INCIDENCE AND DEVELOPMENT OF BACTERIAL LEAF SCORCH OF ELM ON THE NATIONAL MALL

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Abstract. Approximately 600 elms on the National Mall in Washington D. C. were surveyed for 6 years for symptoms of bacterial leaf scorch caused by *Xylella fastidiosa*. The mean disease incidence over the course of the study was 30% and increased by approximately 10% over 6 years. Twenty-eight percent of the affected trees had symptoms in more than 25% of their crowns. Symptom severity fluctuated from year to year. Of the trees first detected with symptoms in 1986 only 18% had a higher symptom rating after 6 years, while 51% had fewer or no symptoms. Trees 20-30 cm dbh were the most affected, while those in the 1-10 cm class were the least affected. Affected trees occurred throughout the planting.

Bacterial leaf scorch of elm is a vascular disorder causing leaf necrosis and dieback (3,5,12,17). The disease was first recognized in Washington D.C. by Fowler in 1931 (16). Wester and Jylkka later found that the disease had become serious in Washington, D.C. in the 1950s and was widespread throughout the southeastern states (17). The leaf scorch symptoms and transmissibility of the causal agent in scion wood containing xylem tissue prompted Wester and Jylkka to postulate that elm scorch was caused by the same xylem-inhabiting virus then believed to cause Pierce's disease of grape (17). Pierce's disease, almond leaf scorch, alfalfa dwarf, phony disease of peach, periwinkle wilt, and citrus variegated chlorosis are among several diseases now known to be caused by the fastidious xylem-inhabiting bacterium *Xylella fastidiosa* (1,4,15). Leaf scorch of red oak, mulberry, sycamore, and red maple are also known to be caused by *X. fastidiosa* (2,8,11,14). Recently, a strain of *X. fastidiosa* isolated from elm was shown to be pathogenic in inoculated elm seedlings. In the same study, however, it was found that strains causing elm leaf scorch and sycamore leaf scorch did not show cross pathogenicity (10).

Bacterial leaf scorch of landscape trees is a chronic disorder in which trees exhibit symptoms of marginal leaf necrosis and dieback over several years. Severely affected trees are weakened, enhancing their susceptibility to other debilitating biotic and abiotic factors. Elms infected with *X. fastidiosa* exhibit decreased hydraulic conductivity, a decrease in starch reserves, and a reduction in stem elongation (7). Leaf scorch affected elms have been found to be more prone to contract Dutch elm disease than unaffected trees (18). It is suspected that scorch-affected elms, like other stressed elms, are prone to breeding attacks by the European elm bark beetle, *Scolytus multistriatus*, the Dutch elm disease vector (18).

The American elm is probably the most aesthetically significant tree species within the Monumental Core of Washington D.C. Approximately 2500 elms grace the avenues and monument grounds of the Nation's Capital. The most prominent component of the elm population is the 600 elms of the National Mall which flank the vista between the Washington Monument and the Capitol. The planting was established in the mid 1930s and today the area is enjoyed by millions of visitors each year. Considerable effort is expended in maintaining the health of these trees, particularly in the management of Dutch elm disease. Although *X. fastidiosa* was isolated previously from leaf scorch-affected elms on the Mall (13), no assessment of the disease throughout the planting has been made. This study was designed to assess the incidence of elm leaf scorch on the National Mall and to monitor annual symptom development.

Materials and Methods

The elms of the National Mall were examined in late summer when leaf scorch symptoms were optimal in 1986 - 1990 and in 1992. The popula-

tion ranged from 583 to 608 trees including, in addition to *Ulmus americana*, 27 *U. hollandica*. Only trees with a leaf scorch pattern characteristic of *X. fastidiosa* infection were rated. Two or three trained people completed each survey in approximately three consecutive work-days. Trees were rated for the percent crown area showing leaf scorch using the following scale: 0 = no symptoms; 1 = trace - 5%; 2 = 6 - 25%; 3 = 26 - 50%; 4 = 51 - 75%; and 5 = 76 - 100%. When necessary, crown examinations were made with binoculars.

Symptom development was followed from 1986 through 1992 for trees first detected in 1986. An annual symptom index was developed for each set of trees rated 1 - 5 in 1986 using the formula (# trees rated 1 X 1) + (# trees rated 2 X 2) +... (# trees rated 5 X 5) / # initial 1986 trees per symptom rating - trees removed).

Trunk diameter-at-breast-height (dbh) was determined in conjunction with the symptom surveys conducted in 1988, 1989, 1990, and 1992. Leaf scorch ratings and trunk diameters were compiled and analyzed with an existing elm tree inventory data base maintained on dBase IV, Version 1.1, Ashton Tate.

The mean disease rating of the six surveys was determined for each panel of the Mall delineated by roads and walks. The mean rating was plotted with GRASS 4.0 Geographic Information System software.

In order to determine if the disease incidence was affected by precipitation, regression correlations between disease incidence and precipitation were determined using the cumulative precipitation for February through September, and for August and September separately. Precipitation data were obtained from Washington National Airport, located approximately 4.7 kilometers from the Mall. The correlations were determined from 1986 through 1992 using the Statistical Analysis System (SAS), (SAS Institute, 1989).

Results

During the initial survey conducted in 1986, 126 trees representing 21% of the population, exhibited leaf scorch symptoms (Table 1, Fig. 1). Progressively fewer first-time detections were found in the subsequent five surveys (Fig. 1). Most first-time detections were Category 1 trees. However, some trees were detected for the first time with symptoms evident in more than 5% of their crowns (Fig. 1). Throughout the six annual surveys, 371 trees comprising approximately 60% of the population, exhibited leaf scorch on at least one survey. The mean annual disease incidence from 1986 to 1992 was 30% (21 - 36%) (Table 1) and increased by approximately 10% in six years (Fig. 2).

Approximately 50% of the trees were mildly symptomatic with 5% or less of the crown affected

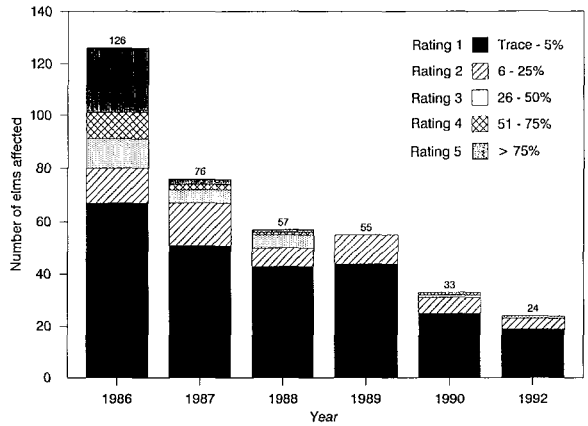

Fig. 1. Number of elms on the National Mall detected for the first time with symptoms of bacterial leaf scorch. Bar for 1986 represents the first survey; subsequent bars represent symptomatic trees which had no symptoms in previous years.

Table 1. Leaf scorch of the elms of the National Mall.

Sympton rating*	Year 1986	1987	1988	1989	1990	1992	Mean
0	475	419	441	397	392	392	419
1	67	86	85	95	104	91	88
2	13	34	31	52	52	50	39
3	11	16	22	23	21	25	20
4	10	6	4	22	17	16	13
5	25	22	8	12	22	16	18
Total	601	583	590	601	608	590	597
%**	21	28	25	34	36	34	30

*0 = no scorch, 1 = trace to 5%,2 = 6 - 25%, 3 = 26 - 50%, 4 = 51 - 75%, 5 = 76 - 100%.
** Percent affected each year

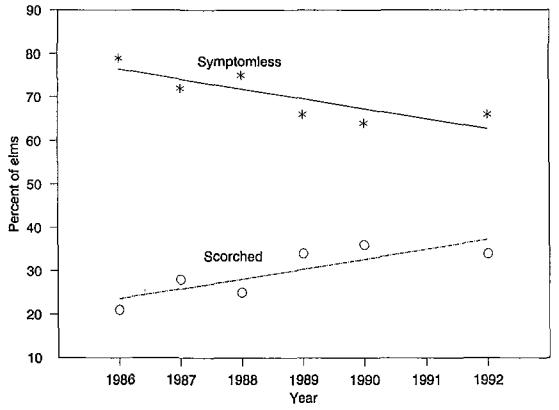

Fig. 2. Percent of symptomless and leaf scorch-affected elms on the National Mall.

(Table 1). Moderate symptoms, 6 - 25% affected 22% of the trees, and 28% had severe symptoms involving over 25% of their crowns (Table 1).

Symptom development for trees in all symptom categories ranked in 1986 showed a decline in expression from 1986 to 1988. Symptom severity in all groups rose in 1989 (Fig. 3), however, by 1992 all categories except No. 1 were rated lower than in 1986. Of the 126 trees showing symptoms in 1986 (Table 2), 51% had less or no symptoms in 1992. Symptoms remained the same for 21% and increased in 18%. Six of the trees (17%) with a rating of 4 or 5 in 1986 and six trees (9%) with a rating of 1 died in the course of the study. Five of the 12 trees died from Dutch elm disease.

Bacterial leaf scorch affected trees in all diameter

Table 2. Leaf scorch symptom rating of elm trees six years after first symptoms.

1986		1992						
		No. of trees per symptom category						
Rating*/	No.	0	1	2	3	4	5	Removed
1	67	31	14	5	6	3	2	6
2	13	6	1	3	1	0	2	0
3	11	3	2	1	3	2	0	0
4	10	1	1	2	1	1	2	2
5	25	5	2	0	5	3	6	4
total	126	46	20	11	16	9	12	12

*0 = no scorch, 1 = trace to 5%,2 = 6 - 25%, 3 = 26 - 50%, 4 = 51 - 75%, 5 = 76 - 100%.

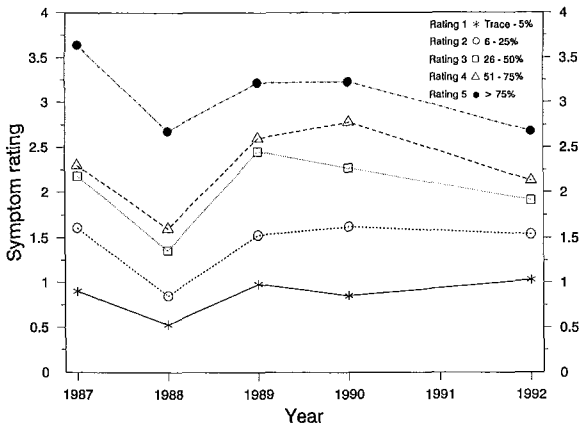

Fig. 3. Annual symptom index for elms first detected with leaf scorch in 1986 and evaluated through 1992. The symptom index for trees in each symptom category in 1986 was determined annually by the formula (# trees rated 1 X 1) + (# trees rated 2 X 2) +... (# trees rated 5 X 5) / # initial 1986 trees per symptom rating - trees removed after 1986).

classes (Fig. 4). Of the diameter classes represented by 20 or more trees, the 20 - 30 cm class was the most affected with approximately 50% (range 36% - 63%) of the trees exhibiting symptoms (Fig. 4). The 20 - 30 cm category also had the largest percentage of trees with a symptom Rating of 5. Trees in the smallest diameter class (1 - 10 cm) were the least affected with only 16%

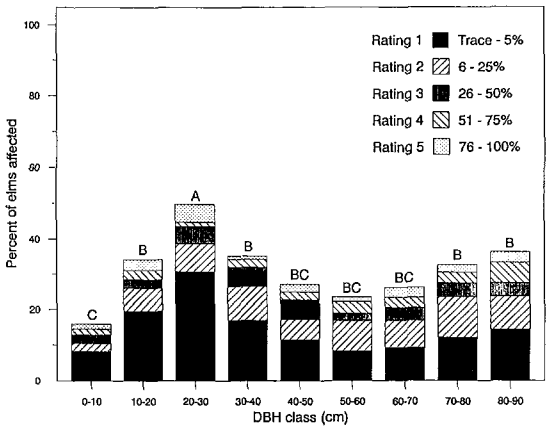

Fig. 4. Mean percent of elms with leaf scorch symptoms by trunk diameter class (1988-1990, 1992). Bars labeled with the same letter are not significantly different at $P \leq 0.05$ (Duncan's multiple range test)

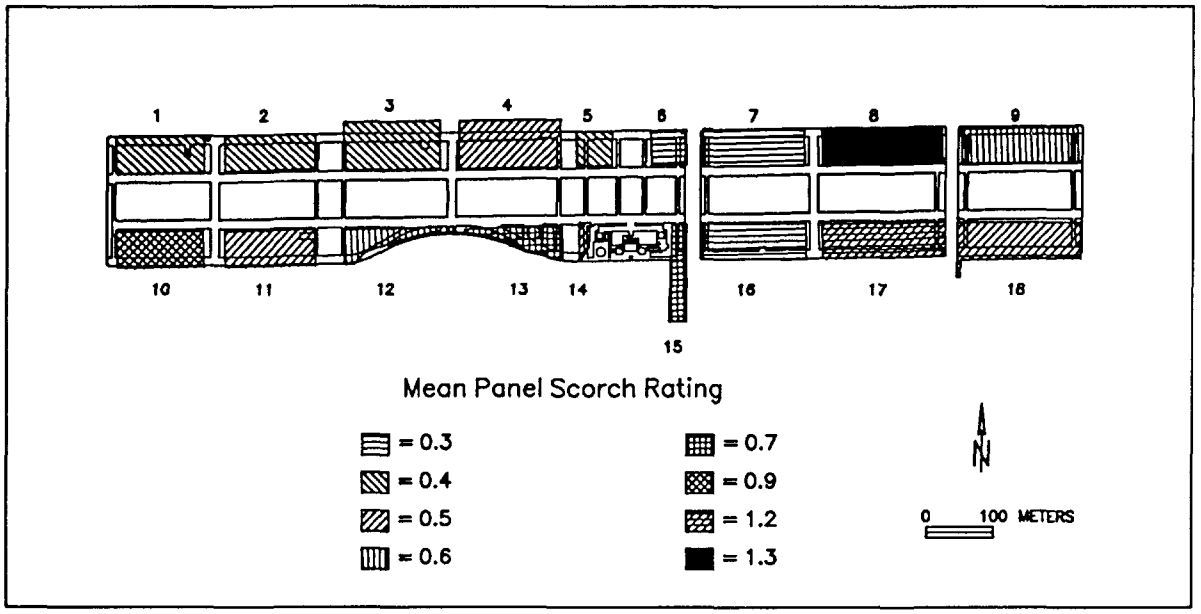

Fig. 5. Six year mean symptom rating of leaf scorch-affected elms mapped by panel on the National Mall.

(11% - 22%) exhibiting symptoms.

Bacterial leaf scorch affected elms throughout the Mall. All panels delineated by walks and streets contained affected trees (Fig. 5). The disease, however, was most severe in the eastern half of the planting. The most severely affected, Panel 8, had a mean symptom rating of 1.3 for the six survey years, which is four times greater than the least affected Panels, 6, 7, and 16.

Precipitation for February through September ranged from 45.64 cm in 1986 to 96.21 cm in 1989. There was a positive correlation, r = 0.717, between disease incidence and the cumulative rainfall from February through September. There was, however, little correlation for August (2.92 cm - 13.54 cm), r = 0.014, or September (1.52 cm - 17.84 cm), r = 0.302, alone when symptoms were most severe.

Discussion

The decline in the number of new detections with each survey reflect the stability of the elm stand, with an annual loss and replacement for all causes of about 2%. Most new detections were of trees that had been present previously, but which did not exhibit symptoms in earlier surveys. Although examined in previous years, some trees were first detected with symptoms in more than 5% of their crowns. This suggests that some infections develop systemically before symptoms are apparent.

The annual incidence of bacterial leaf scorch on the Mall is high. Each year approximately 30% of the trees exhibited symptoms. Twenty-eight percent of the affected trees exhibit symptoms in 25% or more of their crowns. There was a 10% increase in the incidence over the six years in which the study was conducted.

It was anticipated that infected trees would show an annual increase in symptom expression. The six surveys showed that 60% of the elm population exhibited leaf scorch symptoms on at least one survey. The mean annual disease incidence was 30%. Since 60% of the trees did not show symptoms each year it is apparent that symptom expression fluctuates annually with some trees not showing symptoms every year and some trees possibly recovering completely. The annual symptom indices for the 1986 trees showed a general decline in symptom expression through 1992, except Rating 1 which remained constant. Thirty-six percent of the trees detected with

symptoms in 1986 were symptomless in 1992, while only 18% had a symptom rating greater than when first detected. Six years may not be sufficient time to note a trend in symptom development.

As in any chronic disease there is vacillation in the development of the pathogen within the host. In some cases infections may be naturally arrested while in others the pathogen may merely remain inactive until factors optimize development. It is not known whether *X. fastidiosa* persists in trees after symptom remission or whether it occurs in trees that remain asymptomatic. *X. fastidiosa* has been found in symptomless branches of trees where other portions of the crown are exhibiting symptoms (3).

Wester and Jylkka (18) reported that elms affected by leaf scorch are prone to attack by the elm bark beetle and are more likely to contract Dutch elm disease. The annual mean incidence of Dutch elm disease on the Mall since 1986 has been 1%. Consequently it was not likely that a distinction in susceptibility between scorch-affected and noninfected trees would be seen. However, 4 of the 7 1986 trees with bacterial leaf scorch symptom ratings of 4 & 5 were diagnosed with Dutch elm disease and removed before 1992. As long as bark beetles are managed by sanitation, leaf scorch may not significantly increase the Dutch elm disease incidence within the planting.

Symptoms were most common in trees that were in the 20 - 30 cm dbh Class (15 - 20-yr-old). Elms in the 1 - 10 cm Class (3 - 5-yr-old) were recently planted, and the least affected. Older trees may out grow the pathogen or the bacterium may not be able to move as readily in older, slower growing trees. Lee et al. (9) report that citrus trees greater than 15 years old were not totally affected with citrus variegated chlorosis and may have only one or two branches showing symptoms, while younger trees were more severely affected. Although the youngest elms (1 - 10 cm) seem to be least affected, given the prevalence of the disease, these trees are readily exposed to infection. The vector for *X. fastidiosa* in elm is not known, but it is likely that the same sharpshooter leafhoppers responsible for transmission in other crops play a role in the transmission of the bacterium in landscape trees. Mechanical transmission has not been reported, however, there is a likelihood of root graft transmission. The organism has been transmitted by stem grafts (3,17) and *Ophiostoma ulmi*, the xylem inhabiting fungal pathogen, is well known to be transmitted by root grafts.

Panels #s 8 and 17 in the eastern half of the Mall had the highest cumulative disease ratings. Panel #17 had the largest number of trees (29%) in the most susceptible size class (20 - 30 cm dbh), however, only 8% of the trees in Panel #8 were in the same class. There did not appear to be a discernable pattern of disease distribution within the planting.

Since leaf scorch results in a reduction in leaf moisture, a likely consequence of vessel blockage, it would be expected that the disease incidence might decrease with an increase in precipitation. In the course of this study there was no indication that decreased precipitation enhanced disease incidence. Rather, there was a slight positive correlation between increased precipitation and disease incidence.

Current studies are underway to determine how *X. fastidiosa* is transmitted in landscape trees and what management tactics might be employed to reduce transmission. Although affected elms do not consistently progress in symptom expansion, symptoms do intensify in many trees reducing their vigor and aesthetic value. It is not known what cultural practices or therapeutic treatments may improve chances for recovery. Oxytetracycline injections have been found effective in suppressing symptom development in elm (6). Further study is necessary to determine if extended treatments can achieve recovery by possibly allowing trees to compartmentalize infections. If infections can be detected early, while the pathogen is localized in a single limb, pruning may be an effective therapeutic tactic. It is necessary, however, to determine how far beyond symptomatic branches *X. fastidiosa* occurs in infected trees before specific treatment recommendations can be given. Resistance to the vector(s) or the pathogen are other tactics that also must be explored. *X. fastidiosa* has a wide host range and has been detected in *U. pumila* and *U. glabra* (5).

The long-term consequences of bacterial leaf scorch in landscape plantings of susceptible hosts

is still largely unknown. Many factors may alter the success or failure of chronic infections. Further studies of naturally infected plantings as well as controlled studies will help elucidate the impact of this unique bacterium on landscape trees.

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Résumé. Environ 600 ormes du National Mall de Washington ,D.C., ont été inventoriés et suivis durant six années pour les symptômes de la brûlure bactérienne des feuilles causée par Xillela fastidiosa. Le taux moyen d'incidence de la maladie durant la période sous étude était de 30% et s'accroissait d'approximativement 10% par année au cours de ces six ans. Vingt-huit pourcent des arbres affectés présentaient des symptômes sur plus du quart de leur cime. La sévérité des symptômes observés fluctuait d'année en année. Des premiers arbres détectés avec des symptômes en 1986, seulement 18% avaient un taux plus élevé de symptômes après six années, tandis que 51% avaient un taux plus bas ou aucun symptôme à la fin de cette période. Les arbres de 20 à 30 cm de D.H.P. étaient les plus affectés, alors que ceux de la classe de 1 à 10 cm l'étaient le moins. L'affectation des arbres se produisait lors de la plantation.

Zusammenfassung. Schätzungsweise 600 Ulmen entlang der National Mall in Washington, D.C. wurden sechs Jahre auf die Symptome von bakterieller Blattdürre, verursacht durch Xylella fastidiosa, untersucht. Das durchschnittliche Auftreten der Krankheit im Verlauf der Untersuchung lag bei 30% und verstärkte sich um 10% über in den sechs Jahren. 28% der betroffenen Bäume zeigten die Symptome in über 25% ihrer Kronen. Die Gravität der Symptome änderte sich von Jahr zu Jahr. Von den ersten Bäumen, die 1986 Symptome zeigten, hatten nur 18% nach sechs Jahren höheren Befall, während 51% wenig oder keine Symptome aufwiesen. Bäume mit 20 - 30 cm Stammdurchmesser in Brusthöhe (Bhd) waren am stärksten bzw die in der Klasse von 1 - 10 cm Bhd am wenigsten befallen. Betroffene Bäume traten im gesamten Bestand auf.