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Sugarberry Dieback and Mortality in Southern Louisiana: Cause, Impact, and Prognosis

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Abstract

A sudden widespread decline of sugarberry trees (*Celtis laevigata*) was observed in southern Louisiana during the period between the early fall of 1988 and spring of 1990. Approximately 3 million acres or 5,000 square miles of forested lands were affected by the decline. In addition, sporadic reports of sugarberry decline also were reported at numerous locations in Mississippi. Investigations into the long list of potential causal agents led to the conclusion that the most probable causes of the damage were due to an opportunistic exotic insect pest, *Tetragonocephala flava*, a psyllid that caused defoliation and twig dieback, followed by a hard freeze which killed new regrowth following the insect damage. The psyllid has a very narrow host range attacking only *Celtis* species. Many sugarberry trees that survived the decline event now appear to be slowly recovering.

Keywords: *Celtis laevigata*, crown dieback, episodic event, exotic pest, psyllidae, sugarberry decline, *Tetragonocephala flava.*

Introduction

Sugarberry (*Celtis laevigata* Willd.), a common, medium size tree of the Southern United States, comprises 40 to 80 percent of the basal area in many bottomland hardwood stands, primarily on clay soils within the flood plains of major southern rivers and their tributaries. It is often planted as a shade and landscape tree in yards and along streets in residential areas (Kennedy 1990). The dry, sweet fruits are eaten by birds and wildlife in the late fall and winter months (Vines 1960). Sugarberry wood is used primarily in furniture manufacturing, but it is also used to produce dimension lumber, veneer, and containers (Kennedy 1990). The Mississippi Delta area of Arkansas, Louisiana, and Mississippi is the only region in the South that contains sufficient quantities of sawtimber-sized sugarberry to support commercial production (Smalley 1973).

Southern Louisiana landowners reported a sudden and widespread dieback and decline of sugarberry in the late 1980's and early 1990's (Goyer and others 1991, Solomon 199 1). The dieback event became very noticeable as trees began to die at an alarming rate. Although the cause of the dieback and mortality was not immediately apparent, landowners cited many possible causal agents ranging from adverse weather conditions and air pollutants to biotic pests. Numerous insect and disease pests of *Celtis* spp. have been reported (Riley 1890, U.S. Department of Agriculture 1985), but no records describe dieback episodes like those in southern Louisiana. This paper provides descriptions of communications, contacts, and consultations with many scientists, professors, extension-service specialists, forestry consultants, and landowners. In addition, we present and discuss results of research from data collections and observations made on study plots, including analyses of samples collected during trips to the affected area, as well as followup observations of the study plots between 1988 and 1996. We also discuss the most probable cause(s) of the decline based on the best information available from recent investigations. The objectives of this study were to investigate the cause(s) of sugarberry dieback and mortality, to assess the current status of symptoms, to evaluate the effects of the dieback, and to determine whether conditions were worsening, improving, or remaining static.

Methods and Materials

Scientists at the Southern Hardwoods Laboratory (SHL) made initial contacts in early 1989 with forestry consultants and landowners within areas affected by sugarberry decline. Samples of foliage, twigs, and branches collected from symptomatic trees by these cooperators were received for examination shortly after at the SHL. The scientists returned to the affected area to collect additional samples and study the problem in 1990. They interviewed a number of local residents to assess their observations. Some landowners had kept records of tree symptoms from the time they first observed the problem. Scientists from the SHL, Louisiana State University, and Forest Health Protection (U.S. Department of Agriculture, Forest Service, State and Private Forestry) met with landowners and forestry consultants to assess the problem. In an attempt to determine possible causes of the dieback problem, specialists were consulted and more local landowners were interviewed. Observations and records from these contacts are presented to provide some background and a chronology of the sugarberry dieback in southern Louisiana.

Research study plots were installed in July 199 1 within and outside of the area affected by sugarberry decline (fig. 1). Four variable radius study plots (BAF 5) were established randomly at each of four selected locations. Two sites in the affected area included a saw-log sized stand near Brusly and an open woodlot near Houma. Two additional sites were selected outside the affected area in a saw-log sized stand west of St. Francisville, and a similar saw-log sized stand southwest of Clinton. Data for the following variables were recorded for all trees over 3 inches in diameter at breast height (d.b.h.) in each plot: species, d.b.h., crown class, crown condition, injury by insects and disease, and whether the tree was alive or dead. Crown condition was measured by a visual assessment of the percentage of the total twigs, branches, and sprouts exhibiting dieback. The crown variables were rated using the following scale: 1 = 0 percent, 2 = 1 to 10 percent, 3 = 11 to 33 percent, 4 = 34 to 66 percent, 5 = 67 to 99 percent, and 6 = 100 percent, indicating the percentage of plant parts that were symptomatic.

Two increment cores were taken from opposite sides of 12 sugarberry trees at each of the 4 study sites. Annual growth increments from 1969 to 1991 were measured to $\pm$ 1 μm using a color scanner, desktop computer, and WinDENDRO™ v. 6.0 tree ring analysis software (Regent

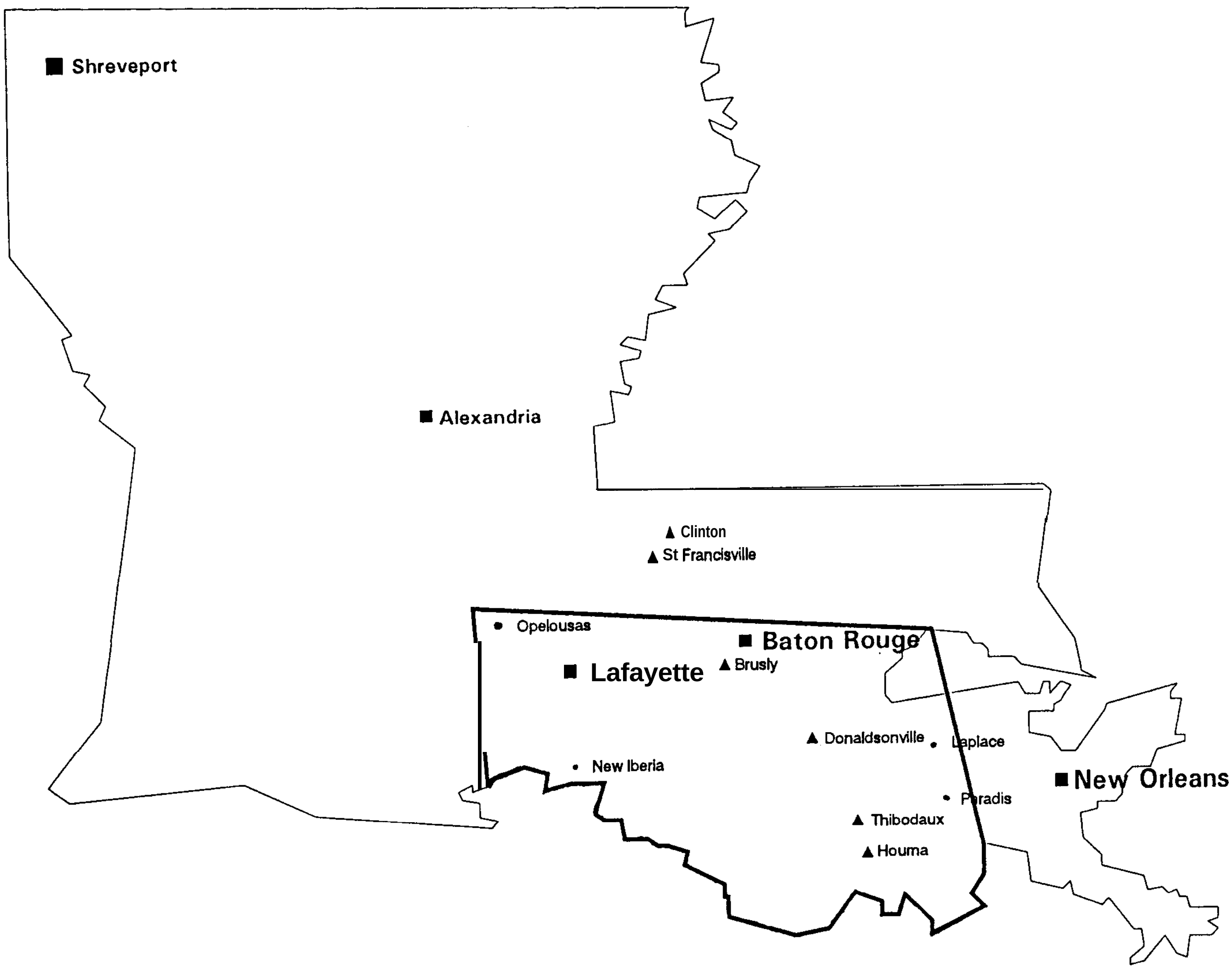

Figure l-Area in southern Louisiana affected by sugarberry decline during and after the 1988-89 dieback episode.

Ltd., Quebec, Canada). Ring widths for each year at each site were averaged and plotted against time. Trend lines were fit to the data from each site using simple linear regression.

A composite soil sample, composed of a mixture of five subsamples, was collected from the top 60 centimeters of soil at random locations within each plot to examine edaphic factors that may have contributed to the decline. Soil characteristics-including soil pH, cation exchange capacity (CEC), percent organic matter (percent OM), sodium concentration in parts per million, and extractable macronutrient and micronutrient levels in pounds per acre for phosphorus, potassium, calcium, magnesium, sulfur, and zinc-were measured by soil analyses. The soil texture at each plot site was classified as sandy, silty, or clayey. Any evidence or records of site disturbance, such as changes in drainage or flooding, were noted.

Sugarberry trees were examined for the presence of fungal pathogens by collecting six samples each from twigs, branches, and roots. Samples were transported in plastic bags on ice to the laboratory for isolation and identification of pathogens. Insects from sugarberry foliage were sampled with sweep nets (25 sweeps per plot) and preserved for identification in the laboratory.

Records of temperature and rainfall were examined for any radical departures from normal which might have adversely affected tree growth and physiology. Preliminary observations were made of any adverse effects from chemical pollutants.

A small-scale survey of yard and street trees within residential areas was conducted in 1992 to provide additional data on the extent of sugarberry crown dieback and mortality. Five communities were selected for study along a north-south axis in the affected area. The communities included St. Francisville, Brusly, Donaldsonville, Thibodaux, and Houma. The starting point within each community was randomly selected along a major road or street. Every third block having at least 3 sugarberry trees, including street and yard trees on both sides of the street, was sampled systematically until 10 blocks had been sampled. All sugarberry trees (including stumps) were scored as alive or dead, and the extent of crown dieback (twigs and branches combined) was rated using the scale described above. Followup observations in the affected area between 1993 and 1996 were made to identify any new defoliation and dieback as well as continuing tree recovery.

Results

History and Chronology

Sugarberry trees exhibited light defoliation in the spring and noticeable premature defoliation in the late summer and early fall of 1988.' Widespread defoliation occurred twice during the 1989 growing season, once in late spring and early summer and again in late summer and early fall.' Foliage and twig samples from affected trees near Thibodeaux were submitted to the SHL on June 9, 1989. The leaf samples exhibited many white, silky covers containing psyllid nymphs which were identified as *Tetragonocephala flava* Crawford (Stemorrhycha: Psyllidae). Isolations failed to yield any disease-causing agents.

Dieback of sugarberry trees became increasingly noticeable the following spring (1990). In early May 1990, SHL employees met in Baton Rouge with representatives from a forestry consulting firm, Forest Health Protection, Louisiana State University, and several private landowners to evaluate the problem. They examined many affected trees in the Baton Rouge area and visited a 2,000-acre natural stand of sawtimber near Brusly which contained a significant component of sugarberry. Most trees examined had noticeable crown (twigs and branches) dieback. The timber tract had been marked for a sugarberry salvage cut because the landowner feared that all the sugarberry trees were going to die. On one side of the tract, loggers were cutting every sugarberry tree that was large enough to produce either saw logs or pulpwood. A number of other timber tracts in the area were being marked for salvage by landowners or forestry consultants who feared widespread sugarberry mortality.

Large numbers of sugarberry trees of all age classes were affected on the 2,000-acre Brusly tract. Twig and branch mortality exceeded 50 percent on trees that were felled and closely examined. Some small cankers were found by removing bark from the twigs, but beyond the cankered areas, the tissues were white and normal with no significant

[1] Personal communication. 1990. O.E. Monier, Jr., Vice President, Houma Fabricators, Inc., Houma, LA 70360; and Dale Pollet, Extension Entomologist, Louisiana State University, Baton Rouge, LA 70803.

[2] Personal communication. 1990. Dale Pollet, Extension Entomologist, Louisiana State University, Baton Rouge, LA 70803; and Sevem Doughtry, Extension Entomologist, LSU Agricultural Center, 107 Bronson Hall, 1 University Place, Louisiana State University, Shreveport, LA 71115.

browning, streaking, or staining. Disks cut from large branches, the bole, and at stump level were clear and white with no evidence of stain or decay. However, the fresh cut surfaces felt exceptionally dry. There was no visual evidence of root rot or fungal fruiting. Eleven insects were found feeding on foliage, twigs, and trunks, but none was implicated in causing the dieback. The psyllid, *T. flava*, prevalent in 1989, was not found in 1990.

Further investigations were conducted by examining trees from Baton Rouge southward through Donaldsonville, Napoleonville, and Thibodeaux to Houma. Sugarberry dieback was progressively more noticeable southward from Baton Rouge. High levels of dieback were present in a large percentage of sugarberry trees along streets, in yards and woodlots, and along roadsides and ditch banks. In May 1990, trees in the Baton Rouge-Brusly area seemed to have been affected very recently, because almost all the dead fine twigs and small branches were still intact. This indicated that the dieback probably occurred in late 1989 and early 1990. Further south in the Thibodeaux, Raceland, and Houma areas, the dieback also appeared to have occurred recently, but there the dead twigs on some trees had begun to fall off leaving small and large bare branches in the crowns. In these areas, twig dieback could have begun as early as 1988 or early 1989.

Symptomology

Sugarberry trees examined during 1988 and 1989 appeared chlorotic and exhibited premature defoliation. However, affected trees quickly refoliated. Yellowing leaves, premature leaf drop, and refoliation occurred at least once in 1988 and twice in 1989. When trees refoliated in 1989, new foliage appeared on the bases of twigs and branches, leaving many twigs and branch ends bare (fig. 2A). The bare branch ends eventually broke off to form larger bare branch terminals (fig. 2B), a process that was especially noticeable after the second defoliation in 1989. After that defoliation, stressed trees grew many epicormic sprouts and suckers along their large branches and trunks (fig. 2C), which were observed on sugarberry trees in the woods (fig. 2D) and on individual trees in residential yards (fig. 2E). The severe chlorosis and premature defoliation symptoms did not appear in 1990, although for years following the damage in 1989 most sugarberry trees in the affected area exhibited severe twig and branch dieback in the upper crown, epicormic branches, and suckers along the larger branches and trunk. Leaves on surviving basal portions of twigs and branches were smaller than normal, slightly chlorotic, and often exhibited necrotic margins. Leaves on new sprouts were generally green and nearly normal in size. Much of the sprouting was clustered along large branches and trunks, giving trees the striking water-sprout appearance typical of trees that have lost apical dominance due to top dieback (fig. 2F). Symptoms were so noticeable in 1989 and 1990 that many landowners feared widespread mortality was imminent.

Impact

Range and delineation-The range of area affected by sugarberry decline was delineated, in part, using information from the Louisiana Forestry Commission, Louisiana State University, forestry consultant firms, and landowners. To more exactly define the affected area, the Louisiana State University Staff conducted an aerial survey. However, that and other aerial surveys were inadequate to distinguish damaged sugar-berry from healthy sugarberry. To date, our best estimation of the area affected by sugarberry decline includes land within imaginary lines that extend from Baton Rouge southward to just beyond Houma, and west to Lafayette and Opelousas. Lighter symptoms of the decline extend to the vicinity of Jennings, and east to La Place and Paradis (just west of New Orleans). The total area included about 5,000 square miles, or 3 million acres, of southern Louisiana. Sporadic reports of sugarberry dieback also were noted in the Starkville and Jackson areas of Mississippi.

Tree crown dieback and mortality-The extent of sugarberry crown dieback and mortality in forests and woodlots near St. Francisville, Clinton, Brusly, and Houma in 1991 and 1992 is shown in table 1. In 1991, average crown ratings of 1.3 to 1.5 for sugarberry at the St. Francisville and Clinton sites (outside the affected area) indicated normal twigs, branches, sprouts, and foliage. Twig and branch ratings of 2.6 and 2.5 at Brusly indicated moderate sugarberry dieback, but new sprout growth and foliage were green, indicating little evidence of continuing dieback. At the southern most location near Houma, dieback ratings averaged 5.0 and 4.5, respectively, for twigs and branches, indicating that severe dieback had occurred. At Houma, ratings for sprout growth and foliage were slightly worse than those at other locations, but sprout growth and foliage were in fair-to-good condition, indicating an apparent recovery.

Ratings in 199 1 for the crown variables of species other than sugarberry, including Nuttall oak, water oak, willow oak, overcup oak, water hickory, green ash, American elm, sweetgum, cottonwood, black willow, honeylocust,

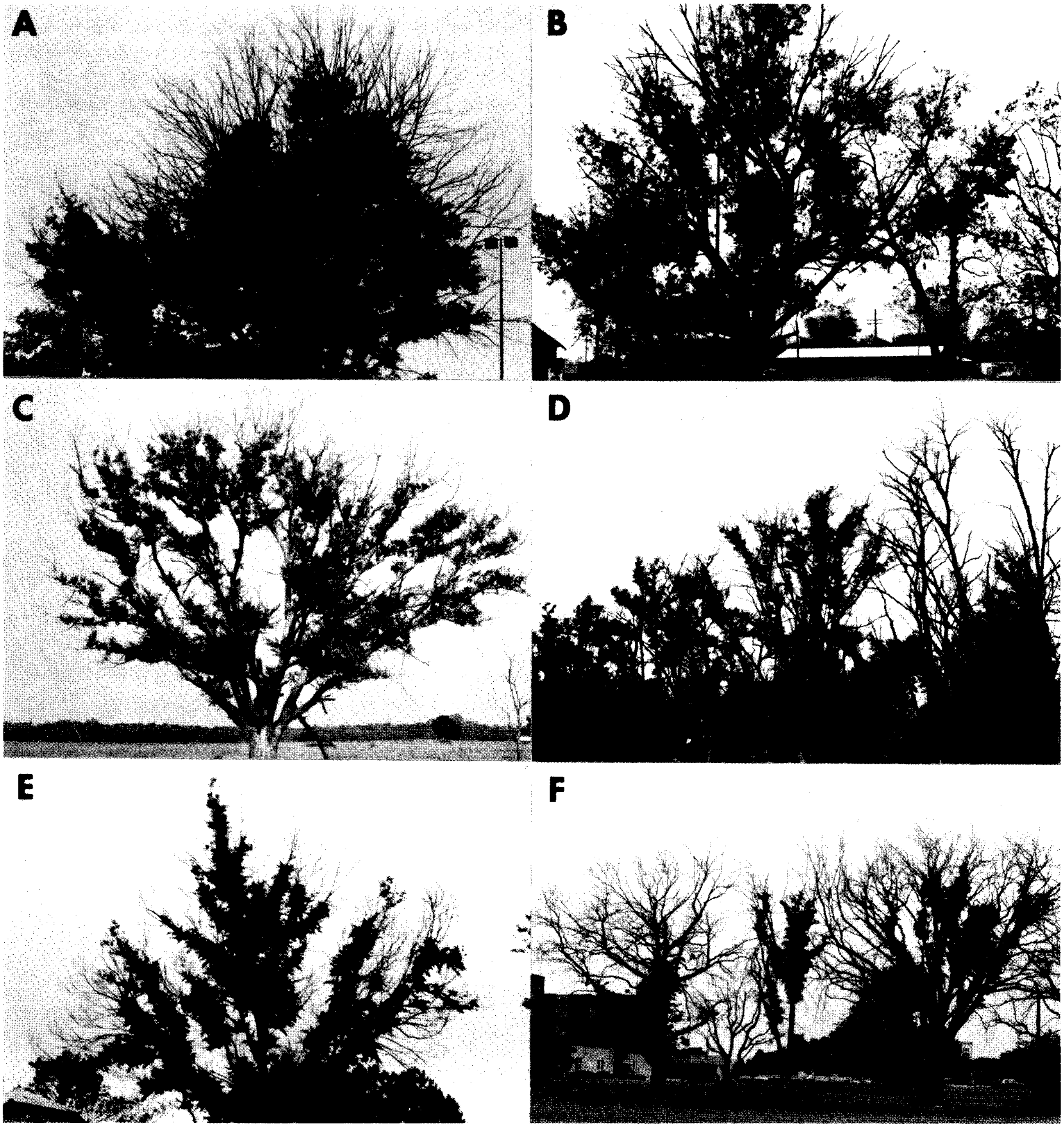

Figure 2—Symptoms of sugarberry dieback and decline observed in southern Louisiana. (A) Twig and branches with bare ends following defoliation, (B) breakage of branches following defoliation, (C) epicormic sprouts and suckers along the main branches and trunk of a tree in an open field, (D) dieback and epicormic branching of sugarberry trees in a woodland setting, (E) twig dieback and epicormic branching of a sugarberry tree in a residential yard, and (F) water sprouts arising along large branches and trunks of large trees.

sycamore, red maple, pecan, and boxelder were considered normal, i.e., those species exhibited no comparable dieback (table 1). Average ratings for crown variables at Houma were not noticeably different from those at other locations, indicating that the cause of serious dieback in sugarberry trees did not adversely affect other tree species.

Crown ratings taken in 1992 showed that there remained marked differences in the extent of sugarberry dieback between sites outside and inside the affected area (table 1). However, most dieback had occurred prior to 1991, and we observed little subsequent dieback. A comparison of crown ratings indicated very little change in dieback between 1991 and 1992 for sugarbeny or any other species. Although Hurricane Andrew blew through the study area in August 1992 causing considerable damage to some trees in the study, such damage could generally be distinguished from dieback.

Five (15 percent) of the sugarberry plot trees near Houma died in 199 1. Mortality increased to 22 percent in 1992 (table 1). Trees in plots at St. Francisville, Clinton, and Brusly showed some wind damage, but none of the standing sugarberry trees had died. Among the other species, two oaks had died, one each in the St. Francisville and Brusly plots.

Table l-Crown dieback ratings and mortality of sugarberry compared to other tree species within study plots in southern Louisiana from evaluations in 1991 and 1992

Location	Number of trees	Percent mortality	Dieback Rating[a] Twigs	Branches	Sprouts	Leaves
1991 Evaluations						
Sugarberry						
Houma	33	15.2	5.0 ± 0.1	4.5 ± 0.2	1.6 ± 0.1	1.8 ± 0.1
Brusly	30	0.0	2.6 ± 0.2	2.5 ± 0.2	1.2 ± 0.0	1.7 ± 0.1
Clinton	37	0.0	1.4 ± 0.1	1.5 ± 0.1	1.0 ± 0.0	1.1 ± 0.0
St. Francisville	43	0.0	1.3 ± 0.1	1.4 ± 0.1	1.0 ± 0.0	1.1 ± 0.1
Other Species						
Houma	13	0.0	1.6 ± 0.1	1.6 ± 0.2	1.0 ± 0.0	1.1 ± 0.1
Brusly	32	3.1	1.3 ± 0.1	1.3 ± 0.1	1.0 ± 0.0	1.1 ± 0.0
Clinton	23	4.4	1.4 ± 0.1	1.4 ± 0.1	1.0 ± 0.0	1.0 ± 0.0
St. Francisville	24	4.2	1.3 ± 0.1	1.4 ± 0.1	1.0 ± 0.0	1.0 ± 0.0
1992 Evaluations						
Sugarberry						
Houma	32	21.9	4.6 ± 0.2	4.2 ± 0.2	1.3 ± 0.1	1.3 ± 0.1
Brusly	30	3.3	2.8 ± 0.2	2.5 ± 0.2	1.4 ± 0.1	1.6 ± 0.1
Clinton	37	2.7	1.4 ± 0.1	1.7 ± 0.1	1.0 ± 0.0	1.2 ± 0.1
St. Francisville	43	2.3	1.2 ± 0.1	1.4 ± 0.1	1.0 ± 0.0	1.2 ± 0.1
Other Species						
Houma	12	0.0	1.5 ± 0.1	1.8 ± 0.3	1.0 ± 0.0	1.3 ± 0.1
Brusly	31	0.0	1.6 ± 0.1	1.7 ± 0.1	1.1 ± 0.0	1.2 ± 0.1
Clinton	23	0.0	1.5 ± 0.2	1.8 ± 0.2	1.0 ± 0.0	1.3 ± 0.1
St. Francisville	24	0.0	1.3 ± 0.1	1.5 ± 0.1	1.0 ± 0.0	1.0 ± 0.0

[a] Dieback rating scale: 1 = 0 percent, 2 = 1 to 10 percent, 3 = 11 to 33 percent, 4 = 34 to 66 percent, 5 = 67 to 99 percent, 6 = 100 percent, where percentages indicate percent dieback (mean ± SEM) of twigs, branches, sprouts, and leaves.

Effects on sugarberry reproduction-During 1991 and 1992, sugarberry seedlings and saplings in study plots were counted. Reproduction was evident in most plots. Combined seedling and sapling counts per plot ranged from 0 to 5 in the St. Francisville and Clinton plots, 11 to 19 in the Brusly plots, and 0 to 10 in the Houma plots. Dieback on reproduction varied from light to moderate at the Brusly and Houma sites.

Analysis of sugarberry growth trends-Simple linear regression models, with year as the independent variable and ring width as the dependent variable, indicated that year was not a good predictor of ring width. The data were not distributed normally, precluding comparisons of slopes between sites using these models. However, trend lines based on simple linear regressions do suggest differences in the amount and rate of growth among the sites (fig. 3). Sugarberry trees at Houma had average annual ring widths that were about double those at Brusly, St. Francisville, and Clinton. Average growth rates of trees at all four sites were declining, but the average growth rate of trees at the Houma site was declining more rapidly than at the other three sites. The rate-of-growth decline of trees at Brusly was only slightly greater than those at the St. Francisville and Clinton sites. Differences in average ring widths and average growth rates among sites likely were due to differences in stand density, stand age, soil type, and historical site-use factors which were not documented.

The average annual increment for sugarberry trees at the Houma site in 1990 was about one-third less than the combined average annual increments for the previous 4 years (fig. 3A). In 199 1, average annual growth at Houma was about 60 percent less than the combined average growth between 1986 and 1989, indicating that sugar-berry growth at the Houma site decreased sharply immediately following the 1988-89 severe dieback. The lack of a growth decrease in 1989 suggests that the sugarberry trees had already completed most of their annual growth prior to the first defoliation in late spring or early summer. The defoliation and refoliation events that occurred in 1988 and 1989 would have severely reduced or eliminated starch reserves in the roots. Reductions in sugarberry annual growth in 1990 and 1991 likely were due to the physiological stress caused by the three earlier defoliations, reductions in starch reserves caused by refoliation, and the concomitant reductions in carbon replenishment resulting from smaller leaves and reduced crowns. At the Brusly, St. Francisville, and Clinton sites, sugarberry ring widths for 1990 and 199 1 were not far removed from the trend lines for these sites, a condition that indicates normal growth (fig. 3B-D). The amount of sugarberry dieback at Brusly, within the affected area, apparently was not severe enough to reduce radial growth.

Dieback and mortality of street and yard trees— Observations of noticeable sugarberry dieback and mortality within residential areas prompted a survey of trees along streets and in yards. The survey was conducted in 1992 in St. Francisville, Brusly, Donaldsonville, Thibodeaux, and Houma. The results of that survey are given in table 2.

Table 2Survey of crown dieback and mortality of sugarberry trees in residential areas of southern Louisiana in 1992

Location	City blocks surveyed	No. trees examined	Tree size distribution (%)[a]			Percent mortality	Crown[b] rating
			Sapling	Pole	Saw log		
Inside decline area							
Brusly	10	116	6.0 (0.9)	37.9 (28.5)	56.1 (33.6)	12.9	4.7 ± 1.1
Donaldsonville	10	91	5.5 (3.3)	35.2 (35.2)	59.3 (44.0)	16.5	4.0 ± 0.1
Houma	10	104	0.0 (0.0)	25.0 (18.3)	75.0 (63.5)	18.3	4.9 ± 0.1
Thibodeaux	10	117	6.8 (6.0)	20.5 (17.1)	72.7 (55.6)	19.7	4.2 ± 0.1
Outside decline area							
St. Francisville	10	67	10.4 (3.0)	29.9 (9.0)	59.7 (9.0)	1.5	1.9 ± 0.1

[a] Percentage of survey trees in each size class (size-class distribution). Values in parentheses indicate the percentage of surveyed trees that had crown ratings of 3.0 or greater (exhibiting substantial symptoms of decline).

[b] Crown rating scale: 1 = 0 percent, 2 = 1 to 10 percent, 3 = 11 to 33 percent, 4 = 34 to 66 percent, 5 = 67 to 99 percent, 6 = 100 percent, where percentages indicate percent dieback (mean ± SEM) of twigs and branches (combined) on living trees.

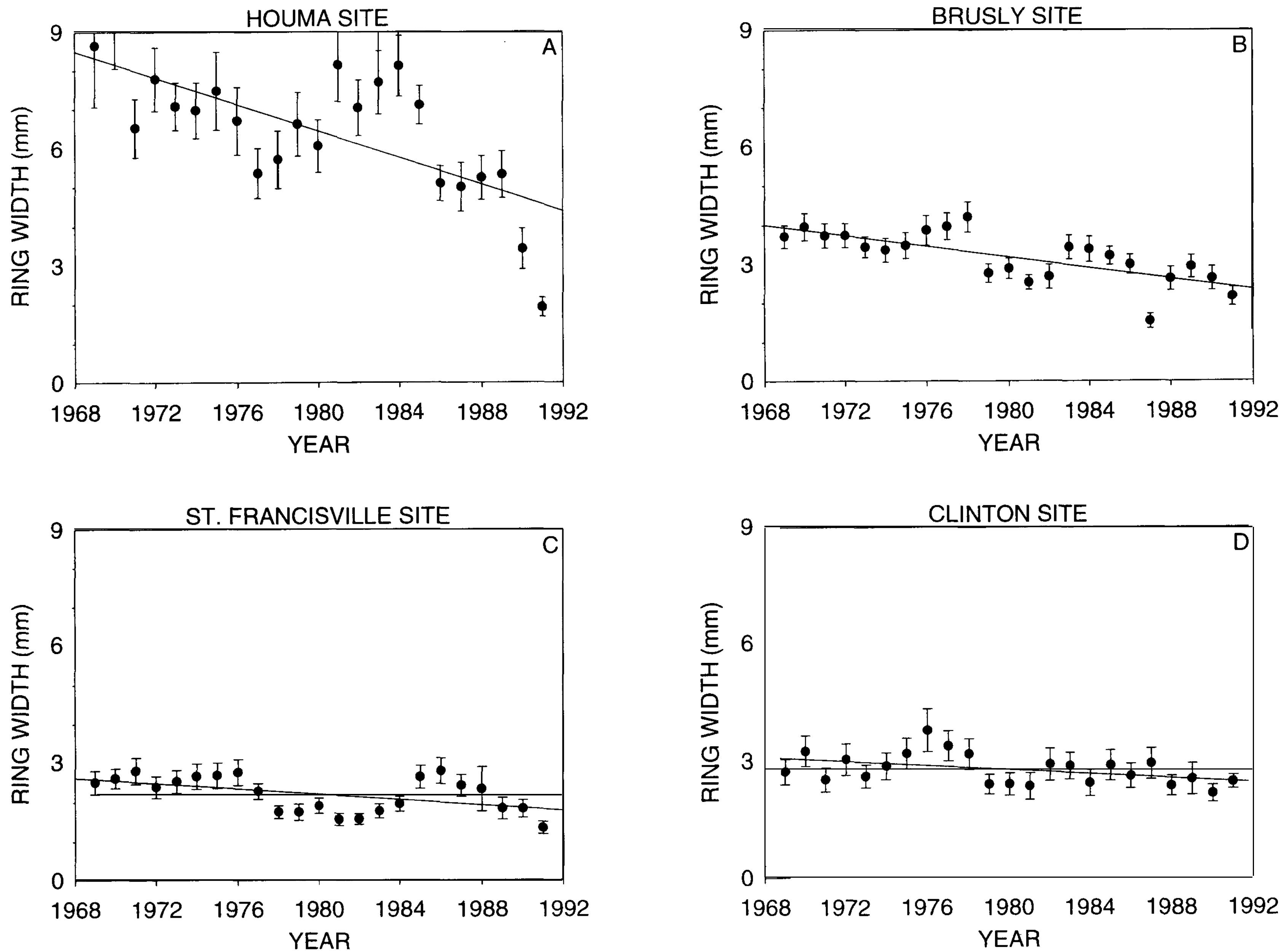

Figure 3—Annual growth (mean ± SEM) of sugarberry trees at four study areas in southern Louisiana. Study plots at Houma (A) and Brusly (B) were inside the area affected by sugarberry dieback, those at St. Francisville (C) and Clinton (D) were outside the affected area. Trend lines are based on simple linear regressions.

Every sugarberry examined in the affected area exhibited moderate to serious dieback, as indicated by crown ratings >4.0. Mean crown dieback ratings increased progressively from north to south and ranged from 4.0 in Donaldsonville to 4.9 in Houma where the dieback was most noticeable. Trees surveyed in St. Francisville and Clinton, outside the affected area, had an average crown rating of 1.9, indicating relatively healthy crowns.

Many dead sugarberry trees that had been cut were identified by the remaining stumps. Interviews with several homeowners revealed that the cut trees had exhibited severe twig and branch dieback. Therefore, dead tree counts include both standing trees and stumps. Generally, the incidence of sugarberry mortality increased southward from Brusly where 12.9 percent mortality was recorded, to Houma and Thibodeaux where mortality rates of 18.3 and 19.7 percent were recorded, respectively. Only 1 of 67 trees examined in St. Francisville and Clinton had died.

Trees surveyed within five towns inside and outside the affected area were predominantly saw-log sized trees (56 to 75 percent) with one-fourth to one-third pole size and < 7 percent saplings. A further analysis of the sizes of trees with symptoms of crown dieback and decline (crown rating ≥3.0) indicated that the percentage of symptomatic trees increased with age. For example, <10 percent of saplings at all locations within the affected area exhibited symptoms of dieback, while 17.1 to 35.2 percent of pole-sized trees, and 33.6 to 63.5 percent of saw-log sized trees were symptomatic. These results may suggest either that older trees are more frequently (possibly preferentially) affected by or were more susceptible to damage by the causal agent.

Factors Considered as Possible Causes of the Dieback

Residents, landowners, and foresters living in the affected area, as well as professionals who have examined dying trees, have proposed several factors as the cause of sugarberry dieback. Some of the potential causes, including winter damage, soil factors, herbicide drift, air pollution, and specific insect and disease pests are discussed here along with the evidence available to support each explanation.

Climatic factors-Some local residents and extension specialists suggested that the massive, rather sudden dieback and mortality of sugarberry in southern Louisiana was due to extremely cold weather in December 1989. According to official weather records, daily low temperatures (“F) in the affected area were as follows:

	12/21	12/22	12/23	12/24	12/25	12/26	12/27
Brusly	32”	16”	9”	9”	11”	17”	28”
Houma	37”	22”	10”	11”	15”	22”	32”

This early winter cold period apparently caused serious dieback and mortality in scattered Chinese tallowtree, an exotic species known to be susceptible to frost injury. However, except for sugarberry, severe dieback apparently did not affect other tree species in the area. Moreover, at Clinton (outside the affected area) temperatures dropped to lows of 31°,12°,5°,1°,17°,28°, and 30” on the same days listed above, yet sugarberry trees there were not adversely affected. At Mississippi State University, where sugarberry dieback and mortality were noted, temperatures for the same time period dropped to 21°,1°,-8°,-3°,3°, 27°,25°, respectively. Across the State at Stoneville, low temperatures were 20°,2°,1°,1°,3°,28°, and 29” for the same days, yet no dieback or mortality occurred. These findings suggest that low temperatures alone were not responsible for the dieback and mortality. However, the low temperatures coupled with other factors could have contributed to the seriousness of the problem.

Examination of southern Louisiana precipitation records revealed above average rainfall in 1988 (Baton Rouge totaled 76.04 inches, or 20.27 inches above normal) and 1989 (Baton Rouge totaled 88.32 inches, or 32.55 inches above normal). This was followed in 1990 by near average precipitation. Although the flooding history of these sites was not studied, precipitation conditions during that period likely would not have caused the sudden and severe dieback.

Soil Factors

Comparisons of physicochemical properties and extractable nutrient levels in soil samples from study plots inside and outside of the affected area indicated some differences in certain soil properties that may have influenced the health and susceptibility of sugarberry trees to damage by the causal factor (table 3). Among the physical properties, the pH of soils inside the affected area at Houma was significantly more acidic than on sites outside of the damage zone. The CEC of soil samples at St. Francisville and Clinton (outside the affected area) were appreciably lower than those of soils within the affected area. Soils inside and outside the affected area differed very little in percent OM. Nutrient levels of soils within the affected area were higher in potassium, calcium, magnesium, and sodium than at St. Francisville or Clinton, but the phosphorus level was higher

Table 3-Analyses of soil samples taken from study plots inside and outside of areas affected by sugarberry decline

Plot location	Physicochemical properties'			Nutrient composition[b]						
	pH	CEC	% OM	P	K	Ca	Mg	S	Zn	Na
Brusly	6.3i0.0	56.5i0.6	**1.78 ± 0.12**	**72.3 ±** 4.1	**640.8 ±** 1.0	**14,313 ±** 200	**4,100 ± 122**	**255.8 ± 17.5**	5.6 **± 0.4**	327.8 ± 15.2
Houma	**5.5 ± 0.3**	**52.1 ± 7.0**	**3.56 ± 0.69**	**69.8 ± 15.8**	**589.8 ± 23.0**	12,643 ±**1,810**	3,443 ± **403**	512.8 ± 98.6	11.9 ● 2.2	305.3 ± 37.8
Clinton	6.3i0.1	**42.1 ± 0.8**	**2.17 ± 0.10**	**109.0 ±** 5.8	**486.5 ± 10.5**	**10,103 ±** 5 3	3,062 ± 162	312.3 ± 13.7	13.3 **± 0.4**	222.3 ± 12.7
St. Francisville	7.5 **± 0.0**	26.9i1.6	**1.54 ± 0.02**	149.3 ± 3.9	**280.5 ±** 13.5	7,344 ± 474	**1,957 ± 201**	**221.0 ±** 2.5	**10.4 ± 0.3**	**141.5 ±** 8.6

'Symbols: **pH** = -log $[H^+]$, CEC = cation exchange capacity, % OM = percent organic matter content.
[b] Extractable nutrient levels for phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), and zinc (Zn) are in pounds per acre; sodium (Na) is in parts per million.

outside the affected area than inside. Differences in the physicochemical properties and nutrient composition of soils inside and outside of the affected area could have contributed to the response of trees to dieback, but the magnitude of differences in these edaphic factors was not so large as to indicate a physiological cause for the dieback, e.g., nutrient deficiencies, nutrient toxicities, or pH-induced mobilization of toxic heavy metals.

Herbicide drift-Until about 1990, herbicides, especially glyphosates like Palado, Polaris, and Roundup, were used extensively for weed control in southern Louisiana sugarcane fields. Several residents and landowners in the affected area suggested that the extensive use of these herbicides and application drift were responsible for the sugarberry dieback. However, twig and branch samples collected from declining sugarberry trees in 1989 were analyzed chemically at a reputable State chemical laboratory and did not contain glyphosate. Moreover, sugarberry stands with dieback symptoms were observed at a number of locations in southern Louisiana that were many miles from any treated sugarcane fields. Trees exhibiting the same dieback also were observed at Starkville and Jackson, MS, where there had been no heavy use of herbicides. Furthermore, no sugarberry dieback was reported or observed in areas like the Mississippi Delta, where the species is common and glyphosate herbicides are used extensively. The evidence clearly does not support the hypothesis that herbicides were the primary cause of sugarberry dieback.

Air pollution-Some landowners believe that toxic pollutants released into the air by large chemical plants in the affected area caused the problem. Indeed, there are hazardous waste incinerators as well as a large chemical manufacturing industry in southern Louisiana. One concerned landowner who kept notes of various biological events beginning in the mid- 1980's strongly suggested that airborne chemical pollutants were responsible. His notes describe at least a dozen deciduous and coniferous trees that exhibited symptoms ranging from top dieback, thin crowns, decay, poor nut crops, abnormal sprout growth, and a blighted appearance to dieback and repeated leaf-out during the growing season. Furthermore, he plotted on a map a triangular area extending from Baton Rouge southeastward to the vicinity of Larose, Houma, and Theriot, where the symptoms were most severe.

A literature search failed to reveal any previous episodes of pollutant-related dieback on sugarberry or other *Celtis* species. Several references stated that *Celtis* spp. were tolerant and/or resistant to several pollutants produced by nitrogenous fertilizer plants, airborne fluoride, and chlorine from winter road salting (Klincsek 1986, Kovacs and Klincsek 1982, Rhoads and Brennan 1975). Hepting (197 1) reported that sugarberry was among the species most resistant to air pollution in the Houston, TX, area. Additionally, C. *occidentalis,* a closely related species, has been reported as quite tolerant to urban pollution in general (Kovacs and Klincsek 1982). Although our studies revealed some decline symptoms among other tree species, none exhibited the sudden and widespread dieback found in sugarberry. If airborne pollutants had caused the dieback, other species would have been affected as well. Moreover, sugarberry dieback was common in areas quite distant from large chemical plants. Although chemical pollutants could have stressed sugarberry trees, it appears that factors other than pollutants probably contributed more to the problem.

Diseases-Sixteen genera of fungi as well as bacteria were isolated from branch and root samples of sugarberry trees on plots both inside and outside the affected area (table 4). *Fusarium* species were isolated most often from sugarberry tissue, but Fusaria were readily found inside and outside the

Table 4-Microorganisms isolated July 1991 from declining sugarberry trees in study plots of southern Louisiana

	Number of plots from which microbes were isolated[a]							
	St. Francisville		Clinton		Bruslv		Houma	
Microorganism	Branch	Root	Branch	Root	Branch	Root	Branch	Root
Hyphomycetes								
Aspergillus sp.	2	0	2	1	0	1	0	0
Fusarium sp.	4	3	4	4	4	4	4	4
Penicillium sp.	2	0	1	0	2	2	1	1
Oidiodendron sp.	0	0	1	0	0	0	0	0
Nigrosporium sp.	1	1	0	1	0	0	0	0
Alternaria sp.	0	0	0	1	1	0	0	0
Fusicoccum sp.	0	0	0	0	1	0	0	0
Agonomycetes								
Rhizoctonia sp.	3	1	3	4	2	2	4	1
Oomycetes								
Pythium sp.	1	2	1	2	0	2	0	1
Zygomycetes								
Mucor sp.	0	1	0	3	2	3	0	3
Libertella sp.	0	0	0	0	0	0	1	0
Coelomycetes								
Phoma sp.	3	0	1	0	0	0	0	0
Phomopsis sp.	0	0	0	0	0	0	1	0
Pestalotia sp.	2	1	0	1	0	1	0	0
Dothiorella sp.	1	1	0	0	2	1	0	1
Basidiomycetes								
Auricularia sp.	0	0	0	0	0	0	1	0
Procaryotes								
Actinomycetes	0	0	0	0	0	0	0	1
Bacteria	3	4	1	3	4	4	4	4
Total	22	14	14	20	18	20	16	16

[a] Microbe incidence is indicated by the number of study plots at each location from which each microbe was isolated. Four study plots were established at each location.

affected areas. Species of *Mucor, Penicillium, Dothiorella,* and bacteria were somewhat more common within the dieback area, but also were present outside. A *Botryodiplodia* species was isolated from other sugarberry samples near Plaquemine. None of these microorganisms previously has been implicated in causing severe dieback and mortality of sugarberry (Hepting 197 1). Leaves collected from affected sugarberry trees in southern Louisiana in 1990 and 1992 were submitted to the University of California to be tested for the presence of mycoplasma-like organisms (MLO's) using a deoxyribonucleic acid (DNA) probe (hybridization blot). Leaves tested negative for MLO's. Symptoms of a ring spot virus were observed on isolated sugarberry foliage near Houma in 1992. In a greenhouse test, an unsuccessful attempt was made to mechanically transmit the ring spot virus from symptomatic to asymptomatic leaves of sugarberry saplings. It is likely that the virus was transmitted to the sugarberry by an insect vector. However, the mildness of the virus symptoms would not have likely resulted in sugarberry dieback.

A literature review revealed a number of leaf-spot fungi, powdery mildews, witches' brooms, and bole rots common to the species, but none has caused serious dieback and mortality (Hepting 1971). However, dead branches and branch stubs provide excellent entry sites for many species of wood-rotting fungi given the extensive crown dieback and slow wound-healing ability of sugarberry. Predictably, then, the incidence of wood decay fungi in timber stands and residential areas would be high for many years and could contribute to such a decline following the primary damage. Nevertheless, diseases do not appear to have caused the sugarberry dieback.

Insects-Twenty-six species of insects were collected from sugarberry trees in the affected area between 1990 and 1993, but most were in relatively small numbers. The insects most commonly collected were hackberry butterfly larvae, *Pachypsylla* leaf-gall insects, cecidiomyiid leaf-gall insects, tussock moth larvae, forest tent caterpillar larvae, and *Agrilus* beetles. None of these was present in numbers sufficient to have caused the degree of dieback that occurred. However, there appeared to be a strong relationship between a psyllid insect (*T. flava*), which was present in very large numbers in 1988 and 1989, and the onset of sugarberry dieback during the same time period. White tests (nymphal coverings or cases) appeared in mass on the forest floor (fig. 4A). As mentioned earlier, sugarberry leaf and twig samples submitted from a location near Thibodeaux in June 1989 contained many of these small, white insect tests. Each test was very white, round [4 to 6 millimeters (mm) in diameter], flat to dome-shaped, silky, flaky, very thin, and attached to the undersides of leaves (fig. 4B). Nearly every leaf had one to several of these white insect tests. Underneath each test was a psyllid nymph (fig. 4C) subsequently identified as *T. flava.* Adults were 3.75 to 4.25 mm long with expanded wings and resembled tiny cicadas (fig. 4D).

Personnel from the Louisiana Agricultural Extension Service and Louisiana State University at Baton Rouge confirmed that there had been a heavy infestation of *T. jlava* in southern Louisiana in 1988 and 1989. Local county agents received reports from residents that indicated the adult psyllids were so numerous that they clogged air conditioner filters. Sugarberry trees reportedly were defoliated by the psyllid infestation in the late summer and early fall of 1988. In May and June of 1989, and again in August and September, sugarberry trees were infested with T. *flava* and sustained two heavy defoliations. During these infestations, there was repeated leaf drop and refoliation accompanied by prolific sprouting on branches and trunks.

Sugarberry dieback was localized in areas of Mississippi during the same time period. Observations in Mississippi supported the findings in southern Louisiana and further implicated *T. flava* as the causal agent. Professors from Mississippi State University and scientists from the SHL observed a heavy infestation of *T. jlava* that caused a noticeable premature leaf drop on sugarberry trees on and around the Mississippi State University campus in the fall of 1989. The ground under many large sugarberry trees near the football stadium and the cooperative extension building was covered with freshly fallen leaves. The leaves contained so many white tests over the psyllid nymphs that the ground appeared to be covered with a light snow. The following spring and summer (1990), campus sugarberry trees were very slow to produce new leaves, and a high proportion of the twigs and branches were dead or dying. Affected trees produced profuse sprouts along large branches and trunks, much like those observed after the heavy psyllid-caused defoliation in southern Louisiana. Survey responses from county extension officers throughout Mississippi revealed that nymphal tests were observed in nine counties along a roughly southwest-to-northeast line extending from Wilkinson to Pontotoc and Lowndes Counties.[3] This linear

[3] Personal communication. 1997. Dr. James Jarratt, Extension Entomologist, Box 9775, Mississippi State University Starkville, MS 39762.

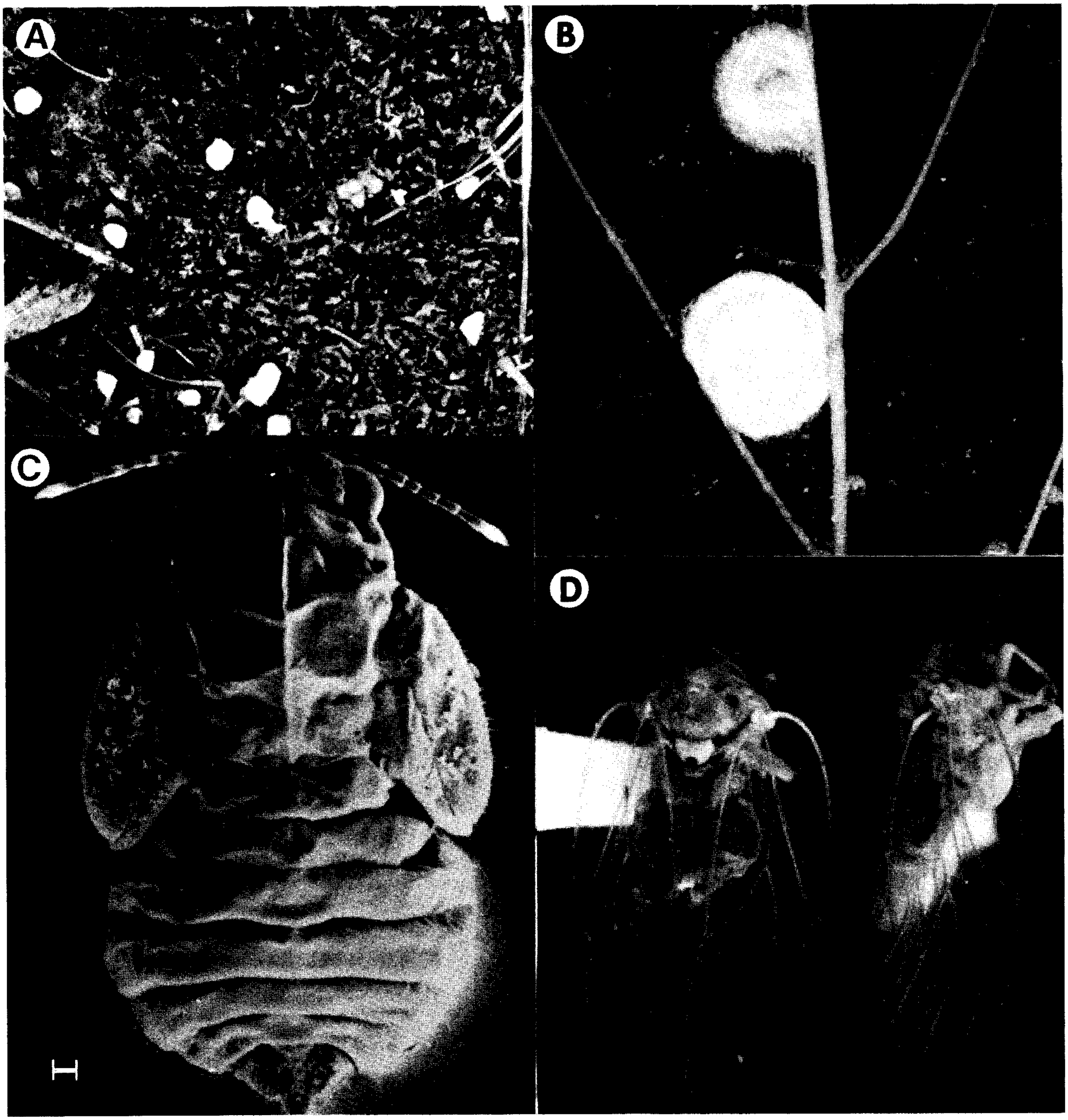

Figure 4—Observed life stages of psyllid *Tetragonocephala flava*. (A) White tests (coverings) resting on leaves in litter on the forest floor; (B) closeup of nymph tests (on the underside of sugarberry leaf); (C) scanning electron micrograph of nymph, scale bar = 0 μM, × 41 magnification; and (D) adults of psyllid.

cluster of sightings may indicate that the insect had been dispersed by wind from Louisiana. Nymphal cases also were observed in a 1 0th county (Harrison) in the southeastern comer of the State.

Discussion

The evidence in this report suggests that the psyllid *T. jlava* alone could have caused the sugarberry dieback. A highly unusual, exceptionally heavy infestation of a *Celtis*-specific exotic pest such as *T. jlava* immediately prior to this decline episode is at least highly suspect and probably the most plausible primary causal agent. However, other factors, especially the unusual cold period in 1989, may have contributed to the stress on sugarberry trees which led to the severe dieback. A likely scenario is that the repeated premature defoliation, refoliation, and new sprout growth caused by the psyllids depleted food reserves of sugarberry trees and severely weakened the trees by the end of the 1989 growing season. In late December 1989, freezing temperatures killed the new regrowth before it could harden off, further stressing the already weakened trees and resulting in the severe dieback episode.

There is very little known about *T. jlava.* As a group, the psyllids have been called jumping plant lice. They look very much like miniature cicadas and bear some resemblance to winged aphids. Nymphs of *T. flava* produce a white, silky covering over themselves rather than a leaf gall such as is produced by the common *Pachypsylla* spp. Adults of *T. flava* are greenish yellow to brown with seven small black spots on the thorax and a body length of 3.75 mm to 4.25 mm from the head to the tip of the folded hyaline wings (Crawford 19 14, Tuthill 1943). The insect apparently has two generations per year (Riemann 1958). There has been only one other record of *T. jlava* in Louisiana based on a 1979 observation in New Orleans.[4] To our knowledge, it was not recorded again in Louisiana until the 1988-89 outbreak. Moreover, *T. flava* had never been recorded in Mississippi until the 1989 infestation.[5] Apparently, *T. flava* is native neither to Louisiana nor Mississippi. Based on limited available literature, it appears to be native to southern Texas and Mexico. The insect has a very limited host range, feeding exclusively on *Celtis* species (Riemann 1958). It has been collected only on sugarberry and netleaf hackberry (C. *reticulata* Torr.) from Brownsville, Ottine, Austin, and Marathon, TX, and has been intercepted on produce coming into the United States from Mexico (Crawford 1914, Ferris 1926, Riemann 1958, Tuthill 1943, Van Duzee 1917). An important question is the mechanism by which the insect moved into Louisiana and Mississippi. Unusual climatic conditions may have allowed it to move northward into Texas, then along the coast for a brief period before being decimated by the extremely cold winter of 1989-90. However, it seems more likely that *T. flava was* either accidentally introduced on plants or produce from Mexico or southern Texas, or was brought in on air currents from these areas. Once introduced into a new habitat ‘with an abundance of susceptible sugarberry trees in southern Louisiana, and in the absence of natural enemies, the psyllid population exploded quickly and briefly before suddenly disappearing. Other psyllid species have caused similar problems on various hosts in other parts of the World. One example is the sudden appearance of the psyllid *(Heteropsylla cubana* Crawford) which caused widespread defoliation and mortality of Leucaena or jumbie-bean *[Leucaena leucocephala* (Lam.) de Wit], a multipurpose tree on the Pacific Islands and in Southeast Asia (McFadden 1989).

Millions of sugarberry trees in southern Louisiana sustained serious dieback during the 1988-89 decline episode, resulting in substantial tree mortality. However, now that the causal agent(s) are gone, many injured trees appear to be recovering. Beginning in 1990, branches and trunks have continued to produce sprouts without repeated defoliation and further dieback. Immediately following the 1988-89 damage, much of the new foliage was small and chlorotic, and some further dieback occurred. Since then, the new growth has been green, healthy, and is continuing to grow. Although some surviving trees that sustained serious dieback undoubtedly have died in the intervening years, most trees are expected to survive and regain vigor. Many trees were misshapened and developed poor growth forms. Perhaps most importantly over the long term is the potential entry of wood decay fungi at dead branch sites. Hepting (197 1) found sugarberry to be quite susceptible to a wide range of wood decay fungi. Therefore, both forest stands and residential trees are likely to be at risk to decay for many years, because many wood decay fungi gain entrance into the bole through dead branches.

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[4] Personal communication. 1991. Joan Chapin, Entomologist, Entomology Department, Louisiana State University, Baton Rouge, LA 70803.

[5] Personal communication. 1990. Richard Brown, Entomologist, Entomology Department, Mississippi State University, Starkville, MS 39762.

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A sudden widespread decline of **sugarberry** trees (***Celtis laevigata***) *was* observed in southern Louisiana during the period between the early fall of 1988 and spring of 1990. Approximately 3 million acres or 5,000 square miles of forested lands were affected by the decline. In addition, sporadic reports of sugarberry decline also were reported at numerous locations in Mississippi. Investigations into the long list of potential causal agents led to the conclusion that the most probable causes of the damage were due to an opportunistic exotic insect pest, ***Tetragonocephala flava*,** a psyllid that caused defoliation and twig **dieback,** followed by a hard freeze which killed new regrowth following the insect damage. The psyllid has a very narrow host range attacking only *Celtis* species. Many sugarberry trees that survived the decline event now appear to be slowly recovering.

Keywords: *Celtis laevigata*, crown **dieback,** episodic event, exotic pest, psyllidae, sugarberry decline, *Tetragonocephala flava*.