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RESEARCH ARTICLE

Forest Vegetation and Development Patterns in Secondary Stands on the Alabama Highland Rim: an Examination of the Largest Landholding in the Region

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ABSTRACT: Redstone Arsenal (RA) is a large federal landholding (15,050 ha) managed by the U.S. Department of the Army located on the Highland Rim of north Alabama. This large landholding provided a unique opportunity to document forest vegetation and development patterns in a region with a paucity of quantitative information. In this study, we quantified land cover types, delineated forest stands on the reserve using a GIS, and assessed forest composition and structural measures. Stands were classed into *Pinus*, hardwood, mixed *Pinus*-hardwood, and forested wetland types. The majority of land area in stands ≥ 2 ha was hardwood dominated, while the majority of the land area in stands < 2 ha was *Pinus* dominated. We used a stratified random scheme to establish sampling points (n = 684) within forest stands through the RA. *Pinus taeda, Liquidambar styraciflua*, and *Quercus phellos* were the three most important tree species in the RA forest. Biodiversity for the forest was relatively high with a tree species richness of 56 and diversity (*H'*) of 2.50. Total forest evenness (*J*) was 0.62, but this value was lowered by the abundance of *Pinus* in plantation management. Average stand age was 38 years with a range from 7 to 90 years. Basal area was 22.6 m^2 ha^{-1} and we expect this value to increase with forest age. Significant differences were noted between tree age and height across the three surveyed forest types. Our results provide information on forest conditions in an understudied region.

Index terms: federal lands, forest patterns, Highland Rim, *Pinus, Quercus*

INTRODUCTION

The United States federal government owns and manages more than 263 million ha of land throughout the 48 conterminous states of North America and in Hawaii and Alaska (National Atlas 2010). The Department of Defense (DoD) manages 12.1 million ha of these federal lands, which are utilized for logistical support, operations, training, and a variety of other needs in maintaining national security of the United States through the four branches of the military (Army, Navy, Air Force, and Marines Corps; Ripley and Leslie 1997; Stein et al. 2008; Department of Defense 2010). In addition to these functions, the DoD is also an environmental steward of these lands and must maintain them in accordance with the National Environmental Policy Act and other federal, state, and local environmental laws and DoD policies (Department of the Army 1995, 2007). Within these laws and policies are the procedures and responsibilities for the conservation, management, and restoration of natural resources which include water, soils, ranges, forests, and fish and wildlife species on DoD lands (Department of the Army 1995). The Department of Defense lands provide an intrinsic value important for ecosystem services such as biodiversity conservation, as they have the highest percentage and densities of federally listed endangered and imperiled species per 1000 km^2 compared to land units managed by the Bureau of Land Management, Forest Service, Fish and Wildlife Service, and National Park Service (Stein et al. 2008). Thus, documentation of the composition, structure, and function of forested ecosystems located on DoD lands is important to the elucidation of regional biodiversity patterns and the ecosystems services provided by these lands. Such research can also provide DoD land managers with necessary baseline information needed in the restoration, conservation, or maintenance of biodiversity and other management goals. Previous studies on DoD lands have investigated the occurrence and distribution of mammals on an Air Force Base in the state of Washington (Freed and McAllister 2008), the understory vegetation indicators of human-caused disturbance in *Pinus palustris* (Mill.; longleaf pine) forests at an army fort in Georgia (Dale et al. 2002), and the status of threatened and endangered species at 32 DoD sites in the deserts of the Southwest (Tazik and Martin 2002) among others.

Another important aspect of DoD lands is their representation in ecoregions in which other large federal, state, or private landholdings are underrepresented or not represented at all (Ripley and Leslie 1997). One such DoD landholding managed by the U.S. Department of the Army (U.S. Army) is Redstone Arsenal (RA). Redstone Arsenal is located on the Eastern Highland Rim of the Interior Plateau of north-central Alabama and is the largest contiguous landholding (15,050 ha) in the Tennessee River Valley of Alabama (Figure 1). This federal landholding provided the

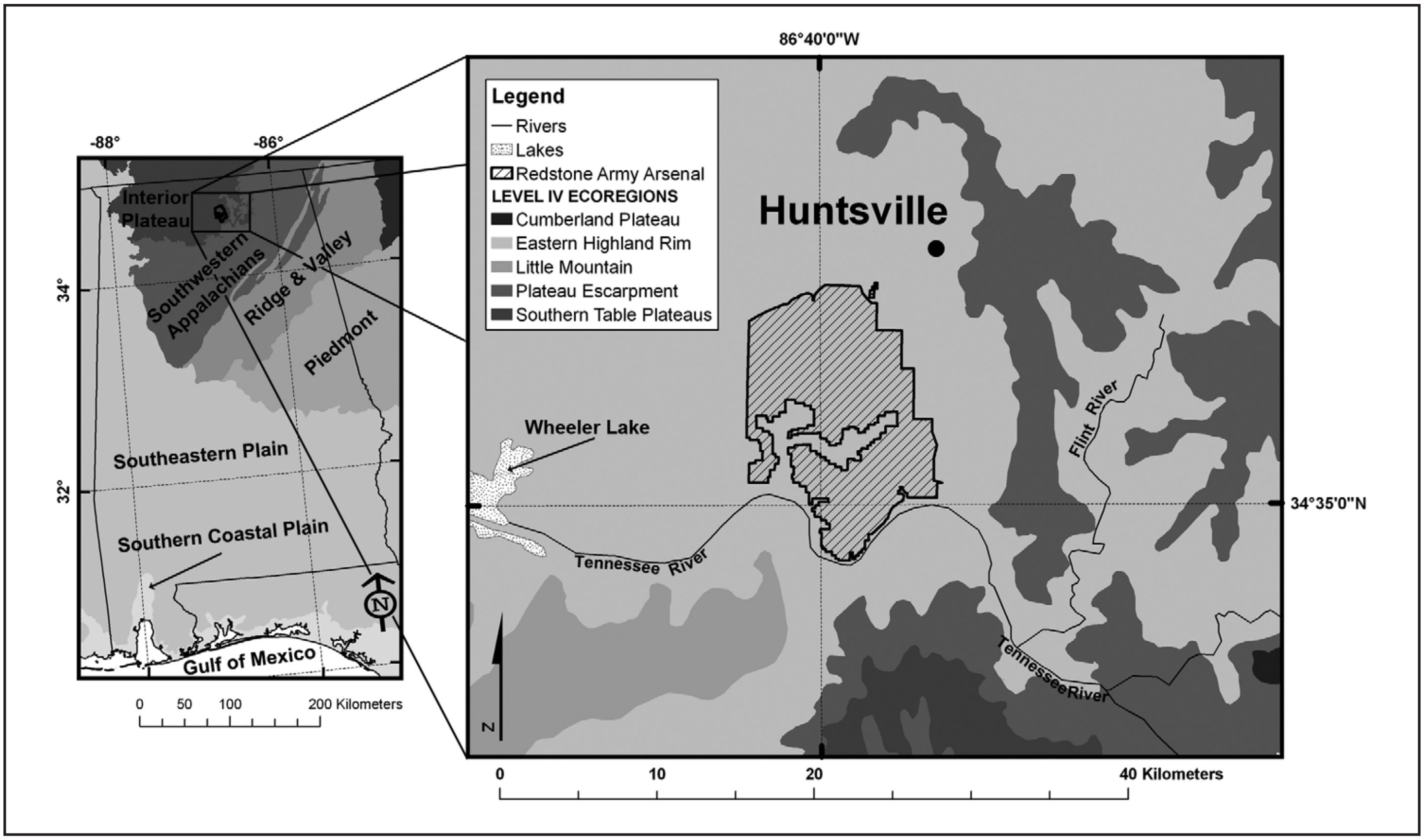

Figure 1. Map area showing the location of Redstone Arsenal and level III ecoregions of Alabama with the inset map showing the boundaries of Redstone Arsenal and the level IV ecoregions of the Interior Plateau and the Southwestern Appalachians. Ecoregions level III and IV from Griffith et al. (2001).

unique opportunity to document forest vegetation and development patterns in a region with a paucity of available data. The primary mission of the RA is to support the U.S. Army in military research, in the development of basic and advanced weapons systems, and with distribution of weapons systems, services, and supplies to both troops and allies of the United States (Redstone Arsenal 2002). In accordance with federal, state, and local laws, RA lands must also be managed for recreational opportunities, enhancement of natural resources, and maintenance of ecosystem health. The RA supports nine animal species that are threatened, endangered, or of special concern and 10 plant species that are listed as threatened or of special concern (Redstone Arsenal 2002). This biodiversity is attributed in part to the geography of the RA, which is situated near the interface of the Interior Plateau and Southwestern Appalachians ecoregions (level III; Griffith et al. 2001). Gamma diversity of this region is relatively high and is largely a function of the influence of topography on microenvironmental conditions, which allows the region to support species that typically occur at higher and lower latitudes across a variety of site types (Harper 1943; Braun 1950; Shanks 1958; Shankman and James 2002). Harper (1943) and Smalley (1983) provided overviews of vegetation-environment relationships, including forest associations in the region; however, quantitative forest composition and structural measures are still lacking. This information is important not only to document regional forest vegetation and development patterns, but also to provide regional land managers with the data required to make informed decisions. The specific goals of our study were to: (1) quantify forest biodiversity measures, (2) document species composition, (3) describe structural attributes of the forest, and (4) provide information on the development of forest stands in the region.

METHODS

Study Region and Area

The RA is located on the Eastern Highland Rim (EHR) of north Alabama (Figure 1). The EHR physiographic section is the easternmost subregion of the Interior Low Plateaus. The EHR borders the Cumberland Plateau to the south and east in Alabama north through Tennessee to Kentucky (Griffith et al. 2001; Woods et al. 2002). The forests of the EHR have been described as western mesophytic and are dominated by *Quercus* spp. (Braun 1950; Smalley 1983). These forests became prevalent *ca*. 8000 years BP after the Wisconsin glaciation (Delcourt 1979). The western mesophytic forest region extends from southern Illinois, Ohio, and Indiana south to northern Mississippi and Alabama, roughly coinciding with the Interior Plateau ecoregion (Omernik 1987; Delcourt and Delcourt 2000).

The western mesophytic forest has been investigated at multiple scales, from the region (Parker 1987; Monk et al. 1989; Bryant et al. 1993; Hinkle et al. 1993; Baskin et al. 1997), to the state (Illinois: Fralish et al. (1991), Kentucky and Tennessee: Fralish and Crooks (1989)), and at locations that support unique habitats such as barrens, outcrops, and upland swamps that occur throughout the region (Penfound and Hall 1939; Baskin and Baskin 1986; Ellis and Chester 1989; DeSelm 1990; DeSelm and Murdock 1993; Baskin et al. 1995). However, only one coarse-scale study has examined the western mesophytic forest of the EHR at the sub-regional level (Smalley 1983).

Smalley (1983) noted that *Quercus alba* L. (white oak), *Quercus falcata* Michx. (southern red oak), and *Quercus velutina* Lam. (black oak) dominated the undulating landscape of the EHR and that they were often associated with *Acer saccharum* Marsh. (sugar maple), *Fagus grandifolia* Ehrh. (American beech), *Liriodendron tulipifera* L. (yellow-poplar), *Carya* spp. (hickories), and *Fraxinus americana* L. (white ash). *Cornus florida* L. (flowering dogwood) was a common understory component in these forests. Swamp and wetland species included *Acer rubrum* L. (red maple), *Quercus bicolor* Willd. (swamp white oak), *Liquidambar styraciflua* L. (sweetgum), *F. americana*, *Platanus occidentalis* L. (American sycamore), and *Nyssa sylvatica* Marsh. (blackgum), while the barrens were occupied by *Quercus stellata* Wangenh. (post oak); *Quercus marilandica* Muenchh. (blackjack oak); *Quercus coccinea* Muenchh. (scarlet oak), *Q. velutina;* and *Q. falcata*. The ravines in the heavily-dissected portions of the EHR resembled the mixed mesophytic forests associated with Cumberland Plateau gorges and included *F. grandifolia*, *L. tulipifera*, *Q. alba*, *A. saccharum*, and *Tsuga canadensis* (L.) Carr. (eastern hemlock), with *F. americana*, *Aesculus flava* Ait. (yellow buckeye), *Tilia americana* L. (American basswood), *Oxydendrum arboreum* (L.) DC. (sourwood), and *Quercus rubra* L. (northern red oak) as associates (Smalley 1983).

The weakly dissected plateau of the EHR of north Alabama consists of broad and gentle sloping ridges surrounded by short and moderately steep slopes. The well-drained deep red soils are clayey and loamy originating from alluvium, limestone, or silty deposits; however, in dissected regions, the deep red and brown soils can be cherty, clayey, or silty originating from alluvium, limestone, shale, or thicker silty deposits (Smalley 1983). Uplands are pitted with sinkholes and depressions which connect in underground drainage ways. Shallow and intermittent drainages are common and a few permanent streams comprise the weakly developed dendritic drainage pattern.

The terrain of the RA is typical of the weakly dissected plateau of the EHR with gently rolling hills ranging from elevations between 170 to 206 m above mean sea level (amsl) and local relief commonly less than 30 m. The highest point in the RA is Madkin Mountain with an elevation of 378 m amsl. Of the total RA landholding, 506 ha are underwater (this occurs in the southern portion of the reserve) and 5892 ha are subject to 100-year floods. Climate is warm and humid with average January and July high temperatures of 9.4 °C to 31.6 °C, respectively, and average low temperatures of -0.5 °C to 20 °C, respectively. Total average rainfall is 140 cm per year, with March being the wettest month and October the driest. The average frost-free period occurs from April to October. Thunderstorms are most common in spring, but may occur throughout the year with about 55 days with thunderstorms annually (Smalley 1983). Tornadoes are common in the region as are atmospheric disturbances related to hurricanes. Tornado damage at RA occurred in December 1967, April 1974, and November 1989; the remnants of Hurricane Opal caused some damage on the reserve in 1995. Dendroecological analyses indicated that several of these atmospheric disturbances resulted in canopy tree removal and influenced forest productivity (Hart et al. 2011).

Prior land use of RA was agricultural, concentrated towards the production of cotton, corn, hay, small grain crops, and livestock (Redstone Arsenal 2002). Originally, 12,948 ha were acquired during 1941–1942 from 320 landowners and the Tennessee Valley Authority for the establishment of what was to become RA. The size of the landholding has fluctuated slightly (increased and decreased) since establishment of the reserve.

Laboratory and Field Methods

Prior to field sampling, we selected training sites for each forest type – conifer, deciduous, mixed, and forested wetlands – from a false color infrared image of RA and used the automated feature extraction extension of Feature Analyst (Overwatch Systems LTD.) in ArcGIS to derive outputs for the forest types of RA. Feature Analyst outputs were then refined several times and manual editing of Feature Analyst outputs was conducted when necessary after field verification. To create our survey points, we first stratified the forest into RA's established 21 compartments and then further subdivided each compartment into separate forest stands. All stands were classified as *Pinus*, hardwood, mixed *Pinus*-hardwood, or forested wetland. Survey points were randomly placed in each stand ≥ 2 ha using Hawth's Analysis Tools (Beyer 2004) in a GIS (forested wetland stands were not sampled because of accessibility issues and they are excluded from active management by RA personnel). The number of points varied in proportion to stand size (1 to 23 points stand^{-1}). Points established near stand edges were moved to ensure all trees sampled would be entirely contained within one stand to avoid edge effects and boundary overlap issues (Avery and Burkhart 2002). The coordinate pairs of all survey points were entered into handheld GPS receivers to georeference the data and so the points could be re-located for future analyses.

At each of the 684 survey points, we conducted prism sweeps using a 10 basal area factor (BAF) prism for live trees only. For borderline trees and those difficult to see we measured distance from tree center to the survey point and tree diameter at breast height (dbh). If the measured distance was below the critical limiting distance (dbh multiplied by 2.75), the individual was included in the sample. For all trees sampled in our prism sweeps we recorded species, dbh, height, and crown class. Crown classifications (dominant, codominant, intermediate, overtopped, and open grown) were based on the amount and direction of intercepted light and distance between adjacent tree crowns (Oliver and Larson 1996). In each sweep we also noted the presence of alien species. To quantify site index and mean stand age we collected tree core samples with increment borers from every stand to ensure adequate spatial coverage. We subjectively selected canopy trees in each stand that appeared to be representative of the stand being sampled in order to assess site index and stand age. Trees with visible damage and trees with rotten cores were rejected as representative site trees. Cored trees were usually 12.7 cm in diameter or larger. Cores were collected at breast height, placed in labeled straws, and transported to the laboratory for age determination. All cores were prepared and processed for crossdating using standard methods (Stokes and Smiley 1996; Orvis and Grissino-Mayer 2002). Composition and biodiversity measures were assessed for the total forest and for each of the three forest types in which we collected field data. Mean stand age, mean diameter at breast height, and mean tree height were also determined from our prism sweep data for the three surveyed forest types. These data were analyzed using a single-factor ANOVA with a Tukey-Kramer HSD test.

RESULTS AND DISCUSSION

Forest Stand Delineation

From our GIS analyses and field verification, we delineated a total of 1215 polygons within the 21 compartments of the RA (Table 1; Figure 2). Feature analyst had an 86% accuracy rate in determining correct forest types even with refinement after field verification. Polygon areas ranged from 0.001 ha to 3409.6 ha with a mean of 10.4 ha ± 116.4 (SD). Five land cover types were identified: (1) *Pinus* forest, (2) hardwood forest, (3) mixed *Pinus*-hardwood forest, (4) forested wetlands, and (5) non-forested land. All forested polygons were defined as forest stands ($n = 1130$) and further classified into stand groups, based on area, of which 619 stands were < 2 ha and 511 were ≥ 2 ha (Table 1). Of these forest stands, stands < 2 ha covered 556.7 ha while stands ≥ 2 ha covered 6261.7 ha. For stands < 2 ha, *Pinus*-dominated stands comprised the majority of the land area, while this trend was different for stands ≥ 2 ha, as hardwood stands comprised the majority of that land area. Mixed *Pinus*-hardwood stands in both groups were always the second land cover type with forested wetland stands representing the smallest amount of land area. Although *Pinus*-dominated stands were the most common of the larger stand types, this type had the lowest mean size and represented the lowest total percent of land area relative to hardwood, mixed *Pinus*-hardwood, and forested wetland types. For stand groups,

Table 1. Number, mean sizes, and total land area by type for A) forest stands < 2 ha and B) forest stands ≥ 2 ha at Redstone Arsenal, Alabama.

A)

Land-Use Type	Number	Mean size (ha)	Total land area (ha)	% Land Area	Minimum	Maximum	Standard Deviation
Pinus- dominated	254	0.90	229.14	38.39	0.00	2.01	0.55
Hardwood-dominated	160	0.84	133.85	22.42	0.08	1.98	0.60
Mixed *Pinus*- hardwood	201	0.94	189.64	31.77	0.00	2.00	0.57
Forested Wetlands	4	1.02	4.09	0.68	0.45	1.56	0.46
Non-forest	54	0.74	40.21	6.74	0.05	1.94	0.74
Total	673		596.93	100			

B)

Land-Use Type	Number	Mean size (ha)	Total land area (ha)	% Land Area	Minimum	Maximum	Standard Deviation
Pinus- dominated	212	7.32	1552.78	12.90	2.04	39.52	6.36
Hardwood-dominated	114	22.38	2550.93	21.19	2.03	782.01	75.43
Mixed *Pinus*- hardwood	170	11.34	1928.50	16.02	2.03	222.94	22.28
Forested Wetlands	15	15.30	229.45	1.91	2.26	46.97	13.33
Non-forest	31	186.30	5775.17	47.98	2.13	3409.60	687.96
Total	542		12036.8	100			
Total All Lands	1215		12633.77				

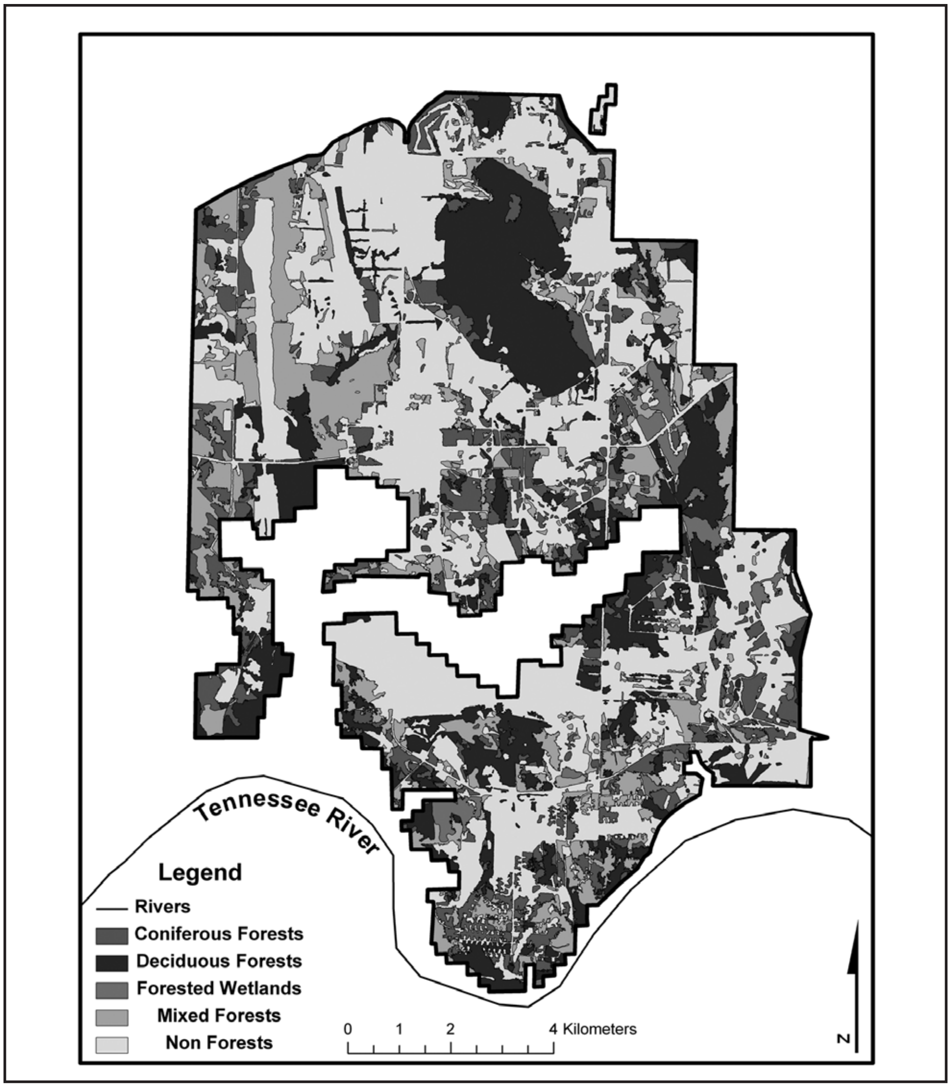

Figure 2. A detailed map of Redstone Arsenal depicting the results of the land covers delineation from the GIS analyses.

mean size of the smaller stands was about the same (*ca*. 0.93 ha) while the mean size of the larger stands was highly variable. Our map of the land cover types of RA (Figure 2) helped to visualize the spatial distribution of the forest types in RA. Based on map observation, the forests of RA are heavily fragmented because of the non-forested lands on the reserve. Non-forested land patches occur throughout the reserve because the RA primarily functions as a military facility. Excessive fragmentation is known to have negative influences on biodiversity patterns. For example, fragmentation may allow for the colonization of alien plant species and may limit the number of animal species which can inhabit the small forest patches (Burkey 1989; Andrén 1994; Knapp and Canham 2000). Stands in the northern portion of RA were larger in area than those in the southern portion of the reserve. The Wheeler National Wildlife Refuge (WNWR), which almost bisects RA and which was not surveyed, may contain similar forest types to those of the RA and may help to reduce some of the forest fragmentation observed in the map, but further surveys in the WNWR would be needed to verify this.

Forest Composition

In our prism sweeps, we documented 6741 trees representing 56 different species (Table 2). Species richness for the RA forest was relatively high even when compared to forests of the adjacent Cumberland Plateau, which is noted for high biodiversity (Martin 1992; Hinkle et al. 1993; Hart and Grissino-Mayer 2008). Species diversity (*H'*) was 2.50 and evenness (*J*) was 0.62 (Table 3). Forest evenness was influenced by the abundance of *P. taeda* and would have been higher if *Pinus* stands were not as abundant. *Pinus taeda* occurred at 67% of all sampling points and was the most important species (based on relative density and relative dominance measures). This single species represented 43% of all trees sampled and 44% of total basal area. The next most important species were *L. styraciflua* and *Q. phellos*. *Liquidambar styraciflua* occurred at the highest density behind *P. taeda*, while *Q. phellos* was the second most dominant (based on basal area of m^2 ha^{-1}) species in the RA forest. The remaining 54 species had relative importance values between 4.92 and 0.01. A total of 11 trees were documented at only one survey point.

Composition and biodiversity patterns exhibited considerable variability by forest type. In *Pinus* dominated stands, *P. taeda* represented over 80% of all trees (Table 4). The second most abundant species was *L. styraciflua,* which represented over 5% of all trees. For this forest type at the RA, species richness was 41, diversity was 1.18, and evenness was 0.32 (Table 3).

Obviously the preponderance of *P. taeda* resulted in biodiversity measures that were lower than the other two studied forest types. However, at the reserve level, the managed *Pinus* stands served to increase overall habitat heterogeneity and provided early successional habitat on the reserve that otherwise would not have been as abundant. Indeed, strategies and recommendations are available to increase plant and animal biodiversity in managed plantations (Sharitz et al. 1992; Schultz 1997; Hartley 2002; Dougherty 2004). The hardwood stands were dominated by *Q. phellos*, *P. taeda*, *C. occidentalis*, and *L. styraciflua* (Table 5). Relative density values were highest for *Q. phellos* and *L. styraciflua*. Tree species richness for the hardwood stands was 46, diversity was 3.18, and evenness was 0.83. The diversity value for this forest type was high, even when compared to mesic forests in nearby ecoregions. For example, this value was higher than what has been reported for hardwood forests on the Cumberland Plateau (Martin 1992; Hart and Grissino-Mayer 2008) and the southern Ridge and Valley (Hart et al. 2008). This was an interesting finding because hardwood forests of the Cumberland Plateau and Ridge and Valley are noted for containing high biodiversity. At the RA, tree species richness was highest (S = 50) for the mixed *Pinus*-hardwood stands, but this forest type did contain the only alien species document in our prism sweeps. The mixed stands were dominated by *P. taeda* which represented over 30% of stand basal area (Table 6). *Liquidambar styraciflua* and *Q. falcata* were the next most dominant species in mixed stands. Diversity and evenness values were 2.88 and 0.74, respectively, and fell between values reported for the other two documented forest types.

As previously stated, only one alien species was observed in our prism sweeps, *Albizia julibrissin* Durazz. (mimosa or silktree). However, multiple non-indigenous species were observed that were below the prism sweep documentation level and/or were not arboreal. These species included: *Lonicera fragrantissima* Lindl. & Paxton (sweet breath of spring); *Lonicera japonica* Thunb. (Japanese honeysuckle); *Ligustrum sinense* Lour. (Chinese privet); *Ailanthus altissima* (P. Mill.) Swingle (tree-of-heaven); *Pueraria montana* (Lour.) Merr. (kudzu); *Rosa multiflora* Thunb. ex Murr. (multiflora rose); *Poncirus trifoliata* (L.) Raf. (hardy orange); *Elaegnus umbellata* Thunb. (autumn olive); *Bambusa multiplex* (Lour.) Raeusch. ex J.A. & J.H. Schultes (hedge bamboo); and *Lespedeza bicolor* Turcz. (perennial lespedeza). Several of these woody species have the potential to recruit to larger size classes and occupy more growing space in the forest. Notably, the shade-tolerant *Ligustrum* species may become problematic for reserve managers as the genus is known to invade the understory of closed canopied forests and preclude regeneration of native species (Merriam and Feil 2002; Ward 2002; Miller 2003). At the time of our field sampling, alien plant species were not as problematic

Table 2. Relative frequency, density, dominance, and importance (mean of relative density and relative dominance) values for trees sampled at Redstone Arsenal, Alabama.

Species	Relative density	Relative dominance	Relative importance
Pinus taeda L.	43.18	44.05	43.62
Liquidambar styraciflua L.	8.90	6.59	7.75
Quercus phellos L.	5.01	7.32	6.17
Celtis occidentalis L.	5.19	4.66	4.92
Quercus falcata Michx.	3.06	4.76	3.91
Quercus nigra L.	3.32	3.28	3.30
Juniperus virginiana L.	4.12	2.24	3.18
Quercus velutina Lam.	1.74	3.24	2.49
Quercus rubra L.	2.12	2.82	2.47
Prunus serotina Ehrh.	2.28	1.79	2.04
Liriodendron tulipifera L.	1.84	2.21	2.03
Fraxinus pennsylvanica Marsh.	1.72	1.45	1.58
Acer rubrum L.	1.54	1.56	1.55
Quercus alba L.	1.50	1.53	1.51
Quercus lyrata Walt.	1.10	1.47	1.28
Platanus occidentalis L.	0.93	1.37	1.15
Carya ovata (Mill.) K. Koch.	1.20	0.87	1.04
Ulmus rubra Muhl.	1.04	0.51	0.77
Quercus montana Willd.	0.80	0.57	0.69
Carya tomentosa (Poir.) Nutt.	0.73	0.61	0.67
Sassafras albidum (Nutt.) Nees	0.67	0.44	0.55
Robinia pseudoacacia L.	0.64	0.44	0.54
Ulmus americana L.	0.68	0.35	0.52
Acer negundo L.	0.65	0.38	0.52
Juglans nigra L.	0.46	0.42	0.44
Quercus marilandica Muenchh.	0.39	0.48	0.44
Quercus pagoda Raf.	0.39	0.40	0.39
Carya glabra Mill.	0.50	0.27	0.39
Diospyros virginiana L.	0.53	0.20	0.37
Pinus virginiana Mill.	0.40	0.27	0.33
Fraxinus americana L.	0.37	0.29	0.33
Quercus coccinea Muenchh.	0.19	0.44	0.32
Quercus shumardii Buckl.	0.22	0.39	0.30
Quercus michauxii Nutt.	0.28	0.32	0.30
Nyssa aquatica L.	0.34	0.24	0.29
Quercus stellata Wangenh.	0.31	0.26	0.28
Maclura pomifera (Raf.) Schneid.	0.13	0.34	0.24
Populus deltoides Bartr. ex. Marsh.	0.15	0.33	0.24
Nyssa sylvatica Marsh.	0.25	0.12	0.19
Pinus echinata Mill.	0.21	0.14	0.17

Continued

Table 2. (Continued)

Species	Relative density	Relative dominance	Relative importance
Gleditsia triacanthos L.	0.18	0.10	0.14
Ulmus alata Michx.	0.19	0.07	0.13
Quercus muehlenbergii Engelm.	0.12	0.11	0.12
Acer saccharinum L.	0.09	0.07	0.08
Ostrya virginiana (Mill.) K. Koch.	0.06	0.02	0.04
Cornus florida L.	0.04	0.01	0.03
Carya cordiformis (Wangenh.) K. Koch.	0.03	0.02	0.03
Fagus grandifolia Ehrh.	0.01	0.03	0.02
Oxydendron arboreum (L.) DC.	0.03	0.02	0.02
Betula lenta L.	0.03	0.01	0.02
Carya illinoensis (Wangenh.) K. Koch.	0.01	0.02	0.02
Cercis canadensis L.	0.01	0.01	0.01
Betula nigra L.	0.01	0.01	0.01
Pinus elliottii Engelm.	0.01	0.01	0.01
Albizia julibrissin Durazz.	0.01	0.00	0.01
Callicarpa americana L.	0.01	0.00	0.01
Totals	100	100	100

as hypothesized given the proximity of the RA to metropolitan Huntsville, Alabama.

Forest Structure

The overwhelming majority of all sampled trees occurred in codominant canopy positions (Figure 3A). A total of 5544 trees were classed as codominant, with the split between *Pinus* and all others being relatively even (range of 32 trees). Approximately 95% of all *Pinus* individuals occurred in codominant crown positions. A total of 170 trees occurred in dominant canopy positions with *Pinus* and all others being 48 and 122 individuals, respectively. Only four *Pinus* individuals occurred in overtopped positions. We documented 189 individuals that occurred in the open grown category. Of these 189, only 14 were *Pinus*. The majority of open grown trees were hardwood species. For open grown, overtopped, and intermediate crown classes, the proportion of *Pinus* to non-*Pinus* individuals was similar (Figure 3B). *Pinus* individuals represented a relatively larger proportion of canopy (codominant and dominant) trees in the forest. In fact, the contribution of *Pinus* trees and non-*Pinus* trees in codominant crown positions was almost equal. Of the 170 trees classed as dominant, 28% were *Pinus*.

Table 3. Biodiveristy measures for trees sampled at Redstone Arsenal, Alabama.

Biodiversity measure	All stands	*Pinus* stands	Hardwood stands	Mixed stands
Species richness (S)	57	41	46	50
Species diversity (H')	2.50	1.18	3.18	2.88
Species evenness (J)	0.62	0.32	0.83	0.74
Alien species	1	0	0	1

The diameter structure of the forest had a normal distribution (Figure 4), with the majority of trees in the 30–35 cm dbh class. The majority of trees in the RA forest were between 20 and 45 cm dbh. When trees were divided into *Pinus* species and others, a similar pattern was evident. However, the apex of the curve was shifted toward larger diameter trees for *Pinus* compared to the distribution of all other species. This pattern may be the result of different growth rates among the taxa. *Pinus* are noted for rapid growth rates relative to co-occurring hardwood species in this region.

Mean dbh of trees in the forest was 35.2 cm ± 0.23 (SE) and 33.7 cm ± 0.23 (SE) for *Pinus* species and all others, respectively. The largest tree documented was a *Celtis occidentalis* L. (common hackberry) at 127 cm dbh, while the next largest tree was a *Maclura pomifera* (Raf.) Schneid. (osage orange) at 109.25 cm dbh. The largest *Pinus* individual had a dbh of 81.25 cm. In total, five trees > 100 cm dbh were documented representing five species. Mean stand age across all forest types was 38 years ± 15 (SD) with a range from 7 to 90 years. The youngest tree documented was six years old (*P. taeda*) and the oldest tree was 101 years old (*Q. rubra*). The relationship between age and diameter at breast height was graphed according to genus (Figure 5). *Carya* and *Quercus* were generally the oldest trees in the forest; however, they were not the largest trees. The largest trees in the forest were typically *P. taeda* which is not surprising given the species is noted for its rapid growth.

The mixed *Pinus*-hardwood stands were statistically older than the other two types with a mean age of 44 years (Figure 6). The mean ages of *Pinus* and hardwood stands were 34 and 39 years, respectively. The mean height of the *Pinus* stands was significantly greater than the mean heights of the hardwood and mixed forest types. The pattern may be attributed to the rapid height growth rate of *P. taeda* in the *Pinus* stands or may be attributed to silvicultural operations under the plantation management. Interestingly, no systematic differ-

Table 4. Relative density, dominance, and importance (mean of relative density and relative dominance) values for coniferous forests in Redstone Arsenal, Alabama.

Species	Relative density	Relative dominance	Relative imp
Pinus taeda L.	77.25	80.35	59.67
Liquidambar styraciflua L.	5.62	4.32	7.57
Prunus serotina Ehrh.	1.90	1.57	4.07
Juniperus virginiana L.	2.72	1.53	3.66
Quercus falcata Michx.	1.62	2.52	3.29
Celtis occidentalis L.	1.48	1.06	2.75
Quercus phellos L.	0.97	1.19	2.04
Quercus nigra L.	0.86	0.77	1.64
Liriodendron tulipifera L.	0.79	0.93	1.62
Quercus velutina Lam.	0.45	1.23	1.49
Ulmus rubra L.	0.69	0.33	1.23
Pinus virginiana Mill.	0.86	0.67	1.11
Quercus rubra L.	0.34	0.45	1.00
Ulmus americana L.	0.38	0.13	0.84
Platanus occidentalis L.	0.21	0.28	0.72
Pinus echinata P. Mill.	0.48	0.35	0.66
Fraxinus pennsylvanica Marsh.	0.31	0.34	0.56
Diospyros virginiana L.	0.28	0.15	0.56
Ulmus alata Michx.	0.24	0.08	0.52
Quercus alba L.	0.31	0.14	0.46
Quercus pagoda Raf.	0.21	0.25	0.42
Quercus marilandica Muenchh.	0.24	0.25	0.42
Carya glabra (P. Mill.) Sweet	0.14	0.03	0.40
Sassafras albidum (Nutt.) Nees	0.31	0.13	0.36
Acer rubrum L.	0.21	0.10	0.34
Quercus stellata Wangenh.	0.10	0.06	0.32
Acer negundo L.	0.14	0.06	0.32
Populus deltoides Bartr. ex Marsh.	0.07	0.22	0.30
Quercus michauxii Nutt.	0.17	0.08	0.23
Cornus florida L.	0.07	0.03	0.21
Quercus lyrata Walt.	0.10	0.15	0.17
Carya ovata (Mill.) K. Koch	0.14	0.10	0.15
Quercus coccinea Muenchh.	0.03	0.04	0.11
Betula lenta L.	0.07	0.03	0.11
Robinia pseudoacacia L.	0.03	0.02	0.11
Juglans nigra L.	0.03	0.02	0.11
Acer saccharinum L.	0.03	0.02	0.11
Nyssa aquatica L.	0.03	0.01	0.10
Fraxinus americana L.	0.03	0.01	0.10
Carpinus caroliniana Walt.	0.03	0.01	0.10
Gleditsia triacanthos L.	0.03	0.00	0.10
Totals	100	100	100

ences were noted in the mean dbh values across the three forest types.

CONCLUSIONS

This research provided information on forest vegetation and development patterns for the largest landholding in a region where little quantitative data are available. The secondary forest of the RA consisted of *P. taeda* plantations, hardwood, mixed *Pinus*-hardwood, and forested wetland stands. The RA forest was highly fragmented with non-forested land. As the primary mission for the reserve is to support military operations – and forest or ecosystem aspects, while important, are somewhat ancillary – this pattern was not unexpected. Despite the negative fragmentation affects, the RA forest exhibited surprisingly high levels of biodiversity even when compared to forests in nearby ecoregions (i.e., the Cumberland Plateau and southern Ridge and Valley), which are noted for their biodiversity. While composition and diversity measures varied across forest type, the mosaic of forest stands across the RA provided heterogeneity that should allow the reserve to support a host of species which represent a range of life history and ecological traits. The ecosystem services provided by the RA forest will be increasingly important as stands mature and develop complex structures and as stands are disturbed by natural mechanisms (such as wind or ice events), which will serve to further increase heterogeneity across the reserve. Also, this landholding will remain protected in perpetuity as forest management is mandated by federal, state, and local laws and policies. Our research filled a gap in the literature on forest patterns in this region and may be applied by resource managers of the RA and other reserves throughout the region to make informed decisions.

Table 5. Relative density, dominance, and importance (mean of relative density and relative dominance) values for deciduous forests in Redstone Arsenal, Alabama.

Species	Relative density	Relative dominance	Relative importance
Quercus phellos L.	12.17	16.77	12.16
Liquidambar styraciflua L.	11.30	8.23	8.61
Celtis occidentalis L.	8.98	8.45	8.27
Pinus taeda L.	7.19	9.48	7.35
Quercus nigra L.	6.27	5.61	6.04
Quercus velutina Lam.	3.57	5.49	5.08
Quercus falcata Michx.	4.06	5.39	4.86
Quercus rubra L.	4.22	4.96	4.64
Acer rubrum L.	3.57	3.56	3.67
Quercus alba L.	2.87	3.00	3.12
Fraxinus pennsylvanica Marsh.	3.41	2.42	3.10
Liriodendron tulipifera L.	3.19	3.10	2.90
Prunus serotina Ehrh.	1.95	1.68	2.73
Quercus lyrata Walt.	2.43	2.82	2.49
Carya ovata (Mill.) K. Koch	2.60	1.66	2.09
Ulmus americana L.	1.14	0.58	1.55
Carya alba (L.) Nutt. ex Ell.	1.68	1.25	1.52
Juniperus virginiana L.	3.14	1.24	1.52
Ulmus rubra L.	1.46	0.66	1.41
Quercus prinus L.	2.06	1.25	1.17
Quercus michauxii Nutt.	0.49	0.80	1.03
Platanus occidentalis L.	1.35	1.86	1.02
Juglans nigra L.	0.70	0.67	0.96
Quercus coccinea Muenchh.	0.43	0.96	0.93
Fraxinus americana L.	1.30	0.94	0.92
Quercus stellata Wangenh.	0.65	0.52	0.89
Nyssa sylvatica Marsh.	0.43	0.25	0.85
Sassafras albidum (Nutt.) Nees	0.59	0.61	0.84
Quercus pagoda Raf.	0.43	0.58	0.83
Robinia pseudoacacia L.	0.43	0.30	0.78
Carya glabra (P. Mill.) Sweet	1.14	0.58	0.74
Diospyros virginiana L.	0.43	0.14	0.70
Acer negundo L.	0.54	0.19	0.63
Maclura pomifera (Raf.) Schneid.	0.32	1.05	0.61
Nyssa aquatica L.	1.30	0.81	0.58
Gleditsia triacanthos L.	0.27	0.19	0.55
Quercus shumardii Buckl.	0.54	0.70	0.53
Populus deltoides Bartr. ex Marsh.	0.22	0.46	0.50
Pinus virginiana Mill.	0.05	0.01	0.45
Quercus muehlenbergii Engelm.	0.32	0.32	0.34

Continued

Table 5. (Continued)

Species	Relative density	Relative dominance	Relative importance
Ulmus alata Michx.	0.22	0.08	0.31
Quercus marilandica Muenchh.	0.16	0.18	0.27
Acer saccharinum L.	0.22	0.13	0.16
Carya cordiformis (Wangenh.) K. Koch	0.11	0.07	0.12
Callicarpa americana L.	0.05	0.01	0.10
Cornus florida L.	0.05	0.01	0.09
Totals	100	100	100

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Table 6. Relative density, dominance, and importance (mean of relative density and relative dominance) values for mixed forests at Redstone Arsenal, Alabama.

Species	Relative density	Relative dominance	Relative importance
Pinus taeda L.	26.97	31.97	29.47
Liquidambar styraciflua L.	11.45	7.85	9.65
Celtis occidentalis L.	7.08	5.47	6.28
Quercus falcata Michx.	4.22	7.10	5.66
Juniperus virginiana L.	7.08	4.14	5.61
Quercus phellos L.	4.27	5.76	5.01
Quercus nigra L.	4.17	4.16	4.16
Quercus rubra L.	2.76	3.73	3.25
Quercus velutina Lam.	1.91	3.57	2.74
Prunus serotina Ehrh.	3.16	2.20	2.68
Liriodendron tulipifera L.	2.11	2.97	2.54
Fraxinus pennsylvanica Marsh.	2.21	1.89	2.05
Platanus occidentalis L.	1.61	2.28	1.94
Quercus alba L.	1.96	1.83	1.89
Quercus lyrata Walt.	1.31	1.82	1.56
Acer rubrum L.	1.61	1.45	1.53
Robinia pseudoacacia L.	1.71	1.11	1.41
Carya ovata (Mill.) K. Koch	1.46	1.06	1.26
Acer negundo L.	1.51	0.98	1.24
Sassafras albidum (Nutt.) Nees	1.26	0.65	0.95
Quercus marilandica Muenchh.	0.80	1.09	0.95
Ulmus rubra L.	1.16	0.57	0.86
Carya alba (L.) Nutt. ex Ell.	0.90	0.76	0.83
Juglans nigra L.	0.85	0.68	0.77
Quercus prinus L.	0.80	0.63	0.72
Diospyros virginiana L.	1.00	0.34	0.67
Ulmus americana L.	0.70	0.40	0.55
Quercus pagoda Raf.	0.60	0.41	0.51
Quercus shumardii Buckl.	0.25	0.57	0.41
Carya glabra (P. Mill.) Sweet	0.45	0.27	0.36
Quercus coccinea Muenchh.	0.20	0.46	0.33
Quercus stellata Wangenh.	0.30	0.25	0.28
Populus deltoides Bartr. ex Marsh.	0.20	0.34	0.27
Nyssa sylvatica Marsh.	0.35	0.13	0.24
Gleditsia triacanthos L.	0.30	0.14	0.22
Quercus michauxii Nutt.	0.25	0.15	0.20
Maclura pomifera (Raf.) Schneid.	0.15	0.09	0.12
Caprinus caroliniana Walt.	0.15	0.07	0.11
Quercus nuttallii Palmer	0.05	0.13	0.09
Ulmus alata Michx.	0.10	0.06	0.08

Continued

Table 6. (Continued).

Species	Relative density	Relative dominance	Relative importance
Fagus grandifolia Ehrh.	0.05	0.11	0.08
Oxydendron arboreum (L.) DC.	0.10	0.06	0.08
Quercus muehlenbergii Engelm.	0.10	0.05	0.07
Carya illinoinensis (Wangenh.) K. Koch	0.05	0.07	0.06
Acer saccharinum L.	0.05	0.06	0.05
Cercis canadensis L.	0.05	0.04	0.04
Betula nigra L.	0.05	0.03	0.04
Pinus elliottii Engelm.	0.05	0.03	0.04
Albizia julibrissin Durazz.	0.05	0.01	0.03
Pinus virginiana Mill.	0.05	0.01	0.03
Totals	100	100	100

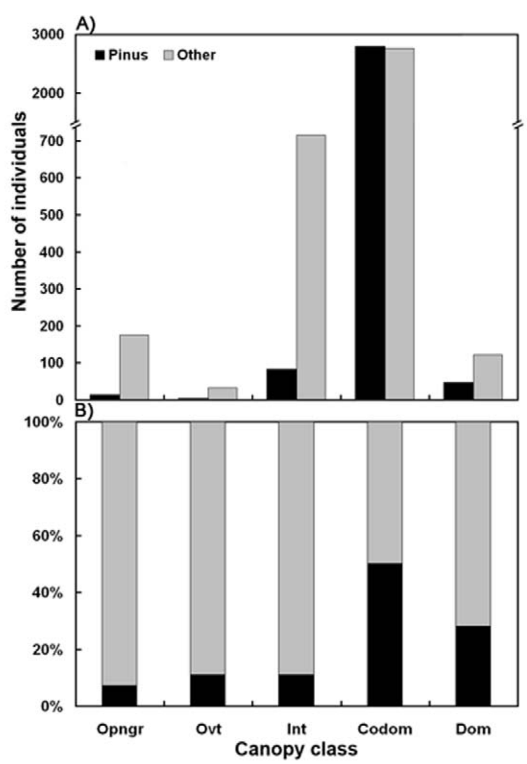

Figure 3. Canopy class groups by A) distributions and B) percentages at Redstone Arsenal. Canopy class categories are based on the amount and direction of intercepted light (Oliver and Larson, 1996). Dom: dominant, Codom: codominant, Int: intermediate, Ovt: overtopped, Opngr: open grown. For a list of species in the 'other' category see Table 2.

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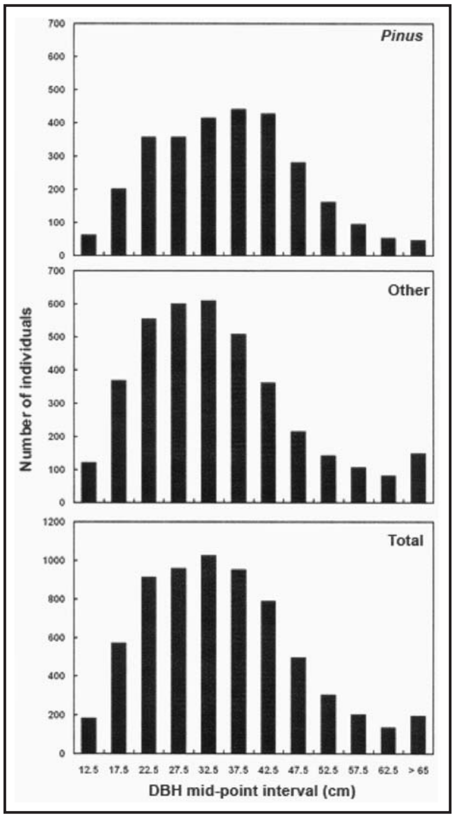

Figure 4. The diameter distribution for Pinus, other, and total trees in Redstone Arsenal. Each dbh interval includes stems ≥ 2.5 cm of the stated value with the exception of the > 65 cm class. For a list of species in the 'other' category see Table 2.

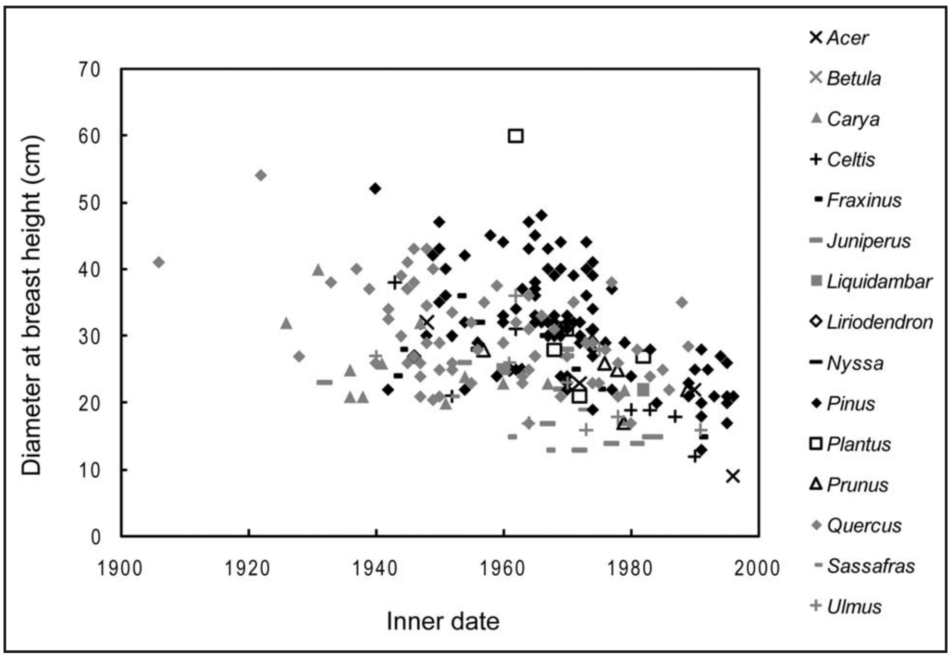

Figure 5. Relationship between diameter at breast height (cm) and tree age (based on the inner most date of trees) for trees (by Genus) at Redstone Arsenal.

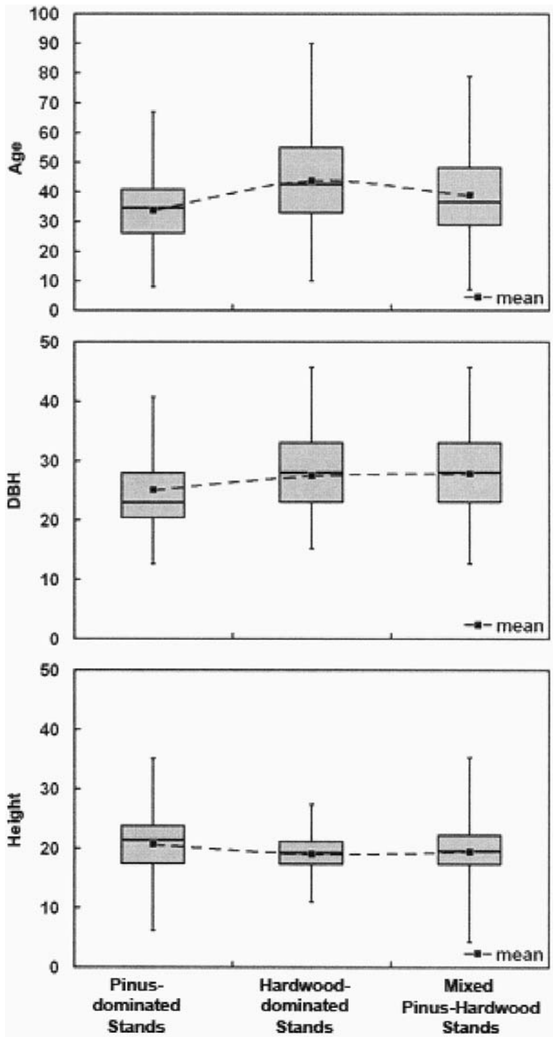

Figure 6. Mean, median, and ranges for mean stand age, dbh, and height for the three forests types in RA.