Pine Decline and *Leptographium* Overview

Background:

The etiology of decline is typically a complex of agents biotic and abiotic, which exacerbate or mitigate the extent of growth reduction and mortality differentially. The model developed by Manion (1981) suggests that declines begin with predisposing factors, related to host genotype, or site or other abiotic factors which may be permanent or long term. The first reports of declining loblolly in the southeastern U.S. were in 1959 on the Talladega National Forest (TNF). Symptoms included trees with short, chlorotic needles, sparse crowns and reduced radial growth in the 40-50 year age class. Mortality occurred two to three years after symptom expression (Hess *et al.* 1999).

In 1966, a five year study was established on the Oakmulgee Ranger District TNF to determine the cause, rate of decline, and degree of mortality of loblolly pine stands (Brown & McDowell 1968). Further evaluations were concluded in 1976. Results of these studies did not confirm a specific pathogen as the causal agent; however, several important observations were made. Decline symptoms appeared at age 40-50, but lateral and fine root deterioration and mortality preceded the presence of foliar symptoms of decline. While *Heterobasidion annosum* (Fr.) Bref. and *Phytophthora cinnamomi* Rands were recovered from some plots, Annosum root rot and littleleaf disease were not implicated as the primary cause of the decline. The conclusions from the evaluation and follow-up study indicated reductions in loblolly pine growth by age 50 and that site conditions, and other interactions were the cause of the stand decline and tree mortality. Recommendations were to reduce rotation age of loblolly pine from 70 to 60 years on these sites, maintain a basal area of 60-70 square feet per acre and convert these stands to longleaf pine management type (Loomis 1976) on the TNF.

In the early 1990's, Forest Health Protection, Pineville field office initiated a 40 paired plot study to look at root pathogens associated with southern pine beetle (SPB) attacked trees. Plots were established in active SPB spots and control plots (without SPB) within the same stand conditions. The objective was to determine if root pathogens were a factor in predisposition of SPB attacks to southern pine stands. The plot network extended from east Texas to central Alabama on National Forest lands. The results of the study indicate that 87% of the SPB attacked trees had *Leptographium* spp. in their root systems and 45% of the control trees (no SPB) also harbored *Leptographium* spp. within their roots. These early results suggested that blue stain fungi were an important factor in the dynamics of susceptibility of southern pines to SPB attack (Otrosina *et al.* 1997).

During the mid-1990's, the Forest Health Monitoring program reported a decline of loblolly pine (*Pinus taeda* L.) based on crown rating data in central and southern Alabama counties. In 1998, a study was established on four compartments of the Oakmulgee Ranger District in order to re-evaluate the decline complex, examine root health, and to update management options. Like the 1966 trial, evaluations of these plots concluded that while *P. cinnamomi* and *Leptographium* spp. were recovered from these plots, their roles in the decline complex were not clearly defined. Revised management options for these sites included managing loblolly pine on 50-year rotations or converting to a longleaf pine type (Hess *et al.* 1999).

In 2000, a Forest Health Monitoring – Evaluation Monitoring project (FHM-EM) was initiated to assess loblolly decline on upland sites in Alabama (Eckhardt *et al.* 2007). This study indicated that predisposing factors included soil nutrients, slope and aspect. Inciting factors (shorter term stressors) included drought, mechanical and fire injury that reduced the defenses against contributing factors, which included the biotic agents *Leptographium* and *Hylastes* spp. These factors may not affect healthy trees, but may attack trees that have been compromised by the predisposing and inciting factors. This study also was the first report of *L. serpens* and *L. truncatum* in the southeastern U.S.

A similar study was established in 2003 to evaluate loblolly decline in Georgia at Fort Benning Military Reservation (Menard *et al.* 2006, Menard 2007). This study also indicated that predisposing factors included soil nutrients, slope and aspect. Inciting factors (shorter term stressors) included drought, mechanical (thinning and military training), fire and hog injury, and soil compaction that reduced the defenses against contributing factors, which included the biotic agents *Leptographium* and *Hylastes* spp. This study was the first to report *Grosmannia huntii*. Additional monitoring plots were established in 2004 – 2005 in Texas, Louisiana and Mississippi to help define the range and impacts of pine decline and further assess *Leptographium* spp. as a component of pine decline (Hess *et al.* 2004). All of these studies implicated the association of root-feeding beetles and weevils and *Leptographium* spp. as a contributing factor in the loblolly pine decline complex. A risk map and model for loblolly were developed from these studies (Eckhardt 2003, Eckhardt and Menard *in press*).

Decline of longleaf pine (*Pinus palustris* Mill.) and the association of root-infecting fungi in the southeastern U.S. was reported by Otrosina *et al.* (1999). This was the first report of *Leptographium* spp. being associated with above-ground symptoms in longleaf pine. *Leptographium procerum* and *L. terebrantis* were significantly associated with increasing crown symptom severity and evidence of insects on roots increased as did the amount of resinosis observed. Otrosina *et al.* (1999) concluded that edaphic and silvicultural factors may interact with these pathogens and insects and place a pathological limitation on longer-term management objectives. In 1997, a study was initiated at the Savannah River Site, New Ellenton, SC, to determine factors involved in decline in longleaf pine associated with prescribed burning. It was concluded that the decline syndrome on these sites involved root pathogens, soil factors, root damage, and physiological dysfunction (Otrosina *et al.* 2002). Current studies are still investigating the relationship between *Leptographium* spp. and longleaf pine decline.

Introduction:

Forest tree declines have been described as resulting from complex interactions of biotic and abiotic stressors (Manion & Lachance 1992). Current studies of several forty year old or older pine stands in the southern U.S. with trees expressing symptoms of decline show strong associations with site conditions, deterioration of fine roots, the presence of root feeding insects and the presence of *Leptographium* staining and resinosis in primary roots (Eckhardt *et al.* 2007). Fire history, previous agricultural practices, lower vegetation density and landform are factors that are also associated with declining trees (Eckhardt 2003).

Loblolly pine decline:

Symptoms expressed by declining loblolly pines include sparse tree crowns with short chlorotic needles, and reduced radial growth of the stem (Fig 1). These symptoms occur primarily in trees above 35 years of age (though trees as young as 12 years of age may also be affected). Mortality can occur within as little as two to three years after the first expression of symptoms (Hess *et al*. 1999). Although symptoms expressed by loblolly pines declining on upland sites, are similar to those of littleleaf disease, site conditions associated with these trees are different (Campbell and Copeland 1954; Eckhardt *et al.* 2007). On many upland sites on federal lands in the South, loblolly pine is the major forest type since it is easily regenerated and was planted on a significant number of these sites to restore watershed capacity. Some of these sites are also managed for red-cockaded woodpecker (RCW) habitat and this decline may be impacting the long-term habitat needs of this endangered bird (Menard *et al.* 2006).

Figure 1. Declining loblolly pine.

Site Conditions:

Risk rating for several root diseases in southern forests is accomplished by evaluating soil and site characteristics. For example, deep, well drained soils are associated with annosum root disease, and, poorly drained, heavy clay soils with littleleaf disease. However, in loblolly pine

decline, tree age, topography (primarily slope and aspect), *Leptographium* spp. incidence in roots, and organic matter content in the soil were significantly correlated with the occurrence of this decline (Eckhardt 2003). Soils on these sites where pine decline has been observed are predominately sandy loam, loam, or sandy clay loam, and are moderately well-drained to well-drained (Fig. 2). Soil chemical characteristics related to nutrient status were more indicative of differences between sites hosting healthy versus declining loblolly pine than were soil physical characteristics.

Figure 2. Soil characteristics, moderately well- drained soil.

Current investigations are focused on the disturbance history of affected sites which also appears to have significant effect on the expression of decline. Fire history and other natural or management based disturbances are the focus of this investigation. Longleaf pine is the preferred management species for RCW habitat recovery. Due to concern about the potential for loblolly pine to survive to adequate age on these upland sites restoration to longleaf pine is currently being recommended for managing these sites.

Insect/*Leptographium* spp. Association:

Species of *Leptographium* are most commonly reported as causes of blue-stains in sapwood of pine, spruce, and other conifers (Jacobs and Wingfield 2003). These stain fungi rarely kill healthy trees, but they do reduce the value (or degrade the quality) of timber and may be associated with mortality in stressed trees. In addition, a few *Leptographium* species are known to be virulent pathogens under appropriate field conditions. *Leptographium wageneri* causes a serious root disease of conifers in the western United States (Cobb 1988). And, two *Leptographium* species affect conifers in the eastern U.S.: *L. procerum* is associated with a syndrome known as eastern white pine decline and *L. terebrantis* has been implicated as a contributor to a decline of red pine. *Leptographium serpens* has been associated with root disease resulting in significant decline of *Pinus radiata* and *P. pinaster* in Africa and *P. pinea* in Italy, although there is debate as to its role in these diseases.

Both *L. procerum* and *L. terebrantis* have consistently (and frequently) been recovered from the roots of declining southern yellow pines, (loblolly, shortleaf, and longleaf pines) (Fig. 3); *L. procerum* is consistently recovered from deteriorating fine roots and primary roots while *L. terebrantis* is only recovered from primary roots. In preliminary studies, *L. serpens* has also been recovered from the primary roots of declining southern yellow pines (Menard *et al.* 2006;

Eckhardt *et al.* 2007) (Fig. 4). It has recently been discovered to be widely distributed in the South and, based on recent research results, appears to be the dominant *Leptographium* sp. recovered when pine mortality is occurring as a result of decline (Eckhardt *et al.* 2007). The level of pathogenicity and the specific role of these three *Leptographium* species with respect to southern pines is uncertain and research is continuing on this topic (Eckhardt *et al.* 2004a, Matusick and Eckhardt *unpublished*).

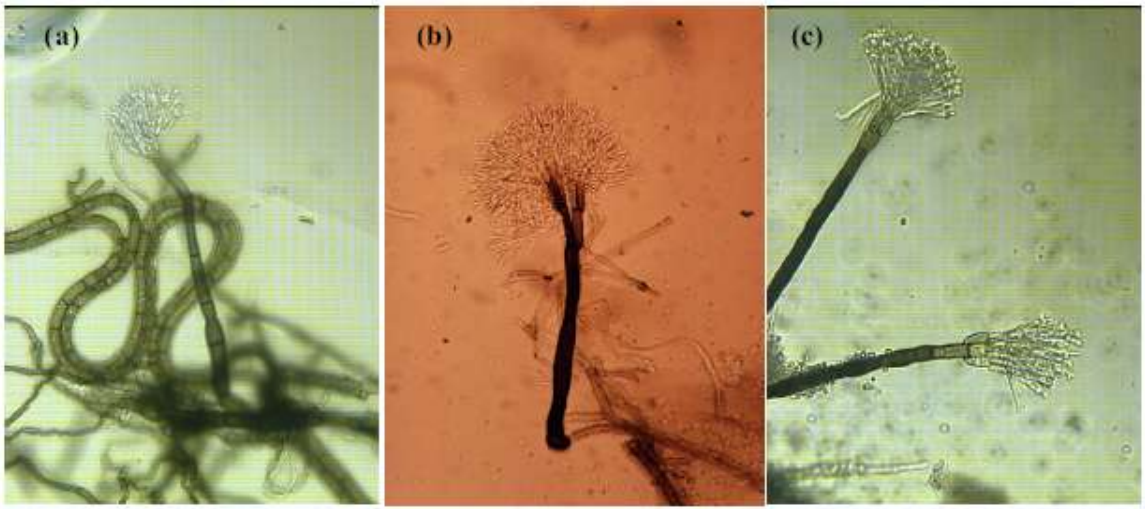

Figure 3. Three examples of *Leptographium* species: (a) *L. serpens*, (b) *L. terebrantis*, (c) *L. procerum*.

Leptographium species are commonly associated with various species of root feeding bark beetles, which attack stressed trees (Wood 1982; Klepzig *et al.* 1991). They *may* serve as vectors introducing these fungi into tree roots or as wounding agents creating infection courts which permit the infection by these fungi (Eckhardt *et al.* 2004b) (Fig. 4 & 5).

Figure 4. *Hylastes* species feeding.

Figure 5. Black streaking and resinosis caused by *Leptographium* species.

The predominant root feeding insects associated with an increased incidence of *Leptographium* spp. fall in two groups: root weevils (*Hylobius pales, Pachylobius picivorus* and possibly others) which consistently carry *L. terebrantis* and *L. procerum* as they feed on the phloem of roots; and, bark beetles which feed on phloem in the roots (e.g., *Hylastes salebrosus, H. porculus, H. tenuis,*

D. terebrans, and possibly others) and are often associated with *L. terebrantis*, *L. serpens* and *G. huntii* (Fig. 6). Both groups may introduce fungi into feeding and oviposition wounds, and the bark beetles may also spread fungi during maturation feeding.

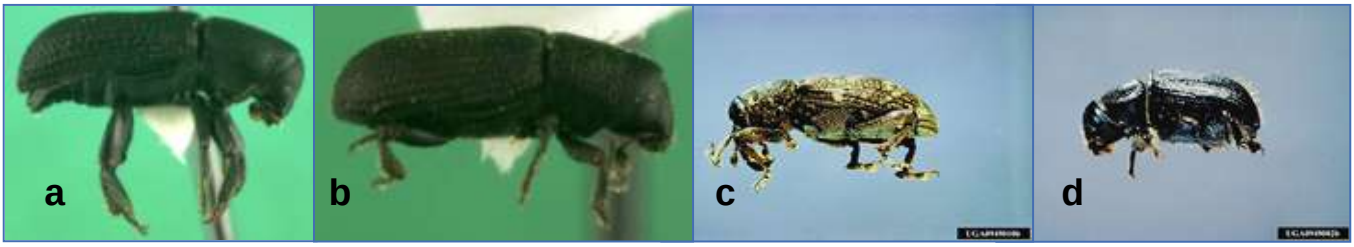

Figure 6. Vector insects of *Leptographium* species: (a) *Hylastes salebrosus*, (b) *Hylastes tenuis*, (c) *Hylobius pales*, (d) *Dendroctonus terebrans*.

Disturbance/Stressors:

Fire regimes, wind events, drought, silvicultural treatments, and a variety of other stress factors likely play major roles in causing premature decline of trees (Fig. 7). Effects may be direct (physical injury, stress) or indirect including increased attraction of, or susceptibility to secondary insects such as the *Hylastes* species. However, the exact roles and possible interactions among disturbances, stain fungi and associated insects in the premature decline of loblolly pine remains unclear, and are still being researched.

Figure 7. Examples of disturbance which affect tree vigor.

Other pines in the South:

In preliminary studies of shortleaf pine on decline sites having characteristics similar to those of the loblolly decline sites (Fig. 8), *L. procerum*, *L. serpens*, *L. terebrantis*, and *G. huntii* were consistently isolated from the roots of dead and dying trees as well as from the roots of

asymptomatic trees at the perimeter of the decline area. Root excavations and laboratory cultures revealed the presence of root grafting, *Leptographium* spp., and evidence of insect feeding on these roots.

Figure 8. Shortleaf decline and disease center.

Recent field evaluations have also identified a decline in longleaf pine that is similar to previously reported findings on Savannah River Site, SC. (U.S. Forest Service Southern Forest Research Station study) (Otrosina *et al.* 1999). Longleaf pine is less common than loblolly pine across the southeastern U.S. Longleaf pine, has far more anthropogenic disturbance applied during management (Jose 2006) which are used to establish a favorable habitat for threatened and endangered species e.g. RCW. Longleaf pine tend to exhibit less decline and susceptibility to both abiotic and biotic stress, however when exposed to multiple, successive disturbances, do succumb to these fungi. The foliar symptoms are similar to other pines and include reduction in tree growth, thinning crowns and chlorosis (Fig. 9a). Symptomatic trees have colonized lateral roots which are resinous and blue stained. Fine roots are also reduced in number, deteriorated, infected and dead. This general decline is associated with *L. procerum* and *L. terebrantis*. In addition there is a wilting symptomology in which healthy green trees foliage wilts, becomes chlorotic, dies and is retained after death (Fig. 9b). This symptomology is associated with *L.*

serpens and/or *G. huntii*. The lateral roots have large resinous lesions and staining, with the root beyond the lesion dead. Fine roots on living laterals are reduced in number, deteriorated, infected and dead. In addition, staining and streaking are seen in the butt of the tree. Trees with this symptomology die within 3 to 12 mo. This mortality and symptomology usually presents itself either as a disease center (Fig. 10a) or as a single tree scattered throughout a stand (Fig. 10b). In saplings, needles become chlorotic, brown and die, with root collar and roots resinous and stained and *Hylastes* tunneling and feeding present (Fig. 11). Death in these saplings occurs within 3 mo. This symptomology and mortality is found in plantations and in natural regeneration of diseased mature stands.

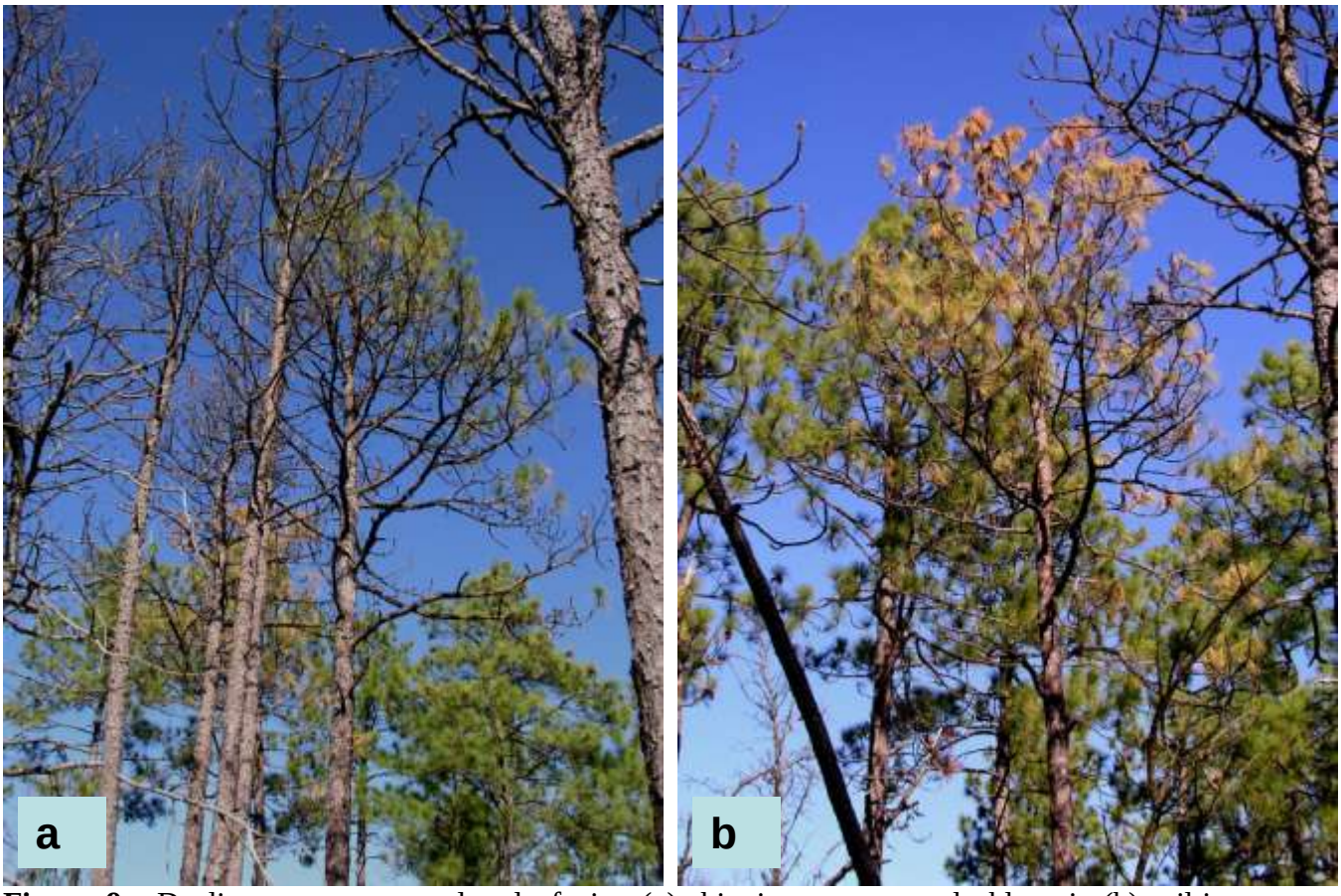

Figure 9. Decline symptoms on longleaf pine (a) thinning crowns and chlorosis (b) wilting foliage, becoming chlorotic, dying and retained after death on tree.

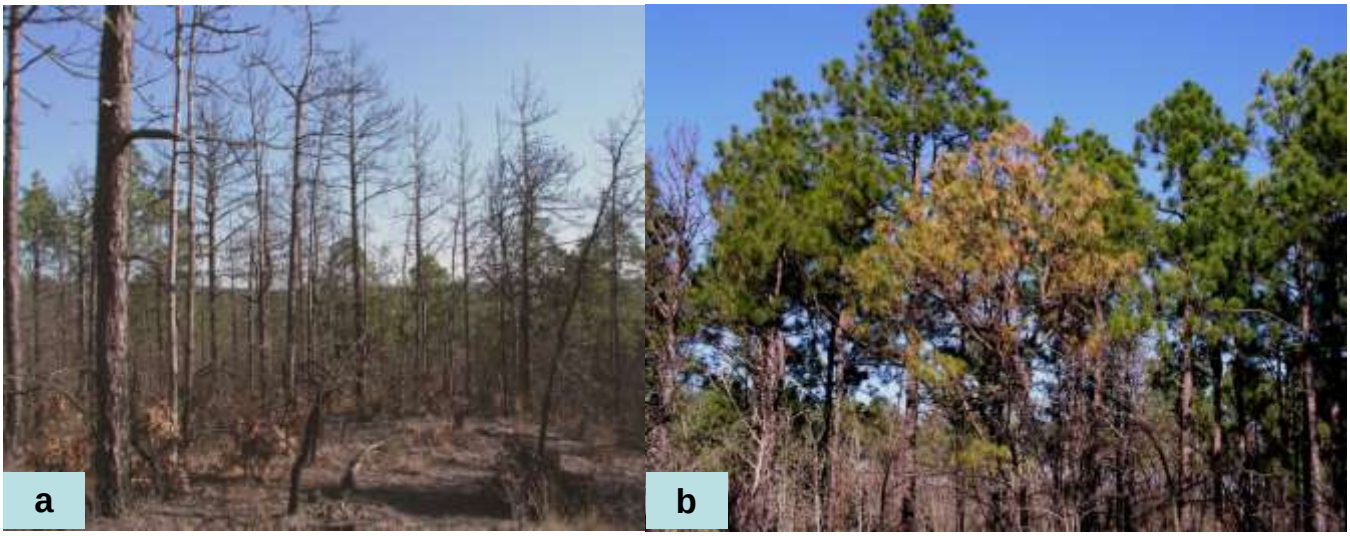

Figure 10. Symptomology presented as a (a) disease center or (b) single tree in a stand.

Figure 11. Longleaf saplings (a) damaged at the root collar by *Hylastes* (b) mortality of longleaf saplings caused by *Leptographium serpens* and *G. huntii* carried by *Hylastes.*

As for the other pine species, the degree to which this decline is due to site history (including fire and other disturbances), management practices, and insects and fungi, remains to be determined.

Conclusions:

Dieback and premature decline of southern pines is a serious problem that deserves urgent attention. It is likely to be associated with interactions among many factors. The key factors currently known to be associated with the problem have been listed in this document.

Current studies are focused on site factors and stressors which may play a role in preconditioning pines to these reported problems, as well as the effects of this complex on longleaf, shortleaf and slash. More research is needed to elucidate the host-insect-fungal interactions and relationships between disturbance and silvicultural activities.

The distribution of *Leptographium* Root Disease and Pine Decline is currently being determined through survey by the Forest Health Cooperative, Forest Health Dynamics Laboratory and Forest Health Protection (Fig. 12).

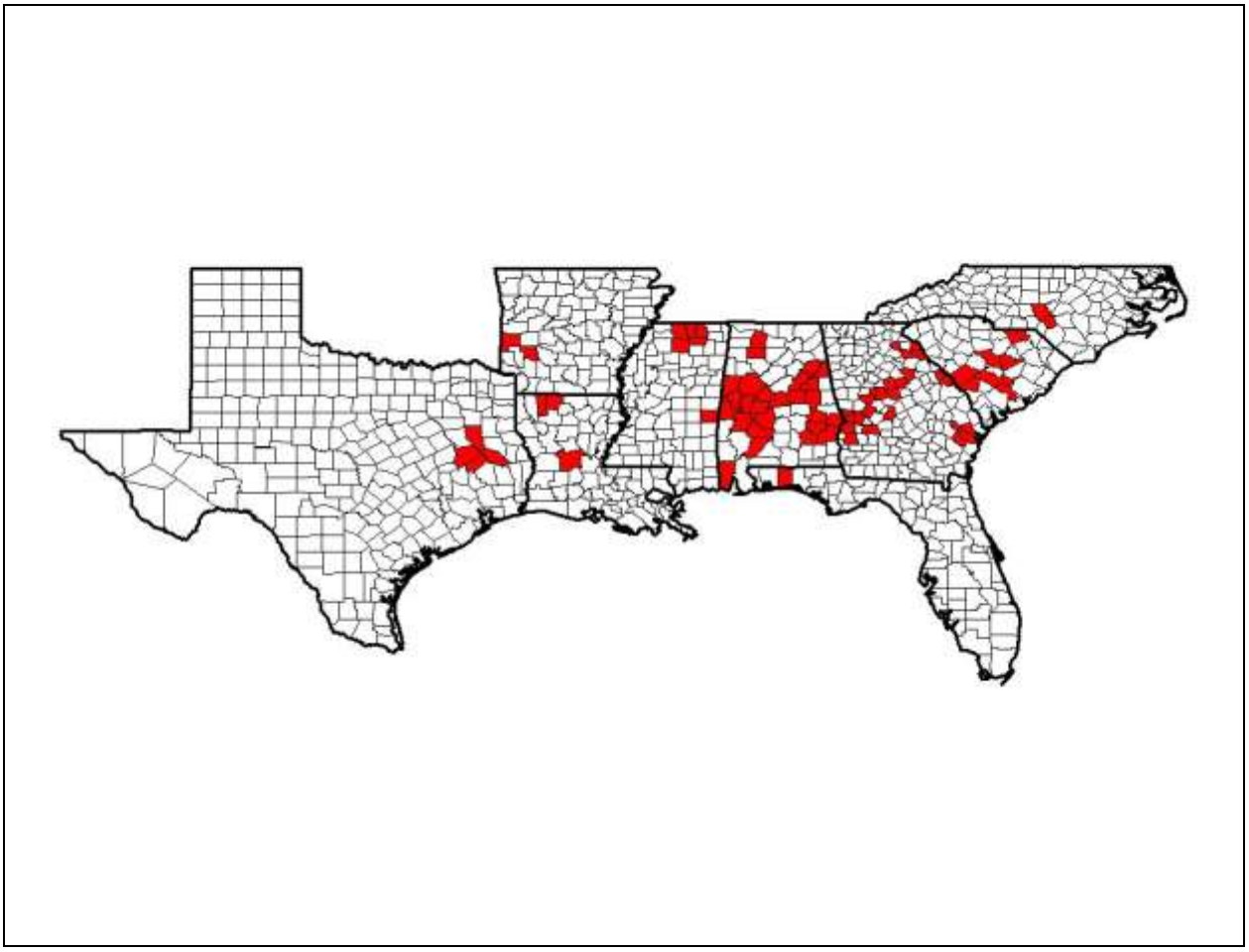

Figure 12. Distribution of Pine Decline associated with *Leptographium* Root Disease by county across the southeastern United States (Survey still in progress, not complete).

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