TECHNICAL NOTE

State of Pine Decline in the Southeastern United States

Lori Eckhardt, Mary Anne Sword Sayer, and Don Imm

ABSTRACT

Pine decline is an emerging forest health issue in the southeastern United States. Observations suggest pine decline is caused by environmental stress arising from competition, weather, insects and fungi, anthropogenic disturbances, and previous management. The problem is most severe for loblolly pine on sites that historically supported longleaf pine, are highly eroded, or are not managed. The purposes of this technical note are (1) to describe the symptomology and extent of pine decline in the southeastern United States; (2) to describe its connection with root disease, resource stress, and silviculture; and (3) to summarize the consensus opinion of scientists and land managers during a workshop sponsored by the US Army Strategic Environmental Research and Development Program regarding the scope of this syndrome and the best research avenues to counter its potential effect on the sustainability of southern pine forests.

Keywords: *Leptographium*, loblolly die-off, off-site, root disease, resource stress

Observations of PD

Several reports have suggested that localized forest health problems are increasing in southern pine forests (Otrosina et al. 1999, Hess et al. 2005, Eckhardt et al. 2007). When these events are accompanied by sparse and chlorotic crowns, low annual stemwood production, and isolation of fungal pathogens from roots other than *Phytophthora cinnamomi* Rands or *Heterobasidion annosum* (Fr.) Bref., they are commonly referred to as pine decline (PD) (Otrosina et al. 1999, Eckhardt et al. 2007). Mortality may occur within 3 years after symptoms (Hess et al. 2002, Eckhardt et al. 2007, Menard 2007). PD has been observed across the southeastern United States from Alabama to South Carolina in the Atlantic and East Gulf Coastal Plains and Piedmont Province, as well as the fall-line Sandhills interfacing these regions. It has primarily been reported on public lands managed for multiple objectives that include but do not emphasize timber production (Hess et al. 2002, Menard 2007). PD has also been observed in southern pine forests managed by nonindustrial private landowners and forest industries (Eckhardt et al. 2007). The majority of these events have occurred in mature loblolly pine (*Pinus taeda* L.) and mixtures of mature loblolly and shortleaf pine (*P. echinata* Mill.). Loblolly pine is considered "off-site" at many of these locations that historically supported longleaf pine (*P. palustris* Mill.) (Hess et al. 1999, Hess et al. 2002). These observations have occurred with a decrease in the growth rate of southern pine forests over the last decade (Gadbury et al. 2004).

The PD Setting

Most of the Atlantic and East Gulf Coastal Plains, lower Piedmont Province, and fall-line Sandhills have similar land-use histories (US Forest Service 1988, Barrett 1995). Prior to European settlement, these areas were periodically burned by Native Americans or were ignited naturally by lightning (Frost 2006). Vegetation was fire-tolerant, consisting of woodlands and sparsely treed savannas with a mixed pine–oak canopy. During the 18th and 19th centuries, European settlers cleared most of the arable land for subsistence agriculture. Erosion and nutrient depletion quickly reduced crop yields and agriculture was abandoned. Afterward, some areas were naturally seeded with loblolly pine and other early successional forest types, but most of the landscape became severely eroded by lack of vegetation. During the early and mid-20th century, federal and state agencies rehabilitated many eroded areas by planting loblolly pine (US Forest Service 1988). To their credit, much of the erosion ceased, but some of these forests remained unproductive (Ward and Mistretta 2002, Gadbury et al. 2004).

Reports of mortality attributed to PD in the early 1970s recognized that its occurrence was tied to unusual physiological and environmental conditions (Roth and Peacher 1971, Miller 1979). Sparse, chlorotic crowns and poor diameter growth, for example, were accompanied by exceptionally large cone crops produced 1 year before mortality and high amounts of lateral root deterioration and fine root mortality before crown symptoms appeared (Brown and McDowell 1968, Roth and Peacher 1971, Miller 1979). It was concluded that root pathogens and adverse soil-water relationships were contributing factors (Brown and McDowell 1968).

Between 1953 and 1999, the average annual mortality of southern pine more than doubled (Conner and Hartsell 2002). It was suggested that this trend is attributed to the lower rate of mortality expected as young stands established in the late 1960s and early 1970s developed, and subsequently, the higher rate of mortality expected when portions of these stands were not actively managed.

Manuscript received August 24, 2009; accepted September 3, 2009.

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Correlation between mortality and an absence of forest management is supported by the fact that 92% of this mortality occurred in naturally regenerated stands, whereas only 8% of it was in planted stands. Overlap between the timing of PD observations and both lower growth rates and accelerated mortality, as well as the tendency for PD to occur in off-site or disturbed settings, or by age 50 years in unthinned stands (Hess et al. 1990, Otrosina et al. 1999, Menard 2007), suggests that one or more resource limitations contribute to this problem.

Recent descriptions of the disease complex associated with PD on public and private land in central Alabama (Eckhardt et al. 2007) and at Fort Benning Military Reserve in central Georgia (Menard 2007) suggest that this problem should be monitored to ensure that the sustainability of southern pine forests is not at risk. Caution is warranted because at broader scales, PD would have serious landscape implications and an effect on local economies that depend on the forest products industry. Based on current pathological examination of forests experiencing PD, this problem appears to be caused by (1) the combined effect of multiple stressors rising from site quality, climate variation, and past and current land use; (2) opportunistic insect damage and root pathogens that impair tree responses to these stressors; (3) a higher susceptibility of mature or maturing stands; and (4) in some situations, imbalances in normal populations of insect pests and root-infesting fungi.

Role of Root Disease in PD

Often, increases in both insect pests and the isolation of fungal pathogens from tree roots coincide with PD symptoms. Three root pathogens have been implicated as factors contributing to PD: *P. cinnamomi*, *H. annosum*, and *Leptographium* spp. Although the symptoms of littleleaf disease, caused by *P. cinnamomi*, are similar to those of PD, several attempts to link *P. cinnamomi* to PD resulted in only a weak relationship (Roth and Peacher 1971, Miller 1979, Mistretta and Starkey 1982). One exception was reported by Hess et al. (1999) in their reassessment of the causal factors of PD in the Talladega National Forest (TNF) in Alabama. They concluded that PD was caused by a combination of edaphic disturbances and root disease attributed to *P. cinnamomi* and *Pythium* spp. Although *Leptographium* spp. were isolated from roots at this location, their pathogenicity was considered secondary to that of *P. cinnamomi* and *Pythium* spp. When evaluations of PD on the TNF were repeated in 2000 through 2002, *Leptographium* spp. rather than *P. cinnamomi* and *Pythium* spp. were the primary root pathogens associated with PD (Hess et al. 2005). Accounts of *H. annosum* occurring with PD are either absent or negligible (Roth and Peacher 1971, Miller 1979, Hess et al. 2005). One exception to this generalization was reported in the early 1980s by Mistretta and Starkey (1982) who surveyed pine mortality on the Shoal Creek Ranger District of the TNF, and the Bankhead and Black Warrior Ranger Districts of the Bankhead National Forest (BNF) in Alabama. They found *H. annosum* sporophores on several stumps and dead loblolly and slash pine trees in the two BNF ranger districts but did not find signs of this pathogen on the TNF ranger district. Elsewhere, Otrosina et al. (1999) found both *Leptographium* spp. and *H. annosum* in declining 35-year-old longleaf pine stands in South Carolina but suggested this did not necessarily indicate that the trees were experiencing annosum root disease.

Leptographium spp. and their root-feeding beetle vectors are a consistent component of PD (Brown and McDowell 1968, Otrosina et al. 1999, Eckhardt et al. 2007). Root-feeding beetles are attracted by secondary metabolites (Hodges et al.1979). In addition to root-feeding injury, there is evidence that the pathogenicity of *Leptographium* spp. increases as beetles begin to feed because of changes in the porportions of oleoresin compounds produced by the tree (Eckhardt et al., unpublished). This new oleoresin environment favors the growth of the fungus (Paine et al. 1997). Successful colonization by *Leptographium* spp., in turn, appears to benefit the development of insect brood within the trees' roots because the fungus either serves as a food source for emerging larvae or makes the environment more habitable (Eckhardt et al. 2004b). The insect-fungus relationship expands the root disease, and the insects are indispensable in vectoring fungal spores from infected roots to healthy roots. In some situations, however, the fungus alone may be a major contributor to PD because it obstructs root vascular tissue (Eckhardt et al. 2004a), which reduces the translocation of water and mineral nutrients within the root system.

Role of Resource Stress in PD

In addition to *Leptographium* root disease, resource limitations arising from the disruption of natural stress avoidance mechanisms may trigger or accelerate PD. A downward shift in whole-crown leaf area, for example, sustains foliar physiology when soil fertility or water availability is suboptimal (Vose and Allen 1988, Pallardy et al. 1995). The elasticity of leaf area ensures that nutrition and water are adequate at the cellular level. Trees may endure resource stress as long as leaf area maintains a neutral or positive whole-tree carbon balance, thus producing enough energy to sustain cellular processes. Vigor may be jeopardized, however, by a drop in leaf area below a critical level or persistent resource deficiencies at the cellular level.

Resource stress may also be evaded or reduced by establishing a pattern of carbon allocation that favors root system growth. This has been demonstrated for loblolly pine on sandy and loamy soils in North Carolina (Hacke et al. 2000) and for longleaf pine on xeric and mesic sites in Georgia (Addington et al. 2006). At both locations, the ratio of surface areas of absorbing roots and foliage was greater on sites with lower plant-available water. This pattern of carbon allocation contributed to the maintenance of stomatal conductances on drier sites that were comparable to those on more moist sites. Water uptake may also rely on deep roots capable of supplying water for immediate aboveground processes or for hydraulic redistribution (Hacke et al. 2000, Domec et al. 2004, Warren et al. 2007). Without hydraulic redistribution, very dry soils may cause root dehydration and the localized cavitation of root xylem (Domec et al. 2004). After drought relief, some lost xylem function could be restored (Domec et al. 2004), but it may not be completely regained until new roots are grown (Hacke et al. 2000).

Together with broad windows of leaf area and root system adjustment, the internal recycling of mineral nutrients also sustains cellular processes when their availability is low (Nambiar and Fife 1991, Oren and Sheriff 1995). In addition to resorption of nutrients before the senescence of older foliage (Dalla-Tea and Jokela 1994), the potential exists for nutrient accumulation in and translocation from nonsenescent foliage, followed by replenishment (Nambiar and Fife 1991, Marschner 1995). The mobility of mineral nutrients with a role in stomatal function and osmotic adjustment, for example, may be key to maintaining photosynthate production and transport and dehydration tolerance during drought (Kramer and Boyer 1995, Cakmak 2005).

Role of Silviculture in PD

Silvicultural choices have the potential to interact with a tree's response to resource stress. If a stand's carrying capacity is exceeded, for example, thinning by natural or prescription-based means increases the likelihood that essential resources will be adequate for stress avoidance. Although density-related mortality is expected at around 50% of maximum stand density index for loblolly pine (Dean and Baldwin 1993), subdominant trees may persist beyond this point. For example, the relative stand density index of overstocked loblolly pine in Louisiana was approximately 85% between age 11 and 13 years, and self-thinning did not proceed until significant water deficit was reached at age 14 years (Sword Sayer et al. 2004).

Once a stand density threshold is reached and if self-thinning is delayed, canopy properties that control whole-crown carbon fixation become insensitive to stand density (Dean and Baldwin 1996, Dean 2001). Similarly, when stands are overstocked, the relationship between canopy properties and root system growth is poor, and carbon allocation to fine roots may be insufficient for adequate soil resource uptake (Dean 2001). These observations suggest that without timely moderation of a stand's carrying capacity, the vigor of residual trees will deteriorate and compromise inherent stress avoidance mechanisms that depend on root system function.

In some situations, the potential also exists for repeated fire to indirectly interfere with root system function and therefore a stand's natural mechanisms of resource stress avoidance. The survival and production of healthy roots is dependent on the supply of recently fixed carbon (van den Driessche 1987, Dickson 1991). In turn, the root system serves as a reservoir of stored starch (Gholz and Cropper 1991, Sword et al. 2000) that is mobilized to support developing foliage (Dickson 1991). The negative effect of defoliation on stemwood production appears to be season-dependent (Johansen and Wade 1987, Weise et al. 1987). Likewise, crown scorch may have a variable effect on carbon sinks other than stemwood growth depending on the time of years when fire occurs (Sword Sayer et al. 2006). In Louisiana, for example, severe scorch in September reduced the root starch content of longleaf pine for 17 months (Sword and Haywood 1999). In Georgia, Guo et al. (2004) found that severe scorch in June also reduced the root starch content of longleaf pine but did not affect this species' fine root biomass. Under normal circumstances, a decrease in root starch may have negligible effects on long-term root production and tree vigor. However, if the re-establishment of foliage after scorch is constrained by the availability of root starch, subsequent foliage and root responses could hinder one or more stress avoidance mechanisms.

Workshop Consensus and Recommendations

A 3-day workshop in June of 2007 was sponsored by the US Army Strategic Environmental Research and Development Program Office. The overall goal of this workshop was to assess the extent and cause of localized declines in southern pine health and identify short- and long-term remedial management actions. Scientists and land managers participated in four discussions of the problem that led to the preparation of three reports and one nontechnical summary (Ecological Society of America 2008). The purpose of one of these discussions was to come to consensus regarding the scope of PD and the research needed to counter its potential effect on southern pine forest health. Before these points could be addressed, workshop participants indicated that two types of information were necessary.

First, it is not known whether PD is new, cyclic, or related to climate change. Second, the locales, species, and forest types exhibiting PD are not well documented. We must first understand whether the problem is new, cyclic, or climate-related before methods of detection, risk analysis, and mitigation can be developed. Once these tools are developed, the locales, species, and forest types susceptible to PD can be defined. With this information, PD can be predicted and mitigation can be prioritized to favor those situations that are the most recoverable. Two caveats are attached to the success of this plan. First, the effect of climate on PD may make it difficult to isolate causal symptomology. Second, management opportunities to sustain forest health may be limited by environmental policies and land-use demands.

Group deliberations identified three activities that would be helpful as PD research is designed:

1. Current forest health monitoring (FHM) variables, frequencies, and intensities should be evaluated to determine whether they are adequate to quantify the scope, severity, and spread of PD, and these efforts should be integrated among established regional Forest Inventory Analysis, FHM, and Eastern Forest Threat programs directed by the US Forest Service.
2. Management effects on critical resources linked to PD should be evaluated, and management practices showing promise as tools to reduce stressors linked to PD should be investigated.
3. Forest conditions that could worsen the regional effect of PD, such as the presence of invasive exotic pests, should be investigated.

Recommended Actions

Based on workshop consensus, several lines of research are needed to understand and respond to PD in the southeastern United States:

1. A current and extensive geographic record of locales exhibiting forest health problems related and unrelated to PD but experiencing mortality should be maintained at the regional scale and made available for the development of models that predict the occurrence, spread, and probability of PD.
2. Models that predict spatial and temporal patterns of species- and forest system–specific pathogenic infection and spread and tree mortality rates should be developed.
3. A better understanding of southern pine physiological responses to interacting stressors associated with PD is needed.
4. Scale- and forest setting–appropriate remote sensing technology that provides information regarding forest health and tree mortality is needed.

Summary

At present, PD is a localized forest health issue caused by environmental stress arising from interaction among several abiotic and biotic factors. There is not enough information about PD at this point to recognize it as a regional forest health threat. However, because PD has been observed among several southern pine species and at locations across the southeastern United States, the scope of this problem has the potential to be broad. We need to know whether PD is new, cyclic, or related to climate change, and we need to know how it correlates to certain locales, species, and forest types to determine its scope. The magnitude of PD may be tempered or exaggerated by changing regional forces (e.g., climate, land-use, invasive species). Therefore, evaluation of this problem requires simultaneous investigation of stand environment and management history. Because the ecological and economic consequences of PD have the potential to adversely affect the sustainability of southern pine forests, research is urgently needed in several areas. Immediate steps should first assess forest health and mortality rates across the southern pine region and develop models that predict the extent and probability of PD. Second, information about the environmental and physiological conditions and management practices that predispose stands to PD is needed. With this, remote-sensing tools that communicate a stand's susceptibility to PD and the expected rate of decline-induced mortality can be created.

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