ASSESSMENT OF LOBLOLLY PINE DECLINE ON FORT BENNING MILITARY RESERVATION

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Assessment of Loblolly Pine Decline on Fort Benning Military Reservation

by

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Abstract

A decline of loblolly pine *(Pinus taeda* L.), characterized by expanding areas of declining and dead trees, has become prevalent at Fort Benning, Georgia. A three year study was conducted to determine the fungi and insects, and site disturbances associated with this problem. *Dendroctonus terebrans, Hylastes salebrosus, Hylastes tenuis, Pachylobius picivorus* and *Hylobius pales* were significantly more abundant in symptomatic than in asymptomatic loblolly pine plots. These root and lower stem-infesting insects consistently carried *Leptographium terebrantis, L. procerum,* and *L. serpens.* Root sampling revealed high levels of root damage and mortality, staining and infestation with *Leptographium* spp. This below-ground damage and mortality precedes the expression of above-ground symptoms such as short chlorotic needles, sparse crowns, and reduced radial growth. A sequence of interactions among this complex of organisms and abiotic factors is proposed as the cause of 'loblolly pine decline'. This study confirms the findings for loblolly pine decline and validates the Loblolly Pine Decline Risk Map as described by Eckhardt (2003).

Introduction

Fort Benning Military Reservation (FBMR) is located in the mid-western portion of Georgia's Muscogee and Chattahoochee Counties. The predominant land base is Upper Coastal Plain with some Piedmont transition zone along the Fall Line. The original Reservation began with the acquisition of approximately 98,000 acres during 1919-1921. An additional 85,000 acres was acquired in 1941-1942. Seventy-five percent of the

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initial forest types of shortleaf and longleaf pines had been cleared and heavily farmed prior to these acquisitions. Commercial forest management began in 1950 with the hiring of the first Army forester. Management during the 1950's-1980 ephasized the use of dormant season prescribed burning and reforestation of open areas with loblolly and slash pine. During 1980-1990, remaining overgrown clear-cut areas were reclaimed by planting loblolly pine. An increase in southern pine beetle (SPB) activity and littleleaf disease were evident during this period.

In the late 1980's management emphasis shifted to red-cockaded woodpecker (RCW) habitat restoration with growing season prescribed burning, aggressive regeneration of longleaf pine, and thinning of overstocked loblolly pine stands. From 1990 to the present, the emphasis on longleaf pine restoration has continued, with protection of existing longleaf stands, replanting of longleaf, thinning to promote natural longleaf regeneration and increased prescribed burning into growing seasons. It was during this time period that Fort Benning resource managers began to observe visual signs of senescence and symptoms of decline in the loblolly stands. The ramification of premature pine die-off could be significant to the RCW habitat. Approximately 70 percent of the RCW cavity trees are currently found in loblolly pines and much of their foraging area is located in loblolly stands. In 2003, the Fort Benning Conservation Branch requested that Forest Health Protection (FHP) complete an evaluation of their upland loblolly sites, to project the impact of forest health on their RCW habitat management. The study objectives were identified:

1. Determine the relative health of current stands of loblolly pine by evaluating standard forest health monitoring parameters (age, basal area, DBH, and radial growth) and condition class (crown, resin, and foliage).

2. Provide to FBMR a Loblolly Pine Decline Risk Map (LPDRM) developed using mapping parameters established in an assessment of loblolly pine decline in central Alabama (Eckhardt 2003) and validated for the Fort Benning area.

3. Integrate root pathology, insect associate data, and site data to evaluate potential impact on the health of individual trees and stands.

Material and Methods

This study was established as a cooperative effort between USDA Forest Service, Forest Health Protection, Pineville, LA and Louisiana State University, Louisiana Agriculture Experiment Station, Department of Plant Pathology, Baton Rouge, LA (via a Participating Agreement). Funding for the project is through the Military Interdepartmental Purchase Request (MIPR) process with additional funding contributed by FHP and the LSU Agriculture Center. The project was initiated in the summer of 2003 with field work scheduled to be completed in the summer of 2005.

Study Design:

Thirty-six 1/6 acre plots (Forest Health Monitoring protocols, Dunn 1999) were established (Table 6). The location of the plots was determined using LPDRM which identified a site as either symptomatic (decline [D]) or asymptomatic (healthy [H]). There were 14 asymptomatic and 22 symptomatic plots established and each plot was categorized in one of four stand age classes; <10, 10 - 19, 20 - 40 and >40 yrs of age.

At each location, a root health assessment was performed on three dominant or co-dominant pines nearest to the center plot location. Root sampling was done with the modified two-root excavation method (Otrosina and others, 1997). Tree species, diameter at breast height (DBH), age, and 5 and 10 year radial growth increments were recorded from each of the root-sampled trees. Root-feeding insects were sampled on subplots of 31 center plots using pitfall traps (3 subplots per plot, 93 total pitfall traps) from March to May for a 3 year period (2002-2005). Insects were collected on a biweekly basis for transport to the laboratory for identification and isolation of associated fungi; special emphasis was placed on those felt to be possible pathogens.

Other data collected at each plot included:

- tree data -- species, DBH, height, and crown rating of other trees greater than 4 DBH
- site data -- basal area of pine and total basal area pine plus other trees > 4 DBH (10 factor prism), aspect of slope, percent slope, elevation, topographic position, land form, percent soil moisture, and soil pH
- tree vigor -- resin weight, crown condition, and root condition
- soil properties -- soil profile, physical characteristic and nutrient status (data pending)

Tree Health Assessment:

Tree health was monitored at each plot utilizing the Forest Health Monitoring (FHM) protocols (Dunn 1999). Tree crown condition was measured on all pine trees with a DBH of 4 inches or greater. The crown measurements included:

- live crown ratio - a comparison of crown length with total tree height
- crown light exposure – a measure of light impacting the crown from all sides and the top
- crown position in the canopy – superstory, overstory, midstory, or understory
- crown density – percent of crown outlined with living branches and foliage
- crown dieback - the ratio of recent fine twig dieback to total live crown
- foliage transparency – percent sunlight transmitted through the living crown

Crown exposure to light and position were combined in the analysis to indicate stand and canopy structure. Crown density, dieback, and transparency were used to give an indication of tree vigor.

Tree vigor was also measured using sampled weights of resin to compare resin production. One hundred ninety eight trees were sampled (33/decline/age class minus precommercial) on the south side of each tree, by punching a hole through the bark. A plastic resin sampler with a removable preweighed 15 ml centrifuge tube was attached over the punch hole with two wood screws and left for 24 hours. Centrifuge tubes with resin were then collected capped and put on ice for transport to laboratory for resin weight determination in the laboratory.

Root Pathogen Assessment:
Root samples were collected from all of the 36 center plots using a two-root excavation method in which three dominant/co-dominant trees nearest to plot center were selected. Two primary lateral roots extending away from the tree base were excavated with hand tools from the root collar out to approximately the drip line of the crown of each selected tree. Primary roots were defined as the major lateral roots extending from the base of the trees to the drip line. Primary root depth was recorded and roots were examined for root feeding insect activity and other damage. All other roots were categorized as fine roots.

In addition to sampling the roots for pathogens, samples of soil were collected from around the excavated primary roots in a specific collection pattern using a soil punch (Eckhardt, 2003). Roots and associated soil samples were sent to Louisiana State University, Plant Pathology Department, where fungal isolations and identifications were made. Of primary interest were fungi in the genus *Leptographium* and *Phytophthora.* Standard laboratory procedures were used as described in Eckhardt (2003).

Topographic Features:
Topographic and geographical data were obtained from the Fort Benning Military Reservation geo-spatial database. Topographic data were derived from 10m Digital Elevation Models (DEM) which were based on contour lines obtained from the United States Geological Service 7.5 minute (1:24,000) topographic quadrangles. Slope and aspect were derived from the DEMs. Fort Benning Military Reservation shape files were used to delineate reservation boundaries, stands, compartments, roads, and streams for the pine decline risk map assessment. All data gathered were georeferenced and projected in UTM83 and thus constitute a geographic database of Fort Benning Military Reservation, Georgia.

ArcView 3.2 (ESRI, 1996) along with the Spatial Analysis extension (ESRI, 1996) was used to combine and analyze the different maps by a series of ArcView 3.2 functions containing multiple steps that create, merge, and intersect parameters of loblolly pine decline. The resulting product spatially presents the prediction of the levels of loblolly pine decline in a multicolored polygon map (green = minimal, yellow = low, magenta = moderate, and red = high).

Each paired comparison was used to form a unique layer composed of basic polygons containing all the data from the combined layers and represents the occurrence of some level of loblolly pine decline as described.

1) Aspect was derived using the DEM and ArcView Spatial Analysis extension ‘Surface’ to ‘Derive Aspect’ for the Fort Benning area. The aspect theme created was reclassified based on biological parameters statistically associated to a measured range of aspect degree orientation where 337.5°-0°-67.5° equals green (minimal risk), 67.5°-

112.5° and 292.5°-337.5° equals yellow (low risk), 247.5°-292.5° equals magenta (moderate risk), and 112.5°-247.5° equals red (high risk).

2) Slope was derived using the DEM and ArcView Spatial Analysis extension 'Surface' to 'Derive Slope' for the Fort Benning area. The slope theme created was reclassified based on biological parameters statistically associated to a measured range of percent slope where 0-5% equals green (minimal risk), 5-10% equals yellow (low risk), 10-15% equals magenta (moderate risk), and >15% equals red (high risk). The final loblolly decline risk map is legend edited to the commensurate color ranking to complete the process.

Applying the above information, probable location of decline was mapped at Fort Benning Military Reservation. The LPDRM was then assessed for predictive accuracy on the Fort Benning Military Reservation.

RESULTS

Age of loblolly trees in the 36 plots ranged from 6 to 84 years. The range of average DBH for loblolly trees sampled for growth and vigor were 4.1 to 21 inches. Other pooled averages representing tree growth and vigor are compared in (Table 1). There was no significant difference in DBH when segregated by symptomology (Table 2). Symptomatic trees did show reduction in radial growth for both 5 and 10 year measurements and a reduction in resin by weight production (Table 2). The range of height for sample trees was 16 to 88 feet. There was no significant difference in average tree height when overall tree-height-averages for symptomatic vs. asymptomatic trees were compared (Table 2). When broken down by age categories a significant reduction in average height and DBH of symptomatic trees appears in the 25-29 yr age category (Table 3).

The 5 year radial growth for trees observed on these plots ranged from 4.5 to 31.4 mm and 10 year radial growth was 9.8 to 58.45 mm. Radial growth for both 5 and 10 yr was decreased in symptomatic as compared to asymptomatic trees (Table 2) and this discrepancy is even more pronounced when broken out by age category (Table 4). Radial growth measures generally indicate that symptomatic trees are progressively decreasing in average radial growth thru all age categories at a greater rate than asymptomatic trees (Table 4). Furthermore, the changes in radial growth of symptomatic trees for the last 5 years of radial growth as compared with the radial growth of the previous 5 years exhibited more variability between all age categories than did asymptomatic tree (Table 4). As well, the last 5 years, radial growth change in the 15-19 and 30-39 yr age category showed a significant difference when average symptomatic growth is compared with average asymptomatic growth (Table 4).

Stand density ranged from 20 to 150 square feet for pine and 30 to 160 square feet total. Symptomatic trees had lower resin production than did asymptomatic trees (Table 2)

The total number of pest insects trapped increased annually during the three year trapping period (1170 to 2423), with the average pest insect numbers per trap per day increasing from 21 to 43. The average for pest insect numbers, when pooled by plot symptomology, was lower on asymptomatic plots (32) as compared to symptomatic plots (62). When plots were segregated as having had a history of disturbance (burning, thinning, or feral hog rooting) or not, the average pest insect numbers when pooled by disturbance, were greater on disturbed plots (65) than undisturbed plots (42). Average pest insect numbers remained higher on disturbed symptomatic vs. asymptomatic plots (87 and 26, respectively) than on undisturbed symptomatic or asymptomatic plots (43 and 21, respectively) (Fig. 2, Fig. 1). Average counts of pest insects on symptomatic and asymptomatic plots varied depending on the disturbance type and also indicated that sites with compound disturbances had higher average pest insect populations than sites with only a single disturbance (Fig. 3).

Leptographium spp. were isolated from the primary and fine root samples from 27 of the 36 plots and from the soil in 4 of the 36 plots (Table 5). *Leptographium* spp. isolated from the primary root samples were *L. terebrantis* Barras & Perry, *L. procerum* (Kendr.) Wingfield, *L. serpens* (Goid.) Wingfield, and an unidentified Ophiostoma sp. Only *L. procerum* was isolated from the fine roots. The overall proportion of *Leptographium* spp. isolated was significantly higher from roots of trees on symptomatic plots (95%) than those from asymptomatic plots (0.01%) (Table 5). In addition, only *L. procerum* was isolated from the soil samples, and was generally more common in soil from symptomatic vs. asymptomatic plots.

Phytophthora cinnamomi Rands was not isolated from any of the root or soil samples. *Heterobasidium annosum* (Fr.) Bref. was found neither in any of the root samples, nor were any fruiting bodies of the fungus found on trees or stumps. Although, during a field survey visit in January 2005, some small fruiting bodies were found on old stumps at other locations on the installation (C0102, C0202), there was no evidence of root infection of trees in the sample plots.

Leptographium spp. were also isolated from the surface of three species of root-feeding bark beetles (Coleoptera: Scolytidae: *Dendroctonus terebrans* Olivier, *Hylastes salebrosus* Eichoff, *and Hylastes tenuis* Eichoff), and two species of root-feeding weevils (Coleoptera: Curculionidae: *Hylobius pales* Herbst., and *Pachylobius picivorus* (Germar)) (Coleoptera : Curculionidae). Eight other bark beetles and fungus-feeding insects [Coleoptera: Scolytidae: *Ips avulses* (Eichhoff), *Ips grandicollis* (Eichhoff), *Xyleborinus saxeseini* (Ratzeburg), *Xylosandrus compactus* (Eichhoff), *Xylosandrus crassiusculus* (Motschulsky), *Gnathotrichus materiarius* (Fitch), and *Monarthrum mali* (Fitch); and Coleoptera: Nitidulidae: *Colopterus unicolor* (Say)] were trapped from the 31 plots. All of the pest insects (the bark beetle and weevil spp.) caught during the three years of trapping had positive isolations for *Leptographium* spp. and *Leptographium* isolations from root samples were positively correlated with high populations of root-feeding bark beetles and weevils. Increased numbers of root-feeding bark beetles and weevils were trapped following prescribed burning, thinning, and feral hog rooting activity. Pest insect populations have increased two fold between 2003 and 2005, while the number of beneficial insects trapped was very low compared to pests (1:66).

Root system deterioration was significantly higher in symptomatic than in asymptomatic trees (Fig. 4). Symptomatic trees consistently had more dead fine roots and fewer fine roots present, more physical damage from insects and fire, more staining of the primary roots, and a higher percentage of isolation of *Leptographium* spp. per root system. The relationship between the degree of root system health and reduced radial growth was found to be significant (Hess and others, 2003).

The predicted location for symptoms of decline as delineated through use of the LPDRM was found to be 95% accurate for symptomatic sites and 99% accurate for asymptomatic sites (Fig 5). Plots with aspect (orientation of the slope) ranges of west northwest to south and south to southeast are more likely to have symptomatic trees. Plots with aspect of north northwest to north and north to east have asymptomatic trees. Plots that had slope of greater than 5% were shown to symptomatic and plots 5% or less slope were shown to be asymptomatic.

DISCUSSION

This study confirms the findings for declining loblolly pine described by Eckhardt (2003) on the Talladega National Forest in a cooperative research project between Forest Health Protection and Louisiana State University (Hess and others 2005). This decline of loblolly pine is characterized by the deterioration of root systems, short chlorotic needles, sparse crowns, and reduced radial stem growth, and may be followed by death of the affected tree. While the described symptomology mimics littleleaf disease, the decline of loblolly pine reported here is consistently associated with the occurrence of *Leptographium* spp. and root-feeding insects. Littleleaf disease is caused in part by the pathogen *P. cinnamomi* (Campbell and Copeland, 1954) which was not isolated from and fine roots or soil samples in this study.

The decline of loblolly pine at FBMR appears to have resulted from the debilitation of root systems inoculated with *Leptographium* spp. associated with root-feeding insects attracted by a weakened condition of potential host trees influenced by stress or onsite disturbances. This finding is consistent with the findings in similar pine decline studies (Eckhardt and others, 2004; Hess and others, 2005). *Leptographium* spp. and root-feeding insects were consistently associated with declining trees and the damage apparent in the root systems was typically higher in symptomatic trees. This is consistent with observations made for other pines with *Leptographium* spp. activity in their roots (Klepzig, 1991; Eckhardt and others, 2004). Symptomatic trees consistently possessed fewer fine roots and generally displayed more insect, fire, and mechanical damage to the primary root systems than the asymptomatic trees.

In longleaf pine (*Pinus palustris* Mill.), prescribed burns affect fine root growth by affecting mineral nutrition and root carbohydrate metabolism (Kuehler, 2003). Fire has a long-lasting effect as a result of the damage it does to shallow roots, making them more vulnerable to infection by a variety of imperfect fungi (Gara and others, 1985). This type of disturbance factor may be critical to loblolly pine since it is less tolerant to fire than longleaf pine (Boyer, 1990).

Implementation beginning in the late 1980 of RCW management which includes prescribed burns may, consequently, be a critical component responsible for negatively impacting fine roots in symptomatic loblolly (Fig. 4). Fire disturbance has a significant impact on pest insect activity near tree roots, and fire disturbance which is compounded with thinning or feral hog activity further increases pest insect activity (Fig 3). Increased pest insect numbers strongly correlated to disturbances, root deterioration, and decline symptomology.

The above ground symptoms of lesser radial growth, increased foliar transparency, and decreased crown density displayed by trees in the symptomatic plots as compared to those in asymptomatic plots, correlate to deteriorated root conditions, and are consistent with results from studies of other pines associated with *Leptographium* spp. (Leaphart and Gill, 1959; Wagener and Mielke, 1961). The trees on symptomatic plots also showed lower resin production (based on the weight of resin-flow in a uniformly timed sample collection) when compared with trees on asymptomatic plots.

The trend of lower vigor trees on symptomatic plots, at the 15-19 yr age category as represented by reduced radial growth for last 5 years compared to that of the immediately previous five years, may constitute an early expression of loblolly pine decline. Symptomatic plot trees tend to becomes more apparent and exhibit significantly reduced average DBH and height measurements at age category 25-29 yrs and this trend continues as the trees age (Table 4). These results suggest that impacts of some disturbance on tree growth may start several years before they become apparent. Stands in the age category (25-29) are the youngest for which visual vigor assessments (like crown condition class) may prove useful for prescriptive purposes. This may also imply that disturbance factors may have impact on tree growth and thus vigor on symptomatic plots, and these effects begin as early as age category 15-19.

This may prompt concerns regarding the need for early mitigation (disturbance reduction) of silvicultural and anthropogenic disturbances on symptomatic sites. However, the trend in symptomatic trees for lowered growth in mature age categories may bring to question the level of effectiveness that any disturbance mitigation may have given the trees lowered growth responses due to age and vigor condition (Table 4). The mitigation efforts for stands at risk of decline may need to be associated with stand age. Stand in age categories less than 40 yrs still have some vigor (Table 4) and may respond to mitigation efforts which yield a sustainable stand. Stand in age categories greater than 40 yrs show reduced vigor and minimal growth (Table 4) and age may be more suited for restoration than to retention with mitigation of current conditions.

Total pest insect numbers showed a two-fold plus increase over the 3 year study. The average daily catch per trap of 30 for southern pine beetles is considered epizootic, and in 2005, an average of 43 root-feeding beetles per day per trap was collected. This association indicates that root-feeding beetles are at an epizootic level. The overall average number of insects and the average number insects associated with some type of plot disturbance (i.e. thinning, burning, and feral hog rooting) were higher in all symptomatic plots compared to the asymptomatic plots. The same pattern occurs when counts made from non-disturbed plots are compared to single disturbance plots. And, multiple disturbance plots had consistently higher average insect catches than single disturbance plots. These data indicate that higher numbers of root-feeding insects are strongly associated with a disturbance, and further suggest that any increase in the number of disturbances to which a site is subjected favor further increase in the population of root-feeding insects. The association of root-feeding insects and *Leptographium* spp. on disturbed sites and the occurrence of loblolly decline suggest that disturbance mitigation may be a management option.

Five insect species (*H. picivorus, H. pales, H. salebrosus, H. tenuis,* and *D. terebrans*) occurred in higher numbers in symptomatic than in asymptomatic plots. This correspnds to the increased levels of associated beetle activity within stands having an elevated incidence of *Leptographium* spp. reported for declining loblolly pine in Alabama (Eckhardt, 2003), for stands showing red pine decline in Wisconsin (Klepzig and others, 1991), and for stands exhibiting black stain root disease caused by *L. wageneri* (Hansen, 1978; Harrington and others, 1985). These root-feeding insects were consistently associated with *L. terebrantis, L. procerum,* and *L. serpens* and may be serving as vectors of these, as well as similar, fungi in other disease complexes (Klepzig and Others, 1991; Rane and Tattar, 1987). Insect damage alone was not found to seriously affect the trees, but the resulting colonization by the introduced *Leptographium* spp. was extensive. Increased insect numbers allow for a potentially greater number of point inoculations of *Leptographium* spp., which in turn may be resulting in stressed, declining loblolly pines.

Microsite conditions, primarily minor changes in topography which create distinctive environmental conditions, appear to be the essential element correlating to (the biology of) decline. Microsite differences are often strongly correlated with: whether the site is symptomatic or not; the presence of an association of root-feeding insects and *Leptographium* spp.; and, loblolly pine vigor. Topography of microsites was correlated to a change (positive or negative) in abiotic stress on loblolly pine and respective changes in numbers of insect onsite, isolation rates of *Leptographium* spp., and root condition of the trees. Physiographic factors exert a general influence on stand quality, but local variation in percent slope, aspect, and moisture are critical components in the distribution of either symptomatic vs. asymptomatic trees within a given stand.

These findings are similar to results reported by Shoulders and Walker (1979) and Zalhner (1958). Slope percentage may have an effect on soil moisture: where gentle slope of less than 5% is optimal; a slope of 1-2% is optimal for tree growth and vigor; and, slope in excess of 5% causes a reduction in tree growth and vigor (Lorio and Hodges1968, 1971; Lorio and others, 1972). Aspect appears to affect the soil temperature (Marshall and Holmes, 1988) and soil water balance in high latitude regions (Hanna and others, 1982). The effects of slope and aspect may combine to create microclimates within microsites. Adverse microclimate acts as a static disturbance that alone or in combination with other dynamic disturbances (Appendix A) reduce tree vigor. Accurate delineation of microsites can provide managers with the opportunity to mitigate some dynamic disturbances and lower the risk of decline.

CONCLUSIONS

The decline of loblolly pine described based on this work may prove to be a definable decline syndrome. Predisposing factors related to site topography, disturbances, and host stress appear to be predisposing factors to this decline. Affected sites are predominantly upland sites with a history of previous agriculture which were planted with loblolly pine. In their current condition they are not well suited for long-term RCW habitat management.

Symptoms and signs of damaging agents observed in declining trees include fine root deterioration, and lateral root staining and damage which result in less radial growth than in healthy trees. (These symptoms are similar to the symptoms of littleleaf disease; however, the associated pathogen *P. cinnamomi* is not present and site conditions are not appropriate for that disease.) Among the factors observed as contributing to the decline of loblolly pine are root-feeding insects on the primary roots and the introduction of *Leptographium* spp. Insufficient insect damage was not found to seriously affect the trees; root colonization by *Leptographium* spp. was extensive, although its significance is as yet to be fully elaborated. The level of *Leptographium* infection appears to be largely dependent upon the numbers of root-feeding insects.

All of the insect species in this study may respond differently to environmental factors. Five insect species (*D. terebrans*, *P. picivorus*, *H. pales*, *H. salebrosus* and *H. tenuis*) occurred in higher numbers in symptomatic than in asymptomatic plots. These insects were also consistently associated with *L. terebrantis*, *L. procerum*, and *L. serpens*, and may be serving as vectors of these fungi.

A very important question to be considered is - what factors affect insect population and behavior? Factors to consider are landform, drought, and the impact of abiotic, biotic and anthropogenic disturbances (Appendix A). Damage to root systems was positively correlated with insect abundance and *Leptographium* incidence. The above-ground symptoms of radial growth reduction, high foliar transparency, and reduced crown density within symptomatic plots as compared to asymptomatic ones corresponded to deteriorating root conditions which may favor or follow insect attack. Further research is currently being conducted to elucidate this last point.

Management Options:

1. Manage current stands recognizing that decline of loblolly pine is affecting the ability of the forest to sustain RCW habitat.
    - Continue utilizing the LPDRM to determine condition class of existing loblolly stands and their projected life expectancy to allow appropriate planning for current and future pine stocking.
    - Assess the loblolly component within the habitat (nesting, foraging, and recruitment) of RCW using the LPDRM provided to Fort Benning.

- Compare U.S. Fish and Wildlife Service RCW habitat guidelines to the decline risk assessment projections to establish loblolly pine management goals that fall within the guidelines for RCW habitat management.
- Identify loblolly sites within RCW habitat that are at risk and modify management to reduce immediate losses and allow time for new regeneration to replace existing high-risk stands.
- Use the decline risk assessment to project the probable sustainability of the loblolly pine component of existing RCW habitat to facilitate guideline implementation for RCW habitat sustainability.
- Prioritize restoration to longleaf pine on high-risk, unsustainable loblolly sites to provide for future habitat needs of the RCW.

2. Longleaf pine is the preferred management species for the upland pine sites on the FBMR. Restoration of the longleaf pine ecosystem on these sites will provide for long-term RCW habitat needs, will reduce SPB risk, and will allow the Army Base to manage for the desired future condition of a healthy forest.

3. Tree Condition
   - Keep trees healthy and vigorous
   - Adjust rotation ages on stressor sites
   - Plant pines more suitable to the stressor sites (no off-site pine)

4. Disturbance Awareness
   - Minimize site disturbance
   - Minimize tree injury
   - Whenever possible, avoid overlapping disturbances

5. Insect Population Control
   - Favor winter cutting (when ground is dry; wet soil [in other seasons] promotes compaction)
   - Remove slash promptly to avoid population buildup in slash
   - Remove stumps where feasable to reduce potential insect habitat
   - Plant more resistant species in mixed stands (longleaf, slash, hardwood)
   - Perform appropriate site preparation to favor desirable, healthy and vigorous trees.

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Table 1. Pooled averages of several measured parameters reflective of tree growth and vigor for trees on all plots by tree age category.

Tree Data by Age Category	**DBH (in)**	**Radial Growth (mm)**		**Height (ft)**	**Basal Area Sq. Ft (10 Factor)**	
		5 yr	**10 yr**		**Pine**	**Total**
15 – 19	5.1	20.39	41.94	31.9	N/A	N/A
20 – 29	7.9	15.38	34.51	50.0	68	73
30 – 39	10.2	11.55	24.54	56.4	70	80
40+	12.3	10.28	21.17	67.6	73	74

Table 2. Average growth and resin weight by symptomology category.

2003 – 2005	**DBH (in)**	**Radial Growth (mm)**		**Radial growth difference[1] (mm)**	**Height (ft)**	**Resin Wt. (g)**
		5 yr	**10 yr**			
Pooled symptomology	10.10	12.45	26.48	-1.58	59.15	6.77
Asymptomatic	10.10	12.78	26.94	-1.38	57.83	7.81
Symptomatic	10.09	7.60	16.45	-1.26	60.14	6.10

[1] Radial growth difference is the change in last 5 years versus previous 5 years growth.

Table 3. Average observed DBH & height by age category and symptomology (P=pooled data, A=asymptomatic, S=symptomatic).

2003-2005	**DBH (in)**			**Height (ft)**		
	P	**A**	**S**	**P**	**A**	**S**
15 -19	5.31	5.24	5.43	33.48	31.60	36.60
20 – 24	7.47	6.90	10.45	44.92	46.90	55.75
25 – 29	8.18	7.51	8.67	52.64	52.45	52.79
30 – 39	10.17	10.96	9.79	61.89	63.00	61.31
40+	12.34	12.90	11.76	67.62	69.16	66.19

Table 4. Radial growth averages by tree age categories and average change over the last 5 years (P = pooled data, A=asymptomatic, S=symptomatic).

2003-2005	**Radial Growth (mm)**								
	5 yr			**10 yr**			**Difference[1]**		
	P	**A**	**S**	**P**	**A**	**S**	**P**	**A**	**S**
15 – 19	20.39	21.27	19.30	41.94	38.81	45.86	-1.16	+3.75	-7.26
20 – 29	15.38	15.23	15.59	34.51	33.98	35.20	-3.75	-3.53	-3.92
30- 39	11.55	12.07	11.27	24.54	26.55	23.47	-1.44	-2.41	-0.93
40+	10.28	11.38	8.83	21.17	23.68	17.89	-0.61	-0.92	-0.23

[1] Radial growth difference is the change in last 5 years versus previous 5 years growth.

Table 5. Isolation of pathogenic fungi from roots, soil, and insects by plot (Neither *P. cinnamomi* nor *H. annosum* were isolated from any of these sites.) [(-) No insects trapped at these locations].

Comp/Stand/Plot #	***Leptographium* Species**					
	Roots		**Soil**		**Insects**	
	Yes	**No**	**Yes**	**No**	**Yes**	**No**
B01, S01, H24(D)	X			X	X	
B02, S02, H7		X		X	X	
B02, S05, D10	X			X	X	
B02, S07, D27	X			X	X	
B02, S23, H30		X		X	X	
B03, S01, D12	X		X		X	
C01, S13, D9	X		X		X	
C01, S14, H14		X		X	X	
C02, S02, H35		X		X	-	-
C02, S02, D25	X			X	X	
C02, S05, H29(D)	X			X	X	
F05, S03, H6	X			X	X	
G05, S10, D2	X		X		X	
G06, S23, D18	X			X	X	
J02, S06, H22(D)	X			X	X	
J04, S20, H32(D)		X		X	X	
K11, S01, H8		X		X	X	
K11, S09, D19	X			X	X	
K11, S16, D20	X			X	X	
K20, S08, H33		X		X	-	-
L01, S15, H37		X		X	-	-
L05, S04, H38		X		X	-	-
M02, S01, D1	X			X	X	
M07, S17, H5		X		X	X	
O03, S07, D17	X			X	X	
O07, S30, D3	X			X	X	
O09, S19, H23		X		X	X	
O10, S23, H13		X		X	X	
P01, S27, H31		X		X	X	
P02, S06, D28	X			X	X	
Q02, S16, H36		X		X	-	-
Q03, S10, H21(D)	X			X	X	
Q04, S01, H16		X		X	X	
Q05, S02, D11	X			X	X	
Q05, S03, D26	X			X	X	
Q06, S16, H15(D)	X			X	X	
U02, S18, D4	X		X		X	

Table 6. Fort Benning plot identifications, GPS locations, and stand age category.

PLOT ID	LATITUDE	LONGITUDE	AGE CATEGORY
D1	32.45543718	-84.80148205	>40
D10	32.29431152	-84.82331523	10-19
D11	32.3203826	-84.81631466	10-19
D12	32.30252981	-84.80400869	10-19
D17	32.50290155	-84.82856699	20-40
D18	32.32300043	-84.69167241	20-40
D19	32.51013279	-84.64518436	20-40
D2	32.34465122	-84.67975804	>40
D20	32.50978947	-84.65324172	20-40
D25	32.34220505	-84.80924972	<10
D26	32.3187089	-84.82315966	<10
D27	32.29040623	-84.82568094	<10
D28	32.39846706	-84.88276907	<10
D3	32.52519608	-84.75726315	>40
D4	32.44475126	-84.87541982	>40
D9	32.34737635	-84.82796618	10-19
H13	32.49955416	-84.77557727	10-19
H14	32.34516621	-84.82392677	10-19
D15	32.30246544	-84.80526933	10-19
H16	32.3107481	-84.82407697	10-19
H21	32.32145548	-84.81739291	20-40
D22	32.40125656	-84.82672163	20-40
H23	32.51204252	-84.76686009	20-40
D24	32.28914022	-84.83678528	20-40
H29	32.33699083	-84.81278487	<10
H30	32.28182316	-84.82206532	<10
H31	32.39389658	-84.84760531	<10
D32	32.40911007	-84.80527469	PC
H33	32.39614964	-84.67189916	PULP
H34	32.52955198	-84.81859454	20-40
H35	32.35010147	-84.81238254	PULP
H36	32.33561754	-84.82941457	PC
H37	32.43872166	-84.78859671	20-40
H38	32.43033171	-84.78867718	20-40
H5	32.46567249	-84.85079178	40+
D6	32.34538078	-84.6818448	40+
H7	32.29770184	-84.81538662	40+
H8	32.50878096	-84.63932642	40+

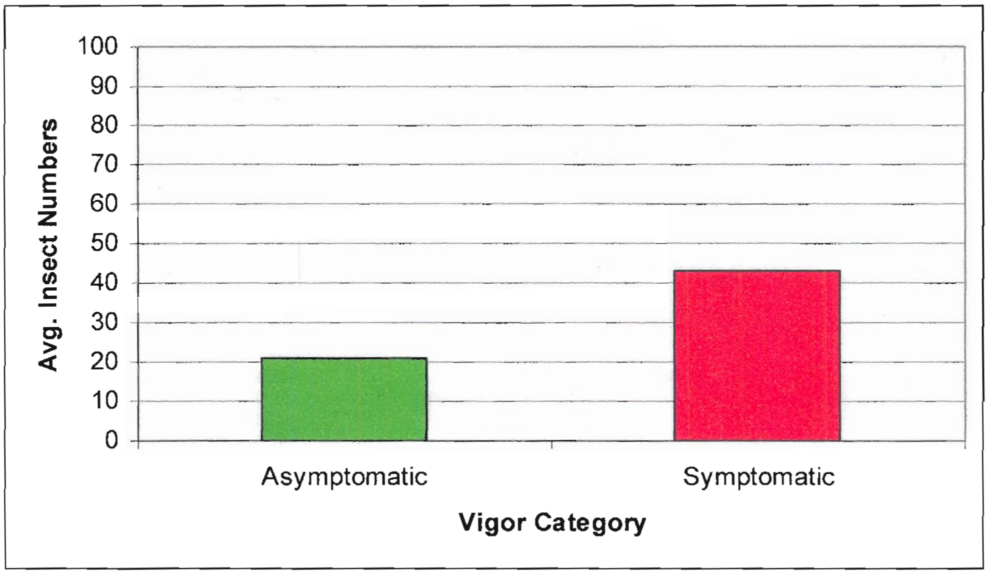

Figure 1. Average number of insects trapped per plot with no recorded fire, thinning or hog disturbance.

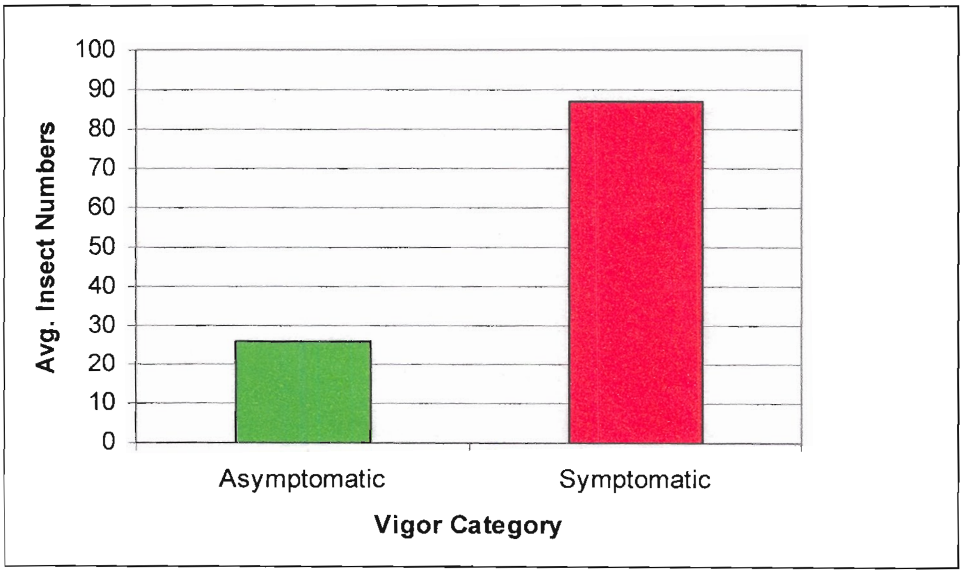

Figure 2. Average number of insects trapped per plot which had either a history of fire, thinning or hog disturbance.

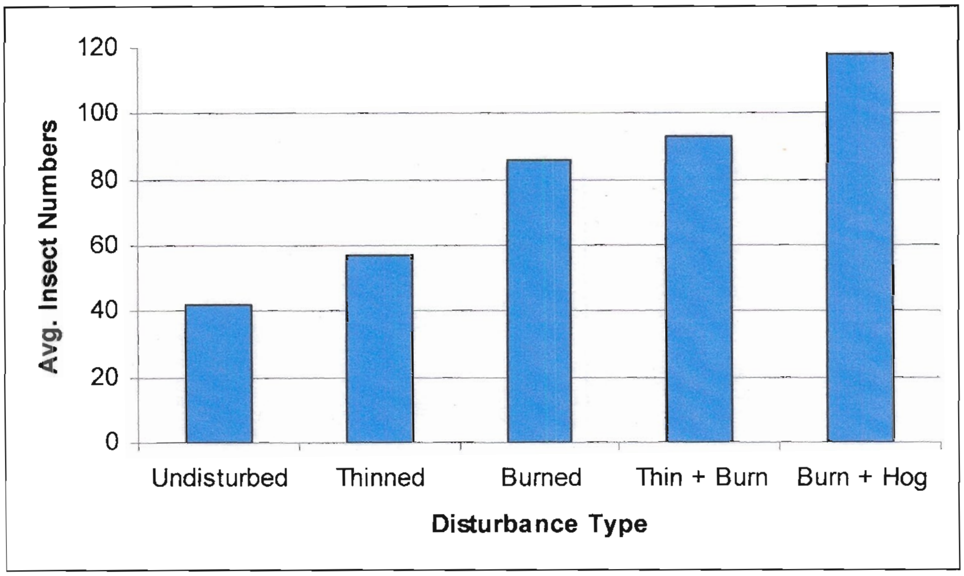

Figure 3. Average numbers of insects per plot segregated by the type of disturbance.

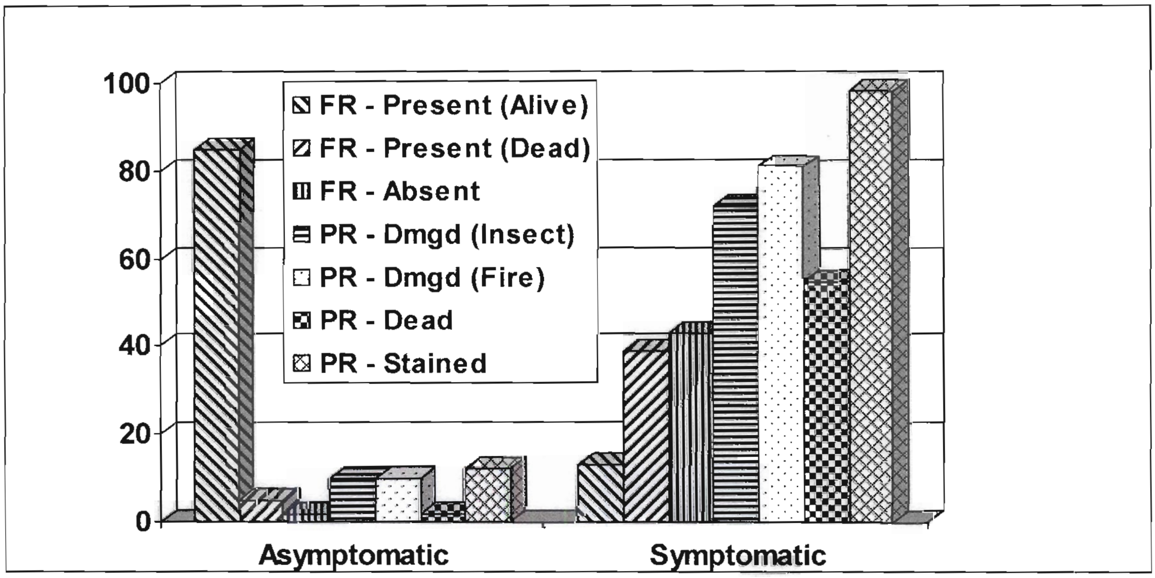

Figure 4. Root condition comparison for symptomatic vs. asymptomatic trees. (Key: FR = Feeder roots; PR = Primary roots)

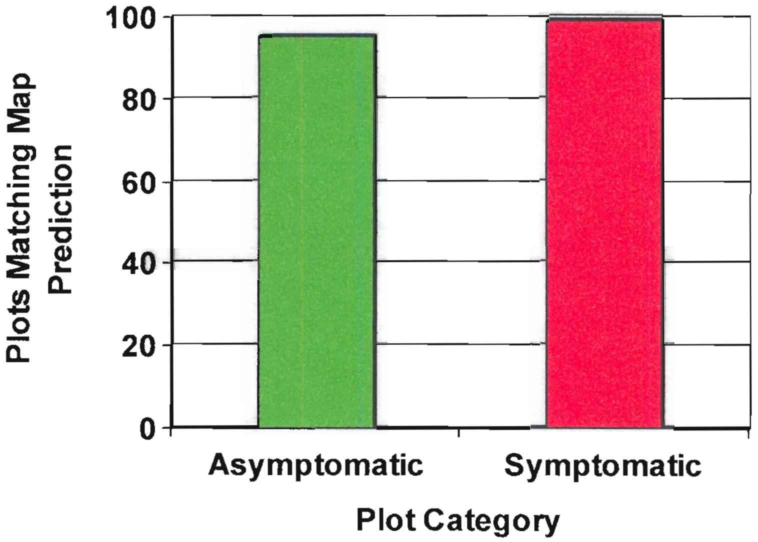

Figure 5. Predictive accuracy of LPDRM on Fort Benning Military Reservation.

Appendix A

Disturbances and Damage

The combination of influences of the following dynamic and static stressor disturbances affect the percent of fallout in a particular risk rating.

Dynamic Disturbances

1. Anthropogenic
    a. Silvicultural (any mgmt)
    b. Recreational (ie. off-road vehicles)
    c. Training (ie. Military)

2. Natural
    a. Weather (ie, drought, flood, storm)

3. Biotic
    a. Stand density
    b. Stand species composition
    c. Understory vegetation density
    d. Vector population[2]

Static Disturbances

1. Abiotic[1]
    a. Slope
    b. Aspect
    c. Convexity
    d. Elevation

These disturbances may cause damage to the tree at three levels.

1. Root
    a. Compaction - caused by logging equipment, training equipment, off-road vehicles, etc.
    b. Wounding - caused by equipment, training, natural (wind throw), hogs, fire, etc
    c. Exposure - caused by erosion, various types of equipment, training, etc. This type of damage exposes roots to fire, insect attack and other types of wounding damage listed above.

2. Bole
    a. Wounding - caused by logging equipment, training equipment, felling of hazard trees, lightning strike, fire, breaks/cracks from storm damage, etc.

3. Crown
    a. Foliage – loss from burning, insect defoliation, disease, etc.
    b. Branches & upper bole - storm damage (wind/ice), fire, lightning, etc.

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[1] Abiotic (topographical features) are listed in order of significance.

[2] This is predicted on other disturbances. These insects are drawn to stress chemicals being volatilized by the tree. These populations will increase with disturbances (Eckhardt, 2003).