
Volume 255, issues 5–6, 5 April 2008
ISSN 0378-1127
ELSEVIER
Forest Ecology and Management

Available online at www.sciencedirect.com

ScienceDirect

Forest Ecology and Management 255 (2008) 1735–1739

Forest Ecology and Management

www.elsevier.com/locate/foreco

Topographic features associated with loblolly pine decline in central Alabama

Lori G. Eckhardt [a,*], Roger D. Menard [b]

[a] *Auburn University, School of Forestry and Wildlife Sciences, 602 Duncan Drive, Room 3301, Auburn, AL 36849, United States*
[b] *United States Forest Service, Forest Health Protection, 2500 Shreveport Highway, Pineville, LA 71360, United States*

Received 24 March 2006; received in revised form 27 November 2007; accepted 27 November 2007

Abstract

Loblolly pine (*Pinus taeda* L.) decline has been present in upland sites of central Alabama since the 1960s. Symptoms of loblolly pine decline (fine root deterioration, short chlorotic needles, sparse crowns, reduced radial growth) begin in the 30–40 year age class, resulting in premature death at ages 35–50. Loblolly pine decline occurs on sandy, well-drained soils and is associated with *Leptographium* spp., as well as with root-feeding bark beetles and weevils. The present article discusses the results of a comparison of biological factors associated with pine decline and topographical features, using the analysis of tree health at the Talladega National Forest and Westervelt (formerly Gulf State Paper) Company in central Alabama. Results of this study suggest that an ecological pattern of tree decline and mortality exists. Loblolly stands were more prone to develop symptoms at sites with increased slope and south/southwest orientation. This report indicates that the dominant determinants, or predictors, of loblolly decline are identifiable topographical features.

Keywords: Decline; GIS; Topography; Loblolly pine; *Leptographium*

---

1. Introduction

Declining loblolly stands have been a management concern of forest managers at the Talladega National Forest in Alabama since the 1960s. Loblolly pine is the most extensively planted pine species in the southeastern United States because of its ability to grow rapidly on diverse sites (Schultz, 1997). Over the past 30 years loblolly pine decline has been reported in areas of central Alabama. Loblolly pine decline (LPD) in the southeastern United States has similar symptomology to Littleleaf Disease (LLD) of shortleaf pine (Campbell and Copeland, 1954) with symptoms including short chlorotic needles, sparse crowns, and reduced radial growth followed by premature mortality (Lorio, 1966; Hess et al., 2002), but LPD is typically found on well-drained sites where as LLD is associated with poorly drained sites. The onset of symptoms in both LLD and LPD is associated with older trees which decline slowly and die prematurely, typically accompanied by symptoms associated with several insect and fungal species. Loblolly pine decline has been associated with root-feeding bark beetles (*Hylastes* species) and pathogenic fungi (*Leptographium* species) (Eckhardt et al., 2007). These symptoms were observed to be more pronounced on areas that had greater slope with a southern aspect and increased root-feeding insect activity associated with higher incidence of *Leptographium* spp. infected roots (Eckhardt et al., 2007). This observed relationship in the field led to the hypothesis that topographic factors may influence the severity of LPD.

Similar relationships have been reported in other tree species. Horsley et al. (2000) correlated sugar maple (*Acer saccharum* Marsh.) decline to topographic position on the Allegheny Plateau. Drohan et al. (2002) reported that in sugar maple decline in Pennsylvania, declining plots were found more often at higher elevations, tended to be found on S, SW, W, and NW aspects, and dead sugar maple basal area increased in higher topographic positions. Thomas et al. (2002) reported that in the Vosges Mountains of France, altitude, slope and aspect were correlated with silver fir (*Abies alba* Mill.) decline. In Argentina, Baccala et al. (1998) reported that the combination of altitude, annual precipitation and slope gradient appeared to be a fairly accurate indicator of decline incidence for Chilean cedar [*Austrocedrus chilensis* (D. Don) Florin et

---

* Corresponding author. Tel.: +1 334 844 2720; fax: +1 334 844 1084.
E-mail address: eckhalg@auburn.edu (L.G. Eckhardt).

0378-1127/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2007.11.036

Boutelje]. They found that incidence of decline corresponded to high precipitation and moderate to low altitudes, while healthy trees correspond to sites with either low precipitation, or with a combination of high altitudes and/or steep slopes with moderate to high precipitation. Terrain slope and precipitation were very important in determining the soil water characteristics of a site, which in turn were associated with the decline incidence of Chilean cedar.

The purpose of this study was to analyze the relationship between LPD and site topography characteristics. Available Geographic Information Systems (GIS) databases were combined with the biological data collected in a previous study (Eckhardt et al., 2007) in order to characterize the topography where LPD occurs.

2. Materials and methods

2.1. Study sites

Thirty-nine sites were established in nine counties located in central Alabama on Choccolocco State Forest, the Talladega National Forest, (Oakmulgee and Shoal Creek Ranger Districts) and Westervelt (formerly Gulf State Paper) properties, representing an area of 880 ha, which encompassed four physioregions. Sites were established using visual crown symptomology. Loblolly pine on 32 sites exhibited decline symptoms (trees with sparse, thinning crowns), and seven sites were asymptomatic (trees with thick, full crowns). At each site, one central plot and three sub-plots were established. Subplots were located 120 m from the central plot at bearings of 120°, 240°, and 360° (Dunn, 1999). The mean temperature for this area is 16 °C and the mean yearly precipitation is 1346 mm. Elevations ranged from 83 to 397 m above sea level. The geology of each plot was determined by overlaying plot locations on a GIS layer of surface geology of Alabama. The substrate in the four physioregions is composed of marine sediments, clay and sand from the Upper Crustaceous (Upper Coastal Plain and Cumberland Plateau), mica schist and chloritic schist from the Precambian/Paleozoic (Piedmont, Ridge and Valley), limestone and shale from the Cambian (Ridge and Valley), and slate and phyllite from the Silurian/Devonian (Piedmont).

2.2. Sampling

In each plot, disease incidence was determined by tabulating trees as symptomatic, dead, or asymptomatic. Disease incidence (%) was calculated as: number of symptomatic and dead loblolly pine trees divided by the total number of loblolly pine trees, times 100 (Table 1). Slope inclination (%), slope aspect (NW, W, SW, S, E, NE, N, NA) elevation, and convexity of each plot were obtained from USGS 1:24,000 digital elevation models (DEMs) (Table 1). Topographic position (ridge-top, nose-slope, side-slope, foot slope, and toe-slope) (Buol et al., 1989) of each plot was determined based on a 7.5 min, 1:24,000 USGS topographic quadrangle map (Table 1). Because of insufficient sample size in some topographic positions classes, the ridge-top and nose-slope positions were grouped into an up-slope class and the foot slope and toe-slope class were grouped into a bottom-slope class (Drohan et al., 2002). Finally, climatic data (annual precipitation and mean temperature) were obtained from the National Oceanic and Atmospheric Administration (NOAA) (Table 1). Ground-truthing verified data derived from 7.5 min, 1:24,000 USGS topographic quadrangle maps and DEMs. When derived data deviated more than 5% from ground data, ground data were used in the analysis.

2.3. Statistical analysis

Descriptive statistics were used to describe the quantitative variables, disease incidence, slope inclination, slope aspect, site elevation, and precipitation. Slope aspect was linearized using the formula [1-cosine (aspect in degrees)] + [1-sine (aspect in degrees)] so that northeasterly aspects had the lowest values and southwesterly aspects had the highest values. In order to observe the relationship between pairs of quantitative variables scatter plots were constructed and both Spearman and Pearson correlation coefficients were calculated (SAS, 2001). These analyses were done with all the plots together ($n = 39$), and also with the asymptomatic ($n = 7$) and symptomatic ($n = 32$) plots separately, with the objective of detecting any distinctive data structure in both types of plots. Categorical variable (convexity and physioregion) were analyzed using Proc GLM in SAS (2001).

An observation matrix was designed based on data for the 39 plots and five variables: disease incidence (DI), slope (SLP), aspect (ASP), elevation (ELV), and precipitation (PRC). Qualitative variables were standardized because they differed in their measurement units. A Principal Component Analysis (PCA) was performed with these values. To verify the grouping of plots obtained with the PCA, a Cluster Analysis (CA) was performed, using the most important components obtained from the PCA variables. For this analysis, the Ward's method order was used to identify data portioning.

We also sought to establish a statistical model that could predict DI using the topographical variables that appeared to be correlated with DI. A step-by-step discriminate analysis was carried out by introducing the variables one-by-one and selecting only those having a significant influence on the DI (Proc GLM, SAS, 2001).

3. Results

3.1. Description of study area

Among a total of 39 plots observed, 18% were symptom free, 28% exhibited mild symptomology (pre-decline, mostly root symptoms but crowns beginning to thin), 31% exhibited moderate symptomology (thinning crowns, short chlorotic needles), and 23% exhibited severe symptomology (sparse crowns, short chlorotic needles, mortality). Plots were distributed across most slopes and aspects. When study plots were ground-truthed against slope and aspect maps, 97% of the

Table 1
Physioregion, topography, precipitation (cm/year), and incidence of disease of the plots

Plot	Physioregion	Slope	Aspect[a]	Conv.	Elev.	Precipitation (cm/year)	Topographic position	Disease incidence (%)
1	Piedmont	14	162	v	327	138	Side-slope	75
2	Piedmont	15	221	v	325	138	Side-slope	60
3	Piedmont	15	220	v	321	138	Side-slope	55
4	Piedmont	6	69	c	332	140	Side-slope	7
5	Piedmont	0	NA	f	336	139	Nose-slope	2
6	Ridge and Valley	2	21	c	328	141	Toe-slope	4
7	Ridge and Valley	0	NA	f	325	141	Nose-slope	3
8	Piedmont	13	82	v	402	135	Side-slope	64
9	Piedmont	17	287	c	399	135	Side-slope	68
10	Piedmont	8	54	c	329	157	Side-slope	12
11	Piedmont	8	287	c	325	159	Side-slope	20
12	Coastal Plain	19	197	v	131	159	Side-slope	84
13	Coastal Plain	21	134	v	104	152	Side-slope	92
14	Coastal Plain	32	164	v	107	164	Side-slope	90
15	Coastal Plain	6	298	c	128	154	Side-slope	10
16	Coastal Plain	14	312	c	135	162	Side-slope	22
17	Coastal Plain	6	267	c	87	157	Side-slope	15
18	Coastal Plain	19	175	v	90	159	Side-slope	89
19	Coastal Plain	23	135	v	135	156	Side-slope	96
20	Coastal Plain	17	221	v	117	158	Side-slope	88
21	Coastal Plain	11	230	v	108	159	Side-slope	83
22	Coastal Plain	22	209	v	133	180	Side-slope	91
23	Cumberland Plateau	11	240	v	123	184	Side-slope	86
24	Cumberland Plateau	6	92	v	126	186	Side-slope	60
25	Cumberland Plateau	0	NA	c	127	181	Toe-slope	3
26	Cumberland Plateau	7	251	c	131	179	Side-slope	24
27	Cumberland Plateau	5	289	c	125	190	Side-slope	25
28	Cumberland Plateau	2	274	c	134	180	Toe-slope	35
29	Cumberland Plateau	8	47	c	126	185	Side-slope	15
30	Cumberland Plateau	6	288	c	131	181	Side-slope	26
31	Cumberland Plateau	6	271	c	128	180	Side-slope	30
32	Coastal Plain	3	110	c	131	159	Toe-slope	12
33	Piedmont	1	349	c	343	160	Nose-slope	2
34	Ridge and Valley	2	352	c	316	165	Nose-slope	3
35	Piedmont	10	327	c	324	160	Side-slope	30
36	Coastal Plain	7	146	v	123	159	Side-slope	82
37	Coastal Plain	8	248	c	142	161	Side-slope	32
38	Coastal Plain	12	200	v	116	160	Toe-slope	85
39	Coastal Plain	4	20	c	150	179	Ridge-top	1

[a] NA: no aspect.

study plots agreed with the map data. Randomly selected points and previously evaluated points checked against combined aspect-slope maps matched 99% of the plots.

3.2. Statistical analysis

When all plots were considered, both Spearman and Pearson coefficients showed a significant positive correlation between DI-SLP and DI-ASP, and ASP-ELV and ELV-PRC showed a negative correlation (Table 2). When asymptomatic plots were considered alone, DI-SLP and DI-ASP showed a positive correlation. When symptomatic plots were considered alone, DI-SLP and DI-ASP were positively correlated and ASP-ELV and ELV-PRC were negatively correlated.

Since the test was run on standardized variables, variable coordinates to each component are the same as their correlation coefficient with each component (Table 3). According to the PCA, it was found that the first two axes explained 82.2% of the

Table 2
Spearman and Pearson correlation coefficients between pairs of variables

Variables	All plots (n = 39)		Symptomatic plots (n = 32)		Asymptomatic plots (n = 7)	
	Spearman	Pearson	Spearman	Pearson	Spearman	Pearson
DI/SLP	0.85[a]	0.82[a]	0.85[a]	0.84[a]	0.75[a]	0.76[a]
DI/ELV	−0.45[a]	−0.31	−0.35	−0.23	−0.75	−0.64
DI/PRC	−0.04	−0.07	0.05	−0.02	−0.63	−0.53
DI/ASP	0.62[a]	0.60[a]	0.59[a]	0.57[a]	0.90[a]	0.76[a]
SLP/ELV	−0.23	−0.19	−0.16	−0.16	−0.61	−0.51
SLP/PRC	−0.23	−0.16	−0.18	−0.14	−0.29	−0.36
SLP/ASP	0.54[a]	0.51[a]	0.49[a]	0.49[a]	0.72	0.76[a]
ASP/ELV	−0.40[a]	−0.39[a]	−0.36[a]	−0.36[a]	−0.61	−0.59
ASP/PRC	0.12	0.12	0.13	0.18	−0.56	−0.59
ELV/PRC	−0.46[a]	−0.67[a]	−0.60[a]	−0.73[a]	0.19	−0.16

DI: disease incidence; SLP: slope; PRC: precipitation; ELV: elevation.
[a] Significant correlation $P < 0.05$.

Table 3
Eigenvalues, percent variance explained, and the coordinates of active variables for the two first components from the PCA

Axis	1	2
Eigenvalues[a]	2.494	1.615
Percent variance explained[b]	49.89	32.31
Incidence	0.93	0.03
Slope	0.91	−0.09
Aspect	0.76	0.28
Elevation	−0.29	−0.87
Precipitation	−0.14	0.93

[a] Eigenvalue = the variance of points over each axis or, the variance explained for each axis.

[b] Percent variance explained = [variance explained for each axis (eigenvalue)/total variance] × 100.

total variance. The first axis explained 49.89% of the total variance, and the variables most correlated with it were DI, SLP, and ASP (0.93, 0.91, and 0.76, respectively). The second axis explained 32.31% of the total variance with ELV and PRC (−0.87 and 0.93, respectively) being the most correlated variables with it (Table 3).

The CA yielded three clusters (Figs. 1 and 2) that resembled the arrangement of plots obtained with the PCA. The first cluster was characterized by plots with southerly aspects, moderate to steep slopes (7–32%), and high disease incidence (55–96%) (Table 4) (plots: 1–3, 9, 12–14, 18–23, 36, 38). The second cluster comprised plots with northerly aspects, mild slopes (0–8%), and low disease incidence (1–12%) (Table 4) (plots: 4–7, 10, 25, 29, 32–34, 39). The third cluster included plots with easterly and westerly aspects, mild to moderate slopes (2–14%) and moderate disease incidence (10–64%) (Table 4) (plots: 8, 11, 15–17, 24, 26–28, 30, 31, 35, 37).

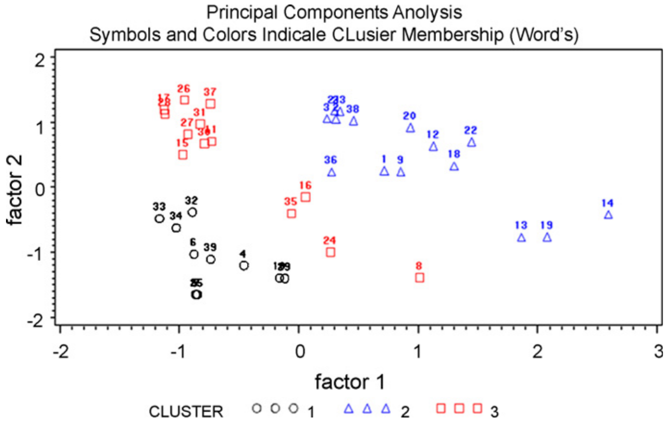

Fig. 1. Cluster membership between factor 1 and factor 2.

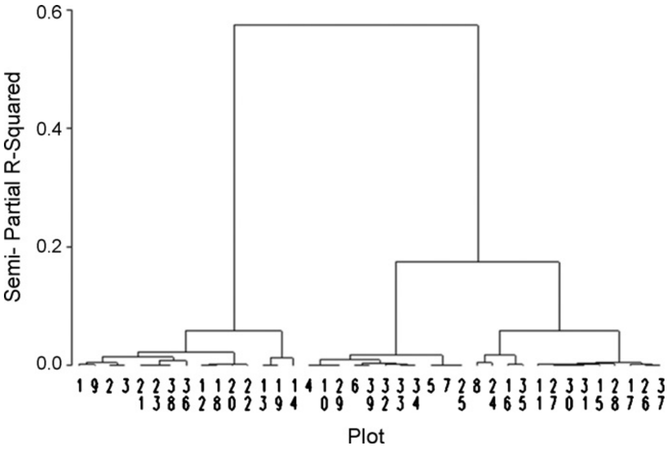

Fig. 2. Dendrogram of cluster analysis using Ward's Method.

Table 4
Plot characteristics associated from clusters produced by Ward's method cluster analysis

	Cluster 1	Cluster 2	Cluster 3
Disease incidence (%)	55–96	1–12	10–64
Slope (%)	7–32	0–8	2–14
Aspect	SE,S,SW,W	N,NE,E	W,NW,E

A step-by-step discriminant analysis was carried out by introducing the variables one-by-one and selecting only those having a significant influence on the incidence of disease (Proc GLM, SAS, 2001). The following model was derived:

$$Y = 42.45 + 1.34\mathrm{SLP} + 5.91\mathrm{ASP} - 43.11I$$

where Y is the discriminant function associated with disease incidence, SLP is the slope of the plot, ASP is the aspect of the plot, and I is the indicator variable for convexity ($I = 1$ for concave and $I = 0$ for convex).

4. Discussion

Slope and aspect on the landscape appear to be correlated with LPD in central Alabama. High disease incidence corresponded to steep slopes, while plots with no to low slope were asymptomatic. Terrain slope (convexity and steepness) are very important in determining the soil water characteristics of a site and could increase effects during drought. While precipitation levels were not statistically significant, water moisture characteristics of the soil were not measured. Other authors have noted the importance of slope gradient and position in determining the distribution of water in soils, given certain characteristics of sites (soil type, amount of precipitation, etc.) (Gerardin and Ducruc, 1990; Lundin, 1995). Lower precipitation or steeper slopes would correspond to drier soils conditions, while higher precipitation or gentle slopes would correlate to a more moist soil condition. Most asymptomatic plots with no or low gradient were located at foot-slope positions, which tended to increase the water saturation of the soils. Asymptomatic areas found on ridge-tops or slope benches were located in concave landforms that had more soil moisture than surrounding landforms.

Aspect was also correlated with disease incidence. For example, plots with SE/S/SW aspects were more likely to be in decline than areas with NE/N aspects. It has been suggested that the aspect markedly affects soil temperature (Marshall and Holmes, 1988) and soil water balance (Hanna et al., 1982) in high-latitude regions. However, it was also observed that when soil water outputs exceed rainfall, soil water was not significantly correlated with aspect, probably because of the influence of the shading of trees on soil microclimate (Hanna et al., 1982). In the case of this study, the effect of aspect (slope orientation) on decline was significant.

The complex relationship of these physiographic factors in combination is associated with varying levels of decline. Combinations of more influential factors such as steep slopes and S/SW aspects are associated with the most severe decline symptoms and mortality, across all age classes studied. Low to moderate slope ratings, in combination with a severe aspect rating (S/SW) were associated with an increased DI.

The results from this study suggest that an ecological pattern of tree decline and mortality exists. Loblolly pine stands seem more prone to symptom development when occurring on sites with steep slopes and a S/SW aspect, while loblolly on mild to no slopes with N/NE aspects show almost no symptoms. It is, thus hypothesized that sites with relatively good drainage are more prone to symptom development. However, it is not clear whether soil moisture directly affects roots (Levitt, 1980; Costello et al., 1991) or it produces a more suitable environment for root pathogen proliferation and infection (Tainter and Baker, 1996) by increasing tree stress and lowering tree vigor.

5. Conclusions

The pattern of pine decline indicates the importance of a better understanding of the ecology and physiology of loblolly pine, in order to determine under what conditions symptoms develop. This requires the realization of extensive surveys at a scale that permits the elucidation of the basic, general, underlying principles and causes of this decline. The potential relationship between site and stand characteristics that have been identified in this analysis represent a snapshot in time for the current stage of the development of LPD in this study area. These relationships help identify areas where LPD will likely spread and/or intensify first. Further study in this area could also help researchers predict future areas at risk for LPD in a region which would help land managers direct mitigation efforts. The implication is that this model could provide a powerful management tool for species restoration, wildlife habitat management or other land management objectives in similar topographic locations.

Acknowledgements

We express appreciation to Westervelt (formerly Gulf State Paper) Corporation for providing study site. Assistance from Shoal Creek, Talladega, and Oakmulgee Ranger District personnel was appreciated for their knowledge and cooperation of National Forest stand conditions and sites. The Alabama Forestry Commission, and the USDA, Forest Health Protection, for providing training, testing, and oversight of FHM standards and plot establishment. The authors also recognize and thank the crews that assisted with field and laboratory work.

References

Baccala, N.B., Rosso, P.H., Havrylenko, M., 1998. *Austrocedrus chilensis* mortality in the Nahuel Huapi National Park (Argentina). For. Ecol. Manag. 109, 261–269.

Buol, S.W., Hole, F.D., McCracken, R.J., 1989. Soil Genesis and Classification, 3rd ed. Iowa State University, Ames, IO, 445 pp.

Campbell, W.A., Copeland, O.L., 1954. Littleleaf disease of shortleaf and loblolly pines. Circular No. 940, USDA, Forest Service, Washington, DC.

Costello, L.R., MacDonald, J.D., Jacobs, K.A., 1991. Soil aeration and tree health: correlating soil oxygen measurements with the decline of established oaks. USDA Forest Service Gen. Technol. Rep. PSW-126, pp. 295–299.

Drohan, P.J., Stout, S.L., Petersen, G.W., 2002. Sugar maple (*Acer saccharum* Marsh.) decline during 1979–1989 in northern pennsylvania. For. Ecol. Manag. 170, 1–17.

Dunn, P.H., 1999. Forest Health Monitoring Field Methods Guide. United States Department of Agriculture, Forest Service, Washington, DC, 120 p.

Eckhardt, L.G., Weber, A.M., Menard, R.D., Jones, J.P., Hess, N.J., 2007. Association of an insect-fungal complex with loblolly pine decline in central Alabama. For. Sci. 53, 84–92.

Gerardin, V., Ducruc, J.P., 1990. An objective approach to evaluating natural drainage of forest mineral soils for non-specialists. Vegetatio 87, 127–133.

Hanna, A.Y., Harlan, P.W., Lewis, D.T., 1982. Soil available water as influenced by landscape position and aspect. Agron. J. 74, 999–1004.

Hess, N.J., Otrosina, W.J., Carter, E.A., Steinman, J.R., Jones, J.P., Eckhardt, L.G., Weber, A.M., Walkinshaw, C.H., 2002. Assessment of loblolly pine decline in central Alabama. In: Outcalt, K.W., et al. (Eds.), Proceedings of the Eleventh Biennial Southern Silvicultural Research Conference, Knoxville, Tennessee, March 20–22, 2001. USDA, For. Ser., SRS, Asheville, North Carolina, pp. 558–564.

Horsley, S.B., Long, R.P., Bailey, S.W., Hallett, R.A., Hall, T.J., 2000. Factors associated with the decline-disease of sugar maple on the Allegheny Plateau. Can. J. For. Res. 30, 1365–1378.

Levitt, J., 1980. Responses of plants to environmental stresses: water, radiation, salt, and other stresses. In: Kozlowski, T.T. (Ed.), Physiological Ecology, 2nd ed., vol. II. Academic Press, New York.

Lorio, P.L., 1966. *Phytophthora cinnamomi* and *Pythium* species associated with loblolly pine decline in Louisiana. Plant Dis. Rep. 50, 596–597.

Lundin, L., 1995. Soil water chemistry dependence on water pathways and turnover. Water Air Soil Poll. 85, 1695–1700.

Marshall, T.J., Holmes, J.W., 1988. Soil Physics, 2nd ed. Cambridge Univ. Press, Cambridge, pp. 111–330.

SAS Institute Inc., 2001. Version 8.02. Cary, North Carolina, USA.

Schultz, R.P., 1997. Loblolly pine: the ecology and culture of loblolly pine (*Pinus taeda* L.). U.S. Department of Agriculture, Agriculture Handbook 713. Washington, DC, pp. 1–16 (Chapter 1).

Tainter, F.H., Baker, F.A., 1996. Principles of Forest Pathology. John Wiley & Sons, Inc., New York, Chichester, Brisbane, Toronto, Singapore, 805 pp.

Thomas, A.L., Gerout, J.C., Landmann, G., Dambrine, E., King, D., 2002. Relation between ecological conditions and fir decline in a sandstone region of the Vosges mountains (northern France). Ann. For. Sci. 59, 265–273.