance. In addition, there is some evidence that aspen is able to persist in conifer-dominated forests by exploiting gaps in the conifer canopy that are caused by insects, disease, windthrow, and other smaller-scale disturbances.

In recent years there has been concern about the future of aspen on the landscape, primarily due to the characteristics of aspen and how they relate to changes in disturbance regimes. The earliest concerns were related to successional change in the Interior West, where fire suppression has decreased disturbance rates and, as a result, aspen regeneration rates. In addition, it has been shown that large populations of herbivores can inhibit aspen regeneration where it occurs spontaneously or after disturbance (e.g., Hessl and Graumlich 2002). The lack of disturbance allows conifers to gain dominance where they are present, and in pure aspen stands, consumption of regeneration by ungulates could lead to loss of senescing overstory trees without replacement. More recent concerns are related to a period of drought that has an impact on aspen and other forest types (e.g., Shaw et al. 2005; Thompson 2009). Drought appears to have contributed to mortality in many low-elevation stands (Worrall et al. 2008), and in some of these regeneration is either lacking or suppressed by herbivores.

Johnson (1994) suggested that the acreage of aspen-dominated stands had declined as much as 46 percent in Arizona and New Mexico between the 1960s and late 1980s, with most of these acres becoming dominated by mixed-conifer forest types. Bartos (2001) suggested that similar changes—aspen acres dropping by 96 percent—had occurred in Arizona as compared with "historical" extent, although the time scale over which this change is believed to have occurred was not specified. These assessments of "lost" aspen acres were based on the assumption that forested acres with a minority aspen component were, at one time in the recent past, dominated by aspen in pure or nearly pure stands. This assumption may not be reasonable because there are many situations where aspen may persist normally as a minor stand component.

The current inventory of Arizona shows that there are over 153 thousand acres of the aspen forest type in Arizona, as compared to just over 147 thousand acres found during the 1999 periodic inventory. When considering all acres where aspen is present, the current inventory shows that aspen is present on over 602 thousand acres, as compared to over 603 thousand acres during the 1999 inventory. This result suggests no net change in the extent of aspen over the past 15 years. However, there appears to have been a decline in aspen live volume since the late 1990s. Using the 1999 values of 603 thousand acres with aspen present and 383 million cubic feet of live aspen volume gives an average volume of 634.4 cubic feet of live aspen per acre. The equivalent computation in the current inventory gives 539.8 live cubic feet per acre, or just over 85 percent of the 1999 average. On an absolute basis, the result is similar; the current volume of 325 million cubic feet is about 85 percent of the live aspen volume found in 1999 (fig. 32).

This is consistent with the recent effects of drought and fire on the forests of Arizona. Younger stands of aspen tend to be less susceptible to drought, but the

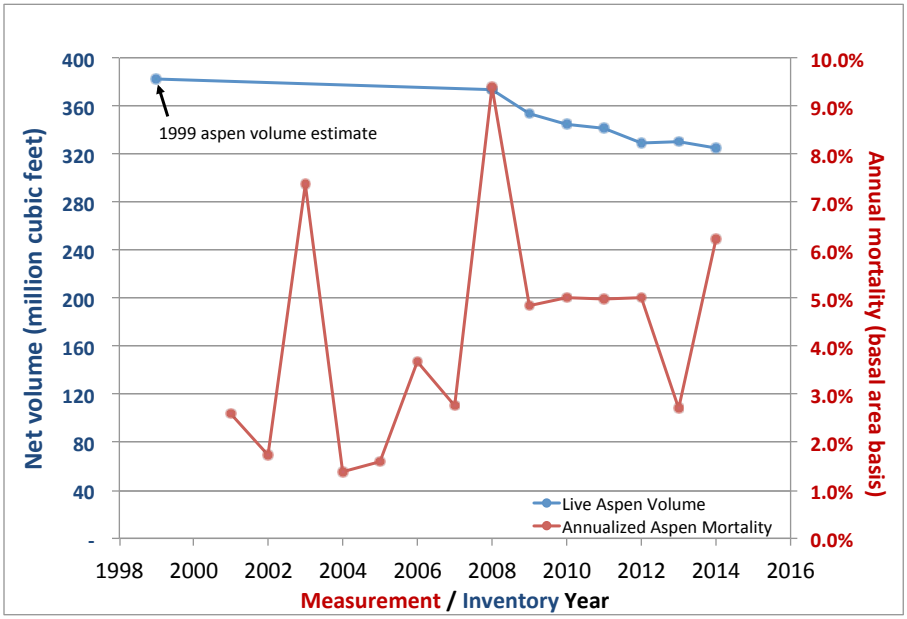

Figure 32—Aspen trends in Arizona by total volume estimate (blue) and annualized mortality rate (red).

effect of drought on aspen stand regeneration has not yet been well-assessed. The response to fire, on the other hand, is well-known; fire is essential to the regeneration of aspen in most of its western range. Recent fires may be responsible for a trend that appears to be emerging from inventory results. In the 1999 periodic inventory, stands where aspen was dominant (aspen forest type) made up over 24 percent of the total area with aspen present. This proportion appeared to decline slightly (19 to 22 percent) during the mid-2000s, but the proportion is again over 25 percent in the current inventory. Whether this fluctuation is due to sampling error or represents a real trend will require more years of monitoring. However, even if the apparent decline in volume persists it would take another 50 years for total aspen volume to reach half its present level. It is unlikely that aspen will not regenerate during that period. In fact, since aspens that have regenerated from recent disturbances will not have an impact on total volume until they reach larger size classes, there may be a surge of aspen volume in the coming years regardless of future regeneration. In any case, Johnson's (1994) projection that "aspen will cease to exist as a distinct cover type" in Arizona and New Mexico before the year 2020 is highly unlikely.

Damage to Live Trees

As field crews measure live trees on subplots (trees 5 inches diameter and greater), they carefully examine those trees for the presence of damaging agents. They record up to three damaging agents if the damages meet one or more of the following three criteria:

1. The damage will prevent the tree from living to maturity if immature, or living 10 more years if mature.
2. It will prevent the tree from producing marketable products.

3. It will seriously reduce (or has reduced) the quality of the tree's marketable products.

Since the last two criteria are less applicable to woodlands species, which produce few marketable products, results from damage data can be quite different between woodland type species and timber type species.

Damaging agents are grouped into several general classes: insects, diseases, fire, animals, humans, and miscellaneous. The miscellaneous group includes suppression, some symptomatic groups whose ultimate causation can be difficult to determine in the field (unhealthy foliage and heartwood scars), unknown causes, and timber form defects that affect commercial products (forking, excessive lean, broken tops, and excessive crook, sweep, or taper). Crews also estimate cull volume percentages (missing top, dead wood, rotten and missing wood, and timber form). When these percentages exceed specific thresholds, the damaging agent must be recorded, although these thresholds can vary by timber or woodland species type.

Of the estimated 1.7 billion live trees 5.0 inches diameter and greater in Arizona, about 405 million, or 23.6 percent, are estimated to have at least one damage meeting one or more of the three damage evaluation criteria above. Of these, 81.7 million (4.7 percent) have a second damaging agent and 8.2 million (0.48 percent) have three. Timber species had damage agents recorded only slightly more frequently than did woodland species (26.4 percent versus 22.5 percent), mostly due to loss of marketable products, although there were other differences between damages to timber and woodland species. For the five most common timber species, the frequency of at least one recorded damage was over 20 percent: quaking aspen (47.3 percent), white fir (26 percent), ponderosa pine (25 percent), Douglas-fir (24.3 percent), and Engelmann spruce (22.8 percent). Many of the less common timber species had higher rates of damage than aspen, but these estimates were based on small samples and their proportions of the total number of damaged trees was very small. The three common woodland species with the highest rates of damage were all oaks: Gambel oak (47.3 percent), Arizona white oak (36.9 percent), and Emory oak (36.4 percent). The remainder of common woodland species had damage rates of less than 25 percent: velvet mesquite (24.1 percent), oneseed juniper (22.9 percent), Utah juniper (21.2 percent), common pinyon (15 percent), and alligator juniper (12.9 percent).

Because the damage criteria above can be divided into pathogenic or life-threatening (#1) and non-life-threatening (#2 and #3) categories, the proportions of damaging agents will be described separately. Of the pathogenic damages, stem decay affected the largest proportion of trees (fig. 33). Arizona white oak accounted for the largest portion of the trees with stem decay (30.9 percent), more than the next two species combined (velvet mesquite, 12.8 percent; Utah juniper, 11.8 percent). The remainder of trees with stem decay were generally well-distributed among 31 other species. Parasitic plants, which include true and dwarf mistletoes, were the next most common damage agent. Of the trees found with parasitic plants, common pinyon and ponderosa pine accounted for the majority, accounting

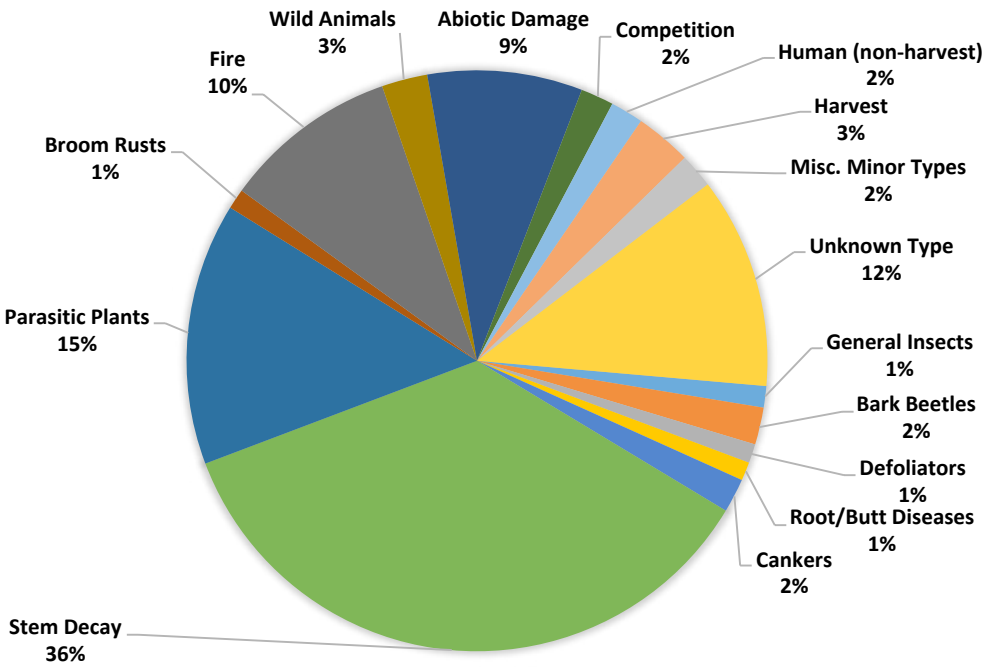

Figure 33—Frequency of damaging agents on an estimated 203 million trees in Arizona, 2005–2014. This represents about half of the trees with recordable damage in the inventory and excludes form-related damage types (see fig. 34). Trees with these damages generally meet criterion 1 above.

for 39.8 and 25.6 percent, respectively, of infected trees. All of the records of parasitic plants on these species were dwarf mistletoes, and the Hawksworth rating (Hawksworth 1977) was 3 or greater.

Two damaging agents that were found relatively infrequently but merit mention are insects and fire, because they are the most common causes of tree mortality. Insect damage, particularly bark beetles, can be difficult to see in live trees but can rapidly lead to tree death. Thus, insect damage would be more commonly recorded as a mortality agent than a damage agent. Bark beetles were the most common insects recorded in timber species, but overall, defoliators were the most common insect damaging agent. Similarly, fires in Arizona kill most trees and leave relatively few survivors that meet damage thresholds with fire damage.

Of the damage agents that primarily affect potential wood products and that are typically non-lethal, dead tops were recorded on more than half of the trees with these kinds of damages (fig. 34). Although dead tops may affect tree vigor, depending on the proportion of live crown remaining, there is not likely to be a substantial effect on the quality of the lower stem. The same is true for broken tops, which only represent 5 percent of the form damages. However, it is possible to quantify the amount of missing stem by taking the difference in actual (as measured) and estimated (as if the top were present) heights. Based on this method, the average length of the upper stem missing from trees with broken tops is about 25 percent for timber species, and 30 percent for all trees. The next three most common form damages, which together account for 41 percent of this class of damages, can have substantial effects on the merchantability of the lower stem. Depending on the location of the fork, forked trees can reduce the merchantable volume by limiting log length or requiring removal of a long section from the butt log. Crook and sweep affect the ability to saw logs efficiently, although modern

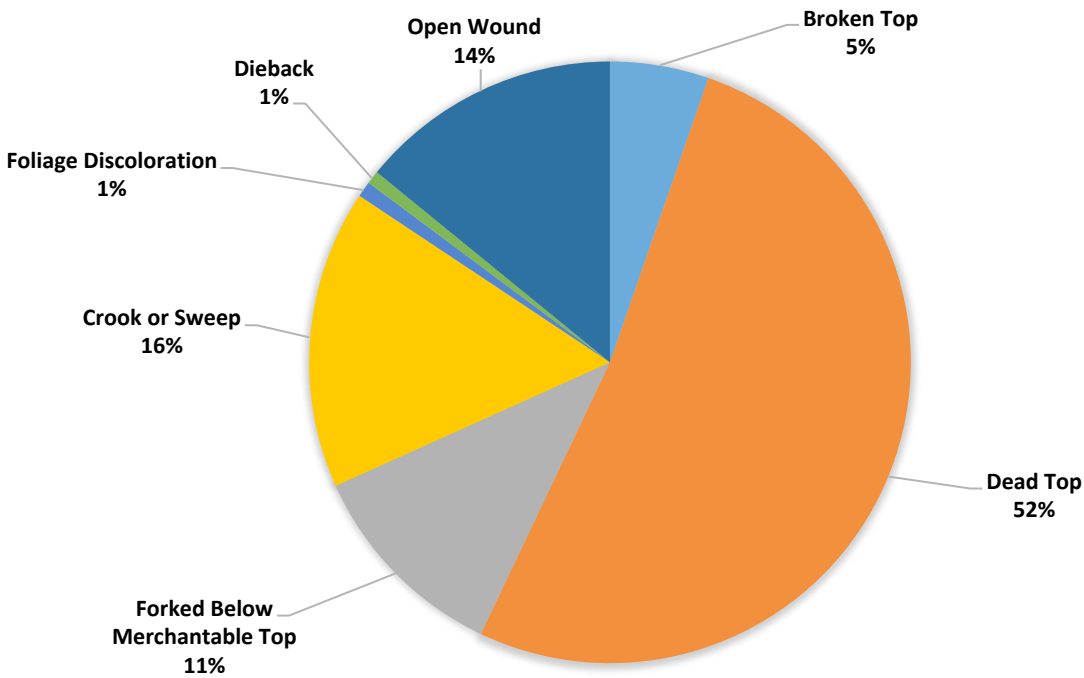

Figure 34—Frequency of form-related damaging agents on an estimated 202 million trees in Arizona, 2005–2014. This represents about half of the trees with recordable damage in the inventory and excludes most pathogenic damage types. Trees with these damages generally meet criteria 2 and 3 above.

sawing methods tend to maximize sawn volume. The impact of open wounds vary considerably, because factors such as the time between the wound and harvest, or the degree to which a wound has allowed decay to the stem, have an effect on the degree of merchantability.

Recent Fires

Fire is an important disturbance that influences the structure and dynamics of Arizona's forests. In some forest types, such as ponderosa pine, fire can maintain open stands and stimulate the growth of grasses and forbs in the understory. Throughout the Interior West, a century of fire suppression has led to a buildup of fuels and stand densification, which may lead to uncharacteristically intense fires in some areas (Reinhardt et al. 2008). Areas that burn intensely may experience slow regeneration, but others may recover relatively quickly. For example, the area inside the boundary of the large 1910 fires in Idaho and Montana (Cohen and Miller 1978; Egan 2009; Pyne 2008) now carries about the same amount of live tree volume per acre as areas outside the fires, although the mean stand age is somewhat lower and the volume is generally distributed among smaller trees (Wilson et al. 2010).

There were many fires and fire complexes in Arizona during the period covered by this report. Some FIA plots within fire boundaries were measured before and some were measured after the fires occurred. As a result, some fire perimeters contain both prefire and postfire plots, while others may contain only prefire or only postfire plots (fig. 35). Prefire plots represent the original conditions in areas that later burned, while only postfire plots provide insight into the short-term effects of fire. This means that normal data compilation methods cannot be used without introducing some element of temporal bias. These limitations on analysis

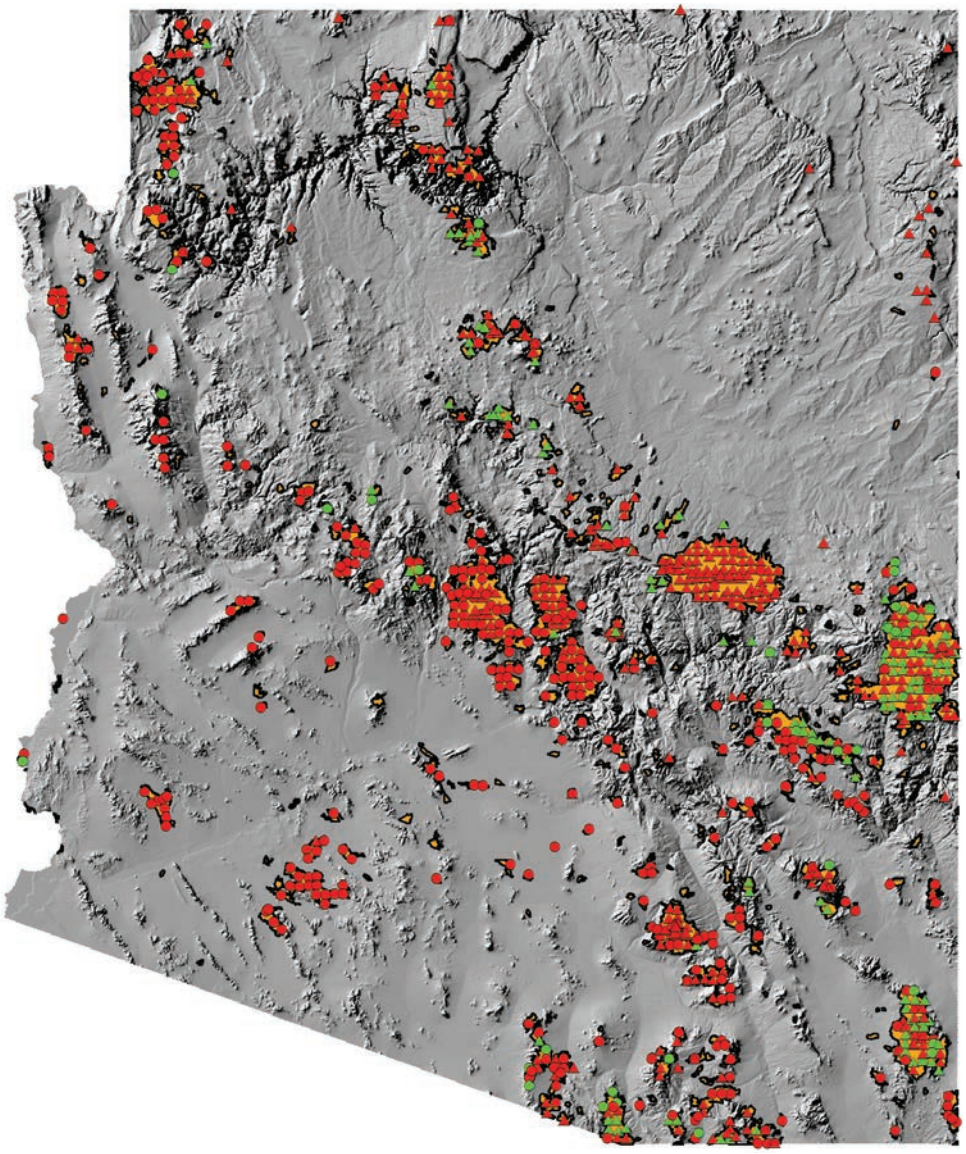

Figure 35—Distribution of FIA plots in Arizona that occur within MTBS fire perimeters for fires occurring between 1984 and 2014, by plot status (forest = triangle; nonforest = circle) and timing of the most recent plot visit (prefire = green; postfire = red). Mapped MTBS fire areas, including those not sampled by FIA plots, shown in orange.

will be reduced as the current inventory cycle is completed and remeasurement data are acquired during the next cycle. However, there are some general analyses that can be conducted with the current data.

We used data from the Monitoring Trends in Burn Severity (MTBS) project, which is an interagency effort being conducted and maintained by the USDA Forest Service Remote Sensing Applications Center and the U.S. Geological Survey National Center for Earth Resources Observation and Science. The purpose of the MTBS project is to map the perimeters and severities of large wildland fires (including wildfire, wildland fire use, and prescribed fire) across all lands of the United States. In western States, the project includes all fires larger than 1,000 acres (Eidenshenk et al. 2007) but usually captures some that are below that threshold. The analysis presented here is based on fire perimeters identified by the MTBS program between 1984 and 2014 and FIA plot data collected between 2005 and 2014 in Arizona.

The MTBS program mapped 823 fires covering a total of 5.7 million acres in Arizona between 1984 and 2014. These fires ranged from 265 acres to more than 563 thousand acres, with an average size of 7.1 thousand acres. FIA plot locations fell within the perimeters of 391 of the 823 mapped fires. Forested conditions measured between 2005 and 2014 fell within the boundaries of 187 fires perimeters, while the remaining 134 fire perimeters encompassed only nonforest or nonsampled plots. Of the 10 largest fires that occurred during the 31-year period covered by MTBS, three occurred in 2011 and three occurred in 2005. Together, the 10 largest fires account for 1.9 million burned acres.

As noted in the early sections of this report, the State of Arizona encompasses 73.1 million acres of land area, of which 18.6 million acres (25.5 percent) are estimated to be forest land by FIA. The unique area burned over the 31-year period is about 4.8 million acres, or only 6.6 percent of the State's area. Totals of area burned do not tell the full story of fire in forest ecosystems. Although MTBS products include severity and cover type data, they cannot be used to differentiate between forest and nonforest as defined by the FIA program. However, we can use the status of FIA conditions as a sample of burned area to estimate the proportions of forest and nonforest area burned, as well as the area of different forest types within burned forest. According to this kind of analysis, 58.3 percent of the burned area in Arizona was on forest land and the remaining 41.7 percent was nonforest. Given that Arizona is only 25 percent forested, this would suggest that far more forest land burned than would be expected given its proportion of the landscape. However, much of the area of Arizona is in "unburnable" land cover types, such as the rocky areas of the Grand Canyon and certain desert vegetation types, so this proportion is difficult to analyze. As the FIA program collects data on nonforest plots, it should be possible to analyze these proportions further.

Plot data from within fire boundaries can also be used to characterize some fires individually. Although most of the small fires were not sampled by FIA plots, several of the largest fires were sampled by enough plots to provide some analysis capability. The largest fire recorded in Arizona, the 563 thousand-acre Wallow fire of 2011, encompassed 94 plots, some of which sampled both forest and nonforest conditions. Based on the number of forest conditions sampled, 82.3 percent of the area of the Wallow fire was forest land. The Rodeo fire of 2002, which until the occurrence of the Wallow fire was the State's largest at over 461 thousand acres, was 95.6 percent forest land. Most of the remaining top 10 fires burned mostly forest land. The Cave Creek complex, in which 61 percent of the 245,013 acres burned were nonforest, and the Goldwater fire, in which the entire burned area of 65,148 acres were nonforest, were the only fires in the top 10 in which forest land was a minority.

In addition to estimating forest vs. nonforest proportions, it is also possible to analyze proportions among forest types. Ninety-three percent of the burned area that was classified as forest fell into seven forest types: juniper woodland, pinyon/juniper woodland, Douglas-fir, ponderosa pine, deciduous oak woodland, evergreen oak woodland, and mesquite woodland. Forest area calculations are based

Table 9—Proportions of all forest area and proportions of burned area for seven forest types representing most burned area between 1984 and 2014.

Forest type	Percent of forest area	Percent of burned area
Juniper woodland	14.1	8.5
Pinyon/juniper woodland	45.2	13.9
Douglas-fir	1.6	5.4
Ponderosa pine	16.7	31.3
Deciduous oak woodland	1.8	6.3
Evergreen oak woodland	7.9	21.8
Mesquite woodland	10.0	5.8

on field-determined forest type instead of calculated forest type, because high rates of mortality on recently burned land tends to result in a large proportions to be classified as nonstocked. Juniper woodland, pinyon/juniper woodland, and mesquite woodland burned in lower proportions than their occurrences on the landscape; the remainder burned in higher proportion, and in some cases, much higher proportion (table 9). The ponderosa pine forest type burned almost double the area in proportion to its forest type, but the actual proportion is likely to be higher because the ponderosa pine type is known to be converted to oak woodland types after fire (table 10).

In most cases, forest type change is related to fire severity. Low-severity fires may leave most overstory trees intact and have a minimal effect on composition. High-severity fires, which by definition kill a major fraction of the overstory, have

Table 10—Forest type group change matrix for 193 plots in Arizona with pre- and postfire measurements. Shaded cells indicate cases where burned plots did not change type.

	Forest-type group (postfire)								
Forest-type group (prefire)	**Aspen/birch**	**Douglas-fir**	**Elm/ash/cottonwood**	**Fir/spruce/mountain**	**Other western softwoods**	**Pinyon/juniper**	**Ponderosa pine**	**Woodland hardwoods**	**Total**
Aspen/birch	1						2		3
Douglas-fir	1	3					3	3	10
Elm/ash/cottonwood									
Fir/spruce/mountain	2			1			1		4
Other western softwoods						1		3	4
Pinyon/juniper			1			36	2	21	60
Ponderosa pine	1	2				12	38	18	71
Woodland hardwoods						3		38	41
Total	5	5	1	1		52	46	83	193

varying effects by forest type. For example, in stands composed of a combination of seeding and sprouting species, such as ponderosa pine (seeding) with associated aspen or Gambel oak (sprouting), a high-severity fire can kill most trees. When all or most of the ponderosa pine overstory is killed by fire, aspen and oak species usually sprout in abundance and can become the dominant species in the stand. This is an example of successional change, and it is expected that ponderosa will re-establish and regain dominance in the future. Lower-severity fires may kill fire-sensitive species like aspen or consume the crowns of low-stature species like Gambel oak but not affect the fire-resistant ponderosa pine component. Therefore, low-severity fire can actually increase and maintain the relative dominance of ponderosa pine.

Our limited data on pre- and postfire conditions, based on 193 conditions with pre- and postfire measurements, show a gradient of mortality within fire boundaries in Arizona (fig. 36). About 16 percent of remeasured conditions had more live basal area at the time of remeasurement than at the time of first measurement, meaning that a combination of the growth of residual trees and regeneration has offset whatever reductions in basal area might have resulted from fire. Only about 12 percent of remeasured plots had no live component with a diameter of 1.0 inches or greater at the time of remeasurement. This is partly because the average time between the fire and time of remeasurement was only 4.1 years, so regeneration might not yet be dense enough to be captured on the 1/300th-acre microplots that are used for seedlings and saplings. However, examination of seedling data shows that seedlings have been recorded on one-third of plots with no trees at least 1.0 inch in diameter, so while seedlings are being captured by the sample, on these plots they have not yet transitioned to sapling size. Seedlings are primarily ponderosa pine and aspen, but Douglas-fir, Gambel oak, and some juniper species

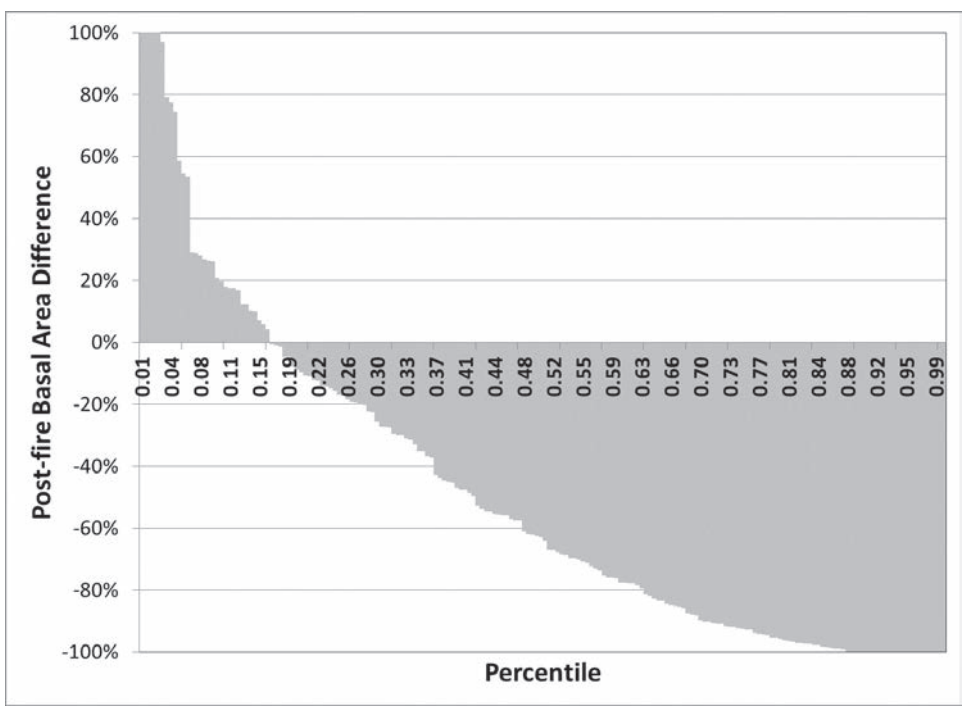

Figure 36—Distribution of basal area change from prefire to postfire measurements. Positive differences indicate more basal area at the time of remeasurement than at initial measurement. Values of negative 100 percent indicate conditions with no remaining live basal area at the time of remeasurement. Graph is truncated at 100 percent positive change (2x original basal area), so the amount of change exceeding a doubling of basal area is not shown for some conditions.

have also been recorded. Many of these plots are coming up for remeasurement in the coming 5 years, so it will be possible to monitor the progress of regeneration of these stands in the near term.

The analysis of fire and fire effects in this section should be considered only a first approximation of fire effects on Arizona's forests. Although the results are generally consistent with expectations, the magnitude of fire-related mortality cannot be stated with precision at this point in the inventory. Nonetheless, the data confirm that there has been only partial mortality within fire boundaries. Additional data and analysis will be required to determine whether, for example, mortality is more or less evenly distributed among plots within the burned areas or mortality tends to be all-or-none at the plot scale. Remeasurement data will be necessary to confirm the portions of standing live and dead trees that are consumed by fire and converted to the DWM pool. The Accelerated Remeasurement and Evaluation of Burned Areas (AREBA) project may also shed light on the actual rates of mortality and conversion of standing dead trees to DWM. The objective of AREBA is to remeasure FIA plots that fall within MTBS perimeters within 1 year of the fire (Megown et al. 2011). Future remeasurements of FIA plots, whether on regularly scheduled inventory cycles or immediately following fire under the AREBA project, will not only enable analysis of fire's effects on specific forest types such as aspen, but they will also provide important information on the amount and rate of recovery in all burned areas over time.

Invasive and Noxious Weeds

Noxious plant species can have many negative effects on forest communities. Noxious species can displace native flora, alter fire regimes, reduce diversity in the plant and pollinator communities, and generally reduce the diversity and resiliency of forest ecosystems. FIA field crews record any instance where a noxious species is found on a plot that contains a forested condition. This allows for the spatial and temporal extent of these species to be documented as plots are revisited. Although cheatgrass (*Bromus tectorum*) is not listed as noxious in Arizona, it is a nonnative annual grass that is quickly invading many areas of the State. There is considerable interest in the occurrence of cheatgrass on Arizona's forests, but since it is not considered noxious by the State of Arizona, cheatgrass data are collected in a different manner and is discussed in the next section.

A total of 2,105 samples were used to assess the occurrence of noxious plant species in Arizona. These samples represent plots or portions of plots that had a forested condition recorded somewhere within the boundaries of the four subplots. Twelve different species were documented on forested plots in Arizona, with one or more found on 37 (1.8 percent) of the sampled plots. Yellow starthistle (*Centaurea solstitialis*) and Canada thistle (*Cirsium arvence*) were the most common noxious species found in the forested condition. These two species accounted for 46 percent of the weed occurrences (fig. 37).

The pinyon/juniper forest-type group has the highest number of locations with at least one noxious species detection (fig. 38). However, when viewed as a

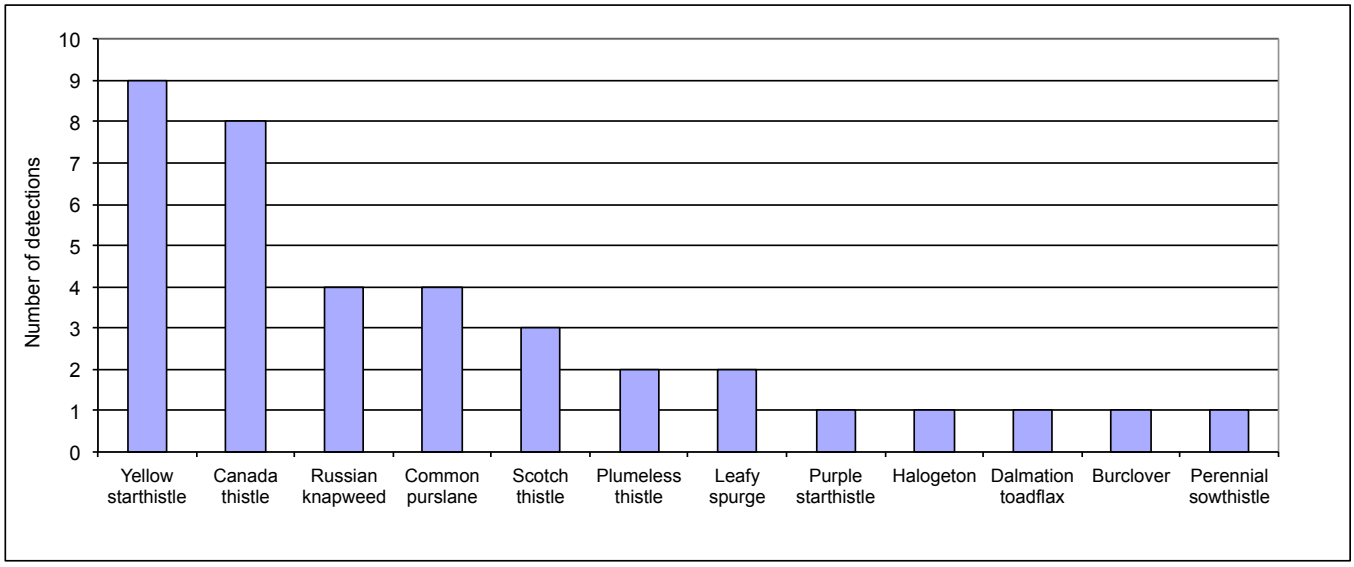

Figure 37—Weed species found on FIA plots and number of occurrences.

percentage of total plots within a forest-type group, the pinyon/juniper group is one of the least-invaded groups found in Arizona (fig. 39). The elm/ash/cottonwood group appears to have the highest percentage of its plots occupied (17 percent), but with such a low sample size in this group, the result should be viewed cautiously. The nonstocked forest type had the next highest occurrence of noxious species with just over 3 percent of the sampled plots found with detections. Many of these stands have recently been disturbed by fire, harvest, disease, or other perturbation that has removed most or all of the trees from it. These plots are more susceptible to invasion because noxious species can compete with native pioneer species for resources that were unavailable when the stand was stocked with mature trees and an established understory component.

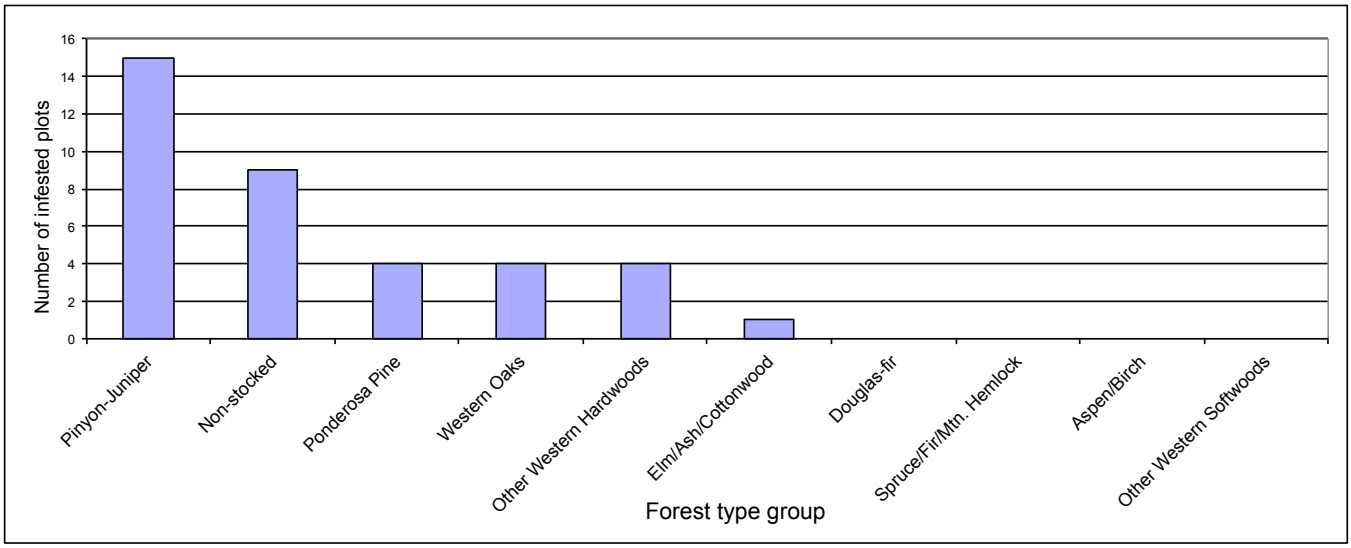

Figure 38—Number of plots within forest-type groups that had occurrences of noxious weeds.

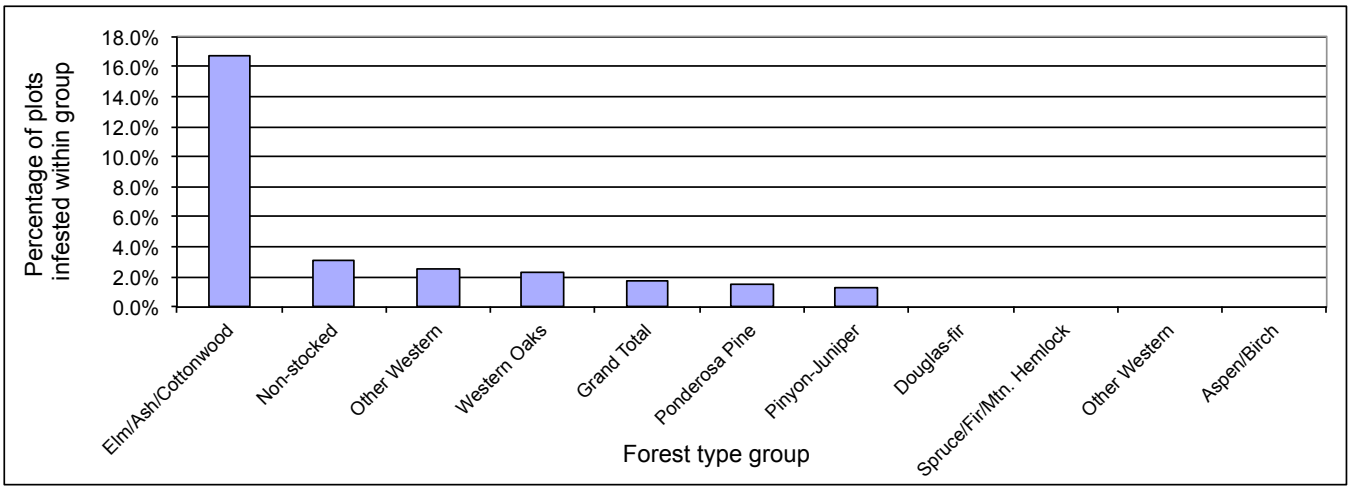

Figure 39—Proportion of plots with noxious weed detections by forest-type groups.

The paucity of noxious species found in Arizona's forests suggests that they are resistant to invasion and/or persistence of listed species. However, these species often occur along linear features such as roads and streams, and FIA sampling may not adequately sample such features for noxious plants. In addition, many noxious species are associated with grasslands, agricultural lands, and developed lands because of the persistent disturbance that occurs in such areas. Arizona certainly has these features but a much larger portion of the State is rural, undeveloped, or remote. The xeric conditions associated with Arizona and its forests may also limit the opportunities for infestation and establishment of noxious species.

Cheatgrass

Cheatgrass (*Bromus tectorum*) is a nonnative annual grass that has invaded and displaced native vegetation throughout the West. Cheatgrass germinates earlier than most native species, thus gaining a competitive advantage for the limited resources in the arid environments of the States of the Southwest. The fine fuels created by cheatgrass alter fire frequency in the areas where it is found in abundance (e.g., Balch et al. 2013). These fuels can perpetuate the spread of the species by creating new areas to invade after a fire disturbance. Both public and private land managers are interested in understanding the spatial and temporal patterns of cheatgrass and any other information that can be used to curb infestation. Because cheatgrass is not listed as noxious by the State of Arizona, FIA field crews document it as understory vegetation. A threshold of 3 percent or greater ground cover must be reached before an understory plant is recorded on a plot. In addition, only those areas with a forested condition present on a plot have understory vegetation recorded. Therefore, these data do not reflect trace amounts of cheatgrass (<3 percent cover) or cheatgrass on nonforested portions of plots.

In Arizona, cheatgrass was documented on 62 occasions in six different forest types at elevations ranging from 2,900 feet to 8,900 feet. Cheatgrass was found in stands that ranged from 0 (nonstocked) to 369 years old. The pinyon/juniper

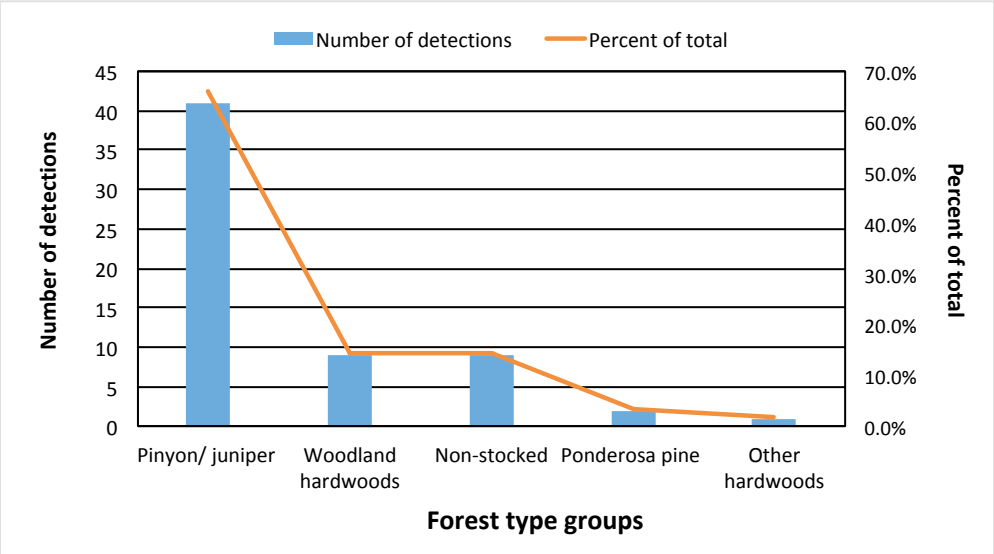

Figure 40—Cheatgrass detections by forest-type group in Arizona, 2005–2014.

forest-type group had by far the most records of cheatgrass (41), with about 66 percent of the total number of cheatgrass occurrences sampled on Arizona forest land (fig. 40). The woodland hardwoods and nonstocked groups had the next highest occurrences with nine records each (15 percent), followed by four records in the ponderosa pine group (3 percent) and one record in the other hardwoods group. Most of the cheatgrass sampled were on plots between 6,000 and 7,000 feet in elevation, with an equal distribution of occurrences in the higher and lower elevation classes (fig. 41). This suggests that adequate growing conditions for cheatgrass exist in forested areas at these elevations in Arizona.

In contrast to species officially listed as noxious in Arizona, cheatgrass is not found in abundance in any timber forest types. With the exception of two occurrences in ponderosa pine and nine in nonstocked forests types, all cheatgrass occurrences that reached 3 percent ground cover were found in woodland forest types—the vast majority in the pinyon/juniper group. These forest types often occur in areas that have lower soil moisture and understory species diversity than

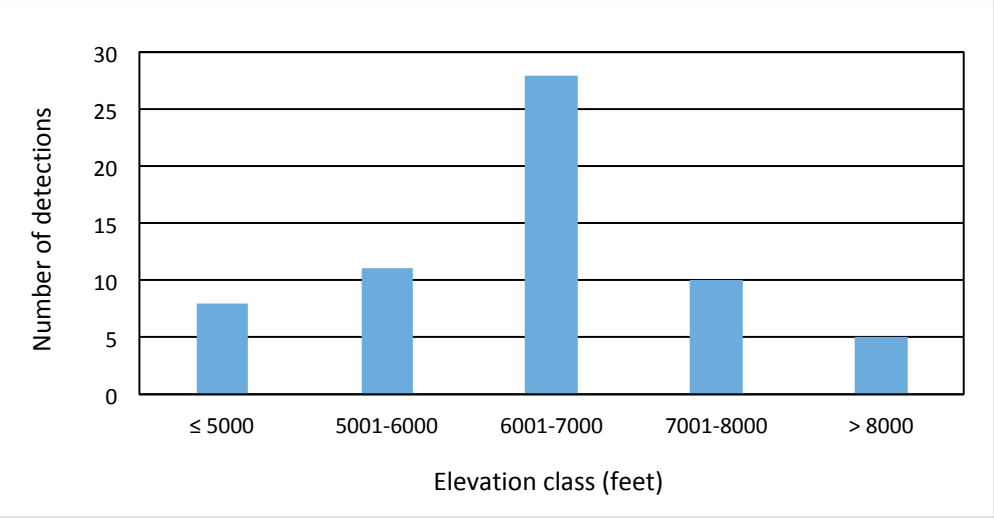

Figure 41—Cheatgrass detections by elevation class in Arizona, 2005–2014

higher elevation sites. These may be factors that affect an area's susceptibility to invasion. Other possible factors include the type, level, and frequency of disturbance (natural and human-induced) in these areas. The pattern of cheatgrass across the elevation gradient may be driven by the corresponding moisture gradient. Plots located at higher elevations typically have more soil moisture, lower temperatures and a shorter growing season. These factors may impede the introduction and/or establishment of cheatgrass in these areas.

Cheatgrass presents a threat to western ecosystems and a challenge to those that manage the lands where it has established a population. FIA data can be used to identify areas infested and/or most susceptible to infestation. This information can also be used to test cheatgrass models currently being developed or refine those already being implemented.

Comparisons Between Arizona's Periodic and Annual Forest Inventories

One purpose of Arizona's annual forest inventory is to provide information about changes in forest attributes over time. Prior to the implementation of the annual inventory, two plot-based periodic inventories were conducted in Arizona. One Statewide periodic inventory was conducted between 1981 and 1986 and is referred to as the 1985 inventory (Conner et al. 1990). Another was conducted primarily between 1995 and 1999 and is referred to as the 1999 inventory (O'Brien 2002). If the definitions and methods used during the periodic inventories were compatible with those used during the annual inventory, we could quantify trends over the past 30 years. However, the sampling and field procedures used during the periodic inventories were different enough from those of the annual inventory to preclude reliable trend analysis. Therefore, direct comparisons of periodic and annual inventories in their entireties are not recommended and may even produce misleading results (Goeking 2015). This section describes the primary differences between the periodic and annual inventories; presents an appropriate method for comparing periodic and annual inventory data at plots that were measured during both inventories, or co-located plots; and summarizes some changes in forest attributes that have occurred at co-located plots.

The primary differences between Arizona's periodic and annual forest inventories pertain to the plot design, sample design, and operational definitions used during field data collection. The periodic inventories of the 1980s and 1990s used a variable-radius plot design with varying numbers of subplots. In contrast, the plot design of the annual inventory consists of four fixed-radius subplots, as described in the *Plot Configuration* section of this report's "Inventory Methods" chapter. Sample designs also changed appreciably, from different sample intensities across ownership groups (O'Brien 2002) to a spatially representative plot grid with consistent sample intensity across all forest types and management categories (Bechtold and Patterson 2005). Arizona's periodic inventories also used an operational definition of "tree" that differentiated between tree-form and shrub-form trees. For example, pinyon pines that were less than 6 feet tall and were not expected to eventually produce a straight, 8-foot trunk section were not considered to be

trees and were not measured, so they were not included in volume-based estimates such as biomass, growth, and mortality. In contrast, the annual inventory identifies trees strictly by their species, regardless of growth form. Therefore, trees on many woodland plots in the current annual inventory would not have been measured under previous definitions.

Due to these differences in forest inventories over time, users of FIA data should be aware of appropriate methods of evaluating trends and avoid inappropriate methods. Examples of inappropriate comparisons between periodic and annual inventories range from comparing the tree volume on a specific forest type to directly comparing the total area of forest land. Instead, an appropriate method of quantifying trends is to first identify forest plots that were measured during both periodic and annual inventories, and then to assess trends at only those plots. FIA refers to such plot locations as co-located plots. Although different plot designs were used during the periodic and annual measurements of co-located plots, each plot design allows estimation of volume, growth, and mortality per acre as well as stand-level variables such as forest type. Therefore, comparisons of multiple measurements at co-located plots are useful for quantifying trends in attributes on a per-acre basis, such as volume, mortality, growth, biomass, and number of trees per acre.

This section presents the results of two analyses of co-located plot data collected during periodic versus annual inventories. The first analysis compares data collected at co-located plots that were measured once between 1990 and 1999 and again during a full cycle of the annual inventory. The second analysis compares co-located plot measurements from 1981–1986 to the annual inventory measurements. Figure 42 shows the distribution of all plots in the 1985 inventory, all plots in the 1999 inventory, all plots in the annual inventory, and the plots that were co-located between the annual inventory and each of the periodic inventories.

The analysis of change between the 1990s and the annual inventory consisted of 1,900 co-located plots that were measured during both periods. Average annual tree mortality at co-located plots increased by 471 percent, from 3.5 to 19.8 cubic feet per acre per year, and net growth decreased by 135 percent, from 16.3 to –5.7 cubic feet per acre per year. Over this same time period, mean net volume of dead trees per acre more than doubled from 78 to 162 cubic feet per acre. Live net volume per acre decreased by 11 percent, from 1,307 to 1,070 cubic feet per acre. The changes in net volume, net growth rates, and mortality rates are similar to those observed for Arizona by Goeking (2015) in a comparison of plots measured during the 1990s and measured again between 2003 and 2012.

The second analysis consisted of 629 co-located plots that were measured during both the 1981–1986 inventory and the annual inventory. The results showed the same patterns as those from the first comparison: large increases in dead net volume and mean annual mortality, and decreases in net growth and live net volume. In both analyses, the mean annual net growth at co-located plots was negative, indicating that mortality exceeds gross growth. One difference between the two analyses is the temporal difference in total net volume, which includes both

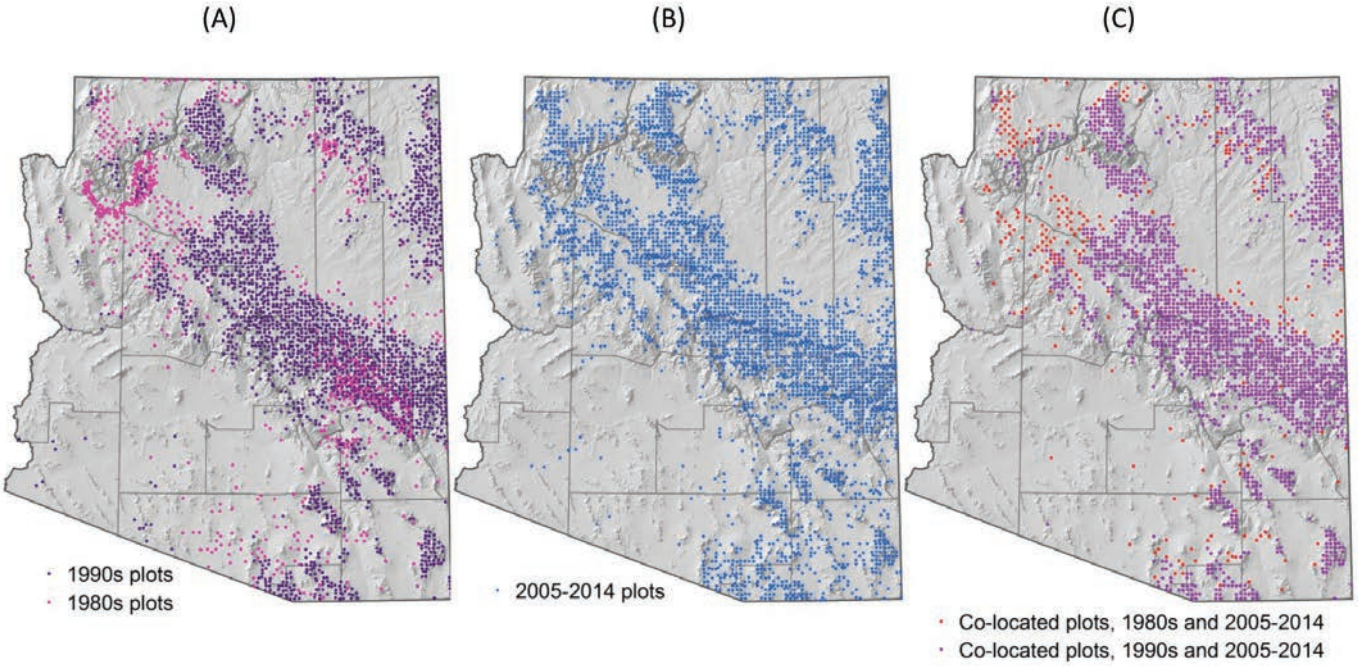

Figure 42—Approximate locations of periodic inventory plots measured in the 1980s and 1990s (A), annual inventory plots measured in 2005–2014 (B), and co-located plots measured during one of the periodic inventories and again during the annual inventory (C).

live and dead trees. Average total net volume at co-located plots measured during the 1990s and again in the annual inventory decreased by about 11 percent, from 1,384 to 1,232 cubic feet per acre. Co-located plots measured during the 1980s and again during the annual inventory showed a slight increase in total net volume, from 669 to 642 cubic feet per acre. Note that the average net volume at co-located plots measured during the 1980s inventory was much smaller than the average net volume at co-located plots from the 1990s inventory. That is likely because the 1990s inventory of Arizona over-represented the ponderosa pine forest type and under-represented pinyon/juniper forest types and, to a lesser extent, the woodland hardwoods forest-type group (Goeking 2015). In contrast, the 1980s inventory was more representative of woodland forest types and therefore shows lower per-acre volumes, on average.

To investigate changes for individual tree species, we quantified live basal area, dead basal area, mean annual growth, and mean annual mortality, as measured at co-located plots in the 1990s inventory and again in 2005–2014, for the six tree species that make up most of Arizona's tree volume. These are, in decreasing order of total volume, ponderosa pine, Utah juniper, common pinyon, oneseed juniper, alligator juniper, and Douglas-fir. Figure 43 shows that all species are exhibiting lower mean annual net growth, and higher mean annual mortality, during the annual inventory period (t2) than during the 1990s (t1). Recent annual net growth rates are positive for three of the species (ponderosa pine, common pinyon, and oneseed juniper), while annual net growth is negative for the other three species (Utah juniper, alligator juniper, and Douglas-fir). Negative annual net growth indicates that mortality rates are greater than gross growth rates on a basis

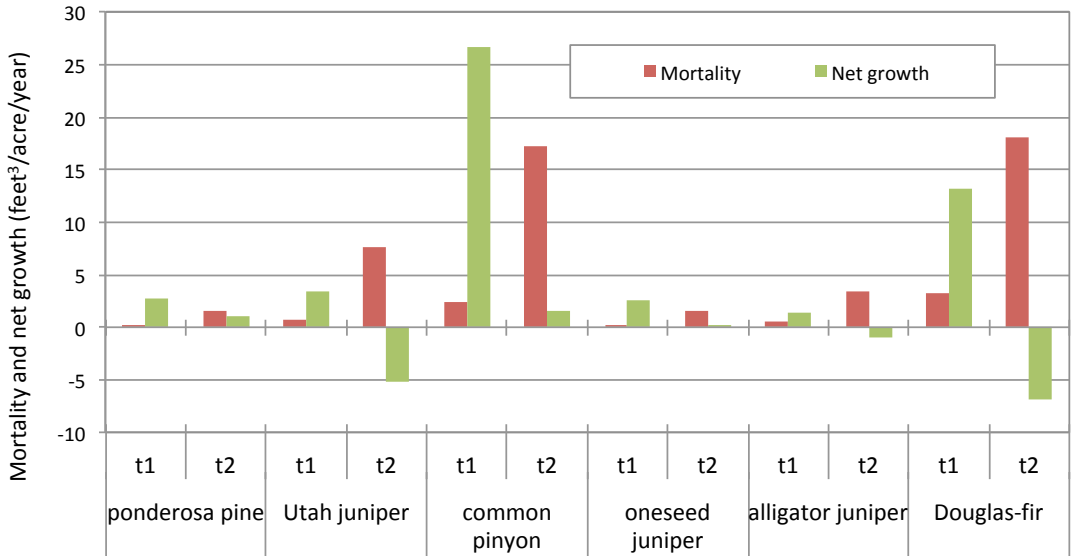

Figure 43—Mean annual mortality and mean annual net growth for major tree species of Arizona, as measured at co-located plots that were measured during the 1990s inventory (t1) and again between 2005 and 2014 (t2).

of cubic-foot volume per year. The total amount of gross growth can be inferred from the combination of net growth and mortality (fig. 43). Gross growth during 2005-2014 was greater than gross growth during the 1990s for three species: Utah juniper, common pinyon, and alligator juniper. However, the negative net growth of Utah juniper and alligator juniper, as well as the small yet positive net growth of common pinyon, show that high mortality rates are approximately offsetting gains due to relatively high growth rates.

In 2005–2014, all six major species except Utah juniper had less live basal area per acre, and all species except for oneseed juniper had more dead basal area per acre, than in the 1990s (fig. 44). Given the recent negative net growth of some of these species (fig. 43), we could expect that the decline in live basal area will continue into the next few years of measurement in Arizona's forest inventory. Total basal area declined for most of these species; the exceptions were alligator juniper and Douglas-fir, which actually have slightly more total basal area in the annual inventory than in the 1990s.

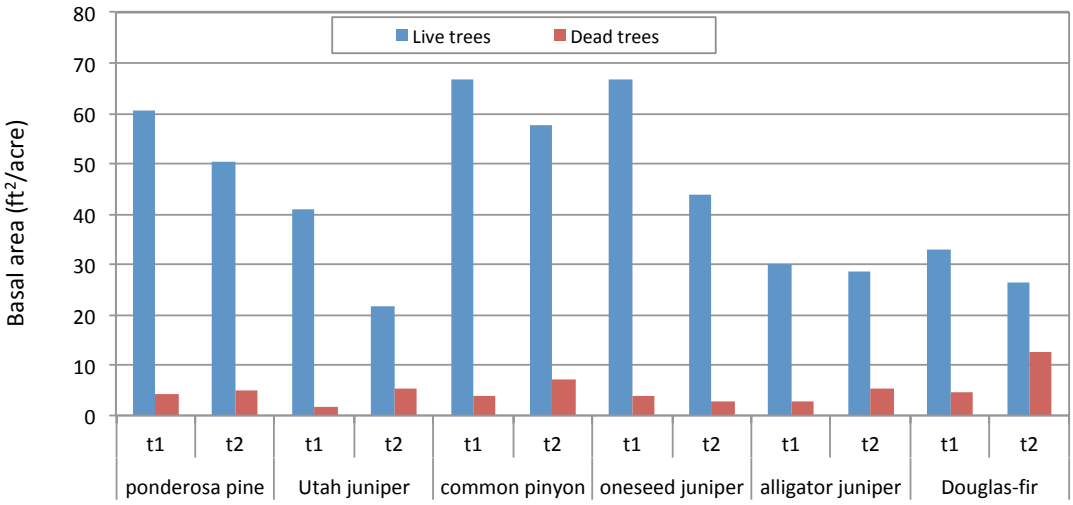

Figure 44—Mean basal area for major tree species of Arizona, as measured at co-located plots that were measured during the 1990s inventory (t1) and again between 2005 and 2014 (t2).

The caveat of the co-located plot analysis presented here is that results cannot be scaled to the entire State and cannot overcome the limitations of the periodic sample design. For example, the periodic inventory under-sampled some woodland forest types, and any analysis of co-located plots will still under-represent that forest type and will instead exhibit trends that occurred on forest types that were sampled more intensively when all plots are considered together. Nonetheless, it provides an indication of the direction of change in Arizona's forests. As Arizona's forest inventory continues into its second cycle and plots are remeasured at a consistent 10-year interval, FIA's ability to quantify trends in forest attributes will expand from analyses of co-located periodic plots to robust Statewide estimates of change based on the spatially representative annual plot grid.

Conclusions and Future Analyses

There has been considerable change in Arizona's forests since annual inventory was started in the State in 2001. Several of the large fires that occurred in the early 2000s, such as the Rodeo fire, were only partially sampled before the occurrence of fire, so most of the plot visits have occurred afterward. Later large fires, such as the Wallow fire, occurred after a complete first cycle of annual inventory. As a result, there is both a good baseline inventory and several years of remeasurement, and every new year of annual inventory brings in new remeasurement data.

The situation is similar with drought and its effects on several species in the State. Shortly after annual inventory began in Arizona, the cumulative effects of several years of drought began to affect several species. Of particular note were localized outbreaks of bark beetles in ponderosa pine and widespread die-off of aspen. The most notable drought-related event was the pinyon ips beetle outbreak that caused high levels of mortality in common pinyon nearly range-wide, and most severely along the Mogollon Rim in Arizona. The outbreak accelerated and peaked during the period of 2003–2006, but small pockets of mortality have occurred during the intervening years.

Because of the timing of these events, FIA annual inventory was able to capture widespread change with annual resolution—something that was impossible to do with the periodic inventory system. Periodic inventories effectively took only "snapshots" of forest conditions at intervals of a decade or more, providing very little information on how the forest changed between inventories. As a result of the timing of disturbance events and implementation of annual inventory, the most recent 10 years of annual inventory, on which all of the standard tables (Appendix B) and many analyses are based, mostly describe a recovering forest.

However, recovery from past events occurs even as new changes affect Arizona's forests. It is impossible for forests to grow indefinitely, so one goal of FIA inventory is to monitor the near-term trends in accumulation of live and dead forest biomass, including transitions between the major pools of woody material. In the process, FIA data provide information on forest composition, structure, and age-class distribution, all of which can provide some insight to changes that might

be coming in the future. Younger and more diversified forests tend to be more resilient forests, so a potential positive effect of the recent, relatively high rates of disturbance includes a forest that is not as susceptible to the same kinds of disturbances that created it. As the forest continues to change, FIA will monitor the change and compare the outcome to expectations that are formed by past research.

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Appendix A: Standard Forest Inventory and Analysis Terminology

Note: For the FIA national glossary please go to https://www.nrs.fs.fed.us/fia/data-tools/state-reports/glossary/default.asp.

Average annual mortality—The average annual volume of trees 5.0 inches d.b.h./d.r.c. and larger that died from natural causes.

Average annual net growth—Average annual net change in volume of trees 5.0 inches d.b.h./d.r.c. and larger in the absence of cutting (average annual gross growth minus average annual mortality).

Basal area (BA)—The cross-sectional area of a tree stem/bole (trunk) at the point where diameter is measured, inclusive of bark. BA is calculated for trees 1.0 inch and larger in diameter, and is expressed in square feet. For timber species, the calculation is based on diameter at breast height (d.b.h.); for woodland species, it is based on diameter at root collar (d.r.c.).

Biomass—The quantity of wood fiber, for trees 1.0 inch d.b.h./d.r.c. and larger, expressed in terms of oven-dry weight. It includes aboveground portions of trees: bole/stem (trunk), bark, and branches. Biomass estimates can be computed for live and/or dead trees.

Board-foot volume—A unit of measure indicating the amount of wood contained in an unfinished board 1 foot wide, 1 foot long, and 1 inch thick. Board-foot volume is computed for the sawlog portion of a sawtimber-size tree; the sawlog portion includes the part of the bole on sawtimber-size tree from a 1-foot stump to a minimum sawlog top of 7 inches diameter outside bark (d.o.b.) for softwoods, or 9 inches d.o.b. for hardwoods. Net board-foot volume is calculated as the gross board-foot volume in the sawlog portion of a sawtimber-size tree, less deductions for cull (note: board-foot cull deductions are limited to rotten/missing material and form defect—referred to as the merchantability factor—board-foot). Board-foot volume estimates are computed in both Scribner and International ¼-inch rule, and can be calculated for live and/or dead (standing or down) trees.

Census water—Streams, sloughs, estuaries, canals, and other moving bodies of water 200 feet wide and greater, and lakes, reservoirs, ponds, and other permanent bodies of water 4.5 acres in area and greater.

Coarse woody debris—Down pieces of wood leaning more than 45 degrees from vertical with a diameter of at least 3.0 inches and a length of at least 3.0 feet.

Condition class—The combination of discrete landscape and forest attributers that identify, define, and stratify the area associated with a plot. Such attributes include reserved status, owner group, forest type, stand-size class, stand origin, and tree density.

Crown class—A classification of trees based on dominance in relation to adjacent trees in the stand as indicated by crown development and amount of sunlight received from above and the sides.

Crown cover (Canopy cover)—The percentage of the ground surface area covered by a vertical projection of plant crowns. Tree crown cover for a sample site includes the combined cover of timber and woodland trees 1.0 inch d.b.h./d.r.c. and larger. Maximum crown cover for a site is 100 percent; overlapping cover is not double counted.

Cubic-foot volume (merchantable)—A unit of measure indicating the amount of wood contained in a cube 1-by-1-by-1 foot. Cubic-foot volume is computed for the merchantable portion of timber and woodland species; the merchantable portion for timber species includes that part of a bole from a 1-foot stump to a minimum 4-inch top d.o.b, or above the place(s) of diameter measurement for any woodland tree with a single 5.0-inch stem or larger or a cumulative (calculated) d.r.c. of at least 5.0 inches to the 1.5-inch ends of all branches. Net cubic-foot volume is calculated as the gross cubic-foot volume in the merchantable portion of a tree, less deductions for cull.

Diameter at breast height (d.b.h.)—The diameter of a tree bole/stem (trunk) measured at breast height (4.5 feet above ground), measured outside the bark. The point of diameter measurement may vary for abnormally formed trees.

Diameter at root collar (d.r.c.)—The diameter of a tree stem(s) measured at root collar or at the point nearest the ground line (whichever is higher) that represents the basal area of the tree, measured outside the bark. For multi-stemmed trees, d.r.c. is calculated from an equation that incorporates the individual stem diameter measurements. The point of diameter measurement may vary for woodland trees with stems that are abnormally formed. With the exception of seedlings, woodland stems qualifying for measurement must be at least 1.0 inch in diameter or larger and at least 1.0 foot in length.

Diameter class—A grouping of tree diameters (d.b.h. or d.r.c.) into classes of a specified range. For some diameter classes, the number referenced (e.g., 4”, 6”, 8”) is designated as the midpoint of an individual class range. For example, if 2-inch classes are specified (the range for an individual class) and even numbers are referenced, the 6-inch class would include trees 5.0 to 6.9 inches in diameter.

Diameter outside bark (d.o.b.)—Tree diameter measurement inclusive of the outside perimeter of the tree bark. The d.o.b. measurement may be taken at various points on a tree (e.g., breast height, tree top) or log, and is sometimes estimated.

Field plot/field location—A reference to the sample site or plot; an area containing the field location center and all sample points. A field location consists of four subplots and four microplots.

- **Subplot**—A 1/24-acre fixed-radius area (24-foot horizontal radius) used to sample trees 5.0 inches d.b.h./d.r.c. and larger and understory vegetation.

- Microplot—A 1/300-acre fixed-radius plot (6.8-foot radius), located 12 feet from the center of each subplot at an azimuth of 90 degrees, used to inventory seedlings and saplings.

Fixed-radius plot—A circular sample plot of a specified horizontal radius: 1/300 acre = 6.8-foot radius (microplot); 1/24 acre = 24.0-foot radius (subplot).

Forest land—Land that has at least 10 percent cover of live tally tree species of any size, or land formerly having such tree cover, and not currently developed for a nonforest use. The minimum area for classification as forest land is 1 acre. Roadside, stream-side, and shelterbelt strips of trees must be at least 120 feet wide to qualify as forest land. Unimproved roads and trails, streams and other bodies of water, or natural clearings in forested areas are classified as forest if less than 120 feet in width or 1 acre in size. Grazed woodlands, reverting fields, and pastures that are not actively maintained are included if the above qualifications are satisfied. (Note that the canopy cover threshold for forest land was formerly 5 percent rather than 10 percent, and field crews in New Mexico from 2008 to 2012 used the 5 percent threshold. However, sampled conditions with 5-9 percent cover were treated as nonforest for the purposes of this report, and forest attributes are therefore based on the new 10-percent threshold.)

Forest type—A classification of forest land based on the species forming a plurality of live-tree stocking.

Gross growth—The annual increase in volume of trees 5.0 inches d.b.h. and larger in absence of cutting and mortality. Gross growth includes survivor growth, ingrowth, growth on ingrowth, growth on removals before removal, and growth on mortality prior to death.

Growing-stock trees—A live timber species, 5.0 inches d.b.h. or larger, with less than 2/3 (67 percent) of the merchantable volume cull, and containing at least one solid 8-foot section, now or prospectively, reasonably free of form defect, on the merchantable portion of the tree.

Growing-stock volume—The cubic-foot volume of sound wood in growing-stock trees at least 5.0 inches d.b.h. from a 1-foot stump to a minimum 4-inch top d.o.b. to the central stem.

Hardwood trees—Dicotyledonous trees, usually broadleaf and deciduous.

Inventory year—The year in which a plot was scheduled to be completed. Within each subpanel, all plots have the same inventory year. Inventory year may differ from measurement year.

Land use—The classification of a land condition by use or type.

Litter—The uppermost layer of organic debris on a forest floor; that is, essentially the freshly fallen, or only slightly decomposed material, mainly foliage, but also bark fragments, twigs, flowers, fruits, and so forth. Humus is the organic layer, unrecognizable as to origin, immediately beneath the litter layer from which it is derived. Litter and humus together are often termed duff.

Logging residue/products—

- **Bolt—**A short piece of pulpwood; a short log.
- **Industrial wood—**All commercial roundwood products, excluding fuelwood.
- **Logging residue—**The unused sections within the merchantable portions of sound (growing-stock) trees cut or killed during logging operations.
- **Mill or plant residue—**Wood material from mills or other primary manufacturing plants that is not used for the mill's or plant's primary products. Mill or plant residue includes bark, slabs, edgings, trimmings, miscuts, sawdust, and shavings. Much of the mill and plant residue is used as fuel and as the raw material for such products as pulp, palletized fuel, fiberwood, mulch, and animal bedding. Mill or plant residue includes bark and the following components:
- **Coarse residue—**Wood material suitable for chipping, such as slabs, edgings, and trim.
- **Fine residue—**Wood material unsuitable for chipping, such as sawdust and shavings.
- **Pulpwood—**Roundwood, whole-tree chips, or wood residues that are used for the production of wood pulp.
- **Roundwood—**Logs, bolts, or other round sections cut from trees.

Mapped-plot design—A sampling technique that identifies (delineates or maps) and separately classifies distinct "conditions" on the field location sample area. Each condition must meet minimum size requirements. At the most basic level, condition class delineations include forest land, nonforest land, and water. Forest land conditions can be further subdivided into separate condition classes if there are distinct variations in reserved status, owner group, forest type, stand-size class, stand origin, and stand density, given that each distinct area meets minimum size requirements.

Measurement year—The year in which a plot was completed. Measurement year may differ from inventory year.

Merchantable portion—For trees measured at d.b.h. and 5.0 inches d.b.h. and larger, the merchantable portion (or "merchantable bole") includes the part of the tree bole from a 1-foot stump to a 4.0-inch top (d.o.b.). For trees measured at d.r.c., the merchantable portion includes all qualifying segments above the place(s) of diameter measurement for any tree with a single 5.0-inch stem or larger or a cumulative (calculated) d.r.c. of at least 5.0 inches to the 1.5-inch ends of all branches; sections below the place(s) of diameter measurement are not included. Qualifying segments are stems or branches that are a minimum of 1 foot in length and at least 1.0 inch in diameter; portions of stems or branches smaller than 1.0 inch in diameter, such as branch tips, are not included in the merchantable portion of the tree.

Mortality tree—All standing or down dead trees 5.0 inches d.b.h./d.r.c. and larger that were alive within the previous 5 years (in most States); for the 2008–2012 New Mexico inventory, this includes trees that were alive within the previous 10 years.

National Forest System (NFS) lands—Public lands administered by the Forest Service, U.S. Department of Agriculture, such as National Forests, National Grasslands, and some National Recreation Areas.

National Park lands—Public lands administered by the Park Service, U.S. Department of the Interior, such as National Parks, National Monuments, National Historic Sites (such as National Memorials and National Battlefields), and some National Recreation Areas.

Noncensus water—Portions of rivers, streams, sloughs, estuaries, and canals that are 30 to 200 feet wide and at least 1 acre in size; and lakes, reservoirs, and ponds 1 to 4.5 acres in size. Portions of rivers and streams not meeting the criteria for census water, but at least 30 feet wide and 1 acre in size, are considered noncensus water. Portions of braided streams not meeting the criteria for census water, but at least 30 feet in width and 1 acre in size, and more than 50 percent water at normal high-water level are also considered noncensus water.

Nonforest land—Land that does not support, or has never supported, forests, and lands formerly forested where tree regeneration is precluded by development for other uses. Includes areas used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining rights-of-way, power line clearings of any width, and noncensus water. If intermingled in forest areas, unimproved roads and nonforest strips must be more than 120 feet wide, and clearings, etc., more than 1 acre in size, to qualify as nonforest land.

Nonstocked stand—A formerly stocked stand that currently has less than 10 percent stocking, but has the potential to again become 10 percent stocked. For example, recently harvested, burned, or windthrow-damaged areas.

Other Federal lands—Public lands administered by Federal agencies other than the Forest Service, U.S. Department of Agriculture, or the Bureau of Land Management, U.S. Department of the Interior.

Other public lands—Public lands administered by agencies other than the Forest Service, U.S. Department of Agriculture. Includes lands administered by other Federal, State, county, and local government agencies, including lands leased by these agencies for more than 50 years.

Poletimber-size trees—For trees measured at d.b.h, softwoods 5.0 to 8.9 inches d.b.h. and hardwoods 5.0 to 10.9 inches d.b.h. For trees measured at d.r.c., all live trees 5.0 to 8.9 inches d.r.c.

Primary wood processing plants—An industrial plant that processes roundwood products, such as sawlogs, pulpwood bolts, or veneer logs.

Private lands—All lands not owned or managed by a Federal, State, or other public entity, including lands owned by corporations, trusts, or individuals, as well as Tribal lands.

Productive forest land—Forest land capable of producing 20 cubic feet per acre per year of wood from trees classified as a timber species (see Appendix D) on forest land classified as a timber forest type (see Appendix C).

Productivity—The potential yield capability of a stand calculated as a function of site index (expressed in terms of cubic-foot growth per acre per year at age of culmination of mean annual increment). Productivity values for forest land provide an indication of biological potential. Timberland stands are classified by the potential net annual growth attainable in fully stocked natural stands. For FIA reporting, Productivity Class is a variable that groups stand productivity values into categories of a specified range. Productivity is sometimes referred to as "yield" or "mean annual increment."

Removals—The net volume of sound (growing-stock) trees removed from the inventory by harvesting or other cultural operations (such as timber-stand improvement), by land clearing, or by changes in land use (such as a Wilderness designation).

Reserved land—Land withdrawn from management for production of wood products through statute or administrative designation; examples include Wilderness areas and National Parks and Monuments.

Sampling error—A statistical term used to describe the accuracy of the inventory estimates. Expressed on a percentage basis in order to enable comparisons between the precision of different estimates, sampling errors are computed by dividing the estimate into the square root of its variance.

Sapling—A live tree 1.0–4.9 inches d.b.h./d.r.c.

Sawlog portion—The part of the bole of sawtimber-size trees between a 1-foot stump and the sawlog top.

Sawlog top—The point on the bole of sawtimber-size trees above which a sawlog cannot be produced. The minimum sawlog top is 7 inches d.o.b. for softwoods, and 9 inches d.o.b. for hardwoods.

Sawtimber-size trees—Softwoods 9.0 inches d.b.h. and larger and hardwoods 11.0 inches and larger.

Sawtimber volume—The growing-stock volume in the sawlog portion of sawtimber-size trees in board feet.

Seedlings—Live trees less than 1.0 inch d.b.h./d.r.c.

Site index—A measure of forest productivity for a timberland tree/stand. Expressed in terms of the expected height (in feet) of trees on the site at an index age of 50 (or 80 years for aspen and cottonwood). Calculated from height-to-age equations.

Site tree—A tree used to provide an index of site quality. Timber species selected for site index calculations must meet specified criteria with regards to age, diameter, crown class, and damage.

Snag—A standing dead tree.

Softwood trees—Coniferous trees, usually evergreen, having needle- or scale-like leaves.

Stand—A community of trees that can be distinguished from adjacent communities due to similarities and uniformity in tree and site characteristics, such as age-class distribution, species composition, spatial arrangement, structure, etc.

Stand density—A relative measure that quantifies the relationship between trees per acre, stand basal area, average stand diameter, and stocking of a forested stand.

Stand density index (SDI)—A widely used measure developed by Reineke (1933), and is an index that expresses relative stand density based on a comparison of measured stand values with some standard condition; relative stand density is the ratio, proportion, or percent of absolute stand density to a reference level defined by some standard level of competition. For FIA reporting, the SDI for a site is usually presented as a percentage of the maximum SDI for the forest type. Site SDI values are sometimes grouped into SDI classes of a specified percentage range. Maximum SDI values vary by species and region.

Standing dead tree—To qualify as a standing dead tally tree, dead trees must be at least 5.0 inches in diameter, have a bole that has an unbroken actual length of at least 4.5 feet, and lean less than 45 degrees from vertical as measured from the base of the tree to 4.5 feet. Portions of boles on dead trees that are separated greater than 50 percent (either above or below 4.5 feet), are considered severed and are included in Down Woody Material (DWM) if they otherwise meet DWM tally criteria. For western woodland species with multiple stems, a tree is considered down if more than 2/3 of the volume is no longer attached or upright; do not consider cut and removed volume. For western woodland species with single stems to qualify as a standing dead tally tree, dead trees must be at least 5.0 inches in diameter, be at least 1.0 foot in unbroken actual length, and lean less than 45 degrees from vertical.

Stand-size class—A classification of forest land based on the predominant diameter size of live trees presently forming the plurality of live-tree stocking. Classes are defined as follows:

- **Sawtimber stand (Large-tree stand)**—A stand at least 10 percent stocked with live trees, in which half or more of the total stocking is from live trees 5.0 inches or larger in diameter, and with sawtimber (large tree) stocking equal to or greater than poletimber (medium tree) stocking.
- **Poletimber stand (Medium-tree stand)**—A stand at least 10 percent stocked with live trees, in which half or more of the total stocking is from live trees

5.0 inches or larger in diameter, and with poletimber (medium tree) stocking exceeding sawtimber (large tree) stocking.

- **Sapling/seedling stand—**A stand at least 10 percent stocked with live trees, in which half or more of the total stocking is from live trees less than 5.0 inches in diameter.
- **Nonstocked stand—**A formerly stocked stand that currently has less than 10 percent stocking, but has the potential to again become 10 percent stocked. For example, recently harvested, burned, or windthrow-damaged areas.

Stocking—An expression of the extent to which growing space is effectively utilized by live trees.

Timber species—Tally tree species traditionally used for industrial wood products. These include all species of conifers, except pinyon and juniper. Diameters for timber species are measured at breast height (d.b.h.).

Timber-stand improvement—A term comprising all intermediate cuttings or treatments, such as thinning, pruning, release cutting, girdling, weeding, or poisoning, made to improve the composition, health, and growth of the remaining trees in the stand.

Timberland—Unreserved forest land capable of producing 20 cubic feet per acre per year of wood from trees classified as a timber species (see Appendix D) on forest land designated as a timber forest type (see Appendix C).

Unproductive forest land—Forest land not capable of producing 20 cubic feet per acre per year of wood from trees classified as a timber species (see Appendix D) on forest land designated as a timber forest type and all forest lands designated as a woodland forest type (see Appendix C).

Unreserved forest land—Forest land not withdrawn from management for production of wood products through statute or administrative designation.

Wilderness area—An area of undeveloped land currently included in the Wilderness System, managed to preserve its natural conditions and retain its primeval character and influence.

Woodland species—Tally tree species that are not usually converted into industrial wood products. Common uses of woodland trees are fuelwood, fenceposts, and Christmas trees. These species include pinyon, juniper, mesquite, locust, mountain-mahogany (*Cercocarpus* spp.), Rocky Mountain maple, bigtooth maple, desert ironwood, and most oaks (note: bur oak and chinkapin oak are classified as timber species). Because most woodland trees are extremely variable in form, diameter is measured at root collar (d.r.c.).

Appendix B: Standard Forest Resource Tables

Table B1—Percentage of plot area by land status, Arizona, 2005–2014.

Land status	Percentage of sample
Accessible forest land	
Unreserved forest land	
Timberland	3.9
Unproductive	18.1
Total unreserved forest land	22.0
Reserved forest land	
Productive	0.3
Unproductive	1.9
Total reserved forest land	2.2
Total accessible forest land	**24.2**
Nonforest and other areas	
Nonforest land	70.7
Water	0.3
Census	0.2
Non-Census	0.1
Total nonforest and other areas	**71.0**
Non-response	
Access denied	3.5
Hazardous conditions	0.7
Other	0.7
Total non-response	**4.8**
All land	**100.0**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the percentage rounds to less than 0.1 percent. Columns and rows may not add to their totals due to rounding.

Table B2—Area of accessible forest land, in thousand acres, by owner class and forest land status, Arizona, 2005–2014.

	Unreserved forests			Reserved forests			
Owner class	Timberland	Unproductive	Total	Productive	Unproductive	Total	All forest land
Forest Service							
National Forest	2,182.1	4,838.8	7,020.8	111.9	554.4	666.3	**7,687.1**
Other Federal							
National Park Service	- -	- -	- -	84.2	286.8	371.0	**371.0**
Bureau of Land Management	5.7	828.5	834.2	12.2	563.0	575.3	**1,409.5**
U.S. Fish and Wildlife Service	- -	- -	- -	- -	86.2	86.2	**86.2**
Departments of Defense and Energy	26.8	34.3	61.1	- -	- -	- -	**61.1**
Other Federal	- -	6.2	6.2	- -	- -	- -	**6.2**
State and local government							
State	7.5	1,616.3	1,623.8	- -	- -	- -	**1,623.8**
County and municipal	0.6	48.5	49.1	- -	- -	- -	**49.1**
Private							
Undifferentiated private	766.0	6,546.4	7,312.4	- -	- -	- -	**7,312.4**
All owners	**2,988.6**	**13,919.0**	**16,907.6**	**208.4**	**1,490.3**	**1,698.7**	**18,606.4**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the acres round to less than 0.1 thousand acres. Columns and rows may not add to their totals due to rounding.

Table B3—Area of accessible forest land, in thousand acres, by forest type group and productivity class, Arizona, 2005–2014.

Forest-type group	Site-productivity class (cubic feet/acre/year)							Total all classes
	0-19	20-49	50-84	85-119	120-164	165-224	225+	
Pinyon / juniper group	11,084.1	- -	- -	- -	- -	- -	- -	11,084.1
Douglas-fir group	- -	51.7	170.8	6.2	- -	- -	- -	228.7
Ponderosa pine group	6.5	1,870.8	528.0	6.0	- -	- -	- -	2,411.3
Fir / spruce / mountain hemlock group	- -	32.0	136.2	45.0	7.7	- -	- -	221.0
Other western softwoods group	11.7	20.3	6.0	- -	- -	- -	- -	38.1
Elm / ash / cottonwood group	10.7	16.4	9.1	4.9	- -	- -	- -	41.1
Aspen / birch group	4.6	85.3	60.4	3.0	- -	- -	- -	153.2
Other hardwoods group	23.0	4.3	- -	- -	- -	- -	- -	27.3
Woodland hardwoods group	3,633.3	- -	- -	- -	- -	- -	- -	3,633.3
Nonstocked	635.5	100.9	32.1	-	- -	- -	- -	768.4
All forest-type groups	**15,409.4**	**2,181.7**	**942.6**	**65.0**	**7.7**	**- -**	**- -**	**18,606.4**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the acres round to less than 0.1 thousand acres. Columns and rows may not add to their totals due to rounding.

Table B4—Area of accessible forest land, in thousand acres, by forest type group, ownership group, and land status, Arizona, 2005–2014.

Forest-type group	Forest Service		Other Federal		State and local government		Undifferentiated private		All forest land
	Timber-land	Other forest land	Timber-land	Other forest land	Timber-land	Other forest land	Timber-land	Other forest land	
Pinyon / juniper group	- -	3,670.0	- -	1,337.8	- -	831.0	- -	5,245.3	11,084.1
Douglas-fir group	135.2	26.1	- -	9.0	- -	- -	58.4	- -	228.7
Ponderosa pine group	1,716.4	38.0	25.3	60.6	6.6	- -	557.9	6.5	2,411.3
Fir / spruce / mountain hemlock group	115.2	12.1	- -	6.0	- -	- -	87.7	- -	221.0
Other western softwoods group	11.9	18.1	1.5	- -	- -	- -	- -	6.5	38.1
Elm / ash / cottonwood group	9.1	6.1	5.7	- -	- -	4.6	15.6	- -	41.1
Aspen / birch group	90.7	17.0	- -	20.9	- -	- -	24.7	- -	153.2
Other hardwoods group	2.8	4.9	- -	6.9	1.5	4.8	- -	6.4	27.3
Woodland hardwoods group	- -	1,484.2	- -	366.0	- -	727.0	- -	1,056.1	3,633.3
Nonstocked	100.7	228.5	- -	94.3	- -	97.5	21.7	225.6	768.4
All forest-type groups	**2,182.1**	**5,505.1**	**32.5**	**1,901.5**	**8.1**	**1,664.8**	**766.0**	**6,546.4**	**18,606.4**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the acres round to less than 0.1 thousand acres. Columns and rows may not add to their totals due to rounding.

Table B5—Area of accessible forest land, in thousand acres, by forest type group and stand-size class, Arizona, 2005–2014.

Forest-type group	Stand-size class				All size classes
	Large diameter	Medium diameter	Small diameter	Nonstocked	
Pinyon / juniper group	9,976.3	727.0	380.8	- -	11,084.1
Douglas-fir group	228.7	- -	- -	- -	228.7
Ponderosa pine group	2,289.6	50.0	71.6	- -	2,411.3
Fir / spruce / mountain hemlock group	220.1	- -	0.9	- -	221.0
Other western softwoods group	38.1	- -	- -	- -	38.1
Elm / ash / cottonwood group	36.4	1.6	3.0	- -	41.1
Aspen / birch group	54.8	7.7	90.8	- -	153.2
Other hardwoods group	13.2	11.3	2.8	- -	27.3
Woodland hardwoods group	2,137.4	633.8	862.0	- -	3,633.3
Nonstocked	- -	- -	- -	768.4	768.4
All forest-type groups	**14,994.5**	**1,431.5**	**1,412.0**	**768.4**	**18,606.4**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the acres round to less than 0.1 thousand acres. Columns and rows may not add to their totals due to rounding.

Table B6—Area of accessible forest land, in thousand acres, by forest type group and stand-age class, Arizona, 2005–2014.

Forest-type group	Non-stocked	Stand-age class (years) 1-20	21-40	41-60	61-80	81-100	101-120	121-140	141-160	161-180	181-200	201+	All classes
Pinyon / juniper group	- -	155.1	210.9	416.3	879.2	1,250.5	1,408.8	1,371.7	1,277.9	1,093.9	786.8	2,233.0	11,084.1
Douglas-fir group	- -	- -	- -	- -	48.9	44.3	73.0	42.4	12.3	6.2	- -	1.6	228.7
Ponderosa pine group	- -	48.8	34.7	55.1	346.3	838.5	651.1	186.3	103.8	73.5	24.1	49.1	2,411.3
Fir / spruce / mountain hemlock group	- -	0.9	- -	- -	30.9	76.3	43.1	31.8	7.5	24.3	6.2	- -	221.0
Other western softwoods group	- -	- -	- -	- -	- -	6.0	6.0	8.4	- -	17.7	- -	- -	38.1
Elm / ash / cottonwood group	- -	3.0	- -	6.5	15.3	6.1	- -	5.7	4.5	- -	- -	- -	41.1
Aspen / birch group	- -	84.6	6.2	7.7	6.2	12.1	24.5	11.9	- -	- -	- -	- -	153.2
Other hardwoods group	- -	2.8	6.4	- -	- -	4.9	1.5	- -	- -	- -	- -	11.7	27.3
Woodland hardwoods group	- -	574.3	247.4	168.7	332.1	481.6	441.8	331.3	424.8	293.5	102.7	235.1	3,633.3
Nonstocked	768.4	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	768.4
All forest-type groups	**768.4**	**869.6**	**505.6**	**654.3**	**1,658.8**	**2,720.3**	**2,649.8**	**1,989.6**	**1,830.6**	**1,509.0**	**919.7**	**2,530.5**	**18,606.4**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the acres round to less than 0.1 thousand acres. Columns and rows may not add to their totals due to rounding.

Table B7—Area of accessible forest land, in thousand acres, by forest type group and stand origin, Arizona, 2005–2014.

Forest-type group	Stand origin: Natural stands	Stand origin: Artificial regeneration	All forest land
Pinyon / juniper group	11,084.1	- -	11,084.1
Douglas-fir group	228.7	- -	228.7
Ponderosa pine group	2,411.3	- -	2,411.3
Fir / spruce / mountain hemlock group	221.0	- -	221.0
Other western softwoods group	38.1	- -	38.1
Elm / ash / cottonwood group	41.1	- -	41.1
Aspen / birch group	153.2	- -	153.2
Other hardwoods group	27.3	- -	27.3
Woodland hardwoods group	3,633.3	- -	3,633.3
Nonstocked	768.4	- -	768.4
All forest-type groups	**18,606.4**	**- -**	**18,606.4**

All table cells without observations in the inventory sample are indicated by --.
Table value of 0.0 indicates the acres round to less than 0.1 thousand acres.
Columns and rows may not add to their totals due to rounding.

Table B8—Area of forest land. In thousand acres, by forest type group and primary disturbance class, Arizona, 2005–2014.

Forest-type group	Disturbance class: None	Insects	Disease	Fire	Wild animals	Domestic animals	Weather	Vegetation	Other	Human	Geological	All forest land
Pinyon / juniper group	9,702.8	727.9	199.5	179.2	- -	30.0	190.2	- -	- -	54.4	- -	11,084.1
Douglas-fir group	154.1	12.7	20.9	41.0	- -	- -	- -	- -	- -	- -	- -	228.7
Ponderosa pine group	1,909.9	79.0	54.6	332.9	- -	- -	24.0	- -	- -	10.9	- -	2,411.3
Fir / spruce / mountain hemlock group	164.7	19.7	36.6	- -	- -	- -	- -	- -	- -	- -	- -	221.0
Other western softwoods group	38.1	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	38.1
Elm / ash / cottonwood group	25.8	- -	- -	9.1	- -	- -	6.2	- -	- -	- -	- -	41.1
Aspen / birch group	94.8	- -	6.2	46.2	- -	- -	6.0	- -	- -	- -	- -	153.2
Other hardwoods group	24.5	- -	- -	- -	- -	- -	2.8	- -	- -	- -	- -	27.3
Woodland hardwoods group	2,958.0	63.9	28.9	386.1	- -	62.2	134.3	- -	- -	- -	- -	3,633.3
Nonstocked	503.3	3.1	6.0	223.0	- -	- -	18.1	- -	6.0	8.9	- -	768.4
All forest-type groups	**15,575.8**	**906.3**	**352.7**	**1,217.6**	**- -**	**92.2**	**381.6**	**- -**	**6.0**	**74.2**	**- -**	**18,606.4**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the acres round to less than 0.1 thousand acres.
Columns and rows may not add to their totals due to rounding.

Table B9—Area of timberland, in thousand acres, by forest type group and stand-size class, Arizona, 2005–2014.

Forest-type group	Stand-size class: Large diameter	Medium diameter	Small diameter	Nonstocked	All size classes
Douglas-fir group	193.6	- -	- -	- -	193.6
Ponderosa pine group	2,191.0	50.0	65.1	- -	2,306.2
Fir / spruce / mountain hemlock group	201.9	- -	0.9	- -	202.9
Other western softwoods group	13.4	- -	- -	- -	13.4
Elm / ash / cottonwood group	27.4	- -	3.0	- -	30.4
Aspen / birch group	48.8	7.7	58.9	- -	115.4
Other hardwoods group	1.5	- -	2.8	- -	4.3
Nonstocked	- -	- -	- -	122.5	122.5
All forest-type groups	**2,677.7**	**57.7**	**130.8**	**122.5**	**2,988.6**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the acres round to less than 0.1 thousand acres. Columns and rows may not add to their totals due to rounding.

Table B10—Number of live trees (at least 1 inch d.b.h./d.r.c.), in thousand trees, on forest land by species group and diameter class, Arizona, 2005–2014.

	Diameter class (inches)															
Species group	1.0-2.9	3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-24.9	25.0-28.9	29.0-32.9	33.0-36.9	37.0+	All classes
Softwood species groups																
Western softwood species groups																
Douglas-fir	30,249	12,396	11,809	9,419	6,721	5,108	3,757	2,662	1,962	840	1,103	412	110	74	37	86,659
Ponderosa and Jeffrey pine	155,865	119,223	75,444	69,746	55,591	44,301	30,219	18,716	13,323	8,431	9,877	3,042	985	144	182	605,089
True fir	34,050	14,125	6,308	5,136	3,490	2,128	1,728	1,097	740	588	549	36	113	- -	- -	70,088
Engelmann and other spruces	20,047	11,408	4,300	3,264	3,086	1,947	1,360	1,170	657	404	550	36	- -	- -	- -	48,229
Other western softwoods	14,777	7,732	3,552	2,995	2,144	1,656	824	713	177	219	259	36	36	- -	- -	35,119
Other																
Western woodland softwoods	644,485	331,675	247,269	196,016	142,327	108,111	74,480	52,383	35,500	26,041	30,167	12,035	6,059	1,442	1,265	1,909,257
All softwoods	899,474	496,559	348,682	286,577	213,359	163,252	112,367	76,740	52,358	36,523	42,506	15,597	7,303	1,660	1,484	2,754,441
Hardwood species groups																
Western hardwood species groups																
Cottonwood and aspen	65,820	18,123	6,589	3,784	3,831	3,311	2,574	1,579	703	149	329	108	-	36	36	106,971
Other western hardwoods	8,751	3,480	1,114	187	146	335	254	73	114	72	- -	- -	- -	- -	- -	14,526
Other																
Western woodland hardwoods	581,231	216,344	132,566	90,744	52,407	29,679	17,413	9,690	5,663	2,631	3,140	1,096	458	37	- -	1,143,100
All hardwoods	655,802	237,947	140,270	94,714	56,384	33,325	20,241	11,342	6,480	2,852	3,468	1,204	458	73	36	1,264,597
All species groups	**1,555,275**	**734,506**	**488,951**	**381,291**	**269,743**	**196,576**	**132,609**	**88,082**	**58,838**	**39,375**	**45,974**	**16,802**	**7,761**	**1,732**	**1,520**	**4,019,038**

All table cells without observations in the inventory sample are indicated by --. Table value of 0 indicates the number of trees rounds to less than 1 thousand trees. Columns and rows may not add to their totals due to rounding.

Table B11—Number of growing stock trees (at least 5 inches d.b.h.), in thousand trees, on timberland by species group and diameter class, Arizona, 2005–2014.

	Diameter class (inches)													
Species group	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-24.9	25.0-28.9	29.0-32.9	33.0-36.9	37.0+	All classes
Softwood species groups														
Western softwood species groups														
Douglas-fir	9,370	7,540	4,866	3,667	2,624	2,370	1,593	768	919	299	37	74	37	34,163
Ponderosa and Jeffrey pine	57,287	56,177	45,737	37,062	25,732	15,572	11,369	6,922	8,118	2,607	836	144	146	267,708
True fir	5,445	4,478	3,055	1,766	1,547	953	702	336	370	36	113	- -	- -	18,801
Engelmann and other spruces	3,973	2,829	2,723	1,512	1,141	953	549	367	514	36	- -	- -	- -	14,596
Other western softwoods	1,528	1,529	1,056	908	365	400	109	147	183	36	36	- -	- -	6,297
All softwoods	77,602	72,552	57,437	44,915	31,409	20,248	14,322	8,539	10,104	3,014	1,022	218	183	341,565
Hardwood species groups														
Western hardwood species groups														
Cottonwood and aspen	5,334	3,314	3,246	2,983	2,283	1,253	588	149	184	36	- -	36	36	19,442
Other western hardwoods	112	76	110	- -	37	- -	- -	- -	- -	- -	- -	- -	- -	334
All hardwoods	5,446	3,390	3,356	2,983	2,319	1,253	588	149	184	36	- -	36	36	19,776
All species groups	**83,047**	**75,942**	**60,793**	**47,899**	**33,728**	**21,501**	**14,911**	**8,688**	**10,288**	**3,050**	**1,022**	**254**	**219**	**361,341**

All table cells without observations in the inventory sample are indicated by --. Table value of 0 indicates the number of trees rounds to less than 1 thousand trees. Columns and rows may not add to their totals due to rounding.

Table B12—Net volume of all live trees (at least 5 inches d.b.h./d.r.c.), in million cubic feet, by owner class and forest land status, Arizona, 2005–2014.

	Unreserved forests			Reserved forests			All
Owner class	Timberland	Unproductive	Total	Productive	Unproductive	Total	forest land
Forest Service							
National Forest	4,332.4	2,859.6	7,192.1	195.5	298.0	493.4	7,685.5
Other Federal							
National Park Service	- -	- -	- -	200.4	161.9	362.4	362.4
Bureau of Land Management	26.7	260.9	287.6	16.7	321.2	338.0	625.6
U.S. Fish and Wildlife Service	- -	- -	- -	- -	20.3	20.3	20.3
Departments of Defense and Energy	51.5	11.4	62.9	- -	- -	- -	62.9
Other Federal	- -	0.1	0.1	- -	- -	- -	0.1
State and local government							
State	8.1	481.7	489.8	- -	- -	- -	489.8
County and municipal	3.4	4.7	8.1	- -	- -	- -	8.1
Private							
Undifferentiated private	1,777.2	3,522.3	5,299.5	- -	- -	- -	5,299.5
All owners	**6,199.3**	**7,140.8**	**13,340.0**	**412.6**	**801.5**	**1,214.1**	**14,554.1**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet. Columns and rows may not add to their totals due to rounding.

Table B13—Net volume of all live trees (at least 5 inches d.b.h./d.r.c.), in million cubic feet, on forest land by forest type group and stand-size class, Arizona, 2005–2014.

	Stand-size class				
Forest-type group	Large diameter	Medium diameter	Small diameter	Nonstocked	All size classes
Pinyon / juniper group	6,103.5	217.8	22.6	- -	6,343.9
Douglas-fir group	649.8	- -	- -	- -	649.8
Ponderosa pine group	4,913.5	47.8	19.4	- -	4,980.7
Fir / spruce / mountain hemlock group	565.6	- -	0.0	- -	565.7
Other western softwoods group	67.7	- -	- -	- -	67.7
Elm / ash / cottonwood group	69.4	0.2	0.1	- -	69.7
Aspen / birch group	234.9	26.1	25.2	- -	286.2
Other hardwoods group	1.8	1.7	- -	- -	3.5
Woodland hardwoods group	1,305.8	218.2	44.1	- -	1,568.1
Nonstocked	- -	- -	- -	19.0	19.0
All forest-type groups	**13,912.0**	**511.8**	**111.3**	**19.0**	**14,554.1**

All table cells without observations in the inventory sample are indicated by --.
Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet.
Columns and rows may not add to their totals due to rounding.

Table B14—Net volume of all live trees (at least 5 inches d.b.h./d.r.c.), in million cubic feet, on forest land by species group and ownership group, Arizona, 2005–2014.

	Ownership group				
Species group	Forest Service	Other Federal	State and local government	Undifferentiated private	All owners
Softwood species groups					
Western softwood species groups					
Douglas-fir	444.5	13.9	- -	200.3	658.7
Ponderosa and Jeffrey pine	3,676.9	203.9	11.5	1,353.5	5,245.8
True fir	192.6	19.9	- -	75.2	287.8
Engelmann and other spruces	145.3	28.2	- -	130.0	303.5
Other western softwoods	106.8	9.8	- -	18.1	134.6
Other					
Western woodland softwoods	2,141.6	670.1	374.7	2,866.7	6,053.0
All softwoods	6,707.7	945.6	386.2	4,643.8	12,683.4
Hardwood species groups					
Western hardwood species groups					
Cottonwood and aspen	144.0	36.7	0.7	201.4	382.7
Other western hardwoods	11.7	0.1	0.8	4.4	17.0
Other					
Western woodland hardwoods	822.2	88.8	110.2	449.9	1,471.1
All hardwoods	977.8	125.6	111.7	655.7	1,870.8
All species groups	**7,685.5**	**1,071.2**	**497.9**	**5,299.5**	**14,554.1**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet. Columns and rows may not add to their totals due to rounding.

Table B15—Net volume of all live trees (at least 5 inches d.b.h./d.r.c.), in million cubic feet, on forest land by species group and diameter class, Arizona, 2005–2014.

	Diameter class (inches)													
Species group	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-24.9	25.0-28.9	29.0-32.9	33.0-36.9	37.0+	All classes
Softwood species groups														
Western softwood species groups														
Douglas-fir	23	41	58	71	79	82	80	46	86	49	16	14	13	659
Ponderosa and Jeffrey pine	123	298	454	605	629	554	549	469	892	406	170	33	64	5,246
True fir	10	22	28	30	38	36	32	31	43	3	15	- -	- -	288
Engelmann and other spruces	8	17	33	33	37	47	35	31	58	4	- -	- -	- -	303
Other western softwoods	5	13	16	20	17	18	5	10	19	5	8	- -	- -	135
Other														
Western woodland softwoods	297	504	649	750	704	641	531	463	686	384	258	74	112	6,053
All softwoods	466	896	1,239	1,509	1,503	1,377	1,233	1,049	1,783	852	467	121	188	12,683
Hardwood species groups														
Western hardwood species groups														
Cottonwood and aspen	14	26	48	67	75	63	36	9	21	8	- -	8	8	383
Other western hardwoods	1	1	2	4	3	1	3	2	- -	- -	- -	- -	- -	17
Other														
Western woodland hardwoods	160	222	222	205	175	137	108	59	101	52	26	3	- -	1,471
All hardwoods	176	249	272	276	254	202	147	70	122	60	26	10	8	1,871
All species groups	**642**	**1,144**	**1,511**	**1,784**	**1,757**	**1,579**	**1,380**	**1,119**	**1,905**	**912**	**493**	**131**	**196**	**14,554**

All table cells without observations in the inventory sample are indicated by --. Table value of 0 indicates the volume rounds to less than 1 million cubic feet. Columns and rows may not add to their totals due to rounding.

Table B16—Net volume of all live trees (at least 5 inches d.b.h./d.r.c.), in million cubic feet, on forest land by forest type group and stand origin, Arizona, 2005–2014.

Forest-type group	Stand origin: Natural stands	Stand origin: Artificial regeneration	All forest land
Pinyon / juniper group	6,343.9	- -	6,343.9
Douglas-fir group	649.8	- -	649.8
Ponderosa pine group	4,980.7	- -	4,980.7
Fir / spruce / mountain hemlock group	565.7	- -	565.7
Other western softwoods group	67.7	- -	67.7
Elm / ash / cottonwood group	69.7	- -	69.7
Aspen / birch group	286.2	- -	286.2
Other hardwoods group	3.462662	- -	3.462662
Woodland hardwoods group	1,568.1	- -	1,568.1
Nonstocked	19.0	- -	19.0
All forest-type groups	**14,554.1**	**- -**	**14,554.1**

All table cells without observations in the inventory sample are indicated by --.
Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet.
Columns and rows may not add to their totals due to rounding.

Table B17—Net volume of growing stock trees (at least 5 inches d.b.h.), in million cubic feet, on timberland by species group and diameter class, Arizona, 2005–2014.

	Diameter class (inches)													
Species group	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-24.9	25.0-28.9	29.0-32.9	33.0-36.9	37.0+	All classes
Softwood species groups														
Western softwood species groups														
Douglas-fir	18	33	44	51	57	75	68	42	72	36	7	14	13	528
Ponderosa and Jeffrey pine	97	246	379	513	542	467	475	388	742	351	148	33	52	4,434
True fir	9	20	25	25	35	32	31	19	28	3	15	- -	- -	241
Engelmann and other spruces	7	15	29	26	30	39	30	27	55	4	- -	- -	- -	262
Other western softwoods	3	7	9	11	8	11	4	7	13	5	8	- -	- -	86
All softwoods	134	320	486	626	671	623	607	483	910	398	178	47	65	5,551
Hardwood species groups														
Western hardwood species groups														
Cottonwood and aspen	12	24	45	62	71	51	32	9	13	4	- -	8	8	339
Other western hardwoods	0	0	1	- -	0	- -	- -	- -	- -	- -	- -	- -	- -	2
All hardwoods	12	24	46	62	71	51	32	9	13	4	- -	8	8	341
All species groups	**147**	**344**	**533**	**688**	**742**	**675**	**639**	**492**	**924**	**402**	**178**	**55**	**74**	**5,891**

All table cells without observations in the inventory sample are indicated by --. Table value of 0 indicates the volume rounds to less than 1 million cubic feet. Columns and rows may not add to their totals due to rounding.

Table B18—Net volume of growing stock trees (at least 5 inches d.b.h.), in million cubic feet, on timberland by species group and ownership group, Arizona, 2005–2014.

	Ownership group				
Species group	Forest Service	Other Federal	State and local government	Undifferentiated private	All owners
Softwood species groups					
Western softwood species groups					
Douglas-fir	356.6	- -	- -	171.2	527.8
Ponderosa and Jeffrey pine	3,263.3	45.3	11.5	1,114.3	4,434.4
True fir	167.1	- -	- -	73.6	240.7
Engelmann and other spruces	131.5	- -	- -	130.0	261.6
Other western softwoods	69.0	4.4	- -	12.7	86.1
All softwoods	3,987.5	49.6	11.5	1,501.9	5,550.5
Hardwood species groups					
Western hardwood species groups					
Cottonwood and aspen	121.2	26.0	- -	191.6	338.9
Other western hardwoods	1.9	- -	- -	0.2	2.1
All hardwoods	123.1	26.0	- -	191.8	340.9
All species groups	**4,110.6**	**75.7**	**11.5**	**1,693.7**	**5,891.4**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet. Columns and rows may not add to their totals due to rounding.

Table B19—Net volume of sawtimber trees, in million board feet (International 1/4 inch rule), on timberland by species group and diameter class, Arizona, 2005–2014.

	Diameter class (inches)											
Species group	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-24.9	25.0-28.9	29.0-32.9	33.0-36.9	37.0+	All classes
Softwood species groups												
Western softwood species groups												
Douglas-fir	155	222	281	397	375	242	413	210	44	90	81	2,511
Ponderosa and Jeffrey pine	1,295	2,231	2,680	2,487	2,666	2,266	4,552	2,174	949	213	312	21,825
True fir	87	108	166	161	161	98	152	11	81	- -	- -	1,024
Engelmann and other spruces	125	128	165	217	170	158	318	23	- -	- -	- -	1,304
Other western softwoods	30	44	36	55	23	39	78	33	42	- -	- -	381
All softwoods	1,691	2,733	3,327	3,318	3,396	2,804	5,514	2,450	1,116	302	393	27,045
Hardwood species groups												
Western hardwood species groups												
Cottonwood and aspen	- -	325	405	307	186	47	82	21	- -	45	51	1,468
Other western hardwoods	- -	-	1	- -	- -	- -	- -	- -	- -	- -	- -	1
All hardwoods	- -	325	406	307	186	47	82	21	- -	45	51	1,469
All species groups	**1,691**	**3,058**	**3,733**	**3,625**	**3,582**	**2,851**	**5,596**	**2,471**	**1,116**	**347**	**444**	**28,514**

All table cells without observations in the inventory sample are indicated by --. Table value of 0 indicates the volume rounds to less than 1 million board feet. Columns and rows may not add to their totals due to rounding.

Table B20—Net volume of sawlog portion of sawtimber trees, in million cubic feet, on timberland by species group and ownership group, Arizona, 2005–2014.

	Ownership group				
Species group	Forest Service	Other Federal	State and local government	Undifferentiated private	All owners
Softwood species groups					
Western softwood species groups					
Douglas-fir	311.6	- -	- -	148.8	460.4
Ponderosa and Jeffrey pine	2,913.5	41.6	11.0	1,016.3	3,982.4
True fir	142.2	- -	- -	61.4	203.6
Engelmann and other spruces	116.2	- -	- -	113.0	229.2
Other western softwoods	59.0	4.3	- -	10.4	73.8
All softwoods	3,542.6	45.9	11.0	1,349.9	4,949.3
Hardwood species groups					
Western hardwood species groups					
Cottonwood and aspen	76.4	22.7	- -	126.6	225.6
Other western hardwoods	0.3	- -	- -	- -	0.3
All hardwoods	76.7	22.7	- -	126.6	226.0
All species groups	**3,619.3**	**68.6**	**11.0**	**1,476.4**	**5,175.3**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet. Columns and rows may not add to their totals due to rounding.

Table B21—Average annual net growth of all live trees (at least 5 inches d.b.h./d.r.c.), in million cubic feet, by owner class and forest land status, Arizona, 2005–2014.

	Unreserved forests			Reserved forests			All
Owner class	Timberland	Unproductive	Total	Productive	Unproductive	Total	forest land
Forest Service							
National Forest	-7.1	-34.1	-41.2	-12.4	-6.8	-19.2	-60.4
Other Federal							
National Park Service	- -	- -	- -	-3.9	-1.3	-5.2	-5.2
Bureau of Land Management	0.7	1.3	2.0	0.2	1.0	1.1	3.1
U.S. Fish and Wildlife Service	- -	- -	- -	- -	0.3	0.3	0.3
Departments of Defense and Energy	0.4	0.1	0.5	- -	- -	- -	0.5
Other Federal	- -	0.0	0.0	- -	- -	- -	0.0
State and local government							
State	0.2	2.3	2.6	- -	- -	- -	2.6
County and municipal	0.1	0.1	0.1	- -	- -	- -	0.1
Private							
Undifferentiated private	14.1	-8.7	5.4	- -	- -	- -	5.4
All owners	**8.4**	**-39.0**	**-30.7**	**-16.1**	**-6.9**	**-23.0**	**-53.6**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet. Columns and rows may not add to their totals due to rounding.

Table B22—Average annual net growth of all live trees (at least 5 inches d.b.h./d.r.c.), in million cubic feet, on forest land by forest type group and stand-size class, Arizona, 2005–2014.

	Stand-size class				
Forest-type group	Large diameter	Medium diameter	Small diameter	Nonstocked	All size classes
Pinyon / juniper group	-5.4	0.7	-3.5	- -	-8.2
Douglas-fir group	-5.4	- -	- -	- -	-5.4
Ponderosa pine group	38.6	0.1	-1.9	- -	36.8
Fir / spruce / mountain hemlock group	-9.6	- -	0.0	- -	-9.6
Other western softwoods group	0.7	- -	- -	- -	0.7
Elm / ash / cottonwood group	0.9	0.0	-0.1	- -	0.8
Aspen / birch group	3.3	0.6	-13.2	- -	-9.3
Other hardwoods group	0.1	-0.1	- -	- -	0.1
Woodland hardwoods group	-6.3	1.1	-24.0	- -	-29.1
Nonstocked	- -	- -	- -	-30.4	-30.4
All forest-type groups	**16.9**	**2.5**	**-42.6**	**-30.4**	**-53.6**

All table cells without observations in the inventory sample are indicated by --.
Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet.
Columns and rows may not add to their totals due to rounding.

Table B23—Average annual net growth of all live trees (at least 5 inches d.b.h./d.r.c.), in million cubic feet, on forest land by species group and ownership group, Arizona, 2005–2014.

	Ownership group				
Species group	Forest Service	Other Federal	State and local government	Undifferentiated private	All owners
Softwood species groups					
Western softwood species groups					
Douglas-fir	-9.5	-0.2	- -	0.2	-9.4
Ponderosa and Jeffrey pine	-4.4	0.8	0.3	12.7	9.4
True fir	-14.3	-1.1	- -	0.3	-15.1
Engelmann and other spruces	-4.7	-0.9	- -	-4.3	-9.9
Other western softwoods	0.0	-0.1	- -	0.2	0.2
Other					
Western woodland softwoods	-10.7	1.3	1.2	-3.5	-11.7
All softwoods	-43.6	-0.2	1.5	5.7	-36.5
Hardwood species groups					
Western hardwood species groups					
Cottonwood and aspen	-2.5	-1.5	0.0	1.1	-2.8
Other western hardwoods	0.2	0.0	0.1	-0.1	0.1
Other					
Western woodland hardwoods	-14.5	0.4	1.1	-1.3	-14.4
All hardwoods	-16.8	-1.1	1.1	-0.3	-17.1
All species groups	**-60.4**	**-1.3**	**2.7**	**5.4**	**-53.6**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet. Columns and rows may not add to their totals due to rounding.

Table B24—Average annual net growth of growing stock trees (at least 5 inches d.b.h.), in million cubic feet, on timberland by species group and ownership group, Arizona, 2005–2014.

	Ownership group				
Species group	Forest Service	Other Federal	State and local government	Undifferentiated private	All owners
Softwood species groups					
Western softwood species groups					
Douglas-fir	-6.2	- -	- -	2.3	-3.8
Ponderosa and Jeffrey pine	18.8	0.3	0.3	13.8	33.1
True fir	-10.6	- -	- -	1.6	-9.0
Engelmann and other spruces	-2.1	- -	- -	-4.3	-6.4
Other western softwoods	0.3	0.1	- -	0.4	0.8
All softwoods	0.1	0.4	0.3	13.9	14.6
Hardwood species groups					
Western hardwood species groups					
Cottonwood and aspen	-1.1	0.6	- -	1.1	0.6
Other western hardwoods	-0.1	- -	- -	0.0	0.0
All hardwoods	-1.2	0.6	- -	1.1	0.6
All species groups	**-1.1**	**1.0**	**0.3**	**15.0**	**15.2**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet. Columns and rows may not add to their totals due to rounding.

Table B25—Average annual mortality of trees (at least 5 inches d.b.h./d.r.c.), in million cubic feet, on forest land by owner class and forest land status, Arizona, 2005–2014

	Unreserved forests			Reserved forests			All
Owner class	Timberland	Unproductive	Total	Productive	Unproductive	Total	forest land
Forest Service							
National Forest	73.8	62.9	136.8	15.2	9.9	25.1	161.9
Other Federal							
National Park Service	- -	- -	- -	6.7	2.6	9.3	9.3
Bureau of Land Management	- -	1.0	1.0	- -	1.6	1.6	2.7
U.S. Fish and Wildlife Service	- -	- -	- -	- -	0.1	0.1	0.1
Departments of Defense and Energy	0.4	0.0	0.4	- -	- -	- -	0.4
State and local government							
State	- -	2.0	2.0	- -	- -	- -	2.0
County and municipal	- -	0.0	0.0	- -	- -	- -	0.0
Private							
Undifferentiated private	18.7	42.8	61.5	- -	- -	- -	61.5
All owners	**92.9**	**108.9**	**201.8**	**21.9**	**14.1**	**36.0**	**237.8**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet. Columns and rows may not add to their totals due to rounding.

Table B26—Average annual mortality of trees (at least 5 inches d.b.h./d.r.c.), in million cubic feet, on forest land by forest type group and stand-size class, Arizona, 2005–2014.

	Stand-size class				
Forest-type group	Large diameter	Medium diameter	Small diameter	Nonstocked	All size classes
Pinyon / juniper group	58.1	3.2	4.0	- -	65.3
Douglas-fir group	15.9	- -	- -	- -	15.9
Ponderosa pine group	36.1	1.1	2.4	- -	39.6
Fir / spruce / mountain hemlock group	20.7	- -	- -	- -	20.7
Other western softwoods group	0.4	- -	- -	- -	0.4
Elm / ash / cottonwood group	1.0	- -	0.1	- -	1.1
Aspen / birch group	1.5	0.0	13.7	- -	15.2
Other hardwoods group	- -	0.1	- -	- -	0.1
Woodland hardwoods group	20.6	2.9	25.0	- -	48.5
Nonstocked	- -	- -	- -	30.9	30.9
All forest-type groups	**154.4**	**7.3**	**45.1**	**30.9**	**237.8**

All table cells without observations in the inventory sample are indicated by --.
Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet.
Columns and rows may not add to their totals due to rounding.

Table B27—Average annual mortality of trees (at least 5 inches d.b.h./d.r.c.), in million cubic feet, on forest land by species group and ownership group, Arizona, 2005–2014.

	Ownership group				
Species group	Forest Service	Other Federal	State and local government	Undifferentiated private	All owners
Softwood species groups					
Western softwood species groups					
Douglas-fir	17.3	0.5	- -	4.1	21.9
Ponderosa and Jeffrey pine	58.2	1.6	- -	9.8	69.5
True fir	18.3	1.6	- -	2.2	22.0
Engelmann and other spruces	7.2	1.3	- -	6.9	15.3
Other western softwoods	1.7	0.2	- -	0.3	2.2
Other					
Western woodland softwoods	30.6	4.1	1.8	28.6	65.2
All softwoods	133.3	9.3	1.8	51.8	196.2
Hardwood species groups					
Western hardwood species groups					
Cottonwood and aspen	5.6	2.3	- -	3.0	11.0
Other western hardwoods	0.1	- -	- -	0.2	0.3
Other					
Western woodland hardwoods	22.9	0.7	0.2	6.5	30.3
All hardwoods	28.6	3.1	0.2	9.7	41.5
All species groups	**161.9**	**12.4**	**2.0**	**61.5**	**237.8**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet. Columns and rows may not add to their totals due to rounding.

Table B28—Average annual mortality of growing stock trees (at least 5 inches d.b.h.), in million cubic feet, on timberland by species group and ownership group, Arizona, 2005–2014.

	Ownership group				
Species group	Forest Service	Other Federal	State and local government	Undifferentiated private	All owners
Softwood species groups					
Western softwood species groups					
Douglas-fir	12.5	- -	- -	1.2	13.7
Ponderosa and Jeffrey pine	29.3	0.4	- -	4.7	34.3
True fir	14.1	- -	- -	0.9	14.9
Engelmann and other spruces	4.4	- -	- -	6.9	11.2
Other western softwoods	0.9	- -	- -	0.0	0.9
All softwoods	61.1	0.4	- -	13.7	75.1
Hardwood species groups					
Western hardwood species groups					
Cottonwood and aspen	3.9	- -	- -	2.7	6.5
Other western hardwoods	0.1	- -	- -	- -	0.1
All hardwoods	4.0	- -	- -	2.7	6.6
All species groups	**65.0**	**0.4**	**- -**	**16.3**	**81.7**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic feet. Columns and rows may not add to their totals due to rounding.

Table B29—Aboveground dry weight of all live trees (at least 1 inch d.b.h./d.r.c.), in thousand dry short tons, by owner class and forest land status, Arizona, 2005–2014.

	Unreserved forests			Reserved forests			All
Owner class	Timberland	Unproductive	Total	Productive	Unproductive	Total	forest land
Forest Service							
National Forest	79,426	52,202	131,627	3,713	5,670	9,382	141,010
Other Federal							
National Park Service	- -	- -	- -	3,630	3,183	6,812	6,812
Bureau of Land Management	504	5,055	5,559	307	6,164	6,471	12,030
U.S. Fish and Wildlife Service	- -	- -	- -	- -	565	565	565
Departments of Defense and Energy	934	234	1,168	- -	- -	- -	1,168
Other Federal	- -	2	2	- -	- -	- -	2
State and local government							
State							
County and Municipal	61	203	264	- -	- -	- -	264
Private							
Undifferentiated private	32,334	64,609	96,943	- -	- -	- -	96,943
All owners	**113,408**	**131,903**	**245,312**	**7,650**	**15,581**	**23,230**	**268,542**

All table cells without observations in the inventory sample are indicated by --. Table value of 0 indicates the aboveground tree biomass rounds to less than 1 thousand dry tons. Columns and rows may not add to their totals due to rounding.

Table B30—Aboveground dry weight of all live trees (at least 1 inch d.b.h./d.r.c.), in thousand dry short tons, on forest land by species group and diameter class, Arizona, 2005–2014.

	Diameter class (inches)															
Species group	1.0-2.9	3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-22.9	23.0-24.9	25.0-26.9	27.0-28.9	29.0+	All classes
Softwood species groups																
Western softwood species groups																
Douglas-fir	99	212	476	847	1,186	1,435	1,585	1,630	1,594	909	984	701	472	487	840	13,457
Ponderosa and Jeffrey pine	283	1,126	2,314	5,482	8,240	10,866	11,217	9,829	9,705	8,261	8,171	7,501	4,308	2,807	4,652	94,763
True fir	84	186	174	369	472	491	620	588	523	505	328	367	43	- -	247	4,997
Engelmann and other spruces	43	171	128	264	501	506	553	708	522	453	583	271	56	- -	- -	4,759
Other western softwoods	25	83	102	244	294	356	304	320	100	179	284	58	- -	101	139	2,588
Other																
Western woodland softwoods	1,590	2,906	4,680	7,993	10,366	12,212	11,570	10,810	9,072	7,974	6,303	5,584	3,827	2,827	7,486	105,201
All softwoods	2,124	4,683	7,873	15,199	21,059	25,864	25,849	23,886	21,516	18,281	16,654	14,483	8,706	6,223	13,364	225,765
Hardwood species groups																
Western hardwood species groups																
Cottonwood and aspen	216	350	295	491	877	1,175	1,292	1,056	602	155	295	70	69	72	298	7,315
Other western hardwoods	48	76	36	11	30	80	71	27	64	41	- -	- -	- -	- -	- -	484
Other																
Western woodland hardwoods	2,497	3,650	3,141	4,364	4,383	4,059	3,420	2,676	2,116	1,170	1,163	784	647	341	568	34,978
All hardwoods	2,761	4,076	3,472	4,867	5,290	5,315	4,783	3,759	2,782	1,366	1,458	854	716	413	866	42,777
All species groups	**4,885**	**8,759**	**11,345**	**20,065**	**26,350**	**31,179**	**30,632**	**27,645**	**24,298**	**19,648**	**18,112**	**15,337**	**9,422**	**6,636**	**14,230**	**268,542**

All table cells without observations in the inventory sample are indicated by --. Table value of 0 indicates the aboveground tree biomass rounds to less than 1 thousand dry tons. Columns and rows may not add to their totals due to rounding.

Table B31—Area of accessible forest land, in thousand acres, by Forest Survey Unit, county and forest land status, Arizona, 2005–2014.

	Unreserved forests			Reserved forests			All
Inventory unit and county	Timberland	Unproductive	Total	Productive	Unproductive	Total	forest land
Southern							
Cochise	7.2	853.6	860.8	18.0	111.2	129.2	990.0
Graham	91.9	765.5	857.4	7.6	80.3	87.9	945.3
Greenlee	141.0	499.1	640.0	12.0	6.0	17.9	658.0
La Paz	- -	4.6	4.6	- -	- -	- -	4.6
Maricopa	1.3	63.2	64.5	- -	17.0	17.0	81.5
Pima	13.1	618.0	631.1	6.6	187.6	194.1	825.3
Pinal	4.7	187.5	192.2	6.9	13.7	20.6	212.8
Santa Cruz	- -	359.6	359.6	- -	24.0	24.0	383.7
Yuma	- -	16.1	16.1	- -	- -	- -	16.1
Total	259.1	3,367.3	3,626.4	51.0	439.8	490.8	4,117.2
Northern							
Apache	876.6	2,015.6	2,892.2	18.5	- -	18.5	2,910.7
Coconino	1,435.7	2,687.3	4,123.0	107.5	267.8	375.4	4,498.3
Gila	115.9	1,515.1	1,630.9	6.1	123.2	129.3	1,760.3
Mohave	- -	902.9	902.9	12.2	562.7	575.0	1,477.8
Navajo	252.3	1,895.4	2,147.6	- -	- -	- -	2,147.6
Yavapai	49.0	1,535.6	1,584.7	13.0	96.7	109.7	1,694.4
Total	2,729.5	10,551.7	13,281.3	157.4	1,050.5	1,207.9	14,489.2
All counties	**2,988.6**	**13,919.0**	**16,907.6**	**208.4**	**1,490.3**	**1,698.7**	**18,606.4**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the acres round to less than 0.1 thousand acres. Columns and rows may not add to their totals due to rounding.

Table B32—Area of accessible forest land, in thousand acres, by Forest Survey Unit, county, ownership group and forest land status, Arizona, 2005–2014.

Inventory unit and county	Forest Service		Other Federal		State and local government		Undifferentiated private		All forest land
	Timber-land	Other forest land	Timber-land	Other forest land	Timber-land	Other forest land	Timber-land	Other forest land	
Southern									
Cochise	- -	354.7	7.2	130.6	- -	247.6	- -	249.9	990.0
Graham	35.7	250.2	- -	121.2	- -	77.1	56.2	405.0	945.3
Greenlee	136.5	446.2	- -	37.5	- -	18.3	4.5	14.9	658.0
La Paz	- -	- -	- -	4.6	- -	- -	- -	- -	4.6
Maricopa	1.3	54.5	- -	3.0	- -	3.0	- -	19.6	81.5
Pima	13.1	206.9	- -	172.2	- -	355.4	- -	77.7	825.3
Pinal	- -	49.6	- -	26.2	- -	78.7	4.7	53.6	212.8
Santa Cruz	- -	298.8	- -	-	- -	31.1	- -	53.7	383.7
Yuma	- -	- -	- -	-	- -	5.8	- -	10.2	16.1
Total	186.6	1,661.0	7.2	495.4	- -	817.0	65.3	884.7	4,117.2
Northern									
Apache	345.7	87.9	- -	23.4	- -	165.5	531.0	1,757.4	2,910.7
Coconino	1,367.4	1,494.5	25.3	316.4	6.6	210.8	36.5	1,041.0	4,498.3
Gila	105.7	1,017.4	- -	- -	- -	7.6	10.1	619.3	1,760.3
Mohave	- -	- -	- -	1,026.9	- -	153.0	-	297.9	1,477.8
Navajo	135.7	268.8	- -	11.4	- -	45.0	116.6	1,570.2	2,147.6
Yavapai	41.0	975.4	- -	28.0	1.5	266.0	6.5	375.9	1,694.4
Total	1,995.5	3,844.1	25.3	1,406.0	8.1	847.8	700.7	5,661.7	14,489.2
All counties	**2,182.1**	**5,505.1**	**32.5**	**1,901.5**	**8.1**	**1,664.8**	**766.0**	**6,546.4**	**18,606.4**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the acres round to less than 0.1 thousand acres. Columns and rows may not add to their totals due to rounding.

Table B33—Area of timberland, in thousand acres, by Forest Survey Unit, county and stand-size class, Arizona, 2005–2014.

Inventory unit and county		Stand-size class: Large diameter	Medium diameter	Small diameter	Nonstocked	All size classes
Southern						
	Cochise	7.2	- -	- -	- -	7.2
	Graham	78.2	6.1	6.1	1.5	91.9
	Greenlee	129.0	6.0	6.0	- -	141.0
	Maricopa	- -	- -	1.3	- -	1.3
	Pima	1.6	- -	11.5	- -	13.1
	Pinal	4.7	- -	- -	- -	4.7
	Total	220.7	12.1	24.8	1.5	259.1
Northern						
	Apache	780.1	24.7	31.7	40.1	876.6
	Coconino	1,330.6	1.5	46.9	56.7	1,435.7
	Gila	109.8	- -	3.0	3.0	115.9
	Navajo	189.0	19.5	22.7	21.1	252.3
	Yavapai	47.5	- -	1.5	- -	49.0
	Total	2,457.0	45.7	105.9	121.0	2,729.5
All counties		**2,677.7**	**57.7**	**130.8**	**122.5**	**2,988.6**

All table cells without observations in the inventory sample are indicated by --.
Table value of 0.0 indicates the acres round to less than 0.1 thousand acres.
Columns and rows may not add to their totals due to rounding.

Table B34—Area of timberland, in thousand acres, by Forest Survey Unit, county and stocking class, Arizona, 2005–2014.

Inventory unit and county		Stocking class of growing-stock trees: Nonstocked	Poorly stocked	Moderately stocked	Fully stocked	Over-stocked	All classes
Southern							
	Cochise	- -	- -	- -	7.2	- -	7.2
	Graham	1.5	24.3	45.6	14.4	6.1	91.9
	Greenlee	1.5	35.9	85.7	17.9	- -	141.0
	Maricopa	- -	- -	- -	- -	1.3	1.3
	Pima	- -	- -	1.6	11.5	- -	13.1
	Pinal	- -	- -	4.7	- -	- -	4.7
	Total	3.0	60.2	137.6	51.0	7.4	259.1
Northern							
	Apache	53.4	297.9	289.2	211.4	24.7	876.6
	Coconino	68.7	428.3	584.9	341.7	12.2	1,435.7
	Gila	3.0	49.7	44.0	19.1	- -	115.9
	Navajo	27.6	108.8	82.0	32.3	1.6	252.3
	Yavapai	- -	13.0	26.1	9.9	- -	49.0
	Total	152.7	897.6	1,026.2	614.4	38.6	2,729.5
All counties		**155.7**	**957.8**	**1,163.8**	**665.4**	**45.9**	**2,988.6**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the acres round to less than 0.1 thousand acres. Columns and rows may not add to their totals due to rounding.

Table B35—Net volume of growing stock trees (at least 5 inches d.b.h.), in million cubic feet, and sawtimber trees, in million board feet (International 1/4 inch rule), on timberland by Forest Survey Unit, county, and major species group, Arizona, 2005–2014.

Inventory unit and county	Growing stock					Sawtimber				
	Major species group					Major species group				
	Pine	Other softwoods	Soft hardwoods	Hard hardwoods	All species	Pine	Other softwoods	Soft hardwoods	Hard hardwoods	All species
	(In million cubic feet)					(In million board feet)				
Southern										
Cochise	4.4	- -	- -	26.0	30.4	24.3	- -	- -	151.7	176.0
Graham	145.5	67.3	4.8	- -	217.7	737.5	352.5	15.2	- -	1,105.2
Greenlee	231.0	66.0	9.0	- -	306.0	1,126.7	312.9	55.0	- -	1,494.6
Pima	- -	11.7	- -	- -	11.7	- -	63.4	- -	- -	63.4
Pinal	- -	- -	- -	5.5	5.5	- -	- -	- -	15.9	15.9
Total	381.0	145.0	13.8	31.6	571.3	1,888.5	728.8	70.3	167.6	2,855.1
Northern										
Apache	1,123.1	568.9	225.9	- -	1,918.0	5,553.6	2,662.5	970.0	- -	9,186.1
Coconino	2,453.7	228.4	56.0	- -	2,738.0	12,122.1	1,034.1	216.8	- -	13,373.1
Gila	178.1	28.9	4.4	7.4	218.9	868.3	139.7	16.7	23.4	1,048.1
Navajo	319.6	17.8	0.2	1.5	339.1	1,459.8	73.3	- -	4.6	1,537.7
Yavapai	65.0	41.1	- -	- -	106.1	314.0	200.2	- -	- -	514.3
Total	4,139.5	885.1	286.6	9.0	5,320.1	20,317.8	4,109.9	1,203.6	28.0	25,659.2
All counties	**4,520.5**	**1,030.1**	**300.4**	**40.6**	**5,891.4**	**22,206.3**	**4,838.7**	**1,273.8**	**195.5**	**28,514.3**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic or board feet. Columns and rows may not add to their totals due to rounding.

Table B36—Average annual net growth of growing stock trees (at least 5 inches d.b.h.), in million cubic feet, and sawtimber trees, in million board feet (International 1/4 inch rule), on timberland by Forest Survey Unit, county, and major species group, Arizona, 2005–2014.

Inventory unit and county	Growing stock					Sawtimber				
	Major species group					Major species group				
	Pine	Other softwoods	Soft hardwoods	Hard hardwoods	All species	Pine	Other softwoods	Soft hardwoods	Hard hardwoods	All species
	(In million cubic feet)					(In million board feet)				
Southern										
Cochise	0.1	- -	- -	0.6	0.7	0.4	- -	- -	3.8	4.2
Graham	1.6	-4.1	0.1	- -	-2.4	12.6	-23.2	0.4	- -	-10.2
Greenlee	0.5	-2.6	0.0	- -	-2.1	5.1	-10.8	0.3	0.0	-5.4
Pima	- -	-0.6	- -	- -	-0.6	- -	-2.6	- -	- -	-2.6
Pinal	- -	- -	- -	0.1	0.1	- -	- -	- -	0.2	0.2
Total	2.2	-7.4	0.1	0.7	-4.4	18.1	-36.6	0.7	4.0	-13.8
Northern										
Apache	11.1	-6.0	1.1	- -	6.2	80.6	-7.6	25.5	- -	98.5
Coconino	21.9	-5.5	-1.4	- -	15.0	148.4	-19.5	-3.3	- -	125.6
Gila	-0.3	0.1	0.0	0.2	0.0	1.7	2.4	0.0	6.8	10.9
Navajo	-0.2	-0.4	0.0	0.0	-0.6	12.5	0.2	- -	-0.1	12.7
Yavapai	-0.7	-0.2	- -	- -	-0.9	-1.4	0.2	- -	- -	-1.2
Total	31.7	-11.9	-0.4	0.2	19.6	241.8	-24.3	22.3	6.7	246.5
All counties	**33.9**	**-19.3**	**-0.3**	**0.9**	**15.2**	**259.9**	**-60.9**	**22.9**	**10.7**	**232.6**

All table cells without observations in the inventory sample are indicated by --. Table value of 0.0 indicates the volume rounds to less than 0.1 million cubic or board feet. Columns and rows may not add to their totals due to rounding.

Table B37—Sampling errors by Forest Survey Unit and county for area of timberland, volume, average annual net growth, average annual removals, and average annual mortality on timberland, Arizona, 2005–2014.

Inventory unit and county	Forest area	Timberland area	Growing stock (on timberland)				Sawtimber (on timberland)			
			Volume	Growth	Removals	Mortality	Volume	Growth	Removals	Mortality
Southern										
Cochise	6.0	84.8	90.0	95.0	- -	- -	90.5	94.6	- -	- -
Graham	5.2	24.2	29.7	100.0	- -	48.9	30.6	100.0	- -	51.8
Greenlee	4.4	18.4	22.5	100.0	- -	43.2	24.1	100.0	- -	45.2
La Paz	100.0	- -	- -	- -	- -	- -	- -	- -	- -	- -
Maricopa	23.9	100.0	- -	- -	- -	- -	- -	- -	- -	- -
Pima	7.9	77.6	100.0	100.0	- -	100.0	100.0	100.0	- -	100.0
Pinal	14.9	100.0	100.0	100.0	- -	100.0	100.0	100.0	- -	- -
Santa Cruz	8.0	- -	- -	- -	- -	- -	- -	- -	- -	- -
Yuma	55.2	- -	- -	- -	- -	- -	- -	- -	- -	- -
Total	2.8	14.1	17.4	84.7	- -	31.0	18.4	100.0	- -	33.2
Northern										
Apache	2.2	6.8	9.4	84.1	- -	17.1	9.8	27.2	- -	17.9
Coconino	1.6	5.4	6.7	35.2	- -	17.7	7.1	22.6	- -	20.4
Gila	3.2	21.6	25.2	100.0	- -	44.4	26.2	97.5	- -	51.6
Mohave	4.3	- -	- -	- -	- -	- -	- -	- -	- -	- -
Navajo	3.0	14.4	18.7	100.0	- -	31.0	20.2	73.1	- -	34.0
Yavapai	4.3	34.6	40.4	100.0	- -	61.3	40.4	100.0	- -	63.1
Total	1.1	4.0	5.2	40.3	- -	11.0	5.4	16.9	- -	12.2
All counties	1.1	3.8	5.0	57.5	- -	10.4	5.2	19.9	- -	11.6

All table cells without observations in the inventory sample are indicated by --. Sampling errors that exceed 100% are reported as 100%.

Appendix C: Arizona Forest-Type Groups and Forest Types, With Descriptions and Timber (T) or Woodland (W) Designations

Forest-type groups and forest types are usually named for the predominant species (or group of species) on the condition. In order to determine the forest type, the stocking (site occupancy) of trees is estimated by softwoods and hardwoods. If softwoods predominate, then the forest type will be one of the softwood types and if hardwoods predominate, then the forest type will be one of the hardwood types. Some other special stocking rules apply to individual forest types and are described below.

Associate species are defined as those that regularly form the majority of the non-predominant species stocking of mixed-species conditions. These descriptions are applicable to the current inventory; species importance, including predominance in some cases, will vary for other States or inventory years. When species are listed, they are in decreasing order of overall forest type stocking.

Aspen/Birch Group (T)

Aspen

Predominant species: quaking aspen

Associate species: ponderosa pine, Douglas-fir, Engelmann spruce,

Other species: blue spruce, white fir, corkbark fir, southwestern white pine, limber pine, bigtooth maple, subalpine fir

Douglas-Fir Group (T)

Douglas-fir

Predominant species: Douglas-fir

Associate species: ponderosa pine, quaking aspen, white fir, Gambel oak, southwestern white pine

Other species: Engelmann spruce, corkbark fir, netleaf oak, Arizona white oak, limber pine, border pinyon, Mexican pinyon pine, common or two-needle pinyon, blue spruce, alligator juniper, silverleaf oak, Rocky Mountain juniper, bigtooth maple, Arizona walnut

ELM/Ash/Cottonwood Group (T)

Cottonwood

Predominant species: Fremont cottonwood, narrowleaf cottonwood

Associate species: none identified

Other species: oneseed juniper, Emory oak, Utah juniper, Arizona white oak, honey mesquite, Arizona walnut, boxelder, velvet mesquite

Special rules: Stocking of cottonwoods must be at least 50 percent of total stocking.

Cottonwood/willow

Predominant species: Fremont cottonwood, narrowleaf cottonwood

Associate species: none identified

Other species: ponderosa pine, Arizona walnut, Gambel oak, Emory oak, Rocky Mountain juniper, Arizona alder, alligator juniper, Arizona white oak, Arizona pinyon pine

Special rules: Stocking of cottonwoods is less than 50 percent, but predominant. In order to meet 50 percent hardwood stocking, other hardwoods must be present.

Fir/Spruce/Mountain Hemlock Group (T)

Blue spruce

Predominant species: blue spruce

Associate species: quaking aspen, ponderosa pine, Douglas-fir, white fir

Other species: subalpine fir, southwestern white pine, Engelmann spruce

Engelmann spruce

Predominant species: Engelmann spruce

Associate species: Douglas-fir, quaking aspen, corkbark fir, white fir, subalpine fir

Other species: ponderosa pine, southwestern white pine, blue spruce

Special rules: In order to use Engelmann spruce stocking predominance, subalpine fir and/or corkbark fir stocking must be less than 5 percent of the total. If subalpine fir and/or corkbark fir stocking is 5 percent or more, Engelmann spruce stocking must be at least 75 percent of the total.

Engelmann spruce/subalpine fir

Predominant species: Engelmann spruce, corkbark fir, subalpine fir

Associate species: quaking aspen, Douglas-fir, white fir

Other species: ponderosa pine, southwestern white pine, Gambel oak

Special rules: The combined stocking of Engelmann spruce with subalpine fir and/or corkbark fir is predominant. Stocking of both Engelmann spruce and subalpine fir/corkbark fir must each be between 5 and 74 percent of the total.

White fir

Predominant species: white fir

Associate species: quaking aspen, Douglas-fir, ponderosa pine, southwestern white pine

Other species: Engelmann spruce, bigtooth maple, Gambel oak, corkbark fir, velvet ash

Nonstocked

Nonstocked

Predominant species: various, most commonly velvet mesquite, but many nonstocked conditions have no live-tree stocking.

Associate species: various, frequently common or two-needle pinyon

Other species: seldom more than two species on a condition. Complete species list: velvet mesquite, Utah juniper, oneseed juniper, common or two-needle pinyon, ponderosa pine, Arizona white oak, Emory oak, redberry juniper, alligator juniper, honey mesquite, singleleaf pinyon, Mexican blue oak, Mexican pinyon pine, Engelmann spruce, California juniper

Special rules: Used when all live stocking is less than 10 percent. Implies disturbance, but may be used for sparse stands with no disturbance, especially with woodland species.

Other Hardwoods Group (T)

Other hardwoods

Predominant species: velvet ash, Arizona walnut, Arizona sycamore

Associate species: none identified

Other species: Gambel oak, oneseed juniper, Utah juniper, velvet mesquite, alligator juniper, Fremont cottonwood, Arizona pinyon pine

Special rules: A “catch-all” type, typically for hardwood species with a limited geographical range. Arizona alder and Arizona madrone are also evaluated for this forest type, but did not determine or appear in the forest type in this inventory.

Other Western Sofwoods Group (T)

Limber pine

Predominant species: limber pine
Associate species: too few occurrences to evaluate
Other species: quaking aspen, corkbark fir, Engelmann spruce

Miscellaneous western softwoods

Predominant species: Arizona cypress, Chihuahuan pine, Apache pine

Associate species: none identified

Other species: Arizona pinyon pine, ponderosa pine, silverleaf oak, netleaf oak, alligator juniper, Douglas-fir, Emory oak, Mexican pinyon pine, Gambel oak, Arizona white oak, Arizona madrone, velvet ash

Special rules: A "catch-all" type, typically for softwood species with a limited geographical range.

Southwestern white pine

Predominant species: southwestern white pine

Associate species: none identified

Other species: Apache pine, silverleaf oak, quaking aspen, white fir, Douglas-fir, Arizona white oak, ponderosa pine, bigtooth maple

Pinyon/Juniper Group (W)

Juniper woodland

Predominant species: Utah juniper, oneseed juniper, alligator juniper, redberry juniper, California juniper

Associate species: Arizona white oak, ponderosa pine, velvet mesquite

Other species: Gambel oak, Emory oak, Douglas-fir, honey mesquite, Rocky Mountain juniper, Arizona walnut, Chihuahuan pine, silverleaf oak

Special rules: Predominance of any combination of junipers other than Rocky Mountain juniper, and live pinyons are NOT present.

Pinyon/juniper woodland

Predominant species: Utah juniper, common or two-needle pinyon, oneseed juniper, alligator juniper, Arizona pinyon pine, singleleaf pinyon, redberry juniper, border pinyon, Mexican pinyon pine

Associate species: Arizona white oak, ponderosa pine

Other species: Gambel oak, Emory oak, Rocky Mountain juniper, silverleaf oak, netleaf oak, gray oak, Arizona cypress, Douglas-fir, Arizona sycamore, white fir, velvet mesquite, Chihuahuan pine, Mexican blue oak, velvet ash, honey mesquite, Arizona walnut

Special rules: Any combination of pinyons and junipers other than Rocky Mountain juniper predominate. Pinyons must be present.

Rocky Mountain juniper

Predominant species: Rocky Mountain juniper

Associate species: ponderosa pine, Gambel oak, alligator juniper, Arizona white oak, Douglas-fir, common or two-needle pinyon

Other species: Utah juniper, Arizona sycamore, Emory oak, oneseed juniper, Arizona alder, Arizona pinyon pine

Ponderosa Pine Group (T)

Ponderosa pine

Predominant species: ponderosa pine, Arizona pine

Associate species: Gambel oak, alligator juniper, Douglas-fir, Arizona white oak, quaking aspen, Rocky Mountain juniper

Other species: white fir, common or two-needle pinyon, southwestern white pine, Utah juniper, Emory oak, Engelmann spruce, netleaf oak, blue spruce, bigtooth maple, oneseed juniper, silverleaf oak, limber pine, border pinyon, subalpine fir, gray oak, Mexican pinyon pine, Arizona walnut, corkbark fir, Chihuahuan pine, Arizona madrone, singleleaf pinyon

Woodland Hardwoods Group (W)

Deciduous oak woodland

Predominant species: Gambel oak

Associate species: ponderosa pine, alligator juniper, Arizona white oak, common or two-needle pinyon, Douglas-fir, Emory oak

Other species: bigtooth maple, Rocky Mountain juniper, white fir, boxelder, southwestern white pine, quaking aspen, oneseed juniper, Utah juniper, netleaf oak, Arizona cypress, velvet ash, Arizona walnut, Chihuahuan pine, silverleaf oak

Special rules: Gambel oak is the only species evaluated for this type.

Evergreen oak woodland

Predominant species: Arizona white oak, Emory oak, silverleaf oak, Mexican blue oak, netleaf oak, gray oak

Associate species: alligator juniper, ponderosa pine, Mexican pinyon pine, common or two-needle pinyon, Gambel oak, Utah juniper, border pinyon, Arizona pinyon pine

Other species: redberry juniper, velvet mesquite, Rocky Mountain juniper, oneseed juniper, Arizona madrone, Douglas-fir, Chihuahuan pine, Arizona alder, Apache pine, Arizona sycamore, southwestern white pine, Arizona pine, Arizona cypress, honey mesquite, Arizona walnut, velvet ash

Special rules: Any combination of southwestern evergreen oaks. The only Arizona oak not included is Gambel oak.

Intermountain maple woodland

Predominant species: bigtooth maple

Associate species: too few occurrences to evaluate

Other species: Gambel oak

Special rules: Currently, bigtooth maple is the only species evaluated for this type. In the previous periodic inventory, Rocky Mountain maple was included.

Mesquite woodland

Predominant species: honey mesquite, velvet mesquite, screwbean mesquite

Associate species: none identified

Other species: redberry juniper, Mexican blue oak, Fremont cottonwood, sugarberry, Emory oak, oneseed juniper, Utah juniper, velvet ash, Arizona walnut

Appendix D: Tree Species Groups and Tree Species Measured in Arizona's Annual Inventory, With Common Name, Scientific Name, and Timber (T) or Woodland (W) Designation

Hardwoods

Cottonwood and aspen group (T)

Fremont cottonwood (*Populus fremontii*)
Narrowleaf cottonwood (*Populus angustifolia*)
Quaking aspen (*Populus tremuloides*)

Other western hardwoods group (T)

Arizona alder (*Alnus oblongifolia*)
Arizona madrone (*Arbutus arizonica*)
Arizona sycamore (*Platinus wrightii*)
Arizona walnut (*Juglans major*)
Boxelder (*Acer negundo*)
Sugarberry (*Celtis laevigata*)
Velvet ash (*Fraxinus velutina*)

Woodland hardwoods group (W)

Arizona white oak (*Quercus arizonica*)
Bigtooth maple (*Acer grandidentatum*)
Emory oak (*Quercus emoryi*)
Gambel oak (*Quercus gambelii*)
Gray oak (*Quercus grisea*)
Honey mesquite (*Prosopis glandulosa*)
Mexican blue oak (*Quercus oblongifolia*)
Netleaf oak (*Quercus rugosa*)
Screwbean mesquite (*Prosopis pubescens*)
Silverleaf oak (*Quercus hypoleucoides*)
Velvet mesquite (*Prosopis velutina*)

Softwoods

Douglas-fir group (T)

Douglas-fir (*Pseudotsuga menziesii*)

Engelmann and other spruces group (T)

Blue spruce (*Picea pungens*)
Engelmann spruce (*Picea engelmannii*)

Other western softwoods group (T)

Apache pine (*Pinus engelmannii*)
Arizona cypress (*Cupressus arizonica*)
Chihuahua pine (*Pinus leiophylla*)
Limber pine (*Pinus flexilis*)
Southwestern white pine (*Pinus strobiformis*)

Ponderosa and Jeffrey pines group (T)

Arizona pine (*Pinus arizonica*)
Ponderosa pine (*Pinus ponderosa*)

True fir group (T)

Corkbark fir (*Abies lasiocarpa* var. *arizonica*)
Subalpine fir (*Abies lasiocarpa*)
White fir (*Abies concolor*)

Woodland softwoods group (W)

Alligator juniper (*Juniperus deppeana*)
Arizona pinyon pine (*Pinus monophylla* var. *fallax*)
Border pinyon (*Pinus dicolor*)
California juniper (*Juniperus califonica*)
Common or two-needle pinyon (*Pinus edulis*)
Mexican pinyon pine (*Pinus cembroides*)
Oneseed juniper (*Juniperus monosperma*)
Redberry juniper (*Juniperus coahuilensis*)
Rocky Mountain juniper (*Juniperus scopulorum*)
Singleleaf pinyon (*Pinus monophylla*)
Utah juniper (*Juniperus osteosperma*)

Appendix E: Volume and Site Index Equation Sources

Volume

Chojnacky 1988 was used for bigtooth maple, honey mesquite, velvet mesquite, Arizona white oak, Emory oak, Gambel oak, Mexican blue oak, silverleaf oak, gray oak, and netleaf oak volume estimation.

Chojnacky 1994 was used for Pinchot juniper, redberry juniper, alligator juniper, Utah juniper, Rocky Mountain juniper, oneseed juniper, common pinyon, Mexican pinyon, and Arizona pinyon volume estimation.

Hann and Bare 1978 was used for white fir, corkbark fir, Engelmann spruce, blue spruce, bristlecone pine, limber pine, southwestern white pine, Chihuahuan pine, ponderosa pine, Douglas-fir, and aspen volume estimation.

Kemp 1956 was used for narrowleaf cottonwood and Fremont cottonwood volume estimation.

Volume equations provided by the USDA Forest Service's Northern Research Station were used for boxelder, velvet ash, Arizona walnut, chinkapin oak, and Siberian elm volume estimation. [Documentation on file at Rocky Mountain Research Station, Ogden, UT.]

Site Index

Brickell 1968 was used for Douglas-fir site index estimation.

Brickell 1970 was used for bristlecone pine, limber pine, Chihuahua pine, ponderosa pine, and southwestern white pine site index estimation.

Clendenen 1977 was used for subalpine fir, corkbark fir, Engelmann spruce, and blue spruce site index estimation.

Edminster et al. 1985 was used for boxelder, velvet ash, narrowleaf cottonwood, Fremont cottonwood, aspen, gray oak, chinkapin oak, netleaf oak, and Siberian elm site index estimation.

McArdle et al. 1961 was used for white fir site index estimation

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