THE HEALTH OF LOBLOLLY PINE STANDS AT FORT BENNING, GA

Soung-Ryoul Ryu, G. Geoff Wang, and Joan L. Walker[1]

Abstract—Approximately two-thirds of the red-cockaded woodpecker (*Picoides borealis*) (RCW) groups at Fort Benning, GA, depend on loblolly pine (*Pinus taeda*) stands for nesting or foraging. However, loblolly pine stands are suspected to decline. Forest managers want to replace loblolly pine with longleaf pine (*P. palustris*), but they must do this gradually to continuously supply RCW habitats. Knowledge of the current decline status and causal factors is therefore needed. We analyzed recent forest inventory data (until 2006) covering 8403 ha of naturally regenerated loblolly pine (LB) and 554 ha of loblolly pine plantations (LBP). Overall, LBP stands were healthier than LB and may be a useful RCW habitat option during a transition period to a landscape with sufficient amount of RCW usable longleaf pine stands. In order to draw conclusions regarding the decline status of loblolly pine forests on a landscape such as Fort Benning, it is necessary to understand natural stand development and dynamics, and to investigate further the causes of decline.

INTRODUCTION

In much of the Southeastern United States, post-European settlement land use practices, especially fire exclusion, have resulted in the replacement of historically dominant longleaf pine (*Pinus palustris* Mill.) with loblolly pine (*P. taeda* L.). This widespread conversion has many land managers concerned, largely due to the ecological significance of longleaf pine. For example, longleaf pine is the preferred habitat for the federally endangered red-cockaded woodpecker (*Picoides borealis*) (RCW), yet on lands supporting RCW populations the lack of longleaf pine has necessitated the use of loblolly pine for foraging and nesting (U.S. Department of the Interior, Fish and Wildlife Service 2003). Fort Benning, GA, is a good example of this phenomenon. The installation has about 36 400 ha of upland pine forest, of which <4 000 ha are classified as longleaf pine, with the balance dominated by loblolly pine (U.S. Army Infantry Center 2006). Consequently, two-thirds of the 330 active RCW clusters currently are in loblolly pine stands, including an estimated 70 percent of the natural RCW cavity trees (U.S. Army Infantry Center 2006).

Forest managers at Fort Benning are currently interested in restoring longleaf pine to upland sites dominated by loblolly pine. Although this goal could be achieved by clearcutting the existing loblolly pine stands and planting longleaf pine seedlings, conversion efforts are complicated in loblolly pine stands that are currently being used for RCW habitat. In such stands, longleaf restoration must occur by gradual conversion of loblolly stands, such that mature loblolly stands are retained for RCW habitat throughout the development of newly planted longleaf stands. This approach rests on the assumption that mature loblolly pine stands will remain healthy enough to support existing RCW populations until enough mature longleaf stands are available to support the RCW population. Recent reports of loblolly decline symptoms in the Southeastern United States (e.g., Eckhardt and Menard 2008) bring this assumption into question. Further, forest managers are concerned that ongoing loblolly decline could limit available RCW habitat and slow population recovery. Knowledge of the current status and underlying cause(s) of loblolly pine decline is needed to address this concern.

Symptoms of loblolly pine decline include short chlorotic needles, sparse crowns, and reduced radial growth by stand age 40 to 50 years, with mortality generally occurring 2 to 3 years after these symptoms are observed (Hess and others 1999). Previous studies report that loblolly pine decline typically occurs on well-drained soils (Eckhardt and Menard 2008, Eckhardt and others 2007), which dominate Fort Benning's upland pine sites. Loblolly pines prefer relatively rich and moist soils (Harper 1965), whereas dry, poor uplands are considered to be "offsite" and are likely to increase stress on pines growing there. Although the mechanisms of loblolly pine decline are not fully understood, poor belowground growth and loss of root function have been implicated as main causes for decline. Further, decline may be exacerbated by a host of abiotic and biotic variables, including landscape position, e.g., slope and aspect, soil physical and chemical properties, water stress, landscape legacy effects, pathogen infection, e.g., *Leptographium* spp., and unusual climate patterns.

The primary objective of this study was to assess the health status of loblolly pine stands at Fort Benning using existing field survey data collected by land managers on the installation. The dataset included traditional inventory measures, e.g., stem densities and basal area, several forest health metrics, e.g., crown vigor class, presence of decline symptoms, insects or other disease indicators, and ground cover data, e.g., vegetation cover and bare ground

[1] Post-Doctoral Research Associate and Associate Professor, Clemson University, Department of Forestry and Natural Resources, Clemson, SC; and Research Plant Ecologist, U.S. Department of Agriculture Forest Service, Southern Research Station, Clemson, SC, respectively.

abundance. The study was conducted in two forest types: naturally regenerated, second-growth upland loblolly pine stands (LB) and loblolly pine plantations (LBP). LB stands provide much of the current RCW habitat, and LBP may provide future RCW habitat, so both were of interest.

MATERIALS AND METHODS

Study Site

Fort Benning is located in westcentral Georgia on the geographical Fall Line (fig. 1). The installation covers two major ecological provinces: the Sandhills in the northeastern two-thirds of the installation, and the Upper Loam Hills in the southwestern one-third. The terrain is rolling and ranges in elevation from 58 to 225 m above sea level (U.S. Army Infantry Center 2006). The climate is classified as warm humid temperate with hot, humid summers and mild winters. Mean annual precipitation is 1240 mm and is evenly distributed throughout the year (National Climatic Data Center, Asheville, NC). Major soil textures are loamy sand, sandy loam, and sandy clay loam.

Field Surveys

Fort Benning's Land Management Branch conducted an extensive, installation-wide inventory in 2005, with the primary objective of providing current stand and habitat information for RCW management. We analyzed the data collected through November 2006, which included information from 8403 ha of natural loblolly pine stands (LB) and 554 ha of loblolly pine plantations (LBP) (fig. 1). Prior to the survey, individual stands were delineated using the most recent aerial imagery. A stand was defined as a contiguous group of trees sufficiently uniform in species composition, age or arrangement of age classes, and site condition to be considered a distinguishable unit. Plantations <30 years old were considered homogeneous and all other stands were considered heterogeneous; minimum stand size was 4 ha, with a few exceptions.

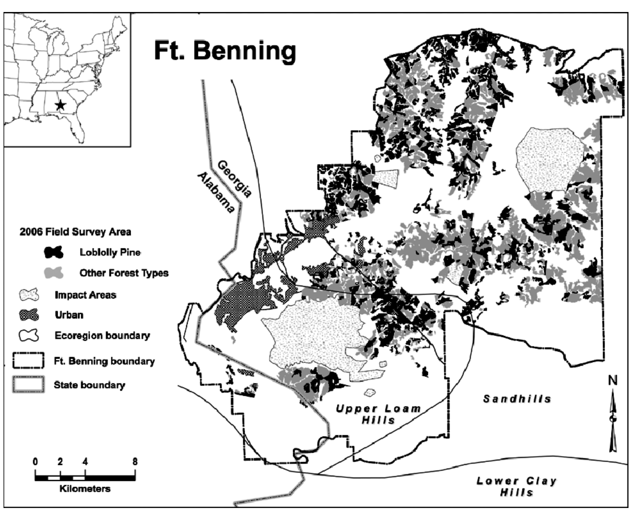

Figure 1—Geographical location of Fort Benning, GA, (inset) and the area surveyed as part of the most recent forest inventory. Loblolly pine indicates stands identified as loblolly pine and loblolly pine plantation within the survey area.

Field crews collected data from 10 sampling points in each homogeneous stand and 20 sampling points in each heterogeneous stand. In stands smaller than 4 ha, one sampling point was established per 0.8 ha in homogeneous stands and one sampling point was established per 0.4 ha in heterogeneous stands. To locate each sampling point, field crews identified a cruise route through the longitudinal axis of the stand and ran a compass line on this route. Cruise lines that tended to follow drains, ridges, trails, or other linear features were avoided. If a stand configuration was such that one line transect through the longitudinal axis did not result in enough sampling points to capture the variability of the stand, then the sampling scheme was modified in one of the following ways: (1) parallel transects were established two chains apart with sampling points 2 to 5 chains apart along each transect; (2) in a circular-shaped stand, sample transects were established in a triangular pattern; or (3) in a square-shaped stand, two perpendicular transects crossing through the center of the stand were established with sampling points established at 2- to 5-chain intervals along this route.

At each sampling point, variable radius 10-factor basal area prism plots were used to collect overstory data. Species and diameter at breast height (d.b.h.) of each tree larger than 12.5 cm (to nearest 0.25 cm) were recorded to describe stand structure and composition. Tree health was assessed by determining crown vigor class (CVC) following U.S. Forest Service, Forest Health Monitoring protocol (U.S. Forest Service 1999). Using this designation, each tree was assigned a "grade" to characterize canopy health (1 = good, 2 = fair, 3 = poor). CVC was mainly determined by crown ratio, crown dieback, and crown density, where CVC1 = crown ratio >35 percent, crown dieback <5 percent, and crown density >80 percent; CVC3 = crown ratio <35 percent, crown dieback >50 percent, and crown density <20 percent; and all other trees were classified as CVC2. Other potential health problems were recorded in an additional "insect or disease" category (ID), recorded as presence/absence of the following: (1) fusiform rust, (2) loblolly pine decline symptom (Symp), (3) annosus root rot, (4) black turpentine beetle [*Dendroctonus terebrans* (Oliv.)], and (5) other. Stand-level percentages of all pines exhibiting insect or disease conditions were used for the analysis. Hog damage (HD) and gopher tortoise burrow (GTB) presence were recorded within 400 m^2 fixed-radius plots centered on each sampling point. The ground cover was characterized by recording percent cover of herbaceous vegetation, woody vegetation, pine straw, and bare ground (including hardwood leaf litter) within 40 m^2 plots at each sampling point. Cover for each group was visually estimated in 10-percent increments, and when these four percentages were added together, their sum equaled 100 percent. Forest inventory data from previous surveys were used to determine stand age and site index (SI). If existing stand-age data were perceived to be incorrect, then dominant or codominant trees were cored to determine age. If the stand was a pine plantation, only one tree was cored.

Statistical Analysis

From the inventory data, we calculated pine basal area (BA, m^2/ha), pine stem density (SD, number of trees/ha), large pine (d.b.h. >35 cm) SD, hardwood BA, large hardwood (d.b.h. >35 cm) SD, and total BA of each stand. Pine tree health and condition data were analyzed at the stand level; mean CVC was calculated for each stand, and the percentage of all pines exhibiting Symp or other ID conditions were calculated for each stand. Differences in forest characteristics, e.g., BA, stem density, and SI, between the two forest types were tested by t-tests. Within each forest type, the effects of HD and GTB on CVC and ID were tested using t-tests, while effects on the Symp variable (percent of trees with decline symptoms) were tested using Wilcoxon rank sum. To meet the normality assumption, pine basal area (BA, m^2/ha), pine stem density (SD, number of trees/ha), hardwood BA, and CVC were transformed using a logarithmic function; SD of pine trees larger than 35 cm d.b.h. and ID were transformed by a square root function; and hardwood SD and total BA were transformed by an arcsine function. Symp data could not be transformed to follow a normal distribution, and data were therefore analyzed using Spearman rank test. All statistical analyses were performed using SAS (Version 9.01. SAS Institute Inc., Cary, NC).

RESULTS

Status of Forest Decline across Forest Types

Mean CVC and percentage of pines with ID were all significantly ($P < 0.05$) higher in naturally regenerated LB than LBP (table 1). Percentage of trees exhibiting Symp, indicated by sparse crowns and chlorotic needles, was also higher in LB than LBP, but the difference was not significant ($P > 0.05$). The majority (54 percent of area) of LB had intermediate to poor crown health, i.e., average CVC between 2 and 3, whereas roughly 25 percent (of area) of the LBP fell within this class. Results for ID were similar to Symp: 7 percent of LB (599 ha) had >50 percent ID, i.e., more than 50 percent of pine trees damaged by insect or disease, while there were no LBP with over 50 percent ID (fig. 2). At the same time, 33 percent (of area) of LB had <20 percent ID and about one-third of LB forest (2500 ha) showed between 20 and 30 percent of the stems with ID. Two-thirds (of area) of the LBP had <20 percent ID (fig. 2). Symp in LBP was always <10 percent, while 84 percent of LB had <10 percent Symp.

Table 1—Characteristics of naturally regenerated loblolly pine forests and loblolly pine plantations on Fort Benning, GA

Characteristics		Forest type, total area: Loblolly pine (ha)[a]	Forest type, total area: Loblolly pine plantation (ha)[a]
		8403	554
Stand condition	Stand age (year)	59 (20) a	31 (22) b
	Site index	79 (12)	84 (24)
	Stand size (ha)	13.9 (10.8) a	7.4 (11.9) b
Overstory condition	Pine basal area (m^2/ha)	10.3 (3.7) b	16.8 (6.6) a
	Pine stem density (number/ha)	179 (124) b	587 (311) a
	Pine (d.b.h. >35 cm) stem density (number/ha)	32 (15) a	6 (15) b
	Hardwood basal area (m^2/ha)	2.2 (1.8) a	0.4 (0.6) b
	Hardwood (d.b.h. >35 cm) stem density (number/ha)	4.7 (4.6) a	0.4 (1.4) b
	Total basal area (m^2/ha)	12.5 (4.0) b	17.1 (6.5) a
Health metrics	Crown vigor class	1.9 (0.3) a	1.7 (0.4) b
	Insect or disease (percent)	27.0 (14.3) a	15.9 (11.8) b
	Pine decline symptom (percent)	4.7 (8.6)	0.4 (1.1)
Ground cover	Herbaceous (percent)	25 (10)	22 (12)
	Woody plants (percent)	22 (10)	20 (11)
	Bare ground (percent)	26 (14) a	13 (11) b
	Pine straw (percent)	27 (11) b	44 (18) a

Data are presented as mean values (1 standard deviation). BA and d.b.h. indicate for basal area and diameter at breast height, respectively.

[a] Different letters within a row indicate a significant difference ($P < 0.05$) between forest types.

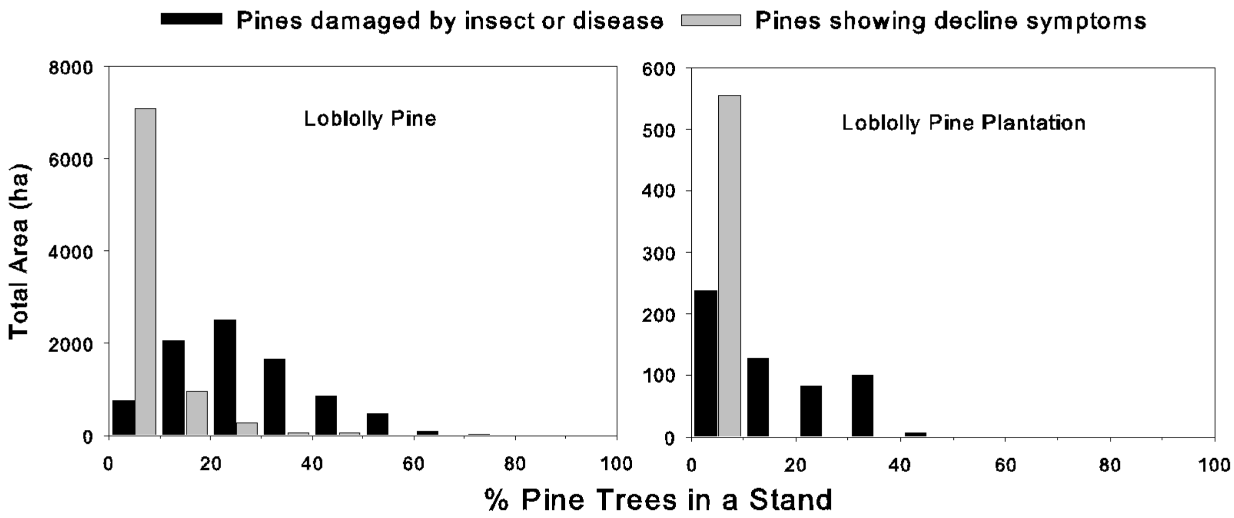

Figure 2—Total area of loblolly natural stands (LB) and loblolly plantations (LBP) surveyed by 10 percentile insect/disease and decline classes.

Relationship of Forest Health Metrics and Environmental Variables

SI was similar between LB and LBP forests. As expected, LBP stands were significantly ($P < 0.05$) younger, denser, and had smaller trees than LB stands (table 1). LBP stands had more than triple the number of pine trees per unit area and 25 percent more BA than LB stands. However, the number of large pine trees (d.b.h. >35 cm) in LBP stands was <20 percent of those in LB stands (table 1).

Although some significant relationships between the health metrics and pine SD emerged, there was no clear pattern (table 2). For example, correlation showed that stands tended to have poorer crowns (higher CVC) with higher SD ($P < 0.05$) in LB, but higher Symp percent occurred at lower SD in LBP stands ($P < 0.05$). LBP stands had significantly ($P < 0.05$) lower hardwood BA and SD compared to LB stands, but again the influence of hardwoods on the health metrics was difficult to discern.

Percent herbaceous and woody ground cover was similar between LB and LBP stands, but LBP had significantly ($P < 0.05$) more pine straw and less ($P < 0.05$) bare ground than LB stands (table 1). Results from the correlation analysis between ground cover variables and the health metrics were noisy but suggested some relationships (table 2). Within LB stands, stands were healthier (lower CVC value) with greater percent woody plant cover and less pine straw cover; pine ID increased with the increase of herbaceous and woody plant cover and the decrease of bare ground and pine straw cover; pine Symp was found with higher herbaceous cover and lower pine straw cover. Within LBP stands, stand health decreased (higher CVC value) and pine Symp increased with the increase of bare ground.

Tree health metrics generally were significantly correlated with one another. Stands were unhealthier (higher CVC value) when pine ID was higher ($r = 0.12$, $P < 0.01$ for LB; $r = 0.41$, $P < 0.01$ for LBP), and when pine Symp was higher ($r = 0.15$, $P < 0.01$ for LBP only). Incidence of decline (Symp) was positively correlated with ID ($r = 0.20$, $P < 0.01$ for LB; $r = 0.36$, $P < 0.01$ for LBP). We did not find any significant ($P < 0.05$) effect of soil surface disturbance from GTB or HD on CVC, ID, or Symp in either forest type.

DISCUSSION

Is Fort Benning at Risk of Loblolly Pine Decline?

All health metrics suggest that LBP are healthier than natural LB stands on Fort Benning. One explanation could be related to age; LBP stands were younger than LB stands (59 and 31 years for LB and LBP, respectively), and loblolly pine decline is generally associated with stands older than 40 years (Hess and others 1999). However, we found no significant ($P < 0.05$) correlation between stand age and the health metrics within each forest type. We hypothesize that there may be a threshold age beyond which the likelihood of decline increases, e.g., 40 years, but we did not find any specific patterns from our data. Regardless of the underlying mechanism, relatively healthier LBP stands may become more valuable over time, especially if existing natural stands continue to decline or decline becomes more widespread in LB stands. Though LBP stands may eventually decline as well, their current status suggests that they may provide critical, short-term RCW habitat until younger longleaf pine plantations develop into suitable RCW habitat.

Interpreting the health status of Fort Benning's pine forest is complicated by the fact that there is no robust, universal definition of loblolly pine decline. It is generally held that forest decline refers to a continuous loss of vigor or health associated with an unclear causal factor or with complex interactions between biotic and abiotic factors, and previous studies (e.g., Eckhardt 2003, Houston 1992, Manion 1991) defined loblolly pine decline as "a gradual deterioration in

Table 2—Spearman correlation of tree health metrics (crown vigor class, insect or disease, and decline) with other variables in naturally regenerated loblolly pine forests and loblolly pine plantations

	Loblolly pine (*n* = 603 except *n* of SI = 577)			Loblolly pine plantation (*n* = 76 except *n* of SI = 41)		
Stand characteristics	Crown vigor class	Insect or disease	Decline symptom	Crown vigor class	Insect or disease	Decline symptom
Site index	–0.09	–0.00	–0.07	–0.06	0.08	0.12
Stand age (year)	–0.06	–0.04	–0.03	0.07	–0.07	0.10
Pine basal area (m^2/ha)	0.05	–0.07	0.01	–0.19	0.09	–0.20
Pine stem density (number/ha)	0.11[a]	–0.19[a]	0.02	–0.19	–0.19	–0.39[a]
Pine (d.b.h. >35 cm) stem density (number/ha)	–0.04	0.04	0.14	0.05	0.17	0.03
Total basal area (m^2/ha)	0.02	–0.14[a]	–0.02	–0.19	0.11	–0.15
Herbaceous (percent)	–0.00	0.14[a]	0.12[a]	0.02	0.06	0.15
Woody plant (percent)	–0.12[a]	0.13[a]	–0.08	–0.20	0.03	0.02
Bare ground (percent)	–0.01	–0.08[a]	0.05	0.22[a]	–0.13	0.31[a]
Pine straw (percent)	0.13[a]	–0.21[a]	–0.12[a]	–0.08	0.11	–0.21
Crown vigor class	—	0.12[a]	–0.05	—	0.41[a]	0.15[a]
Insect or disease (percent)	0.12[a]	—	0.20[a]	0.20[a]	—	0.36[a]
Decline symptom (percent)	–0.05	0.20[a]	—	0.15[a]	0.36[a]	—

SI = site index.

[a] Indicates significant ($P < 0.05$) correlations.

health and vigor of canopy-dominant trees that frequently ends in death." However, this definition does not distinguish natural mortality due to aging from decline and provides no practical threshold for making consistent judgments. Self-thinning mortality is a natural process, common to all stages of forest development, that can be influenced by many stand and site conditions. Despite results from an extensive field survey (>9000 ha of loblolly pine forests), the ambiguity surrounding what constitutes loblolly pine declines makes it difficult to draw definitive conclusions about the presence of decline on the installation.

Factors Associated with Loblolly Pine Health

The results from correlation analysis were inconsistent, making it difficult to draw definite conclusions about relationships between decline and possible causal factors from our dataset. This was especially true in the LBP stands, probably due to the narrow range in health metrics recorded and the smaller sample size of LBP stands. Only 11 stands among 76 LBP stands had pine trees classified as Symp, limiting the interpretation of LBP correlation tests. Therefore, the following discussion will focus on the naturally established LB stands.

CVC was significantly, negatively correlated ($P < 0.05$) with SI, indicating that site conditions may play a role in reduced tree health. Many of the upland pine stands on the installation are on sandy, well-drained, nutrient-poor growing sites. Loblolly pines are known to be mature at age 80 and begin to naturally lose vigor at age 150 (Harper 1965), but poor-growing conditions may accelerate natural senescence, resulting in concern about "decline." Moreover, given that loblolly pine demands more nutrients than other pines (Baker and Langdon 1990), soils on the installation may be insufficient for healthy loblolly pine growth. Symptoms of nutrient deficiency in trees are often quite similar to those reported as loblolly pine decline. For example, Smethurst and others (2007) suggested that potassium (K) deficiency was the main cause of chlorotic needles and sparse canopies of radiata pines (*P. radiata* D. Don) in Australia. Further, Hess and others (1999) reported very low K in the soils of declining loblolly pine stands in Alabama, suggesting a connection between site nutrients and tree health. Although we have no conclusive evidence that currently reported loblolly pine decline is associated with nutrient deficit, it is likely that nutrient deficiencies contribute to a loss of pine vigor.

Patterns of ground cover vegetation are often useful indicators of site disturbance and, in particular, fire history. Understory vegetation (herbaceous and woody plant cover) in pine stands often increases after prescribed fire (e.g., Hendricks and Boring 1999) and prescribed fire combined with thinning (Wayman and North 2007). Prescribed fire and thinning could result in both pine straw cover decrease and understory cover increase, factors we found associated with increasing ID and Symp. This raises questions about the relation between ground cover and overstory tree health; perhaps, rather than a direct link between ground cover and loblolly pine vigor, current ground cover is a reflection of past management history that has influenced both ground cover and overstory health.

Forests on Fort Benning are heavily managed, including recent reintroduction of prescribed burning, and it is possible that management activities have added stress to pines. The installation burns approximately 12 000 ha/year on an approximately 3-year rotation with prescribed fire, and additional wildfires due to military munitions are common. Prescribed fire was introduced at this scale in 1994, following U.S. Fish and Wildlife Service recommendations for RCW management (U.S. Army Infantry Center 2006). Although prescribed burning improves habitat structure for RCW, fire could negatively influence belowground pine production by reducing nutrient availability (Raison and others 1985), decreasing water infiltration rates (DeBano 2000), decreasing water holding capacity (Boyer and Miller 1994), and reducing soil organic matter and soil porosity (Busse and others 2000, Landsberg 1994, Tiedemann and others 2000). At the time of reintroduction, little was known about the precautions managers should take when burning in areas with high organic matter accumulation, i.e., duff.

It is likely that the manifestation of decline symptoms is a response to a combination of stress factors, including many not accounted for within the dataset used in this study. Historical land use, e.g., landscape legacy, has lasting effects on growing conditions that play a critical role in shaping current stand health. Prior to Fort Benning's establishment as a military installation, the region was heavily farmed (U.S. Army Infantry Center 2006), resulting in massive erosion and soil degradation. Present day timber harvesting and feral hogs' behavior may each reduce belowground productivity by increasing soil compaction and physically damaging root systems. Further, effects of military training on tree growth are not fully understood. In addition to land use, climate patterns and/or climate change may affect belowground dynamics by altering temperature and precipitation patterns. For example, Fort Benning has experienced several severe droughts in the last decade, increasing moisture stress on sandy sites with intrinsically low water holding capacity. Understanding the role of climate (and global warming, in particular), as well as many of the other possible contributors to loblolly pine decline in this area, would require extensive, long-term study on a host of biotic and abiotic stress variables.

CONCLUSIONS AND FUTURE NEEDS

It was clear that naturally regenerated LB stands were less vigorous than LBP at Fort Benning and more often exhibited symptoms of ID. It may be strategic to maintain pockets of LBP to serve as a bridge for future RCW habitat. Overall, the percentage of trees with decline symptoms seems modest, making it difficult to determine if LB at the installation is really declining. To make a concrete determination regarding the extent of LB decline, we would require the (1) development of a mortality/vigor threshold to determine stand decline, e.g., stand mortality >15 percent and percent of trees in low vigor >30 percent at a given time indicates decline, and (2) an understanding of the dynamics of tree mortality and stand development at Fort Benning. We did observe a positive relationship between crown health and SI, suggesting that the growing site and associated resource availability may limit LB growth on the installation. Our results suggest that future work should be aimed at evaluating practical criteria to determine LB decline and its underlying causes, including nutrient availability and forest management practices.

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LITERATURE CITED

Baker, J.B.; Langdon, O.G. 1990. Loblolly pine (*Pinus taeda* L.). In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America: 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture Forest Service: 497–512.

Boyer, W.D.; Miller, J.H. 1994. Effect of burning and brush treatments on nutrient and soil physical-properties in young longleaf pine stands. Forest Ecology and Management. 70: 311–318.

Busse, M.D.; Simon, S.A.; Riegel, G.M. 2000. Tree-growth and understory responses to low-severity prescribed burning in thinned *Pinus ponderosa* forest of central Oregon. Forest Science. 46: 258–268.

DeBano, L.F. 2000. The role of fire and soil heating on water repellence in wildland environments: a review. Journal of Hydrology. 231/232: 195–206.

Eckhardt, L.G. 2003. Biology and ecology of *Liptographium* species and their vectors as components of loblolly pine decline. Baton Rouge, LA: Louisiana State University, The Department of Plant Pathology and Crop Physiology. [Number of pages unknown]. Ph.D. dissertation.

Eckhardt, L.G.; Menard, R.D. 2008. Topography features associated with loblolly pine decline in central Alabama. Forest Ecology and Management. 255: 1735–1739.

Eckhardt, L.G.; Weber, A.M.; Menard, R.D. [and others]. 2007. Insect-fungal complex associated with loblolly pine decline in central Alabama. Forest Science. 53(1): 84–92.

Harper, V.L. 1965. Silvics of forest trees of the United States. Agric. Handb. 271. Washington, DC: U.S. Department of Agriculture Forest Service. 762 p.

Hendricks, J.J.; Boring, L.R. 1999. N_2-fixation by native herbaceous legumes in burned pine ecosystems of the Southeastern United States. Forest Ecology and Management. 113: 167–177.

Hess, N.J.; Otrosina, W.J.; Jones, J.P. [and others]. 1999. Reassessment of loblolly pine decline on the Oakmulgee District, Talladega National Forest, Alabama. Rep. 99-2-03. Pineville, LA: U.S. Department of Agriculture Forest Service, Forest Health Protection. [Number of pages unknown].

Houston, D.R. 1992. A host-saprogen model for forest dieback-decline diseases. In: Manion, P.D.; Lachance, D. eds. Forest decline concepts. St. Paul, MN: American Phytopathological Society Press: 3–25.

Landsberg, J.D. 1994. A review of prescribed fire and tree growth response in the genus *Pinus*. Proceedings, 13th conference on fire and forest meteorology. Society of American Foresters. 326 p.

Manion, P.D. 1991. Tree disease concepts. 2d ed. Englewood Cliffs, NJ: Prentice Hall, Inc. 402 p.

Raison, R.J.; Khanna, P.K.; Woods, P.V. 1985. Transfer of elements to the atmosphere during low-intensity prescribed fires in three Australian subalpine eucalypt forests. Canadian Journal of Forest Research. 15: 657–664.

Smethurst, P.; Knowles, A.; Churchill, K. [and others]. 2007. Soil and foliar chemistry associated with potassium deficiency in *Pinus radiate*. Canadian Journal of Forest Research. 37: 1093–1105.

Tiedemann, A.R.; Klemmedson, J.O.; Bull, E.L. 2000. Solution of forest health problems with prescribed fire: are forest productivity and wildlife at risk? Forest Ecology and Management. 127: 1–18.

U.S. Army Infantry Center. 2006. Integrated natural resources management plan, Fort Benning Army Installation, Incremental Revision 2006. Fort Benning, GA: Directorate of Public Works, Environmental Division. 1,037 p.

U.S. Department of Agriculture Forest Service. 1999. Forest Health Monitoring 1998 field method's guide. Research Triangle Park, NC: U.S. Department of Agriculture Forest Service, National Forest Health Monitoring Program. [Number of pages unknown].

U.S. Department of the Interior, Fish and Wildlife Service. 2003. Draft red-cockaded woodpecker recovery plan. Atlanta. [Number of pages unknown].

Wayman, R.B.; North, M. 2007. Initial response of a mixed-conifer understory plant community to burning and thinning restoration treatments. Forest Ecology and Management. 239 (1-3): 32–44.