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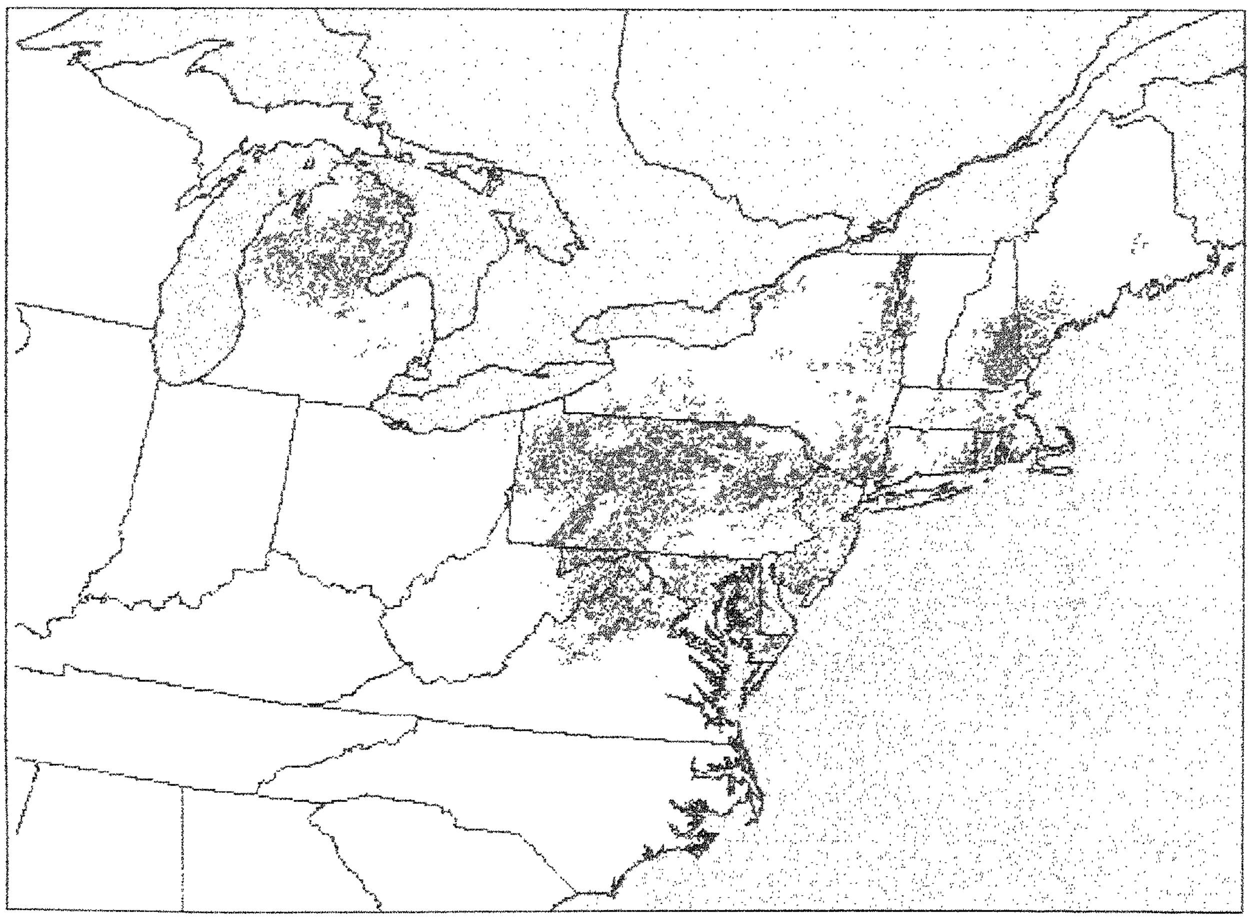
Gypsy Moth in the United States: An Atlas

Forest Health Technology Enterprise Team

Andrew M. Liebhold
Kurt W. Gottschalk
Eugene R. Luzader
Douglas A. Mason
Renate Bush
Daniel B. Twardus



Abstract

This atlas includes 52 maps that document the historical spread of gypsy moth from 1900 to the present, historical forest defoliation in the Northeast from 1984 to the present, and the distribution of susceptible forests in the conterminous United States. These maps should be useful for planning activities to limit the spread of gypsy moth and mitigate the effects of this forest insect pest in areas that have not yet been invaded.

The Authors

ANDREW M. LIEBHOLD is a research entomologist, KURT W. GOTTSCHALK is a research forester, EUGENE R. LUZADER is a computer specialist, and DOUGLAS A. MASON is a computer programmer with the Northeastern Forest Experiment Station's laboratory at Morgantown, West Virginia. RENATE BUSH is a biometrician with the USDA Forest Service's Forest Management Service Center at Fort Collins, Colorado. DANIEL B. TWARDUS is a forest health specialist with the Northeastern Area, State and Private Forestry, Morgantown, West Virginia.

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COVER: Map depicts frequency (number of years) of defoliation by the gypsy moth in the United States, 1984 to 1994 (See Figure 30).

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Introduction

The gypsy moth, *Lymantria dispar*, was accidentally introduced from France to a suburb of Boston, Massachusetts, in 1868 or 1869 (Liebhold et al. 1989). Since that time, its range has extended to include the entire Northeastern United States and portions of North Carolina, Virginia, West Virginia, Ohio, and Michigan (Liebhold et al. 1992). It is believed that the gypsy moth will continue to spread to the south and west over the next century.

In many forests where gypsy moth has become established, populations sporadically reach high densities and cause extensive defoliation of host trees. The diverse impacts of such outbreaks include tree mortality, loss of tree growth, and degradation of scenic quality. Gypsy moth caterpillars are a particular nuisance to homeowners (Campbell and Sloan 1977; Twery 1991). Because of the intensity and economic importance of these impacts, considerable effort is expended each year to suppress gypsy moth populations to nondefoliating densities.

Due to the sustained interest in the history and future of gypsy moth in the United States as the insect continues to spread and damage forests in North America, we have generated maps detailing the historical expansion and defoliation by gypsy moth, as well as maps depicting the distribution of the primary host-tree species, for identification of susceptible areas that have not yet been invaded. The maps in this atlas, as well as additional information about the gypsy moth in North America, are available on the Internet and can be obtained via the World Wide Web at http://www.fsl.wvnet.edu/gmoth.

Gypsy Moth Spread

The invasion of exotic organisms can be divided into three processes: arrival, establishment, and spread (Elton 1958; Dobson and May 1986). The gypsy moth arrived in North America in 1868 or 1869 when E. L. Trouvelot accidentally released the insect in various life stages on his property in Medford, Massachusetts (Liebhold et al. 1989). Establishment presumably took place over the next decade as the first outbreak in Massachusetts was reported during the 1880's (Forbush and Fernald 1896). By 1890, the insect was so abundant and outbreaks were so destructive that the Massachusetts legislature appropriated $25,000 for its control and eradication (McManus and McIntyre 1981). Eradication efforts continued until 1900 when the state legislature withdrew funding following a temporary lull in outbreaks. Dunlap (1980) speculated that had funding continued, the eradication effort would have succeeded. However, this conclusion seems questionable given that the gypsy moth population was fairly widespread by 1900; even with modern control methods that are far more advanced than those at the turn of the century, eradication of such extensive populations is difficult.

Beginning with the enactment of the Domestic Plant Quarantine act of 1912, the U.S. Department of Agriculture (USDA) has regulated the movement of plant material from areas determined to be infested with gypsy moth (Weber 1930). The methods used to designate a particular area as infested have varied, but such designations usually result from multiple finds of the insect in one or more life stages. Trapping of males in pheromone-baited traps is a powerful tool for detecting incipient gypsy moth populations. Traps have been used to define the infested area since the turn of the century (before the isolation, identification, and synthesis of disparlure, agencies often used extracts of live females to bait traps). Official USDA quarantine regulations were used in this atlas in determining the annual spatial distribution of gypsy moth in the United States. Since 1934, the quarantined area has been defined in the annual Code of Federal Regulations under Title 7, chapter 301.45-2a (administrative instructions designating regulated areas under the gypsy moth and brown-tail moth quarantine and regulation). A county was designated as infested if the regulations listed any portion of it as part of a generally infested, suppressive, or high- or low-risk area. In a few situations (mostly isolated infestations), a county was designated as infested one year but subsequently was not listed. For such cases we designated a county as infested only if it did not later become "uninfested." The quarantined area was defined in other publications prior to 1934 (Burgess 1915, 1930). Various other sources were used to determine the distribution of gypsy moth between 1900 and 1912 (Anonymous 1906, 1907; Burgess 1913).

The spatial resolution of the historical descriptions of the infested area varied through time and across regions. Often, the infested area was described on the basis of simple lists of infested counties. As a result, we considered U.S. counties as the smallest unit in describing the annual distribution of gypsy moth within the generally infested area. The GRASS (Army Corps of Eng. 1993) geographical information system (GIS) software was used to generate maps of the infested area. All maps were drawn using a Lambert equal-area projection (Snyder 1987).

Maps of the historical spread of gypsy moth from 1900 to 1994 are shown in Figures 1-18. For a detailed analysis of historical spread of gypsy moth in North America, see Liebhold et al. (1992).

Gypsy Moth Defoliation

Gypsy moth populations often exist for many years at low densities such that it is difficult to find any life stages. Then, for reasons that are not completely understood, populations can rise to high densities and cause substantial defoliation of the canopy.

Each state in the Northeast monitors gypsy moth defoliation annually using aerial sketch maps. Maps are sketched during a series of low-level reconnaissance flights in late July when defoliation is at its peak. Defoliation of 30 percent is considered the lower threshold for detection from the air. Where the cause of the defoliation is in doubt, ground checks are made for the presence of gypsy moth life stages. Initially, aerial sketch mapping is done using standard U.S. Geological Survey (1:24,000) topographical maps as the base. Composite mosaics then are generated for each state on maps of varying scales and projections. Mapping processes vary among state agencies and years, resulting in a strong likelihood of significant data errors from both systematic and nonsystematic sources. The likely presence of these errors dictated the coarse spatial resolution of maps (2 x 2-km rasters) presented in this atlas.

Another GIS software package, IDRISI, was used to assemble, collate, and analyze data on gypsy moth defoliation (Eastman 1989). A raster-based (grid cell) GIS used to capture, store, analyze, and display geographic data, IDRISI was designed for research applications. A base map of boundary coordinates of counties was used to define the study area. A 2 x 2-km grid cell size was selected as standard for all map layers in the GIS. As mentioned previously, this grid size represented the minimum dependable spatial resolution of defoliation data available from state agencies.

In the process of recording defoliation on sketch maps from aircraft (Talerico 1981), spatial error occurs with respect to the exact location, degree, and aerial extent of defoliation; this locational error generally is less than 1 km in magnitude. One advantage of a raster-based GIS is that the inherent uncertainty of data is maintained and displayed by the "sawtooth" effect of adjacent cells. However, such a coarse scale of resolution raises serious issues concerning accuracy and the cascading effect of errors as data layers are manipulated (Chrisman 1987). Without corroborating evidence at a fine scale of resolution, it is not possible to provide accurate estimates of the errors.

GIS analysis is possible by the use of multiple layers of geographical data (map layers), each coordinated with the others by geo-referenced points. To create a uniform set of geographically referenced defoliation data, the composite maps for 1969-89 were first transferred to mylar stable-base sheets. At least four geo-referenced points were located accurately on clearly recognizable intersections of county boundaries. The prepared maps were then scanned with a digital scanner set at a resolution of 150 dots per inch. Binary TIFF files from the scanner were converted to ASCII IDRISI raster format and saved as IDRISI images or map layers. Each map layer was transformed to a common base-map resolution and projection was by a "rubber-sheeting" procedure (Burrough 1988). In transforming maps of various scales and projections, IDRISI resamples each scanned defoliation image to match the location of the four geo-referenced points on the base map (Eastman 1989).

Maps of historical defoliation from 1984 to 1994 are shown in Figures 19-29. Historical maps of defoliation were not available for some states prior to 1984. It is obvious from these maps that outbreaks occur over large regions, often with considerable synchrony, and can persist for many years (Liebhold and Elkinton 1989; Hohn et al. 1993; Williams and Liebhold 1995). Figure 30 depicts the total frequency of defoliation from 1984 to 1994. Obviously, areas that gypsy moth has invaded only recently will have a lower frequency of defoliation, but beyond that pattern, areas with high defoliation frequencies represent forested areas where composition is highly susceptible to defoliation (Liebhold et al. 1994; Gansner et al. 1993).

Forest Susceptibility

The gypsy moth eventually will be present in most of the forested land in the United States, though outbreaks probably will be restricted to areas where forest composition favors population growth. As mentioned earlier, considerable effort is being expended to document the spatial extent of gypsy moth defoliation via aerial sketch mapping and other techniques. This information has been used to map the spatial distribution of forests susceptible to the insect within the generally infested region (Liebhold and Elkinton 1989; Liebhold et al. 1994). Planning for the management of gypsy moth over the next decade and beyond requires that the distribution of susceptible stands be delimited in areas that currently are uninfested.

The gypsy moth is polyphagous; North American populations feed on more than 300 different shrub and tree species (Liebhold et al. 1995). Despite this wide range of host preference, there is considerable variation within northeastern U.S. forests with respect to susceptibility to defoliation. In this atlas, "susceptibility" is defined as the probability or frequency of defoliation. For a description of alternative approaches, see Twery et al. (1990).

Several studies that have focused on relating various characteristics of forests to susceptibility to defoliation by gypsy moth have yielded susceptibility models of varying levels of complexity. Probably the most important factor affecting stand susceptibility is the proportion of basal area represented by species that are highly preferred by the insect (Herrick and Gansner 1986). Other variables, such as the predominance of chestnut oak, abundance of tree structural features (e.g., bark flaps), and various site characteristics (e.g., soils), also are known to be correlated with susceptibility (Bess et al. 1947; Valentine and Houston 1979; Herrick and Gansner 1986), but these correlations often are specific to certain regions or the variables are rarely measured in forest inventories.

Gansner et al. (1993) demonstrated how susceptibility models can be applied to forest inventory data to map susceptibility at the landscape level. We used a similar technique to map forest susceptibility over the conterminous United States. Assessment of forest susceptibility was based on existing forest-inventory data collected throughout the conterminous United States. In the East, all inventory data were obtained from the USDA Forest Service's Forest Inventory and Analysis (FIA) unit (Hansen et al. 1993), which inventories Federal as well as privately held land in this region. Such inventories usually are conducted every 5 to 15 years. Each state in the Northeast typically contains more than 1,000 irregularly spaced FIA plots. In the Western United States, FIA does not inventory National Forests. As a result, information on western forests constitute a mixture of FIA and National Forest inventory data.

Sampling methods used to inventory forest resources varied among regions and organizations (Table 1). All inventory data contained information on individual trees and plots. Individual-tree records were used to sum total basal area by each species for each plot. These plot records were then expanded (using appropriate expansion factors) to county-level estimates of basal area per acre.

Inventory data were available from most portions of the conterminous United States. (Fig. 31). However, state and private land in the western two-thirds of Oklahoma and Texas are not inventoried by FIA. FIA data were available from every state but National Forest inventory data were not available for some areas in the West.

For example, all National Forest data from California (Forest Service Region 5) did not include ranger districts or counties. Therefore, it was necessary to assign plots randomly within a given National Forest to counties (weighted by the proportion of the National Forest in each county). In portions of the Southwest (Region 3), counties were not included and similar assignments were made to those within a ranger district.

We adopted proportion of basal area represented by preferred species as the measure of forest susceptibility. While other variables (e.g., proportion of chestnut oak) may help explain more variation in susceptibility, these models are less likely to be applied successfully outside the range of data originally used to calibrate them. Montgomery's (1991) 3-way classification (preferred, resistant, immune) was used to determine the degree to which each tree species is susceptible to gypsy moth. This classification, based on a summary of field and laboratory studies and on extrapolations based on taxonomic affinity, is described in detail in Liebhold et al. (1995).

Table 2 lists the top 20 preferred species ranked by total basal area over the inventoried area. Of the top 10 species in the rank, only quaking aspen is found in the Western United States. Caution should be used in interpreting this ranking because the lack of inventory data in certain counties in the West (Fig. 31) resulted in a bias favoring eastern species. Nevertheless, these data indicate that most of the susceptible basal area (which is closely correlated to foliage area) is concentrated in the Eastern United States.

White oak was the highest ranking susceptible species (Table 2); the distribution of this species is shown in Figure 32. Although there are high concentrations of white oak throughout the East, the highest are in the Ozark Mountains, Cumberland Plateau, and southern Appalachians. Most of these areas are currently beyond the expanding range of the gypsy moth. Sweetgum, the second most common susceptible species (Table 2), is prevalent throughout the Piedmont from North Carolina to Louisiana; it is mostly distributed beyond the current range of gypsy moth (Fig. 33). Quaking aspen, which ranked as the third most common susceptible species (Table 2), is one of only several tree species whose range extends across the eastern and western portions of the continent. This species is most common in the northern portions of the Lake States (Fig. 34). Most of the areas with a high concentration of aspen are beyond the current range of the gypsy moth. Northern red oak, ranked fourth in total basal area (Table 2), is common throughout the Northeast and in portions of the Lake States (Fig. 35). Much of the range of this species encompasses areas already infested by gypsy moth. The ranges of the other most common preferred tree species are given in Figures 36-51.

Overall forest susceptibility was quantified using the total basal area per acre of all preferred species (Fig. 52). The areas with the highest concentration of susceptible forests were in the central and southern Appalachians, Cumberland Plateau, Ozark Mountains, and northwestern Lake States. Comparison of these maps with the known distribution of individual susceptible species (Figs. 32-51) indicates that oaks are the major component of susceptible forests in these areas, and that quaking aspen is the major susceptible species in the northwestern Lake States. Although sweetgum is the second most common susceptible species (Table 2), it is not sufficiently abundant to achieve high levels of stand susceptibility. In the Piedmont, it is rarely associated with enough other susceptible species for stands to be classified as highly susceptible (Fig. 52).

Table 3 summarizes total acreages of susceptible, highly susceptible, and extremely susceptible forests for each state in the conterminous United States. This classification of forest susceptibility was adopted from Herrick and Gansner's (1986) analysis of susceptibility in the Northeast. These data agree with the geographical trends depicted in Figure 32; susceptible forests are most abundant in the southern Appalachian, Cumberland Plateau, Ozark Mountain, and northwestern Lake States.

Several caveats are attached to the interpretation of these data. As mentioned earlier, inventories were not available for urban forests, and there were no inventory data for several forested areas in the West (Fig. 31). Also, it is important to note that assumptions concerning susceptibility are based on other hypotheses that have not been proven. For example, the suitability of many tree species to gypsy moth often is based on incomplete information. Feeding trials have not been conducted for many species, and for others, there are no data on susceptibility to defoliation in natural forests (Liebhold et al. 1995).

Despite all of the limitations cited, the maps in this atlas should be useful for future planning. The finding that gypsy moth has not yet invaded most of the susceptible forests in the United States suggests that there still may be considerable value in limiting the spread of this insect pest, and that both the impacts of defoliation and cost of managing gypsy moth management are likely to increase.

Table 1.—Description of inventory data used to develop maps of forest susceptibility

Source	Year	Number of forested plots	Number of live trees
Forest Inventory and Analysis Inventory Data			
Alabama	1990	3,915	123,474
Arizona	1985	2,117	69,197
Arkansas	1988	3,032	94,244
California	1982	4,888	59,863
Colorado	1981	1,202	25,553
Connecticut	1985	286	8,653
Delaware	1986	139	4,493
Florida	1987	4,922	74,100
Georgia	1989	6,524	115,338
Idaho	1990	827	12,750
Illinois	1985	1,131	33,497
Indiana	1986	2,119	57,285
Iowa	1990	678	19,184
Kansas	1980	1,143	16,611
Kentucky	1988	1,933	62,351
Louisiana	1991	2,410	75,420
Maine	1985	2,161	87,575
Maryland	1986	678	20,935
Massachusetts	1985	379	12,197
Michigan	1980	7,866	185,784
Minnesota	1990	12,155	343,864
Mississippi	1987	2,898	91,474
Missouri	1989	4,412	146,904
Montana	1989	1,383	35,673
Nebraska	1983	187	3,516
Nevada	1980	1,087	16,512
New Hampshire	1983	590	24,263
New Jersey	1987	252	7,687
New Mexico	1986	1,282	88,976
New York	1980	2,501	98,192
North Carolina	1990	5,366	115,249
North Dakota	1979	142	2,958
Ohio	1991	1,667	62,857
Oklahoma	1993	790	22,896
Oregon	1987	3,509	36,715
Pennsylvania	1989	3,062	116,202
Rhode Island	1985	116	3,204
South Carolina	1986	4,046	77,920
South Dakota	1976	70	1,505
Tennessee	1989	2,274	70,124
Texas	1992	2,085	62,773
Utah	1975	519	19,646
Vermont	1983	624	22,946
Virginia	1992	4,100	87,821
Washington	1990	4,065	70,382
West Virginia	1989	2,561	88,004
Wisconsin	1983	6,872	122,784
Wyoming	1983	495	5,988

Continued

Table 1.—Continued

Source	Year	Number of forested plots	Number of live trees
National Forest Inventory Data			
Angeles	1975	54	1,412
Apache-Sitgreaves	1983	37	21,354
Ashley	1992	96	2,830
Beaverhead	1975	605	26,745
Bitterroot	1980	544	20,480
Boise	1984	511	26,552
Caribou[a]	1993	1	12
Carson	1984	434	24,834
Challis	1988	11	366
Cibola	1986	184	10,751
Cleveland	1975	47	1,877
Coconino	1991	33	7,203
Colville	1973	362	17,729
Coronado	1995	130	2,103
Custer	1976	255	7,783
Deerlodge	1975	463	13,419
Deschutes	1985	617	33,378
Eldorado	1984	68	2,030
Fishlake	1993	139	4,015
Flathead	1974	487	14,500
Fremont	1981	378	26,936
Gallatin	1975	266	11,253
Gifford Pinchot	1981	355	33,013
Gila	1985	33	22,357
Inyo	1979	130	7,584
Kaibab	1989	93	22,958
Klamath	1989	73	804
Kootenai	1974	627	59,736
Lake Tahoe Basin Management Unit	1980	64	4,786
Lassen	1981	89	5,257
Lewis & Clark	1971	803	42,836
Lincoln	1990	73	13,357
Lolo	1974	486	15,660
Los Padres	1975	59	2,079
Malheur	1980	402	22,835
Manti-La Sal	1993	95	2,353
Mendocino	1981	80	3,674
Modoc	1980	100	4,670
Mt. Hood	1986	610	36,701
Nezperce	1973	292	11,093
Ochoco	1982	348	19,381
Okanongan	1977	353	25,763
Olympic	1974	478	34,757
Plumas	1980	154	9,300
Rogue River	1980	466	36,133
Salmon	1989	704	10,978
San Bernardino	1975	101	3,406
Sante Fe	1986	43	12,397

Continued

Table 1.—Continued

Source	Year	Number of forested plots	Number of live trees
Sawtooth[a]	1992	1	33
Sequoia	1980	101	5,630
Shasta-Trinity	1980	145	7,490
Sierra	1975	94	3,150
Siskiyou	1979	183	10,721
Siuslaw	1987	543	26,496
Six Rivers	1978	150	8,485
Stanislaus	1981	60	3,008
Tahoe	1980	110	6,453
Tonto	1981	32	8,669
Uinta	1992	86	1,990
Umatilla	1981	559	38,700
Umpqua	1980	330	26,661
Wallowa-Whitman	1979	502	32,429
Wasatch/Cache	1993	83	2,353
Wenatchee	1977	508	48,937
Willamette	1981	489	46,355
Winema	1981	446	32,554

[a] Only partial inventory data available.

Table 2.—Most common gypsy moth hosts (listed in descending abundance) in the conterminous United States

Common name	Scientific name	Total based area
		100 million ft/acre
White oak	*Quercus alba*	14.3
Sweetgum	*Liquidambar styraciflua*	11.6
Quaking aspen	*Populus tremuloides*	10.1
Northern red oak	*Quercus rubra*	9.62
Black oak	*Quercus velutina*	7.31
Chestnut oak	*Quercus prinus*	6.84
Post oak	*Quercus stellata*	5.47
Water oak	*Quercus nigra*	4.34
Paper birch	*Betula papyrifera*	3.81
Southern red oak	*Quercus falcata*	3.75
Scarlet oak	*Quercus coccinea*	3.31
American basswood	*Tilia americana*	2.41
Western larch	*Larix occidentalis*	2.40
Laurel oak	*Quercus laurifolia*	1.94
Bigtooth aspen	*Populus grandidentata*	1.90
Tanoak	*Lithocarpus densiflorus*	1.64
Willow oak	*Quercus phellos*	1.49
California red oak	*Quercus kelloggii*	1.45
Eastern hophornbeam	*Ostrya virginiana*	1.26
Canyon live oak	*Quercus chrysolepis*	1.14

Table 3.—Total land area (acres) covered by forests in three susceptibility classes by state

State	Area of susceptible forest[a]	Area of highly susceptible forest[b]	Area of extremely susceptible forest[c]	Total forested area	Total land area
Alabama	13,353,833	5,605,784	1,097,587	21,101,941	32,488,960
Arizona[d]	3,467,755	2,196,094	1,366,231	13,438,231	67,446,400
Arkansas	12,627,069	7,126,122	2,019,081	16,933,049	33,327,360
California[d]	6,670,580	3,725,334	1,717,432	19,441,535	96,202,240
Colorado[d]	2,534,751	1,959,807	1,466,463	7,636,892	21,229,440
Connecticut	1,124,263	513,747	135,500	1,833,314	3,117,440
Delaware	134,880	45,896	12,895	370,716	1,237,120
Florida	4,596,883	2,919,942	1,563,682	13,376,393	34,657,920
Georgia	10,591,225	5,140,375	1,518,469	21,416,044	37,157,120
Idaho[d]	1,631,323	647,697	384,079	15,260,411	34,523,520
Illinois	2,849,100	1,470,200	303,900	4,123,600	35,616,640
Indiana	2,151,100	894,400	232,000	4,485,600	22,994,560
Iowa	1,453,500	879,000	313,900	2,087,800	35,816,960
Kansas	502,982	280,460	111,640	1,509,188	52,340,480
Kentucky	7,006,346	3,186,509	725,824	11,320,276	25,388,800
Louisiana	7,735,140	3,327,734	890,932	13,197,070	28,494,720
Maine	2,877,540	988,354	265,452	10,039,385	19,836,160
Maryland	1,167,110	551,950	150,170	2,450,788	6,296,320
Massachusetts	1,491,776	880,466	378,693	3,109,185	5,008,000
Michigan	9,475,633	5,165,969	2,139,662	17,285,062	36,448,640
Minnesota	11,388,800	8,369,600	4,683,000	14,573,800	50,909,440
Mississippi	11,152,861	5,395,255	973,703	16,373,781	30,229,120
Missouri	11,698,100	9,070,500	4,240,400	13,332,400	62,241,280
Montana	2,839,512	1,293,647	617,711	23,285,474	93,047,040
Nebraska[d]	166,500	90,000	25,000	542,500	49,051,520
Nevada[d]	45,111	32,125	32,125	6,154,099	25,484,440
New Hampshire	1,948,416	502,259	58,947	4,868,632	5,754,880
New Jersey	956,877	633,474	269,544	1,741,830	4,778,880
New Mexico	1,488,489	583,945	302,138	14,483,241	77,653,760
New York	5,998,373	2,630,155	853,625	15,149,696	30,320,640
North Carolina	8,920,232	3,735,139	769,014	17,560,691	31,259,520
North Dakota	241,457	203,376	147,332	336,858	44,349,440
Ohio	3,154,099	1,177,289	247,551	7,336,031	26,243,840
Oklahoma	3,528,671	2,197,647	895,582	4,592,688	10,103,680
Oregon	1,962,239	797,186	404,347	19,957,263	61,559,040
Pennsylvania	8,463,412	4,233,856	1,187,996	15,938,953	28,730,880
Rhode Island	289,106	184,623	89,442	371,495	674,560
South Carolina	6,162,602	2,870,525	830,737	11,423,362	19,331,840
South Dakota[d]	25,199	16,629	4,310	112,064	44,206,080
Tennessee	8,691,667	4,334,683	886,443	12,849,100	26,338,560
Texas[d]	7,930,344	3,914,638	1,111,585	11,525,463	21,592,960
Utah	2,433,429	1,801,605	1,434,648	6,770,874	52,528,000
Vermont	1,020,196	322,851	51,399	4,427,467	5,935,360
Virginia	8,962,671	4,718,593	1,317,601	14,773,849	25,408,640
Washington	1,671,447	477,406	118,058	16,152,518	42,568,960
West Virginia	7,157,834	3,544,213	836,105	11,976,604	15,437,440
Wisconsin	10,137,100	6,934,300	3,436,900	14,480,700	34,832,000
Wyoming[d]	504,049	364,215	248,501	3,059,329	20,094,720
Total	222,381,582	117,935,574	42,867,336	484,567,243	1,570,295,320

[a] Areas where preferred species composed > 20% of stand basal area.
[b] Areas where preferred species composed > 50% of stand basal area.
[c] Areas where preferred species composed > 80% of stand basal area.
[d] Only partial inventory data available.

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Index to Figures

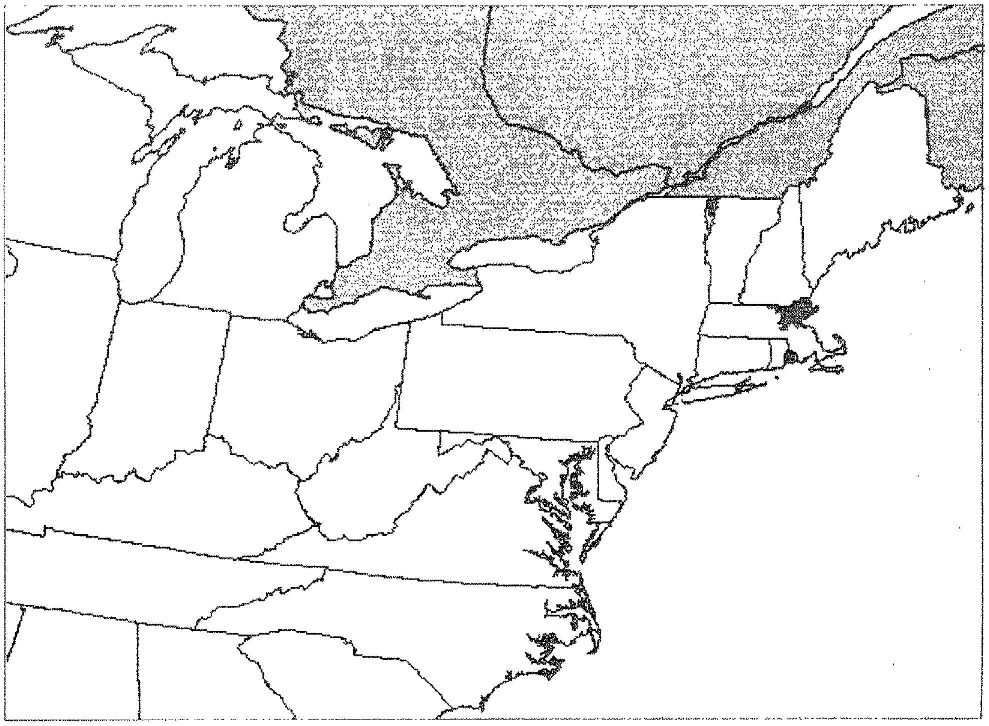

Figure 1.—Area generally infested by gypsy moth in 1900.

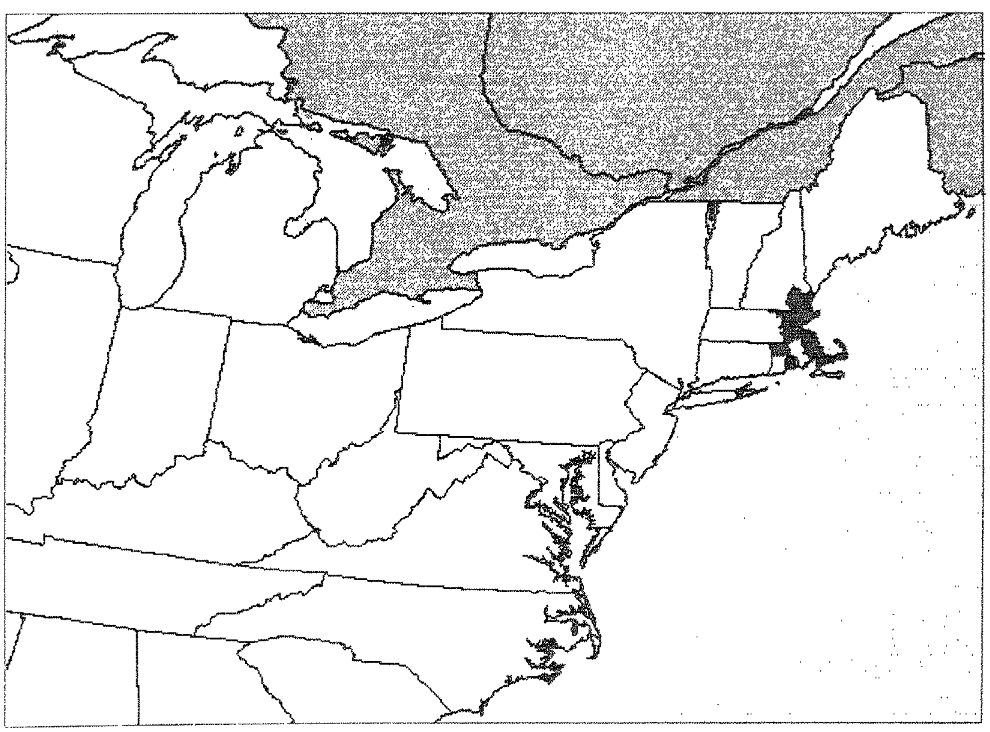

Figure 2.—Area generally infested by gypsy moth in 1905.

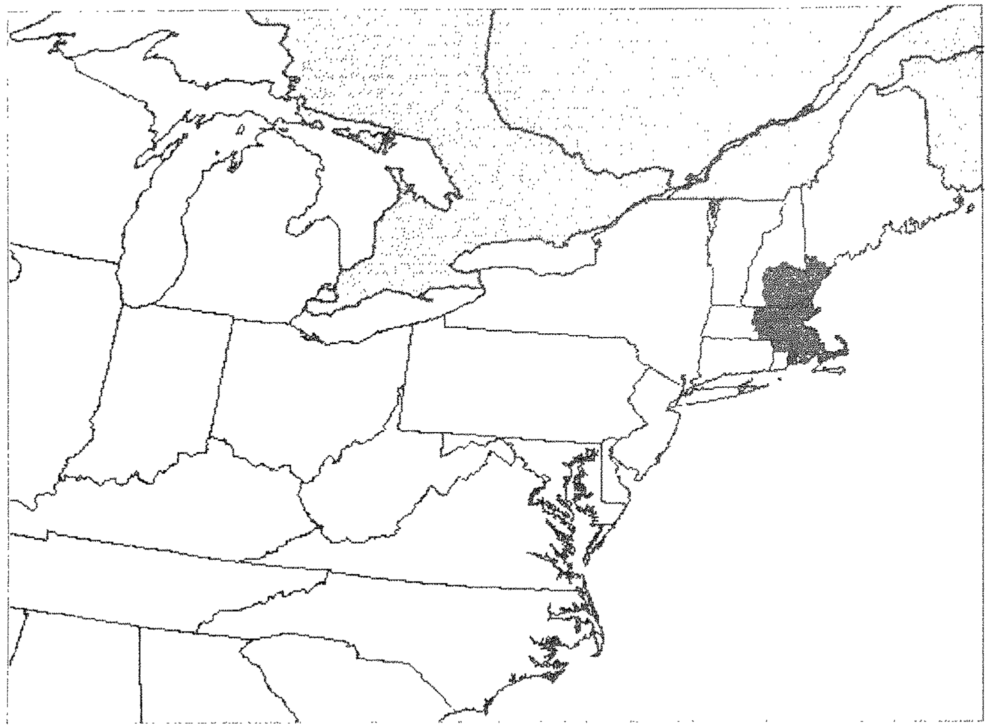

Figure 3.—Area generally infested by gypsy moth in 1909.

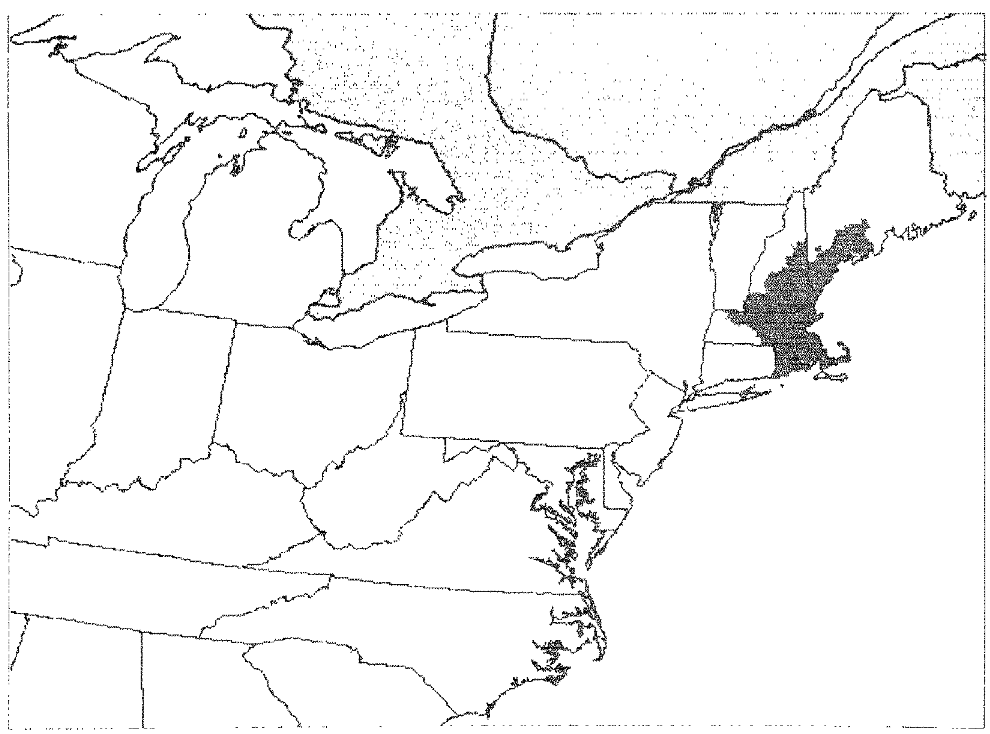

Figure 4.—Area generally infested by gypsy moth in 1912.

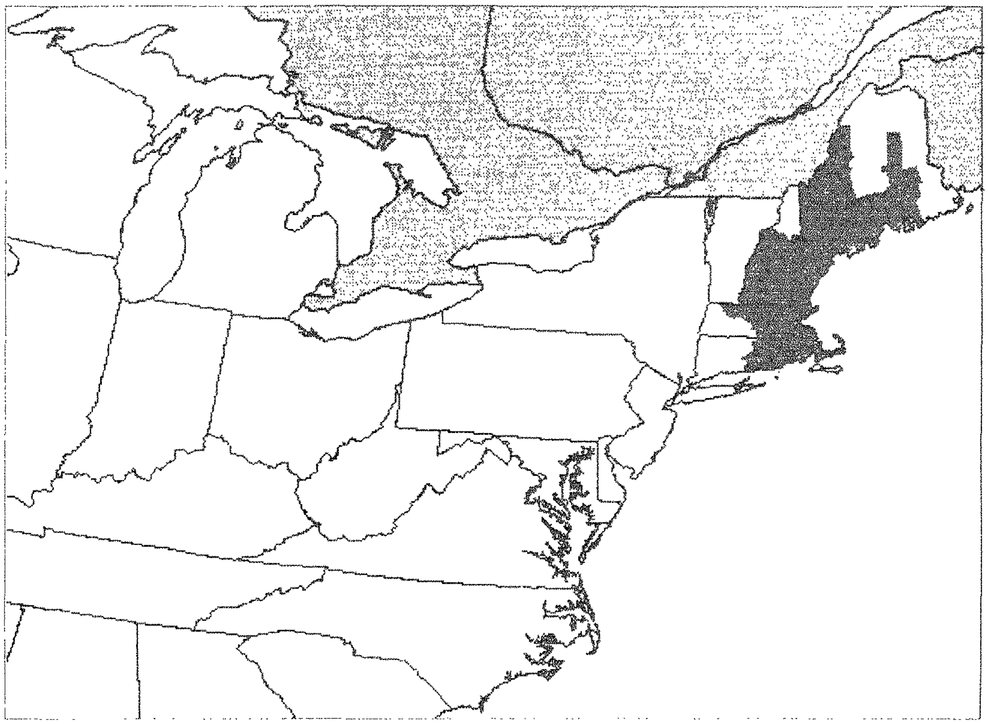

Figure 5.—Area generally infested by gypsy moth in 1914.

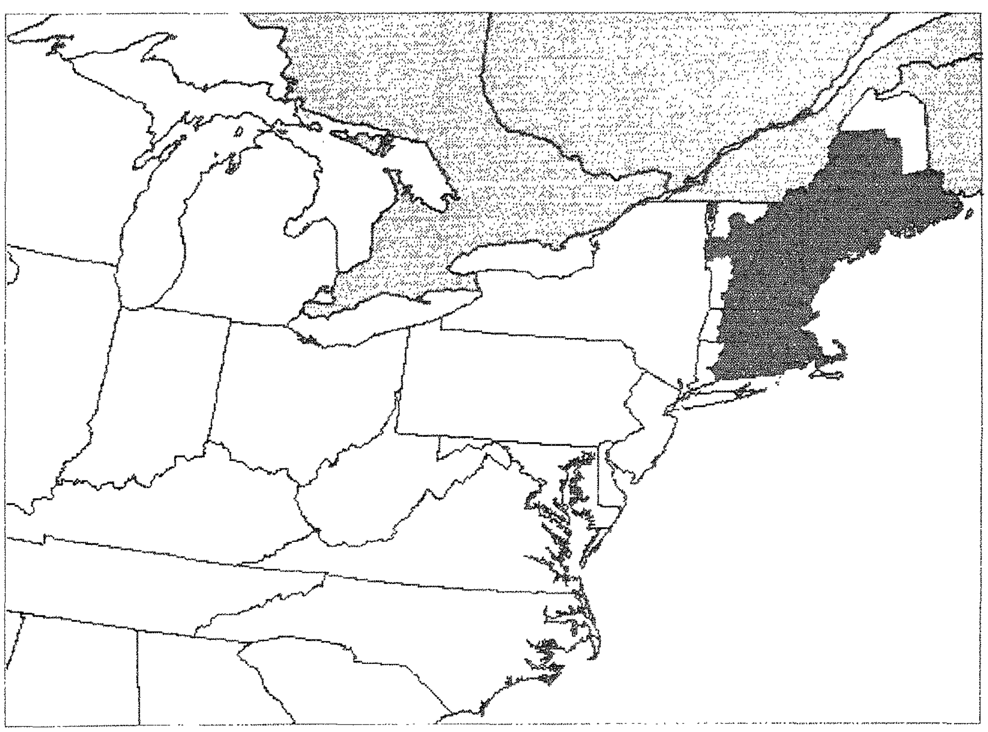

Figure 6.—Area generally infested by gypsy moth in 1934.

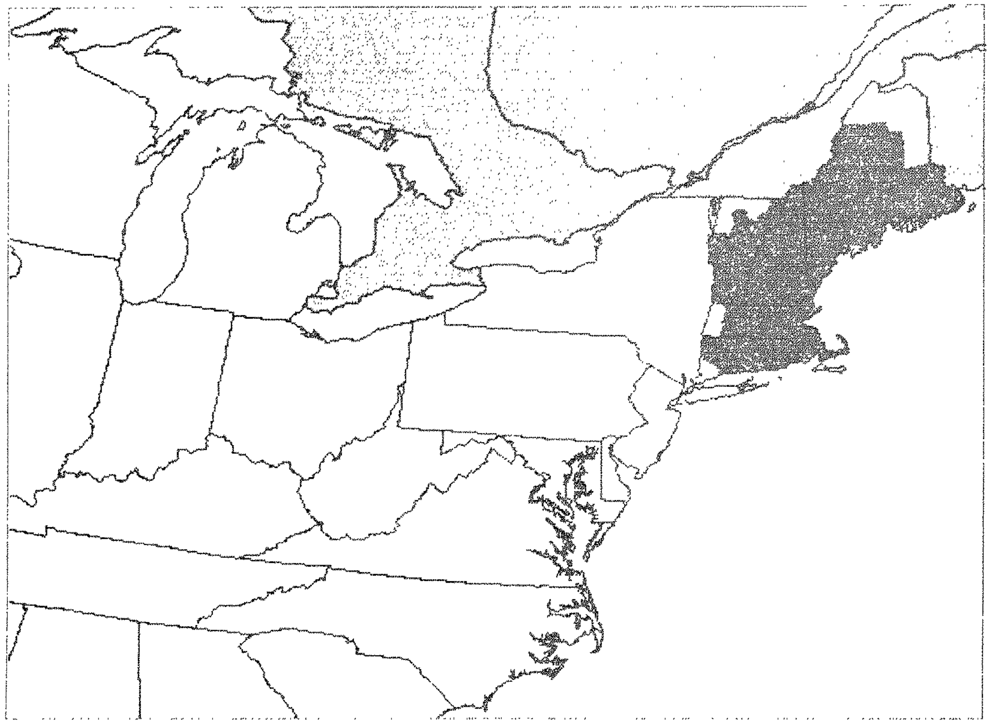

Figure 7.—Area generally infested by gypsy moth in 1938.

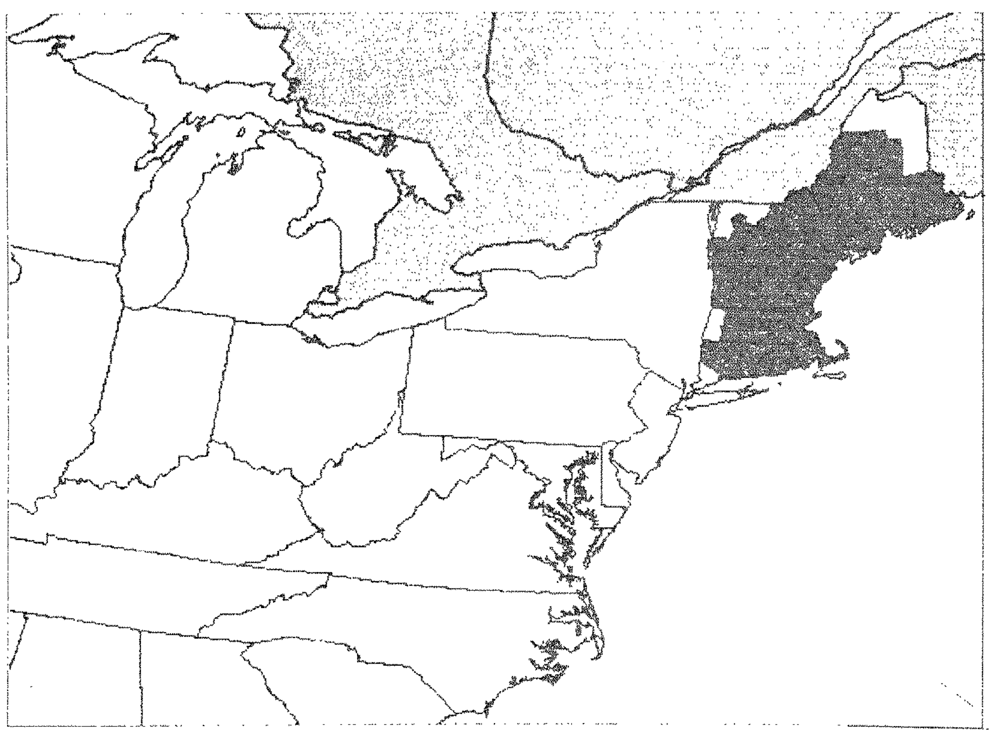

Figure 8.—Area generally infested by gypsy moth in 1943.

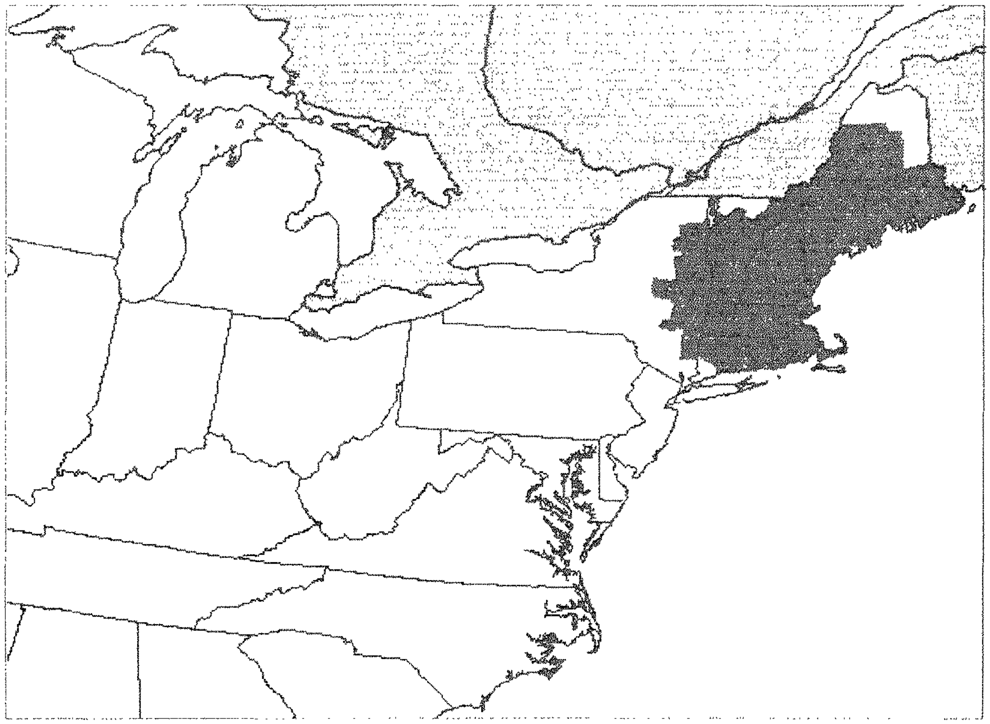

Figure 9.—Area generally infested by gypsy moth in 1949.

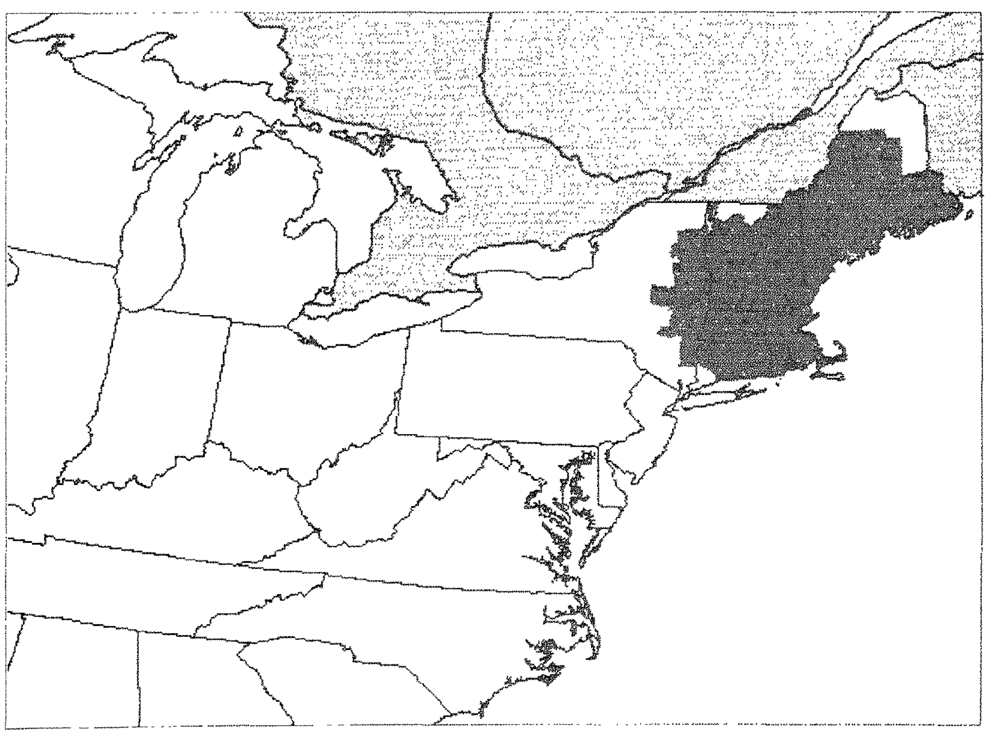

Figure 10.—Area generally infested by gypsy moth in 1955.

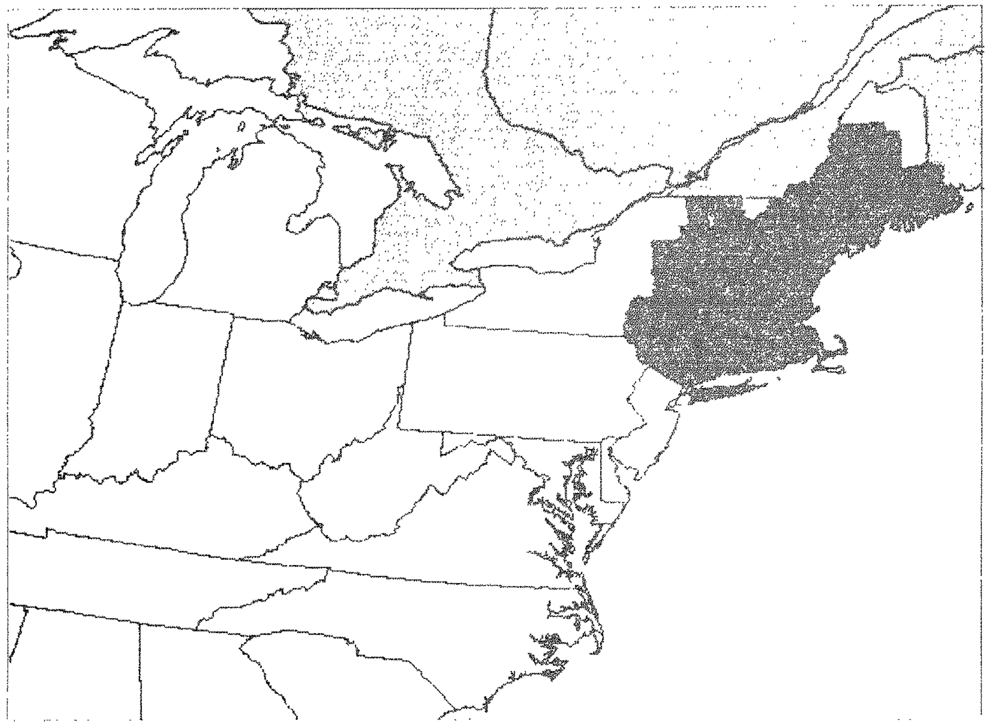

Figure 11.—Area generally infested by gypsy moth in 1960.

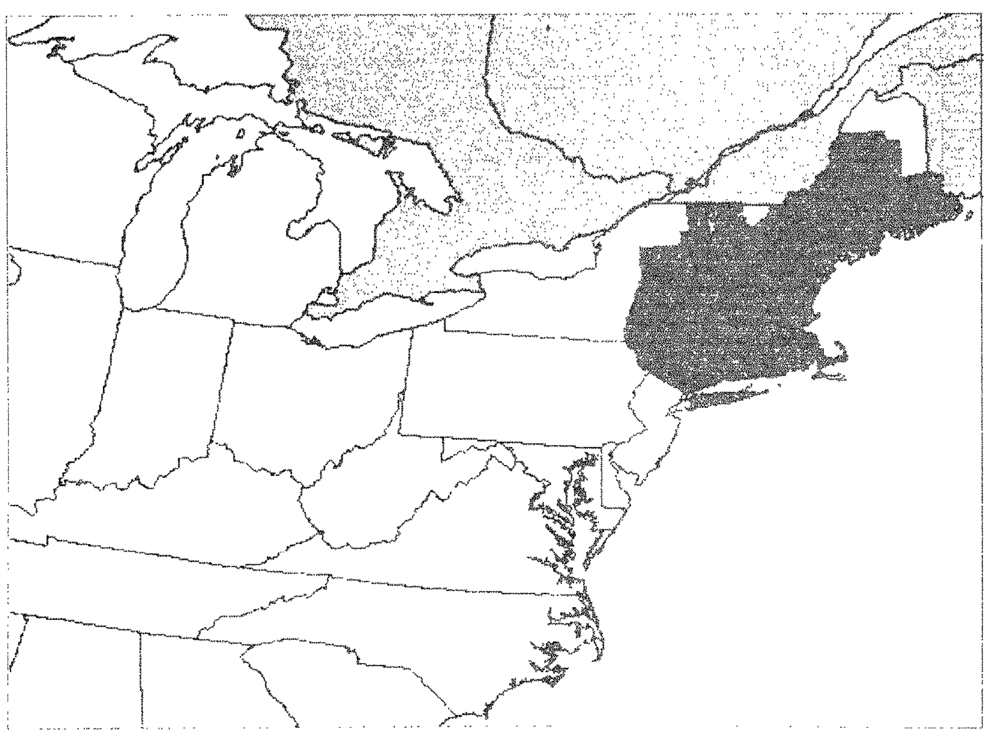

Figure 12.—Area generally infested by gypsy moth in 1965.

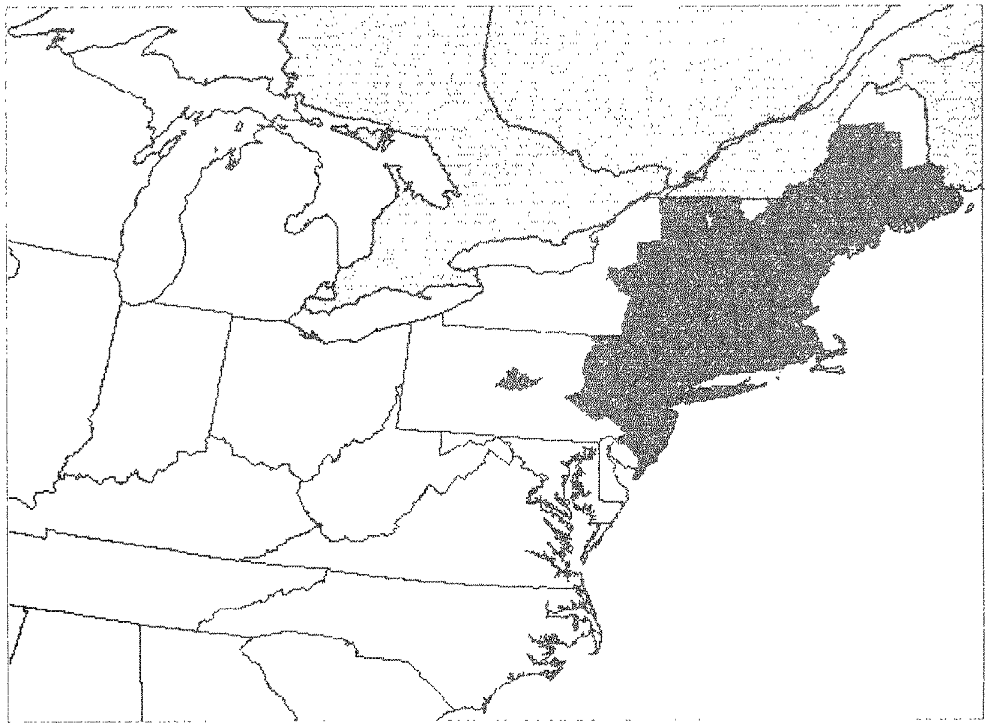

Figure 13.—Area generally infested by gypsy moth in 1970.

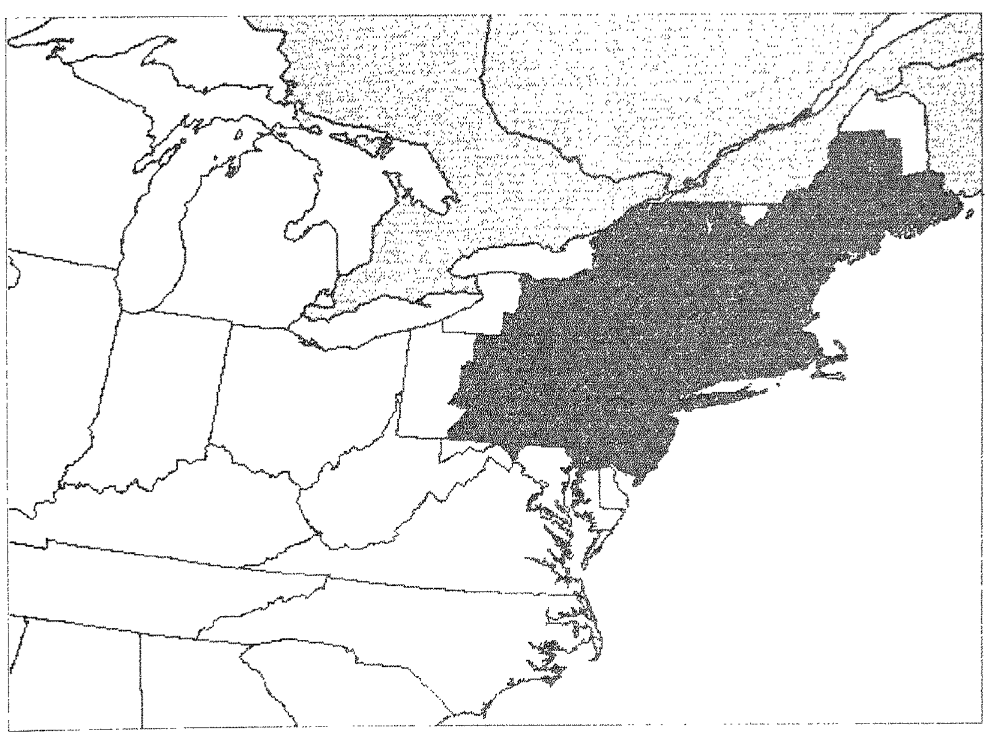

Figure 14.—Area generally infested by gypsy moth in 1975.

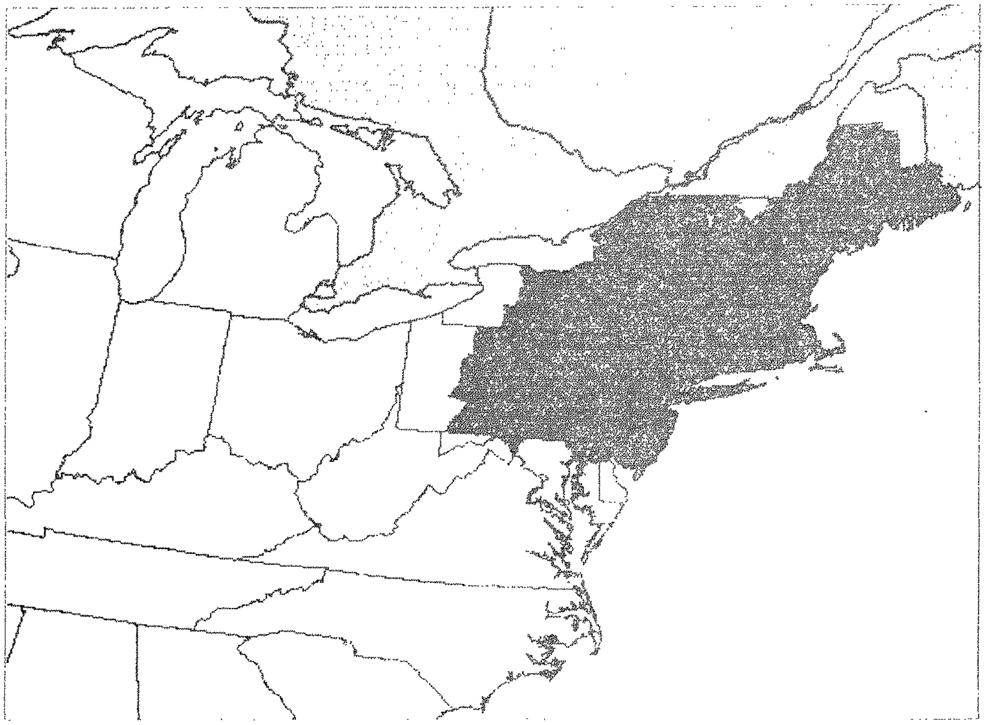

Figure 15.—Area generally infested by gypsy moth in 1980.

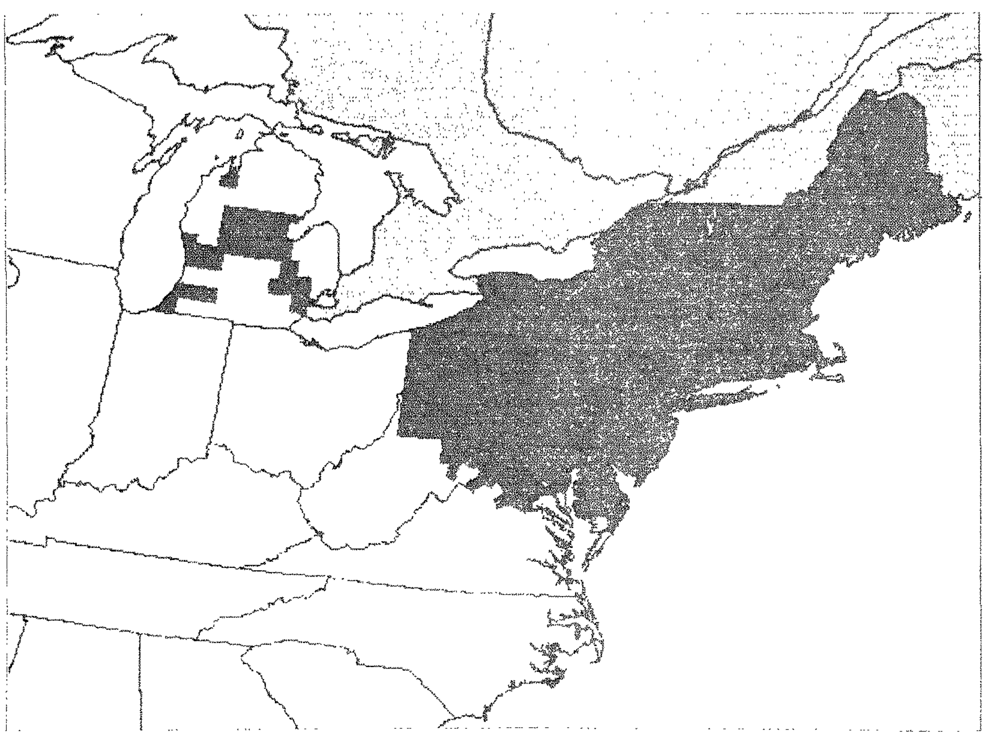

Figure 16.—Area generally infested by gypsy moth in 1985.

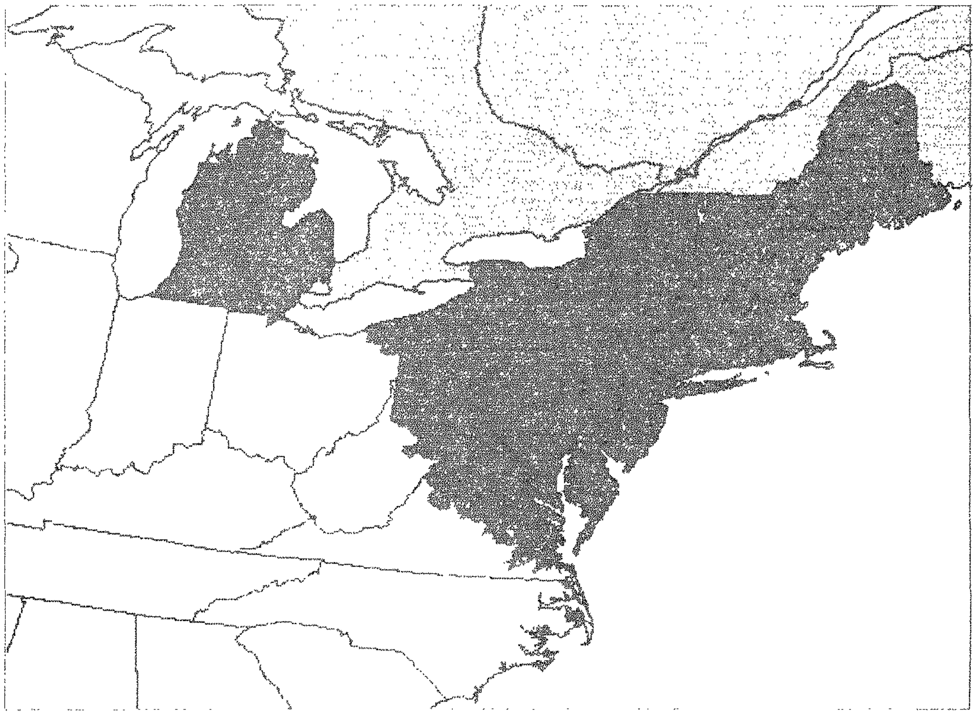

Figure 17.—Area generally infested by gypsy moth in 1990.

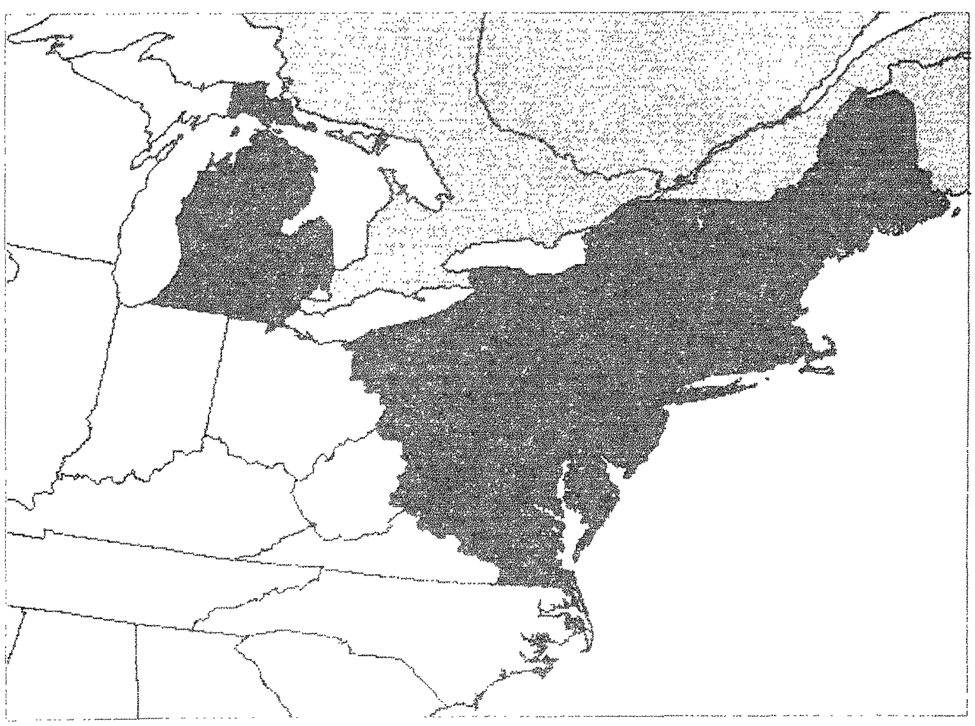

Figure 18.—Area generally infested by gypsy moth in 1994.

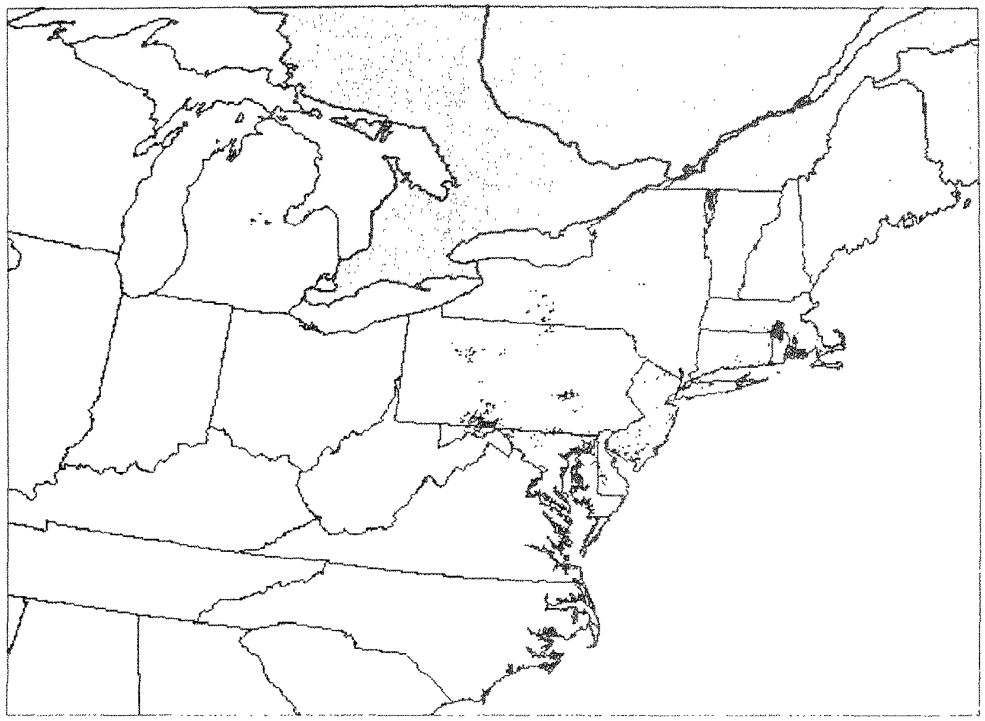

Figure 19.—Area defoliated by gypsy moth in 1984.

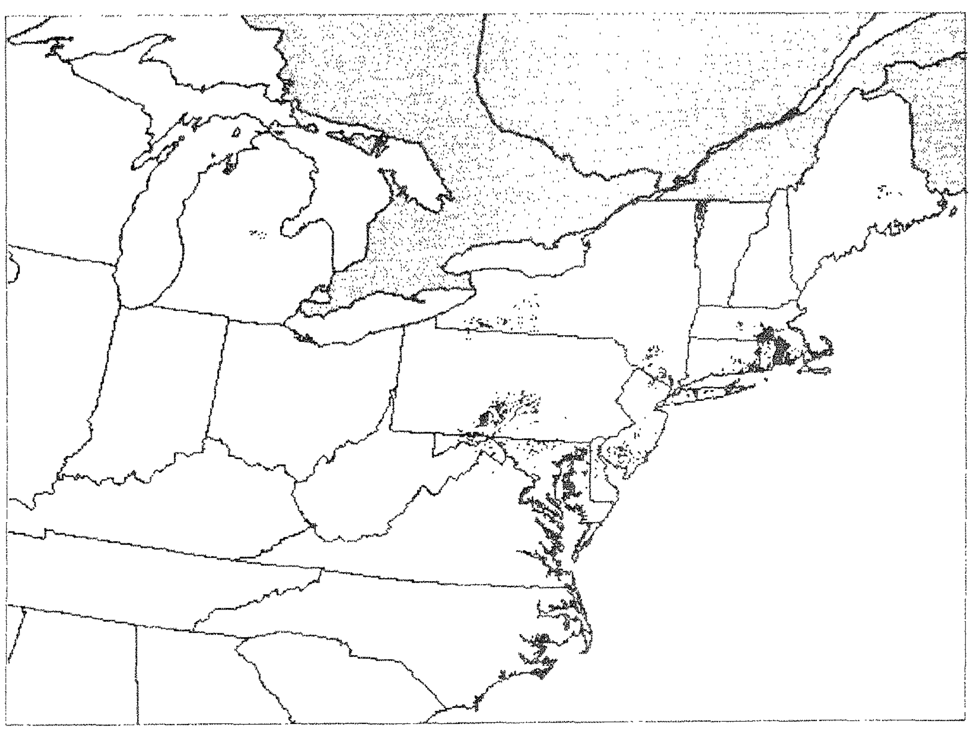

Figure 20.—Area defoliated by gypsy moth in 1985.

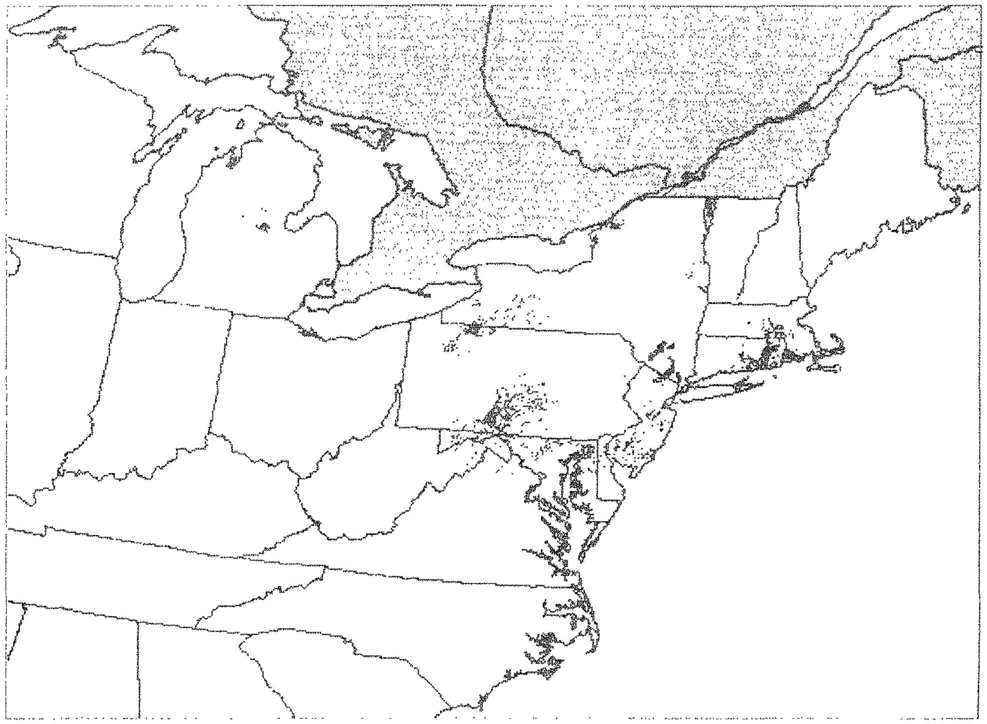

Figure 21.—Area defoliated by gypsy moth in 1986.

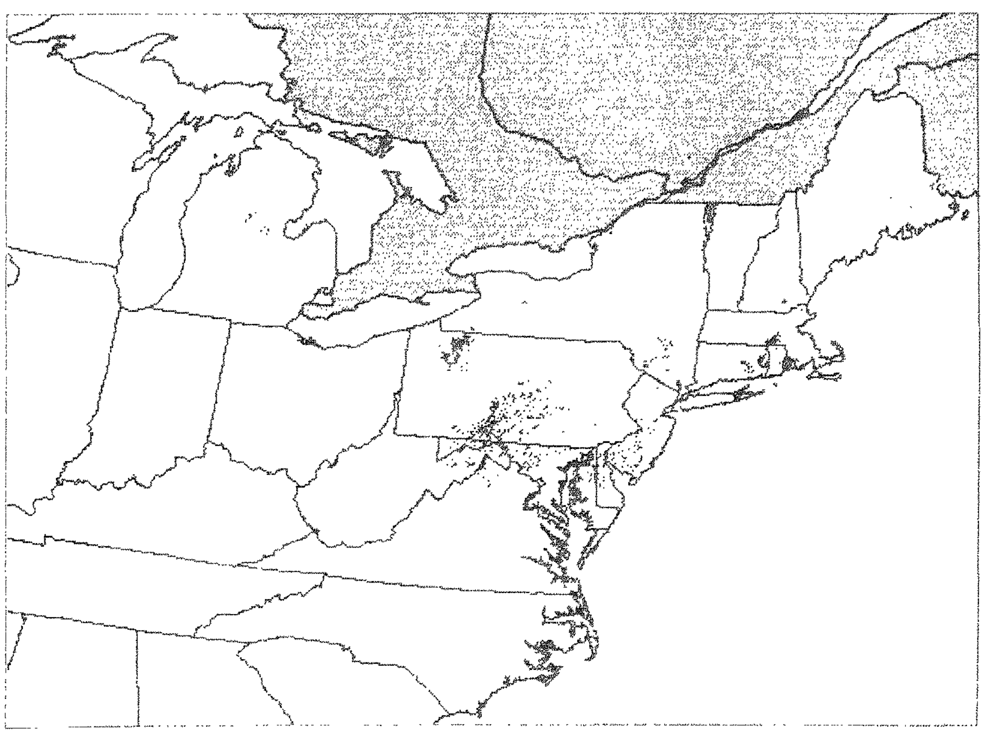

Figure 22.—Area defoliated by gypsy moth in 1987.

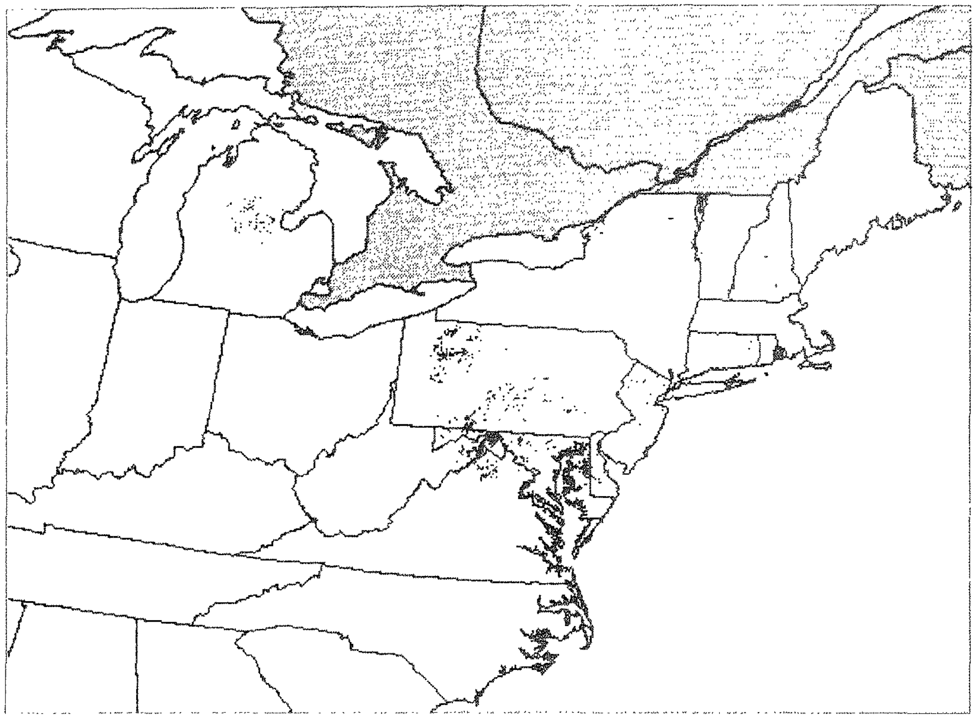

Figure 23.—Area defoliated by gypsy moth in 1988.

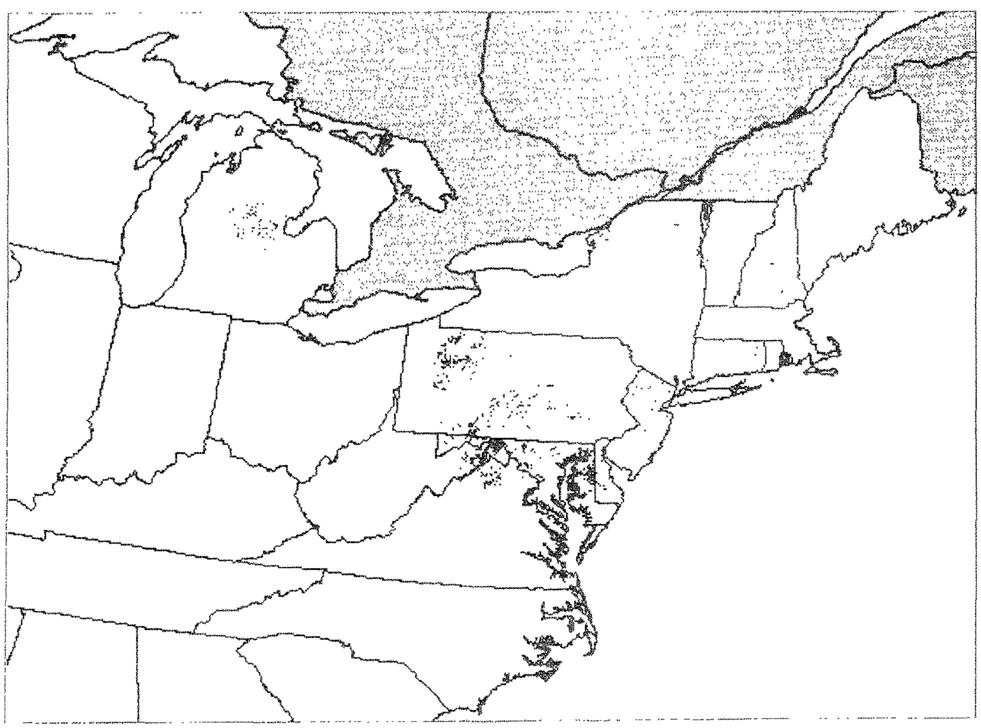

Figure 24.—Area defoliated by gypsy moth in 1989.

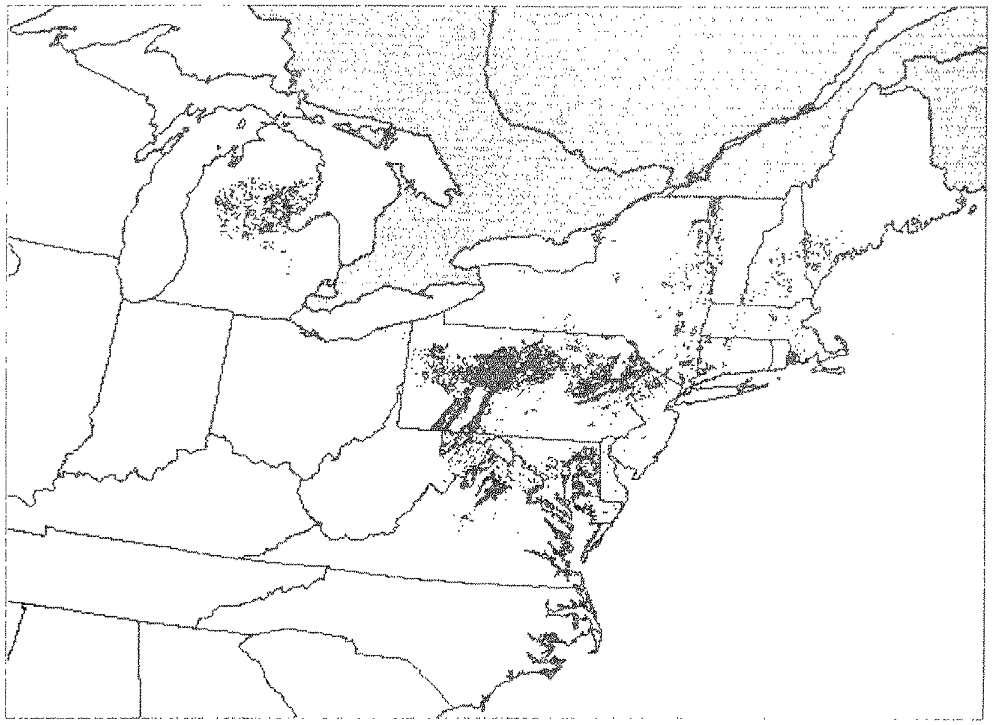

Figure 25.—Area defoliated by gypsy moth in 1990.

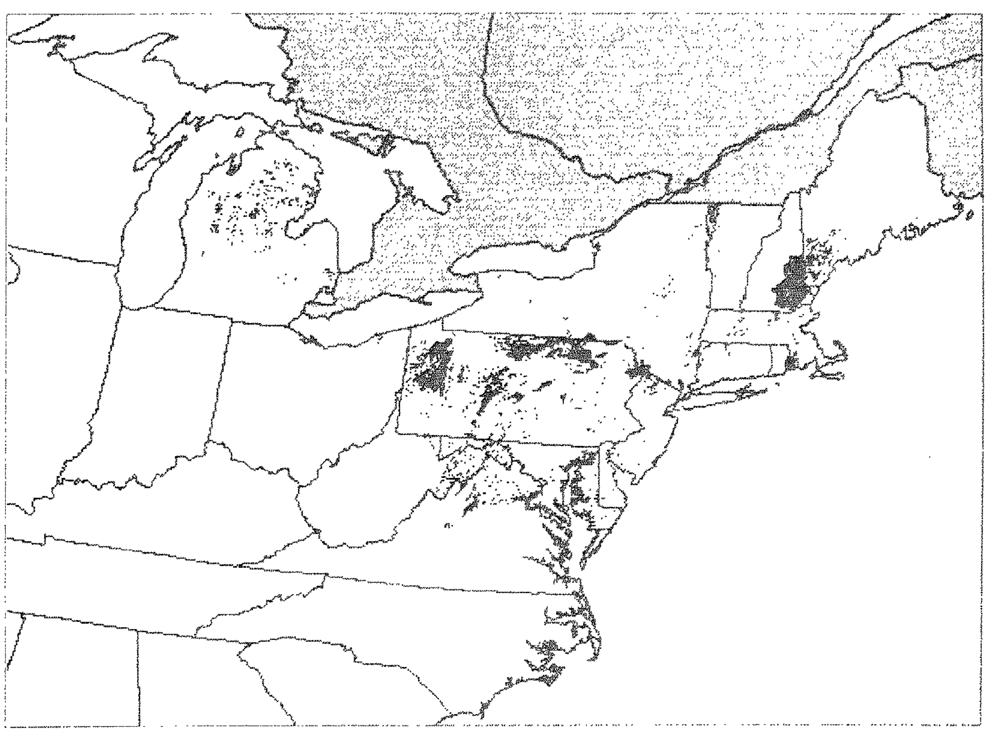

Figure 26.—Area defoliated by gypsy moth in 1991.

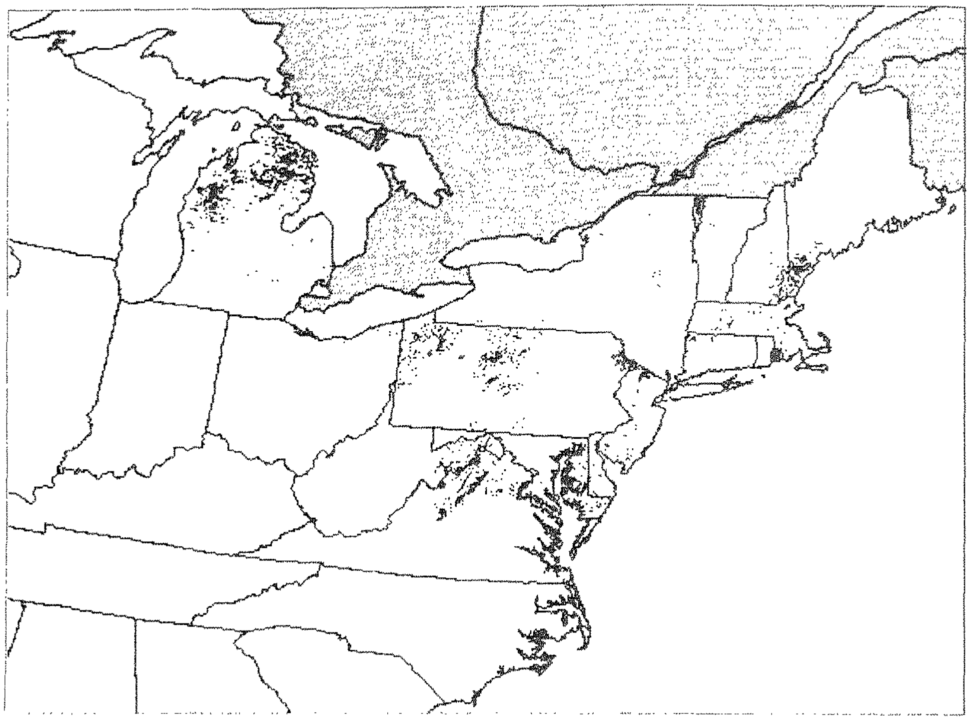

Figure 27.—Area defoliated by gypsy moth in 1992.

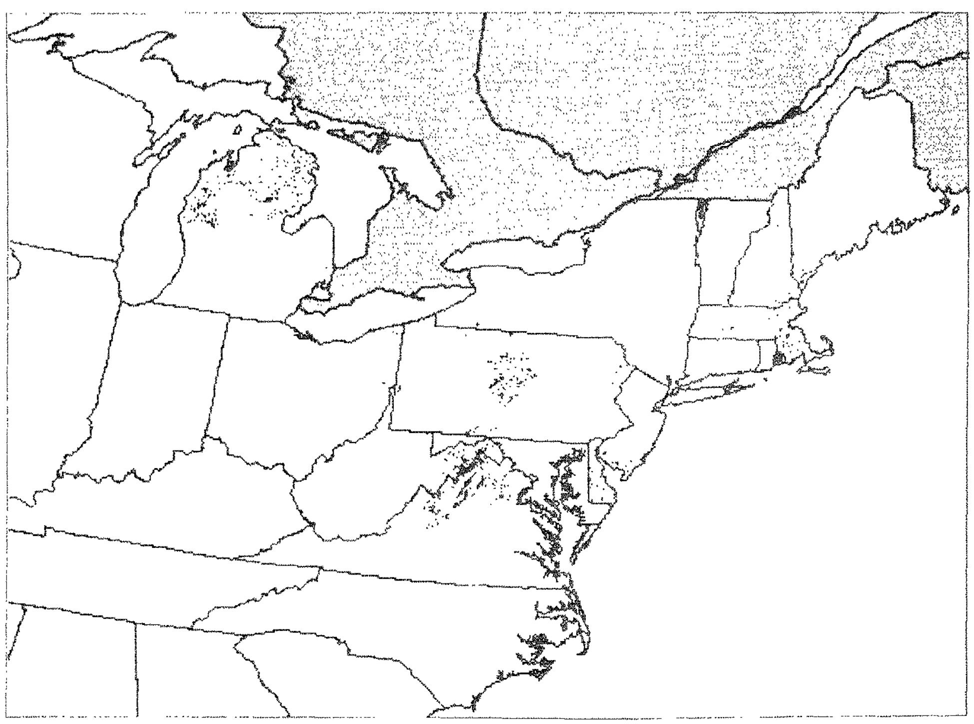

Figure 28.—Area defoliated by gypsy moth in 1993.

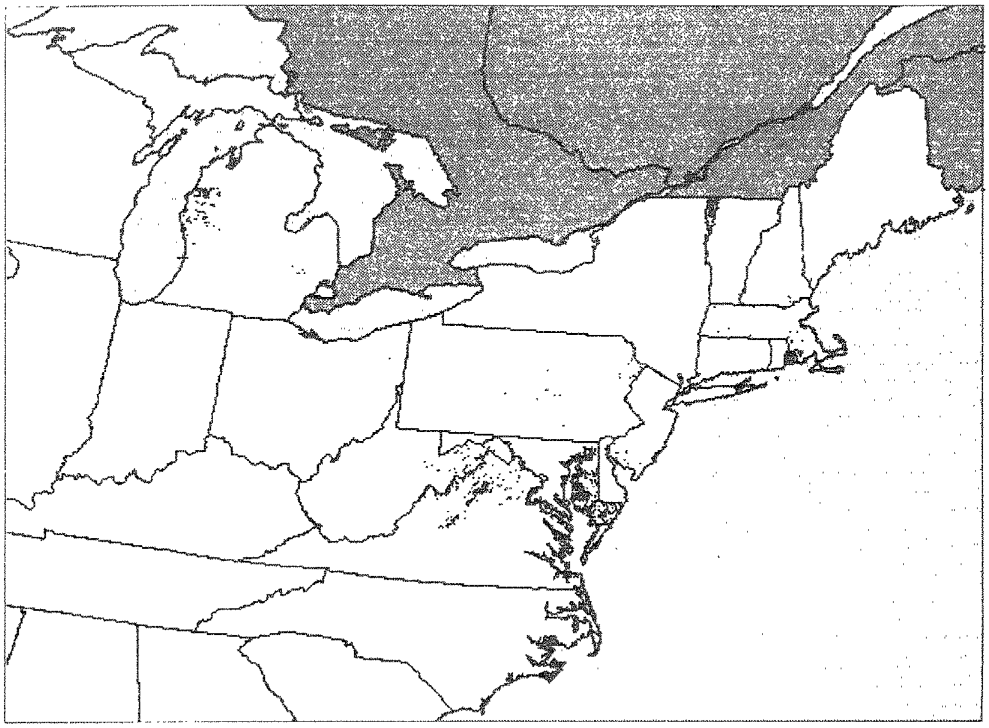

Figure 29.—Area defoliated by gypsy moth in 1994.

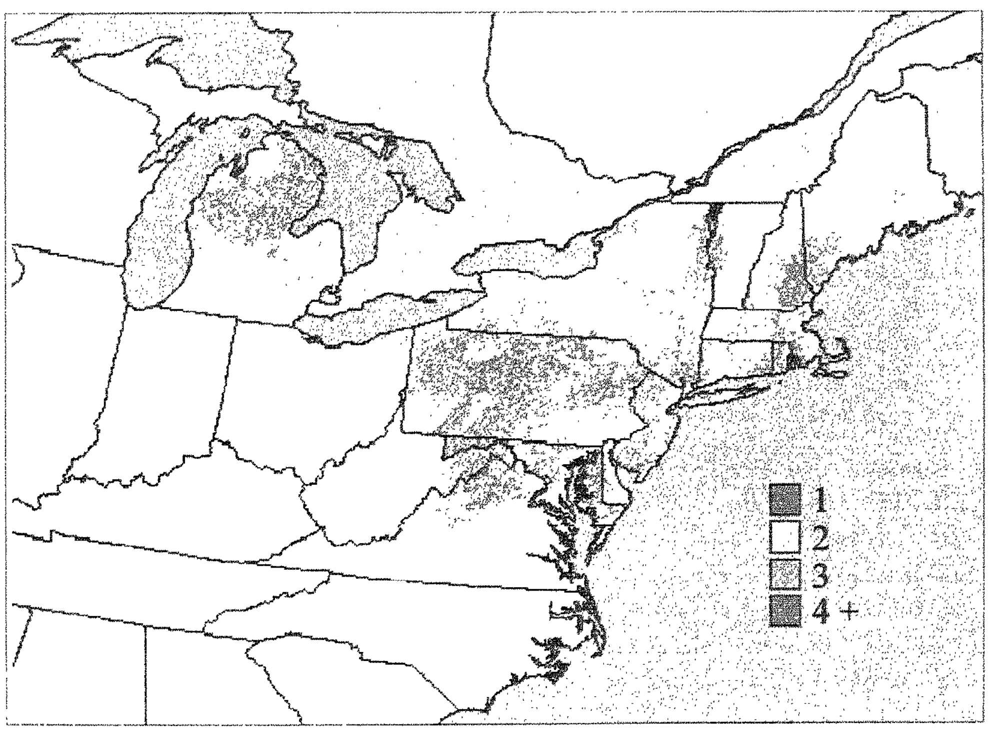

Figure 30.—Frequency of gypsy moth defoliation, 1984 to 1994 (green areas represent one year of defoliation; dark orange areas represent four or more years of defoliation).

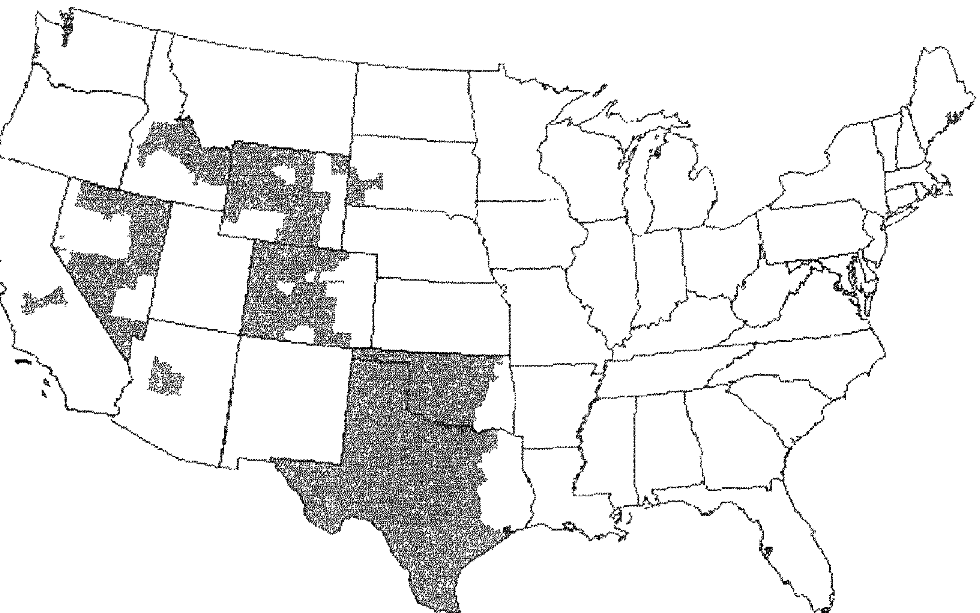

Figure 31.—Areas where lack of complete inventory data did not allow analysis.

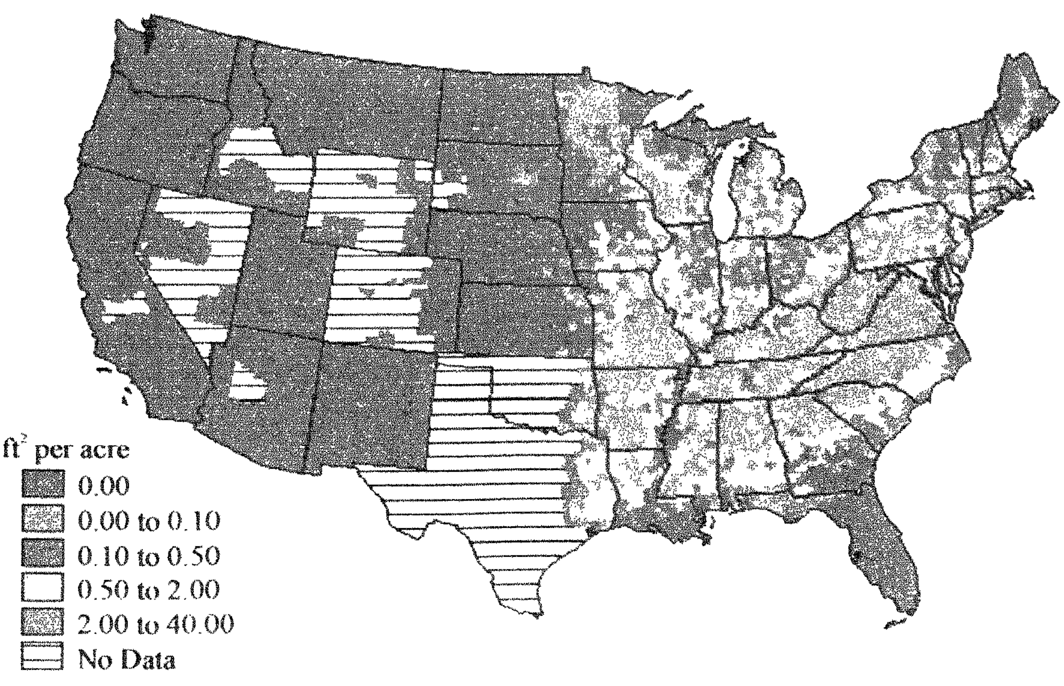

Figure 32.—Density of white oak (basal area/acre).

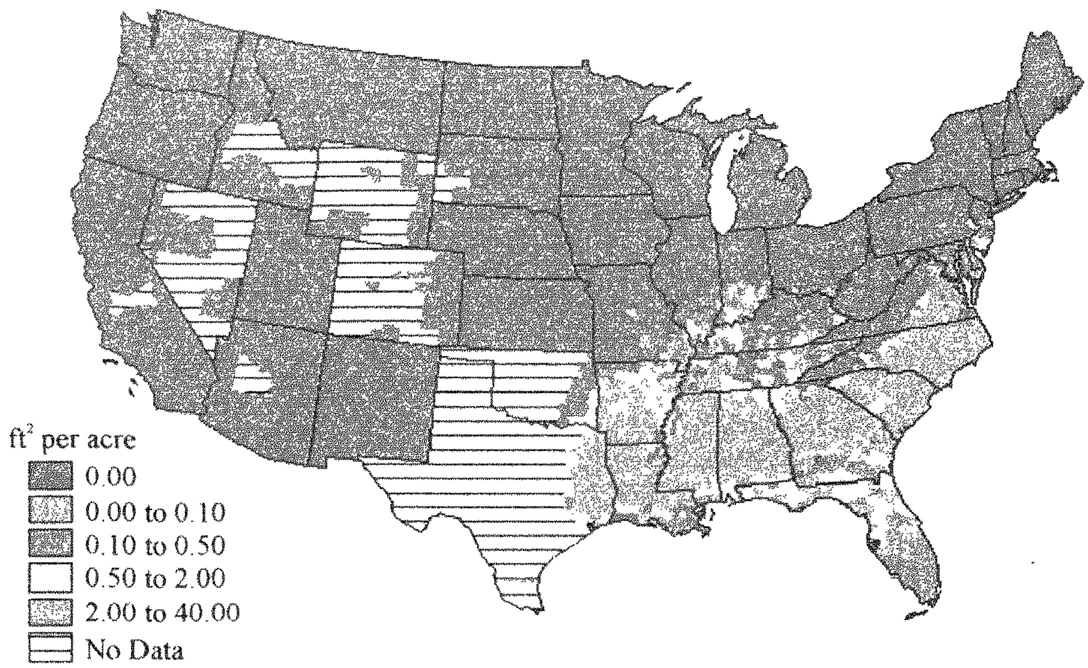

Figure 33.—Density of sweetgum (basal area/acre).

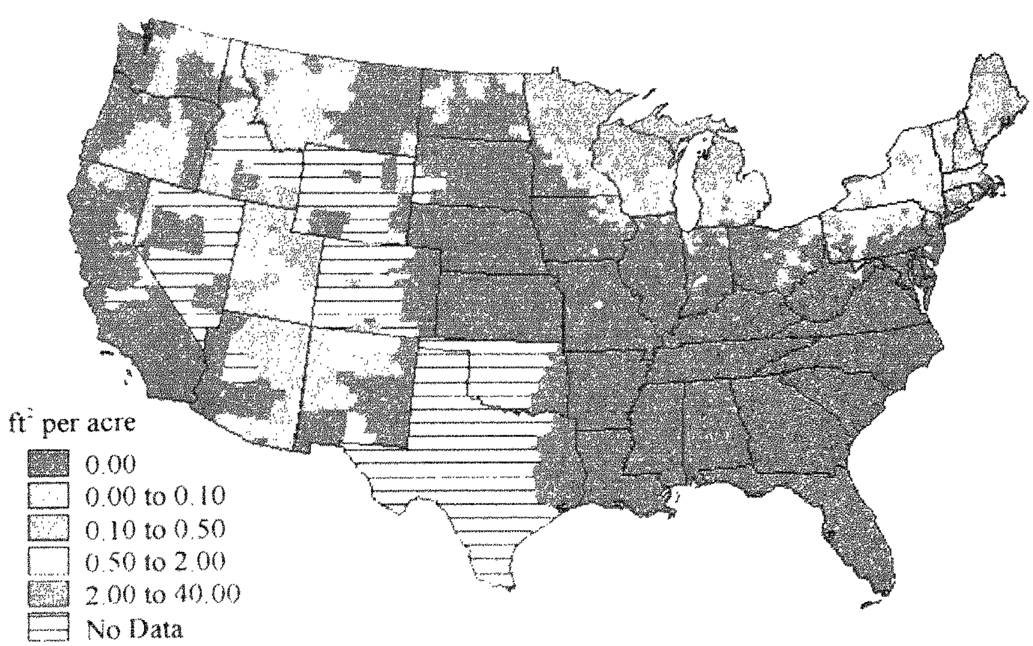

Figure 34.—Density of quaking aspen (basal area/acre).

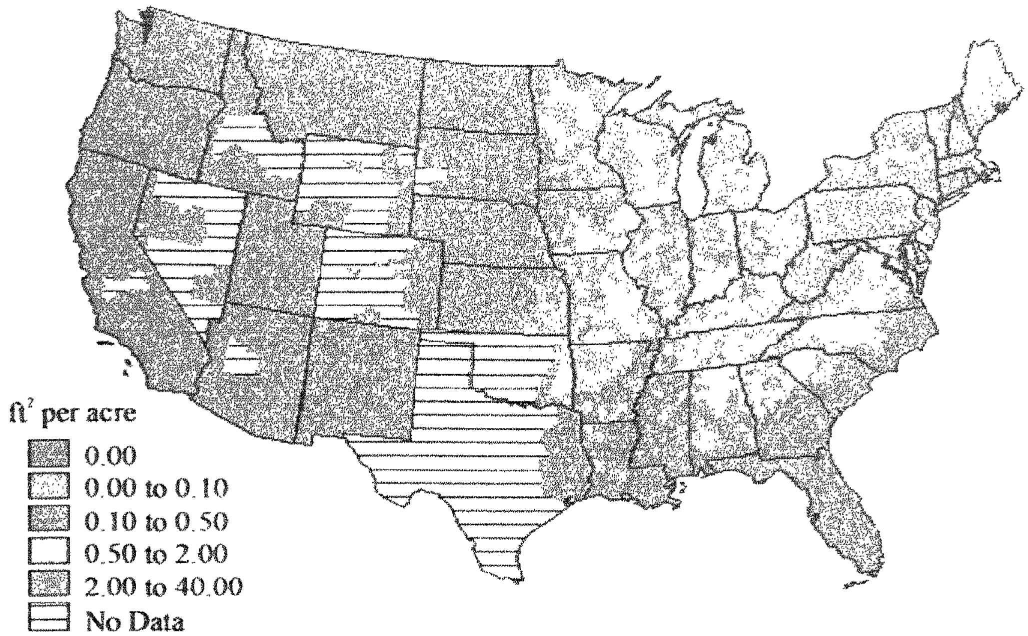

Figure 35.—Density of northern red oak (basal area/acre).

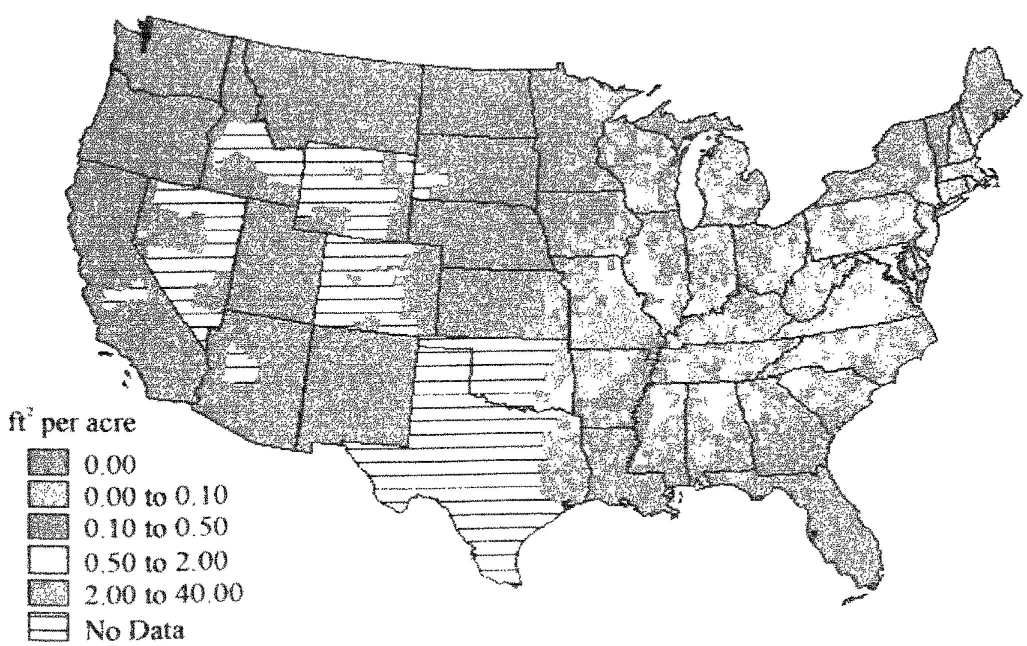

Figure 36.—Density of black oak (basal area/acre).

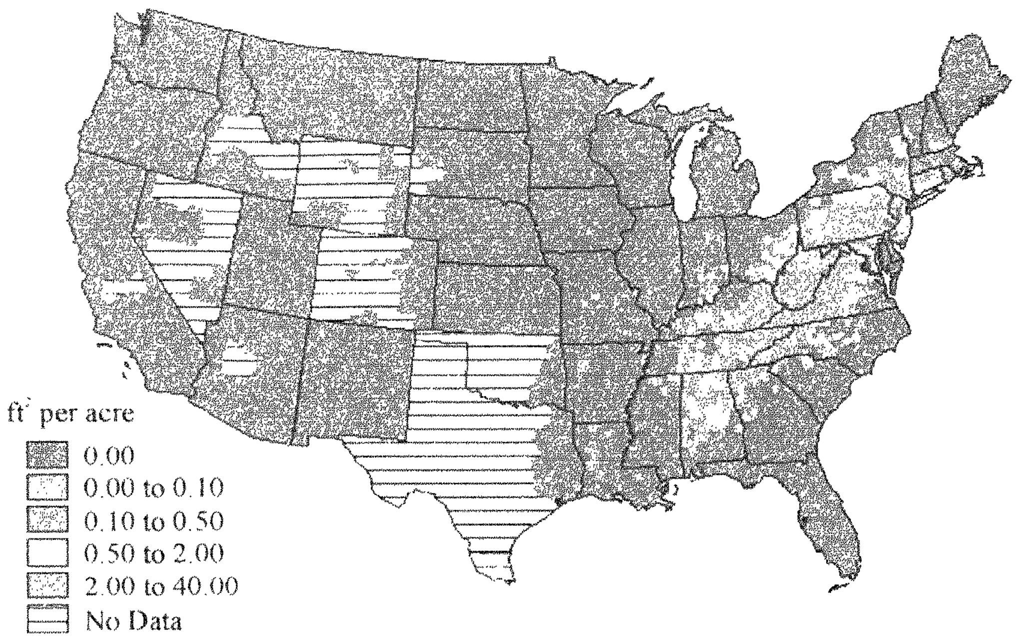

Figure 37.—Density of chestnut oak (basal area/acre).

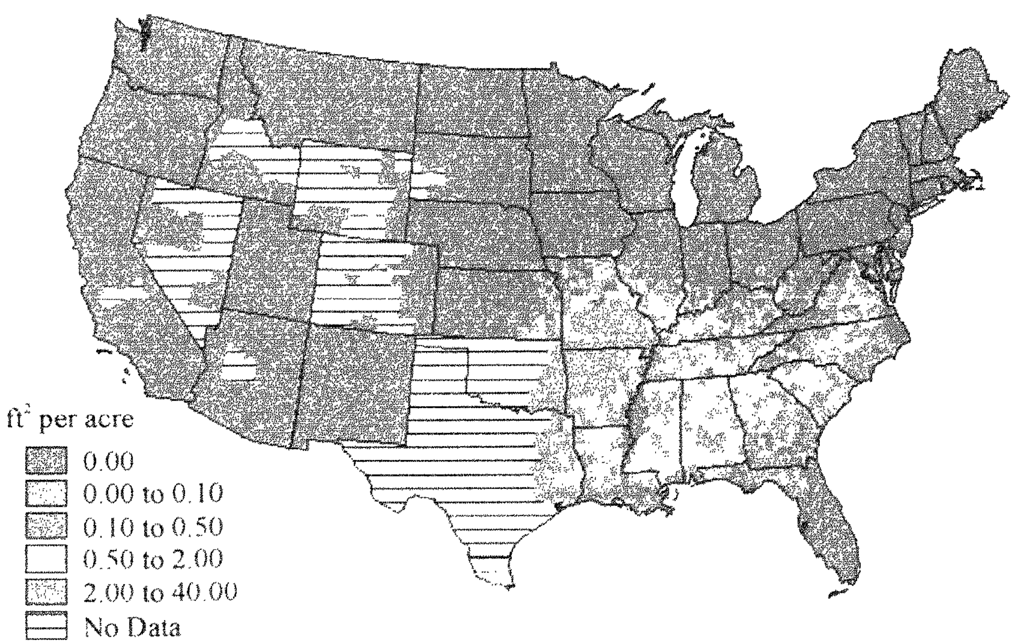

Figure 38.—Density of post oak (basal area/acre).

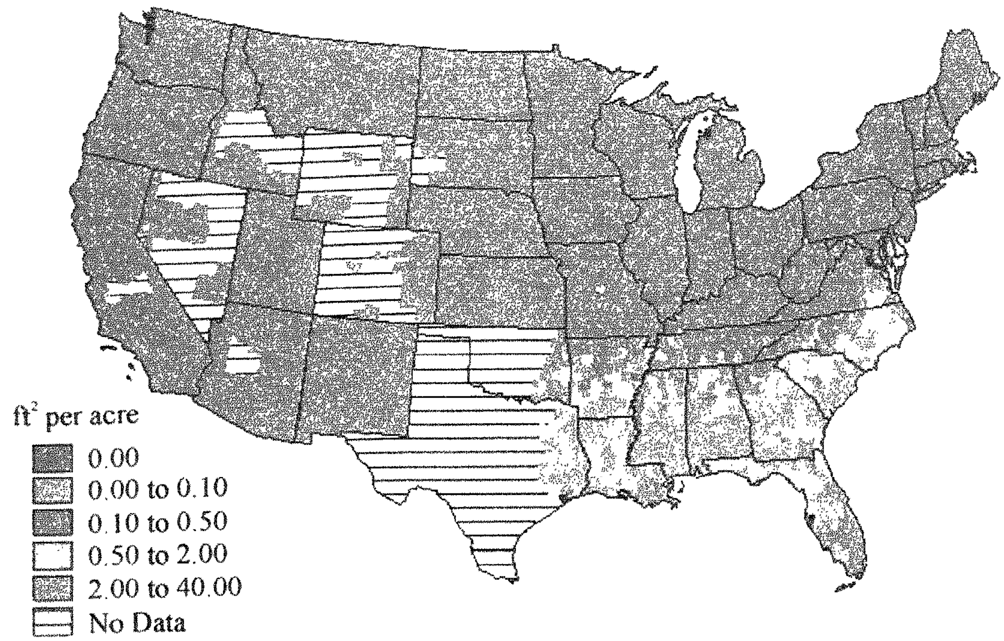

Figure 39.—Density of water oak (basal area/acre).

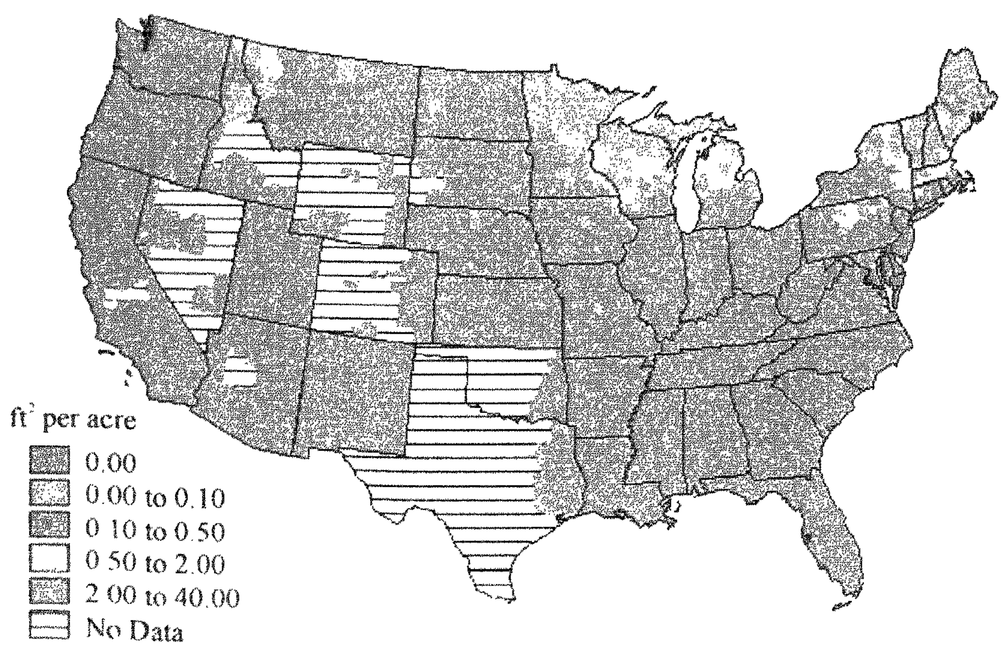

Figure 40.—Density of paper birch (basal area/acre).

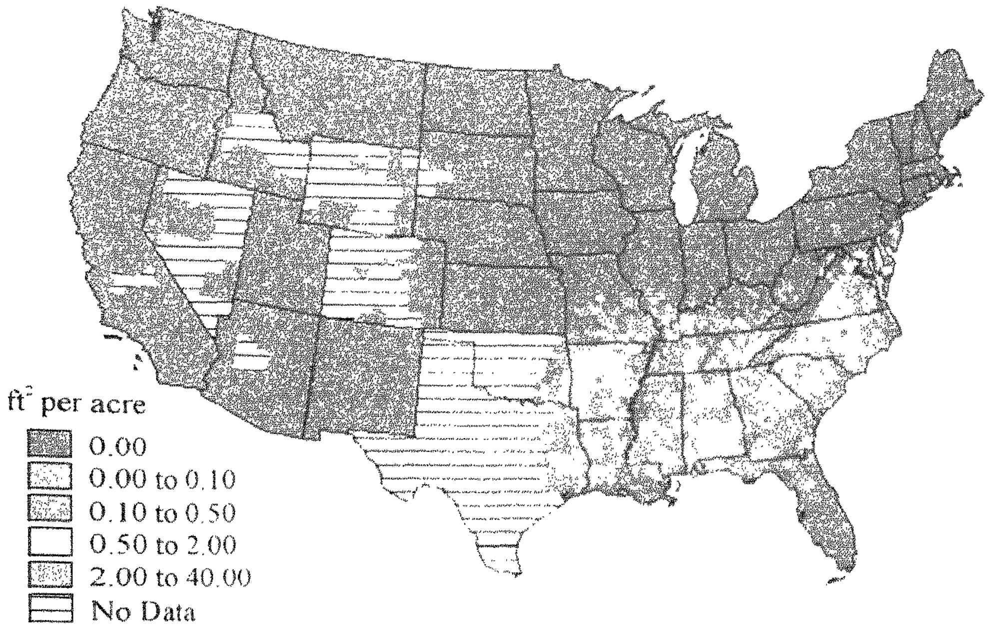

Figure 41.—Density of southern red oak (basal area/acre).

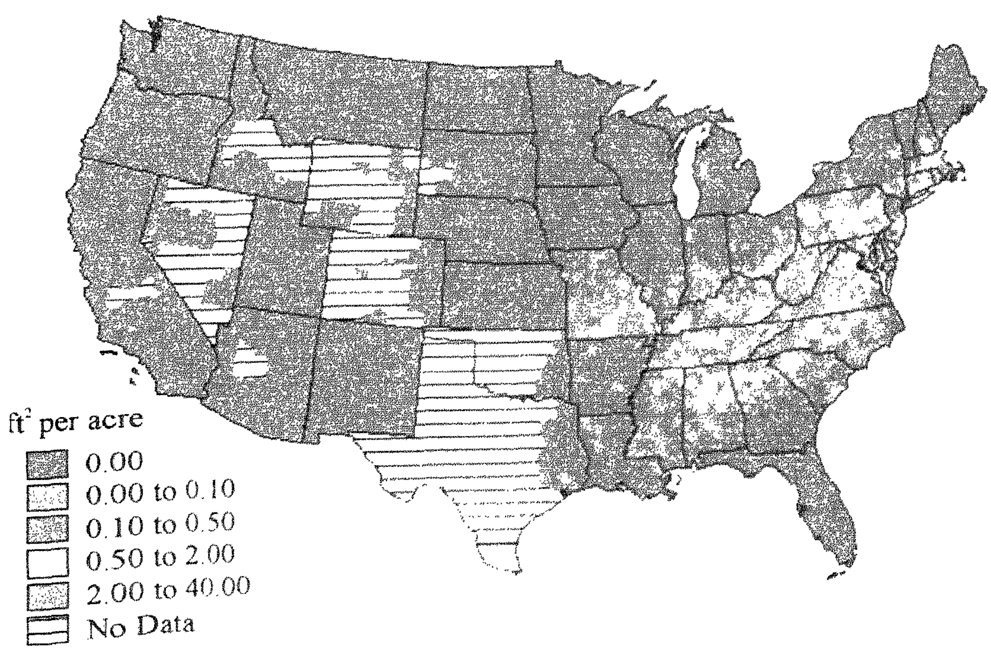

Figure 42.—Density of scarlet oak (basal area/acre).

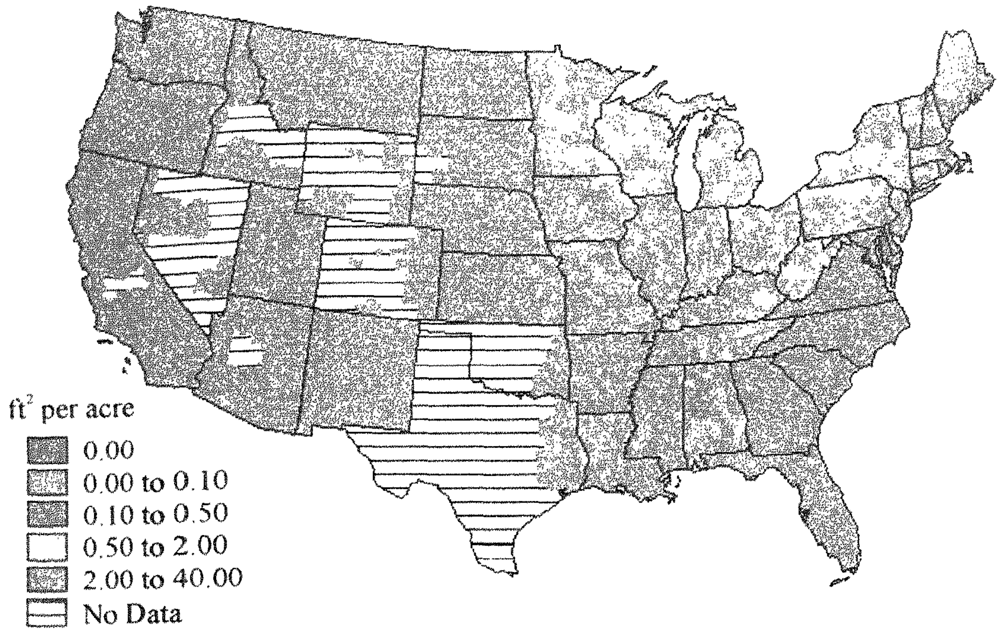

Figure 43.—Density of American basswood (basal area/acre).

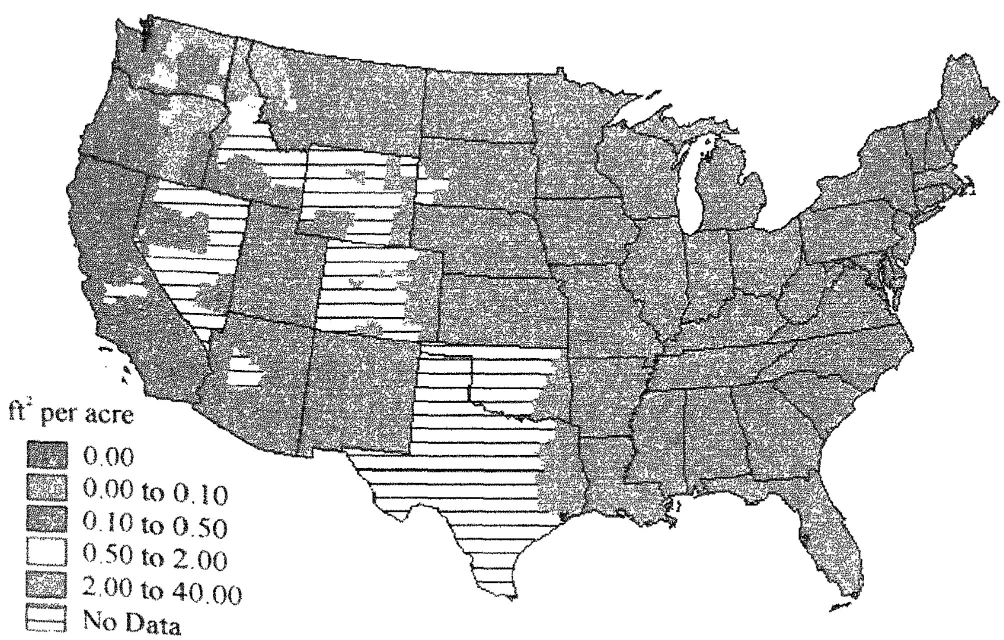

Figure 44.—Density of western larch (basal area/acre).

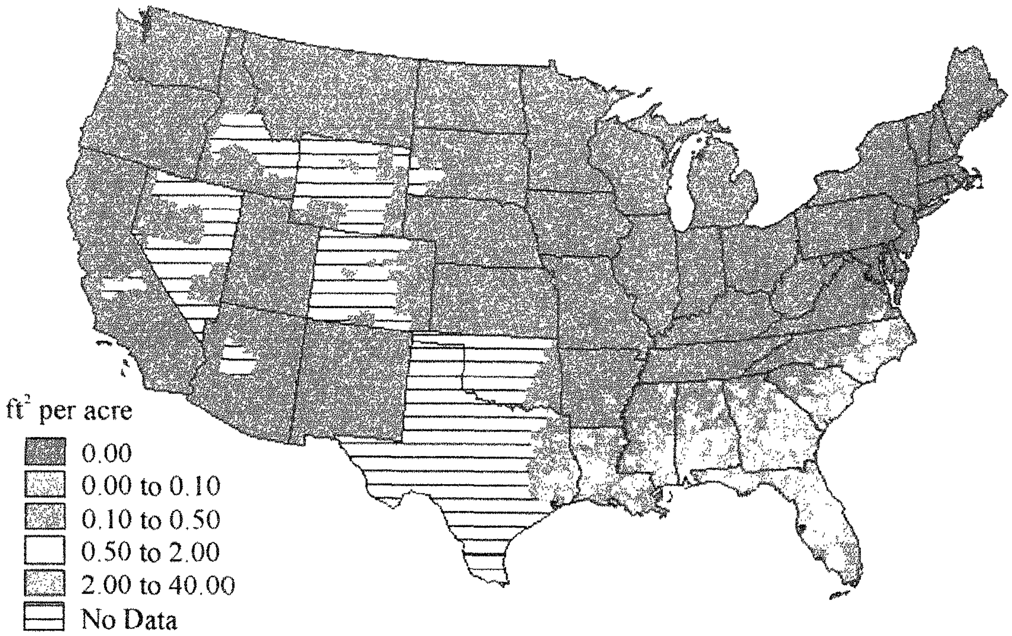

Figure 45.—Density of laurel oak (basal area/acre).

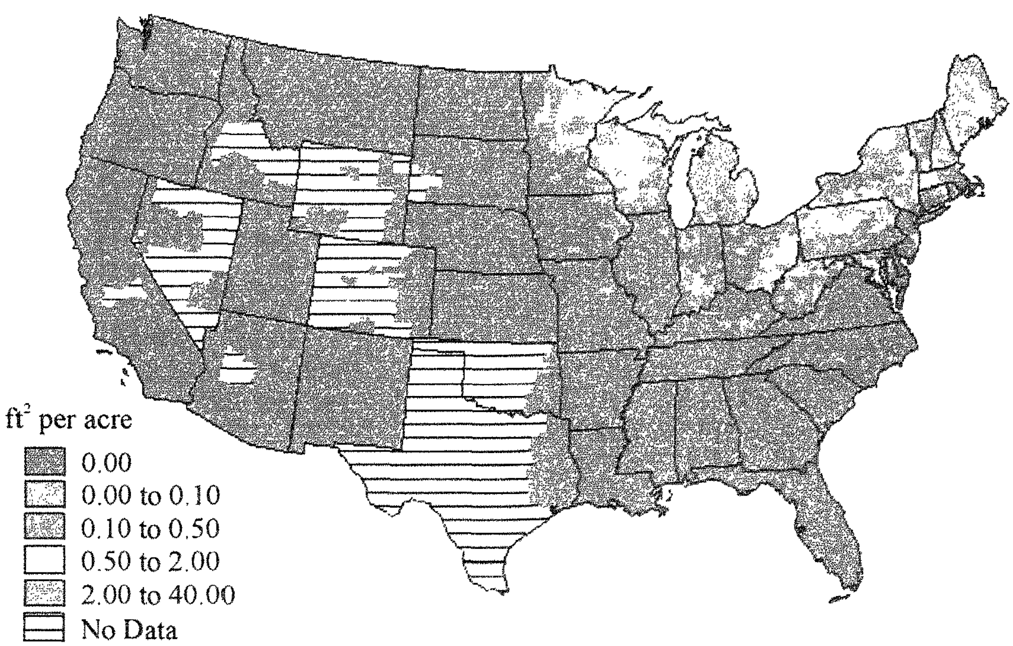

Figure 46.—Density of bigtooth aspen (basal area/acre).

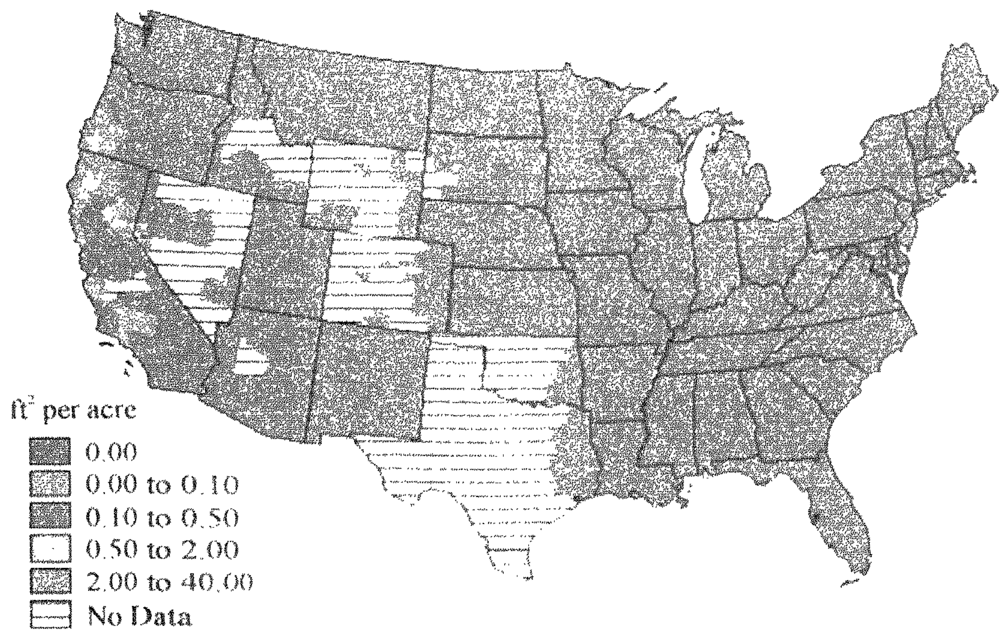

Figure 47.—Density of tanoak (basal area/acre)

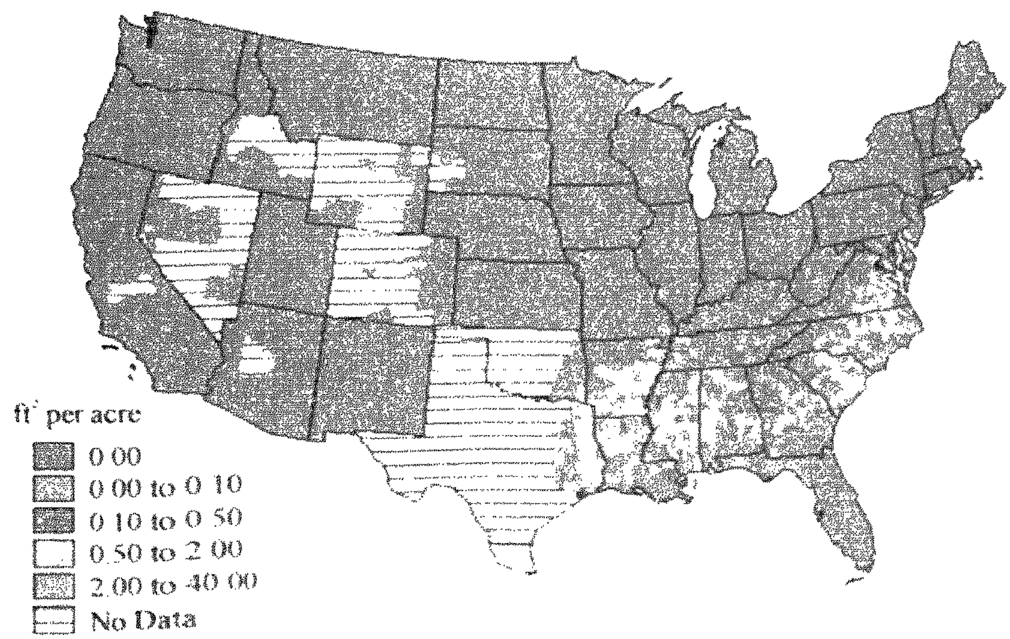

Figure 48.—Density of willow oak (basal area/acre).

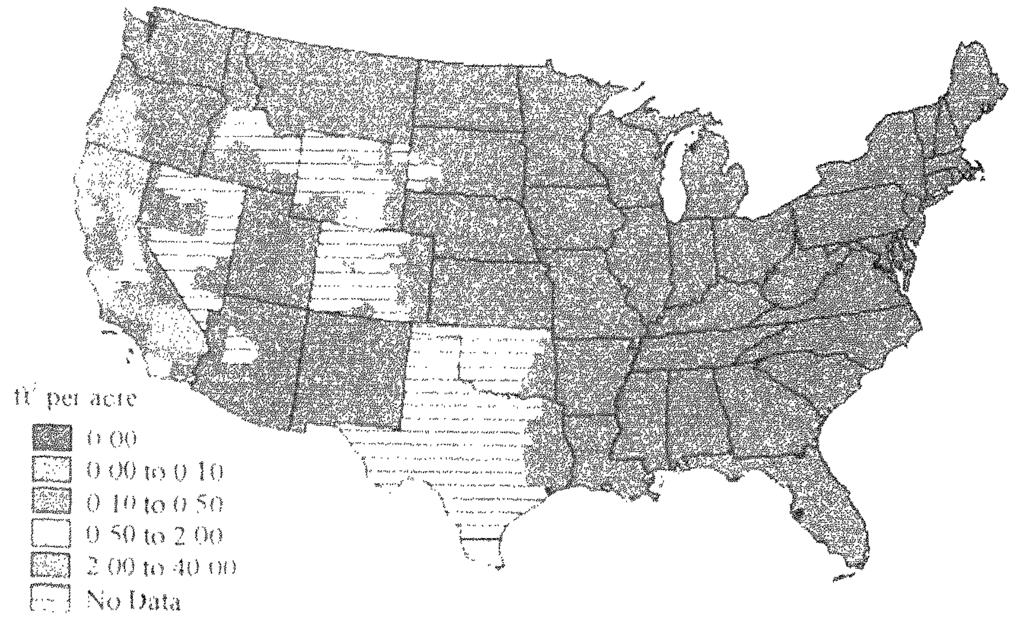

Figure 49. --Density of California red oak (basal area/acre)

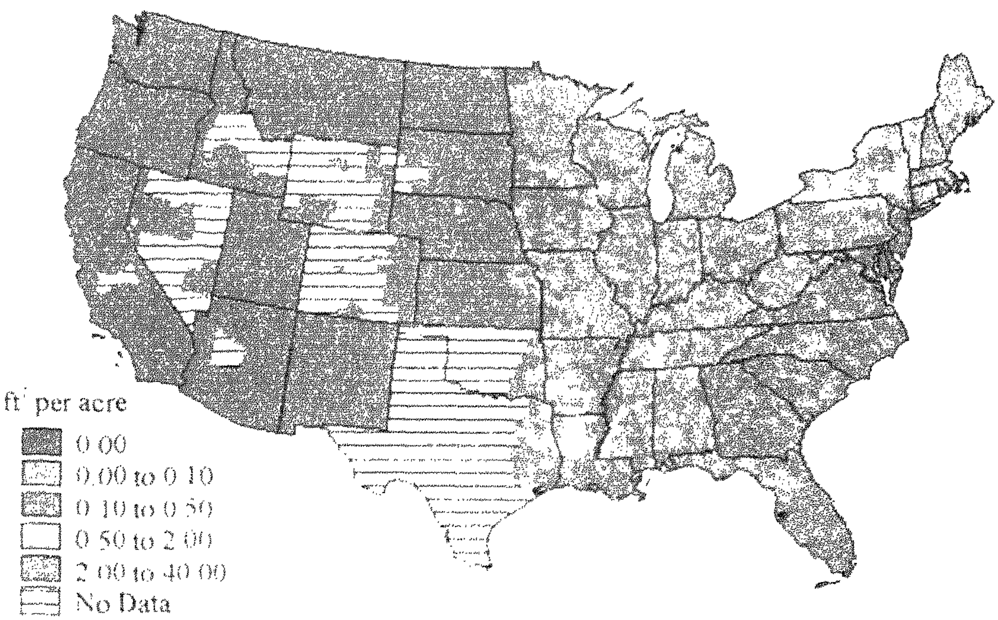

Figure 50.—Density of eastern hophornbeam (basal area/acre).

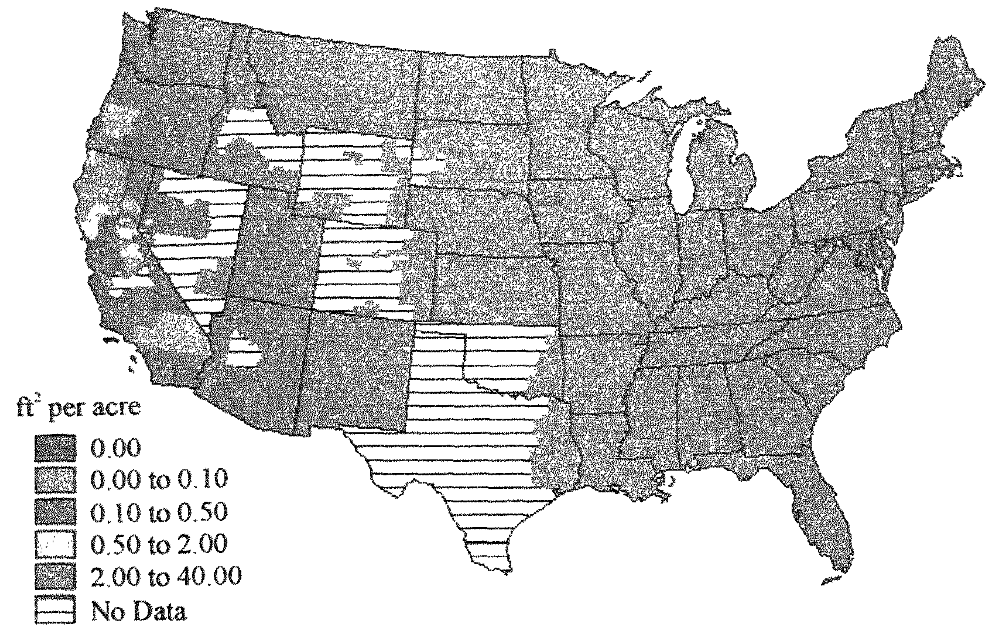

Figure 51.—Density of canyon live oak (basal area/acre).

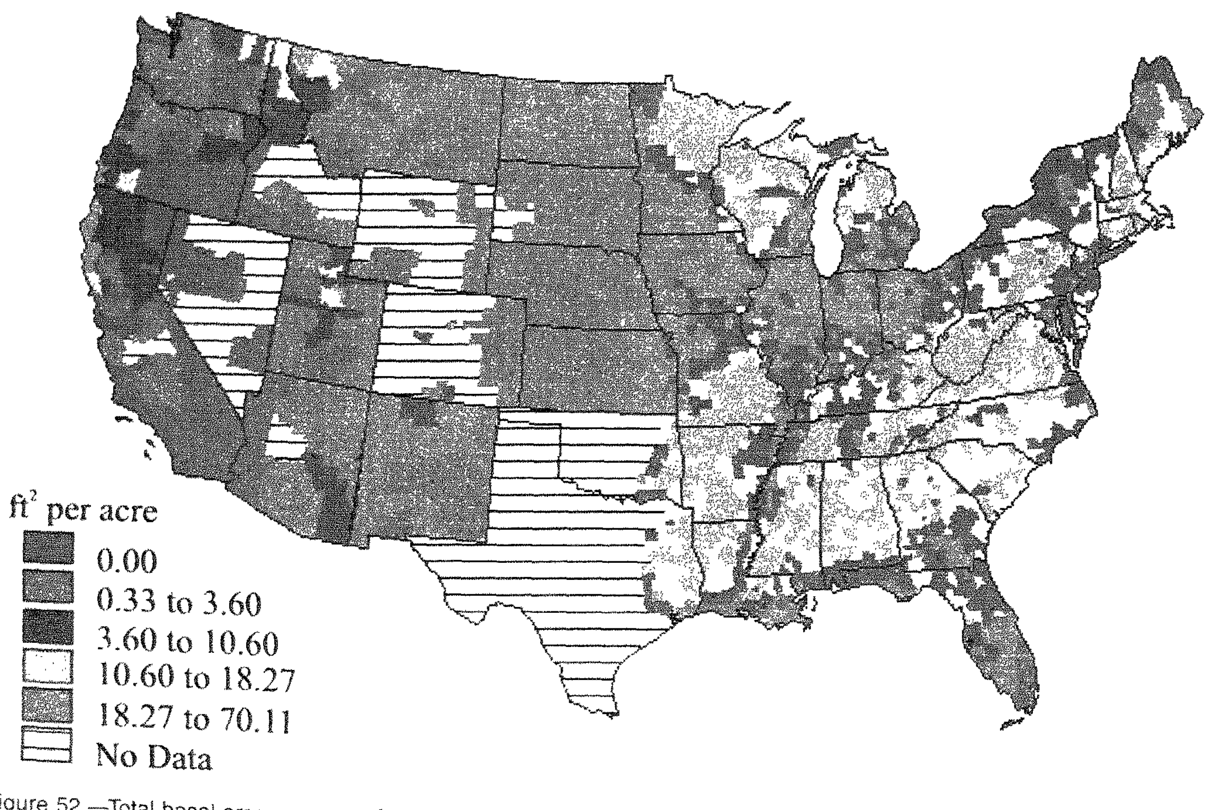

Figure 52.—Total basal area per acre of preferred tree species.

Liebhold, Andrew M.; Gottschalk, Kurt W.; Luzader, Eugene R.; Mason, Douglas A.; Bush, Renate; Twardus, Daniel B. 1997. **Gypsy moth in the United States: an atlas.** Gen. Tech. Rep. NE-233. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 36 p.

This atlas includes 52 maps that document the historical spread of gypsy moth from 1900 to the present, historical forest defoliation in the Northeast from 1984 to the present, and the distribution of susceptible forests in the conterminous United States. These maps should be useful for planning activities to limit the spread of gypsy moth and mitigate the effects of this forest insect pest in areas that have not yet been invaded.

Keywords: *Lymantria dispar*, Lepidoptera, Lymantriidae, forest susceptibility, maps, invasion, defoliation, history