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Mapping Pine Mortality by Aerial Photography, Umstead State Park, North Carolina

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Cover: Sequential aerial photography can be viewed stereoscopically on a hand-held field board.

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IN BRIEF . . .

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Southern pine beetle (*Dendroctonus frontalis*) infestations were large and wide spread in North Carolina during 1973-1976. Infestations at the 2170 hectare (5362 acre) William B. Umstead State Park were selected for study because of their proximity to research and airport facilities at Raleigh and of the "no control" policy of the Park.

Color infrared photography (1:8,000 scale) was used to detect and map tree mortality accumulated up to October 1975 and sequential photography (1:12,000 scale) was used at monthly intervals from March to July 1976 to detect and map subsequent tree mortality. Total number, volume, and value of the killed trees were estimated and the economic and ecologic impacts assessed.

Photos were interpreted stereoscopically at four-power magnification, and all detected tree mortality spots were delineated. On the October 1975 photos, the area of each tree mortality spot was measured, and standing dead trees in selected 1-ha circular plots were counted. Total tree mortality was estimated from these measurements.

Photos taken subsequently in spring 1976 were interpreted for only the recently faded trees, those faded treees that still had healthy foliage on the previous photos. The trees were counted, mapped and a sample, or all, were ground checked. Ground checks used a stereo field viewing board to locate individual trees on the ground. The trees were examined and species, size, crown color, and beetle life stage were recorded. A random sample of measured tree heights was used to correct the estimated tree heights. Total numbers of beetle killed trees were estimated for each photo date. Metric volumes were estimated by regresssion, converted to cubic feet and cords, and the dollar values determined. The ecologic impact on stand composition was assessed.

A photo interpretation data management system PISYS-1 using FORTRAN IV language was developed to assist mapping and cross comparison of photo detected tree mortality. The main elements of the system were a photo base map, a control point network, coordinate digitization, mathematical fitting, accuracy tests, and map plotting.

More than 20,500 trees on 137 ha (339 acres) were killed between 1973-1975 having a volume of 7427 cords and a value of over $236,000. This tree mortality had a significant impact on vegetation types converting 63 ha from pine and mixed species stands to hardwood forests.

Subsequent tree mortality during 1976 was much less, amounting to 248 trees detected at 120 spots in March, 24 trees detected at 13 spots in April, 18 trees detected at 5 spots in May, 2 individual trees detected in June and finally 9 trees detected at 6 spots in July. The total of 301 trees had a volume of 109 cords valued at $3,667. This loss was scattered and caused no changes to vegetation types. Total loss during the outbreak was 20,851 trees containing 7546 cords valued at $240,581.

The PISYS-1 mapping system performed well, fitting control points with an average accuracy on the ground of 12 ± 5 m (40 ± 16 ft). This resulted in tree mortality maps with a ground accuracy of 16 ± 5 m (53 ± 17 ft) with mean errors for individual photos ranging from 1 to 30 m (3 to 99 ft).

The population of southern pine beetle collapsed as the study was getting underway, therefore, we were unable to obtain the within-tree population data necessary to make area wide population estimates. However, the study does illustrate the procedures necessary to incorporate aerial photographic detection, mapping, and estimation of successive cohorts of bark beetle infested trees into population dynamics studies. Such mapping is essential in describing the distribution and abundance of bark beetles.

The southern pine beetle (*Dendroctonus frontalis* Zimm.) has a dichotomous effect on its host plant—an attacked tree is either killed or it survives without apparent damage. Evaluating trends in the beetle population and trends in the damage it causes requires an area-wide measurement of beetle density and pine mortality.

Aerial photography has proved to be an effective tool in detecting beetle-caused pine mortality. Ciesla and others (1967) detected 66 percent of the beetle-killed trees by using 1:3,960-scale color infrared transparencies. Heller and others (1974) reported that imagery recorded on color infrared film, over a range of scales (1:12,000 to 1:32,000), permitted the detection of virtually all large tree mortality spots (greater than 25 trees) caused by the mountain pine beetle (*D. ponderosae* Hopk.). For smaller spots, larger scale (1:4,000 to 1:8,000) photos were required. At the largest scale, 95 percent of the spots with four to six trees and 70 percent of the spots with one to three trees were detectable.

Aerial photo studies to date of trees killed by the southern pine beetle have used photos taken on a single occasion to measure the tree mortality that accumulated over an extended period of time (Ciesla and others 1967, Heller and others 1959). Heller (1974) reported annual assessments of the ponderosa pine mortality caused by the mountain pine beetle, and Klein (1979) mapped trends in mortality in lodgepole pine stands caused by that insect over a 4-year period by using 35-mm color aerial photographs. Sequential aerial photography was also used by Caylor and Thorley (1970) and DeMars and others (1980) to study ponderosa pine mortality in relation to the population dynamics of the western pine beetle (*D. brevicomis* Lec.)

With the sequential approach, photos are taken at intervals and interpreted to measure the change in photo-detectable tree mortality occurring during each interval. In this manner, the rate of tree mortality can be related to the rate of bark beetle survival. Analysis of the relationship between these two rates is the basis of any system to predict trends in beetle populations and the associated tree mortality over large areas.

In late 1975 and early 1976, we used sequential color infrared aerial photography to study pine trees killed by southern pine beetle in central North Carolina.[1] The study area was 2170 hectares (5362 acres) of the William B. Umstead State Park, which lies directly east of the Raleigh-Durham airport. The Park forest includes pine, hardwood, and mixed pine-hardwood stands. The pines are species typical of the Piedmont, including loblolly (*Pinus taeda* L.), short leaf (*P. echinata* Mill.), and Virginia (*P. virginiana* Mill.)—all hosts of the southern pine beetle.

This paper reports estimates of the number and volume of pine trees killed by the southern pine beetle at the Umstead State Park in 1973-1976, and of the ecological and economic effects of that mortality on stand type and resource value.

METHODS

Photo Imagery

The study area was photographed in October 1975, by using color infrared film at a scale of 1:8,000 to locate and catalogue the background of pine mortality that occurred before fall 1975. We chose color infrared film for use in the study because it is superior to normal color film in haze penetration and differentiation of hardwoods from conifers (Ciesla and others 1967).

The Park was photographed from the air at monthly time intervals from March to July 1976. The schedule attempted to synchronize the photography with the beetle generations, so that each set of photographs would image primarily the faded crowns of pines associated with one beetle generation. Medium-scale (1:12,000) photography was taken to provide mapping coverage of the entire study area, and still have reasonably few photos to interpret. Medium scale photography is typically used by the Forest Service, U.S. Department of Agriculture, to map tree mortality over large areas. Concurrently, large scale

[1]The study was done concurrently with a study of southern pine beetle population dynamics by Fred P. Hain, North Carolina State University, and a study of biometeorology by James Taylor, Southeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture.

(1:6,000) photography was used to cover selected areas to provide more accurate individual tree counts at the beetle population sampling spots than could be made on the medium-scale photos.

The processed rolls of film were cut into individual frames, and each was placed into a clear, 8-mil vinyl envelope to protect the film from dust, moisture, and scratching. Photos were labeled with the date, scale, and numbered by flight line and photo number.

The photos were examined stereoscopically at four-power magnification. The transparencies were back lighted by using fluorescent light tables having a split top, translucent, white plastic viewing surface (*fig. 1*). The stereoscopic image was scanned for the presence of pine mortality spots. On color infrared photos, healthy conifers have a dark red-brown appearance, while the fading crowns of dead and dying pines have a pink, white, or yellow-orange image, depending on how long they have been dead (Ciesla and others 1967). This difference corresponds to the normal spectrum color progression from healthy green to yellow-green, yellow, orange, and finally orange-red. When the dead needles fall off, the remaining snag appears blue-gray to gray.

New mortality spots were circled and serially numbered in black ink on clear acetate templates, one for every other photo. The templates were labeled and registered by marking the four camera fiducial points. Nine well distributed control points were transferred from a photo base map to each photo template. These control points were used to fit the photo interpretation data on tree mortality to the photo base map.

The October 1975 photos were taken to provide a baseline of older mortality from which accurate interpretation of subsequent pine mortality could be made. Consequently, these photos were interpreted somewhat differently than were later photo sets. All photo-detected pine mortality on the October photos was circled, but not counted. These dead trees ranged from the oldest snags to the most recent faders. The area of each pine mortality spot was measured.

Each subsequent photo set, starting with March 1976, was interpreted for the presence of newly faded pine crowns. Any faders suspected of being new mortality spots were checked against previous photo sets to ensure that each dead pine was recorded only once and only on the first photo set on which that tree showed a faded crown.

Tree Count Estimates

The October 1975 photography was not ground checked on a statistical basis. Trees with faded crowns were inspected on the ground only to locate centers of current beetle infestation. The total number of dead pines was estimated as follows: a 1-ha area was circled on several of the large tree mortality spots, all dead pine trees detected on the photo were counted, and the mean and standard deviation of the counts were computed and multiplied by the total area of mortality for the study area.

A probability-proportional-to-size (Cochran 1963) sample of five spots was used to estimate the total dead pines detected on the March 1976 photos. For the later photos, all spots detected were ground-checked, and all dead trees were counted.

Figure 1—Aerial photographic transparencies are examined on back lighted split topped fluorescent light tables. The several tables permit cross checking dying trees to determine the earliest date fading was visible.

Ground Check Procedures

Tree mortality spots were visited by first locating the exact faded trees on site, using the photos as a guide, and collecting the desired data. A hand held field-board, using the sun as a light source, permitted stereo-viewing of the transparencies and greatly facilitated accurate location of mortality spot for ground checking.

All trees checked were labeled with a numbered metal tag nailed to the tree, inspected, and recorded, as to:

- Tree species
- Diameter at breast height, 4.5 ft (d.b.h.)
- Estimated total height (ETH)
- Crown color—ground and photo
- Cause of death
- If southern pine beetle killed, predominate lifestage present
- Height to base of infestation (HBI)

The heights of all trees at each spot were estimated and one randomly selected tree was measured by a clinometer. A simple linear regression model was developed to correct the estimated tree heights for all spots and provide an average height (HGT).

Volume and Value Estimates

The total volume killed in each time period during 1976 was calculated by using an equation that is generally applicable to loblolly pine growing on average quality sites in the Piedmont:[2]

Total volume (m^3) = 0.37 d.b.h.^{2} × HGT × no. trees

The average volume per tree killed in 1976 was computed by dividing the total volume by the number of trees. Assuming that the trees killed during 1973-1975 were the same average size as those killed in 1976, the total volume killed in those years was estimated by multiplying the average volume per tree by the number of trees killed in each of those years. These metric estimates were scaled, first to obtain cubic feet (35.61 ft^3/m^3), and then cords (76 ft^3/cd).[3]

The average price per cord for each year reported by Hutchins (1977) was applied to the volume estimates to derive an estimate of the value of the timber killed. Summing these values provided an estimate of the effect on beetle infestations on park resources during the 1973-1976 outbreak.

[2]Personal communication from William L. Hafley, School of Forest Resources, North Carolina State University, June 20, 1980.

[3]Personal communication from Richard L. Welch, Southeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture, July 15, 1980.

Figure 2—Print of a small-scale (1:78,000), high-altitude, black-and-white photo used as a base map to establish geometrical control of photo-detected tree mortality.

Tree Mortality Mapping

A photographic interpretation system called PISYS-1 was developed to provide computer assisted tree mortality mapping and data management in support of the work conducted at the Park (DeMars 1980). With this FORTRAN IV language system, the position of any previously observed point may be quickly located on the current photo and attributes compared as in back-checking tree mortality spots.

The main elements of PISYS-1 are these:

Photo base map—A photo base map with scale small enough to cover the entire test area is required. A high-altitude, black-and-white aerial photograph, from the Geological Survey, U.S. Department of Interior, dated 23 March 1973 was selected (*fig. 2*). The original scale of the photo was 1:78,000; we enlarged it four times to a scale of 1:19,500. The flying height (38,000 ft above mean ground elevation) and the 6 inch focal length lens, combined with the flat terrain at the study area, produced a photograph relatively free of planimetric distortion. This enlarged photo provided an accurate base map which is vital to the mapping system because of the infinite amount of unique detail available for establishing a control point net as compared to that available on a drafted map.

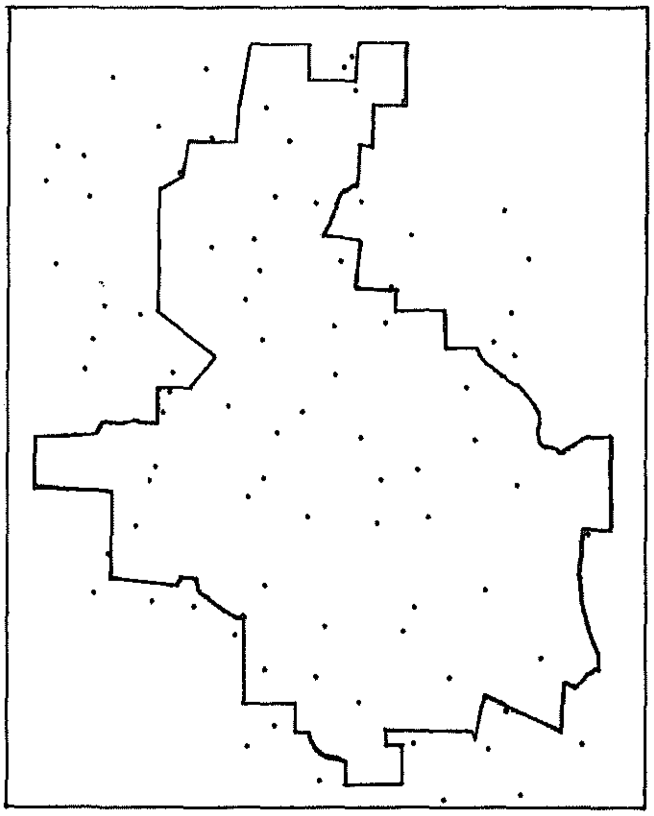

Figure 3—Control point net established for Umstead State Park, North Carolina, as an overlay to the photo base map.

Control points—Each aerial photo required nine well distributed points common to both the interpretation photo and the photo base map. These points were used to fit mathematically points of interest on each photograph to the base map. The control points were selected by choosing points which were readily observable on both the large-scale color infrared photos and the smaller scale photo base map (road intersections, buildings, large trees, bends in a stream, and other geographical features) (*fig. 3*). The chosen points were marked and numbered on both the photo interpretation template and the photo base map.

Digitization—The Cartesian coordinates of all information annotated on the templates of the 9- by 9-inch, large-scale, color infrared photos were digitized using a graphics calculator (*fig. 4*). This information included the locations of the template corners, fiducial marks, photo center, control points, and the centers of tree mortality spots. The coordinates of the control points as plotted on the 1:19,500 scale photo base map were also digitized.

Figure 4—Location coordinates of control points and tree mortality spots were digitized by using a Numonics Graphics Calculator interfaced with an ASR-33 teletype, stored on punched paper tape, then transmitted to a large computer for analysis.

Mathematical fitting—Six of the nine control points on each template were selected to calculate the transformation coefficients needed to fit the unknown point locations (tree mortality spots) to the photo base map. The coefficients were determined by simultaneously solving a pair of bivariate linear regression equations. A FORTRAN IV computer routine called FITIT was used to calculate the coefficients and predict the map positions of the points using the coefficients in the equations:

$$X_{map} = b_0 + b_1X_{photo} + b_2Y_{photo}$$

$$Y_{map} = b'_0 + b'_1X_{photo} + b'_2Y_{photo}$$

The effect of the coefficients in transforming the data are illustrated in *figure 5*.

Accuracy—The accuracy of the tree mortality spot mapping is determined by the fit of an independent set of control points (generally three or more). These additional points were not used in calculating the coefficients used to fit that photo to the base map. The accuracy established by these independent control points for each photo is, by inference, the accuracy with which the tree mortality spots are mapped. The predicted X-Y coordinates for each spot may be visualized as the center of a circle that probably contains the spot location depending upon its radius. A radius of $x + 2.76\ \sigma$ of the accuracy has a 97.5 percent chance of containing the spot at the 95 percent confidence level.

Plotting—The data files created by FITIT were plotted by using the routine GRAF to produce the maps and map overlays. Files of labeled coordinates are retained in plotter inches. For convenience, errors are multiplied by the photo scale so that accuracy is expressed as ground meters. The base map is retained at the scale of 1:19,500 but for this report, all maps have been reduced by 50 or 75 percent to scales of 1:39,000 or 1:78,000.

Vegetation Type Maps

The type boundaries from the 1973 vegetation type map in the Master Plan for the park were transferred by hand to an overlay fitting the photo base map.

The considerable southern pine mortality which occurred at the park between 1973-1975 caused significant changes in the vegetation types. This mortality was delineated on the October 1975 aerial photography. When this mortality was in spots 1 ha or larger, the type boundaries were modified to encompass this updated information on the 1976 type map.

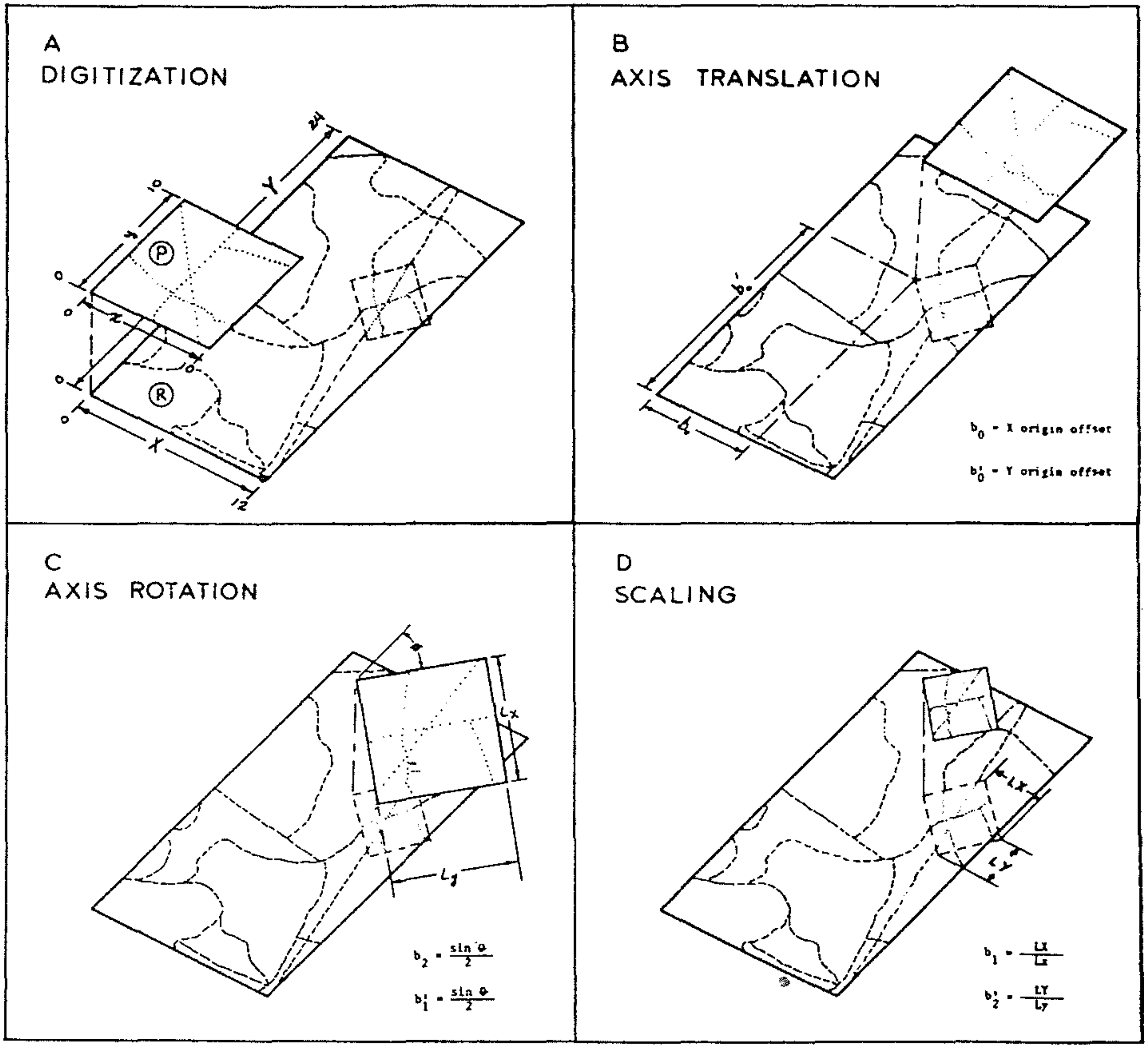

Figure 5—Effects of the affine transformation coefficients in mapping tree mortality data: (*A*) initial digitization, (*B*) translation of X and Y axes, (*C*) rotation of axes, (*D*) scaling.

RESULTS AND DISCUSSION

Tree Mortality 1973-1975

Extensive pine mortality occurred at the Park during the period 1973-1975. Most of the southern pines in 350 infestations occupying 137 scattered ha (339 acres) were killed. This mortality was detected and mapped from color infrared aerial photography taken on October 20, 1975 (*fig. 6*). Observed spot size frequency classes, where size refers to the number of hectares covered with standing dead pines, were computed (*table 1*). We estimated that there were 150 ± 16 dead pines per hectare of photo detected mortality, for a total of 20,550 ± 2,192 dead trees. This is a conservative estimate since it is based on photo counts only, which are generally lower than ground counts. Although no systematic ground check was undertaken, checks made at some of the larger mortality spots indicated that the beetle was responsible for virtually all of the pine mortality recorded on the October photos. The 21 largest spots (greater than 1.3 ha) accounted for only 3 percent of the spots, but accounted for 57 percent of the total tree mortality.

In 1973, the forest at the Park was composed of pine type (4.4 percent), mixed pines and hardwoods (59.3 percent), mixed hardwoods (34.5 percent), and water (5.8 percent) (*table 2, fig. 7*). By October 1975, this proportion had changed significantly owing to the high level of pine mortality during that period. A new type map reflected these changes (*fig. 8*). The area in each vegetation type polygon was computed (*table 3*) and totals were summarized (*table 2*).

The area of hardwood forest showed a net increase of 63 ha caused primarily by the conversion of mixed stands to hardwood. Eleven hectares of pine were converted to mixed or hardwood stands. Thus 4.5 percent of the pine and mixed stands existing in 1973 had been converted to hardwood by 1975. The revised type map and the October 1975 tree mortality map provided an accurate base line for the interpretation of the pine mortality recorded on subsequent aerial photography.

Tree Mortality 1976

A major decrease in the rate of pine mortality was already evident on the October 1975 photos. Mortality spots were composed primarily of snags, with only a few dead pine crowns still retaining faded needles.

Table 1—*Tree mortality 1973-1975, by spot size class at Umstead State Park, North Carolina, from October 20, 1975 photographs*

Spot size class		Spots	Cumulative proportion	Total		Cumulative proportion
ha	acres			ha	Trees	
0.04	0.1	179	0.51	7.2	1,080	0.05
.04- 0.08	.1- 0.2	1	.51	.1	15	.05
.08- 0.16	.2- 0.4	63	.69	6.5	975	.10
.16- 0.32	.4- 0.8	33	.79	7.9	1,185	.16
.32- 0.65	.8- 1.6	27	.87	12.7	1,905	.25
.65- 1.30	1.6- 3.2	26	.94	25.1	3,765	.43
1.30- 2.59	3.2- 6.4	9	.97	13.7	2,055	.53
2.59- 5.18	6.4-12.8	8	.98	28.2	4,230	.74
5.18-10.36	12.8-25.6	2	.99	12.9	1,935	.83
10.36-20.72	25.6-51.2	2	1.00	22.7	3,405	1.00
Total		350	1.00	137.0	20,550	1.00

Table 2—*Vegetation type map summaries for Umstead State Park, North Carolina, 1973 and 1976*

Types	Area						Tree species
	ha		acres		percent		
	1973	1976	1973	1976	1973	1976	
Pine	95	84	234	206	4.4	3.9	Loblolly, shortleaf
Mixed	1287	1235	3180	3052	59.3	56.9	Mixed pine, hardwoods
Hardwood	749	812	1850	2006	34.5	37.4	Mixed hardwoods
Lakes	39	39	98	98	1.8	1.8	
Total	2170	2170	5362	5362	100.0	100.0	

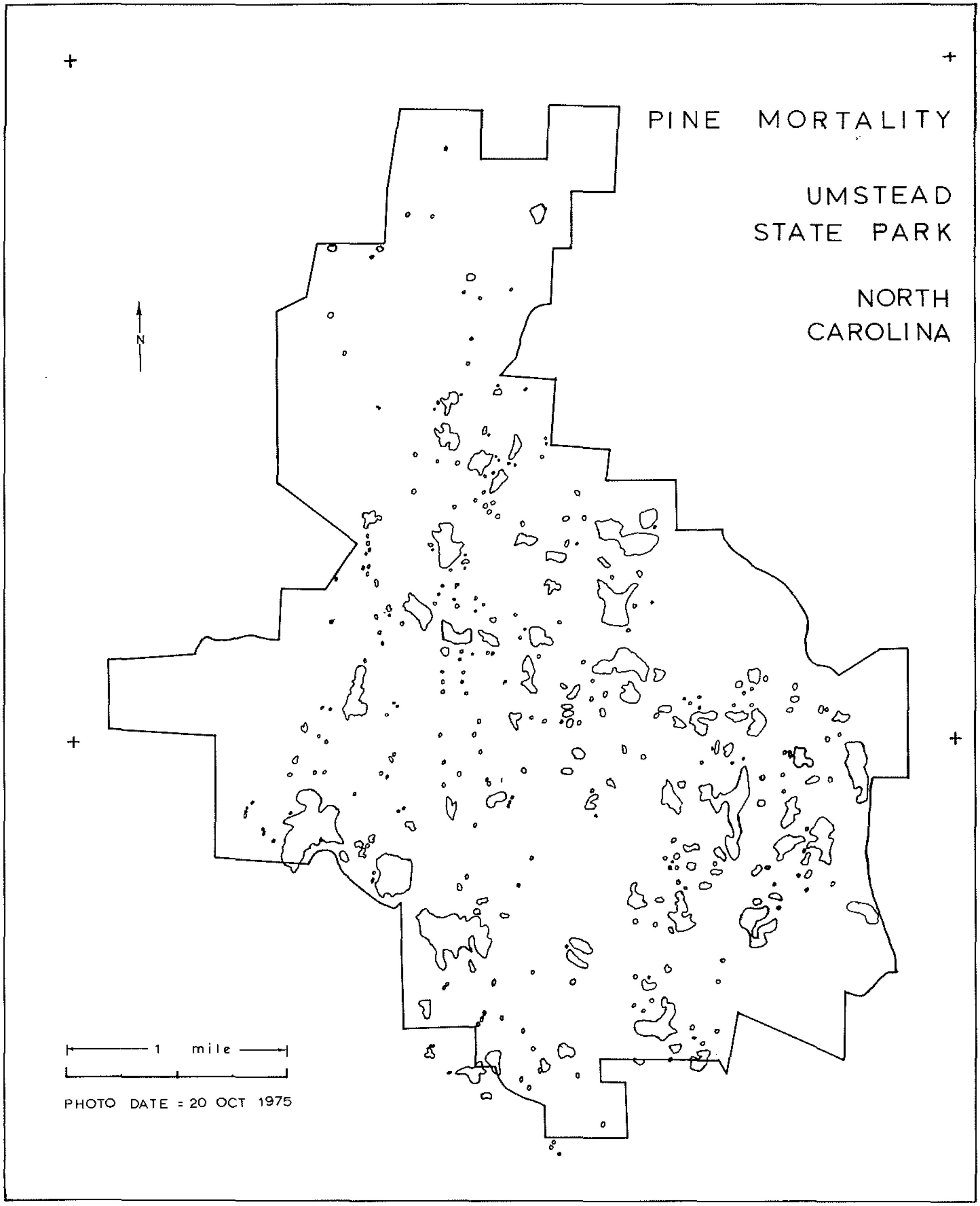

Figure 6—Pine mortality on 137 hectares (339 acres) was detected on color aerial photographs taken on October 20, 1976. Scale of map depicted is 1:39,000.

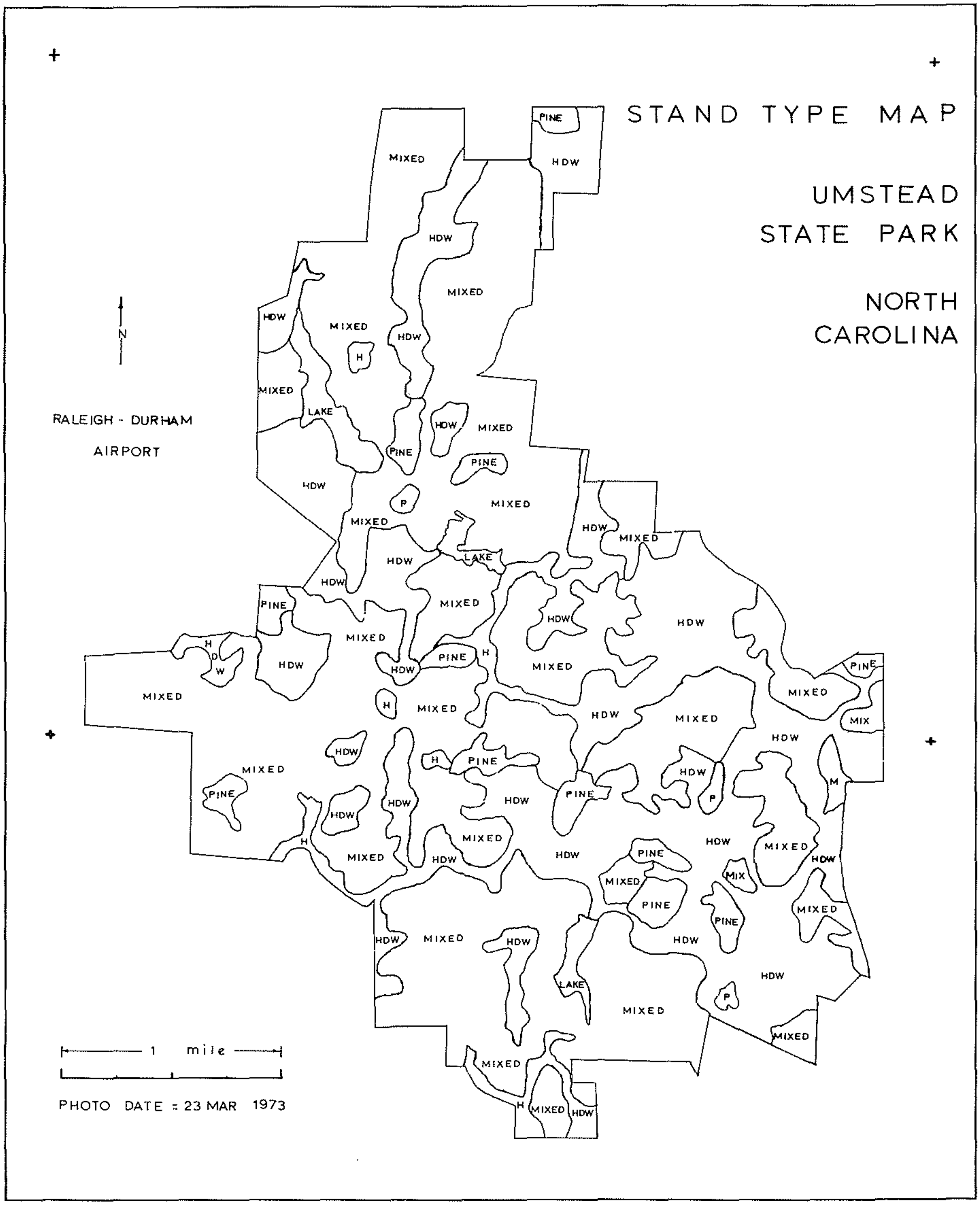

Figure 7—Umstead State Park, photographed in 1973, was composed chiefly of mixed pines and hardwoods, mixed hardwoods, and pine types. Scale of map depicted is 1:39,000.

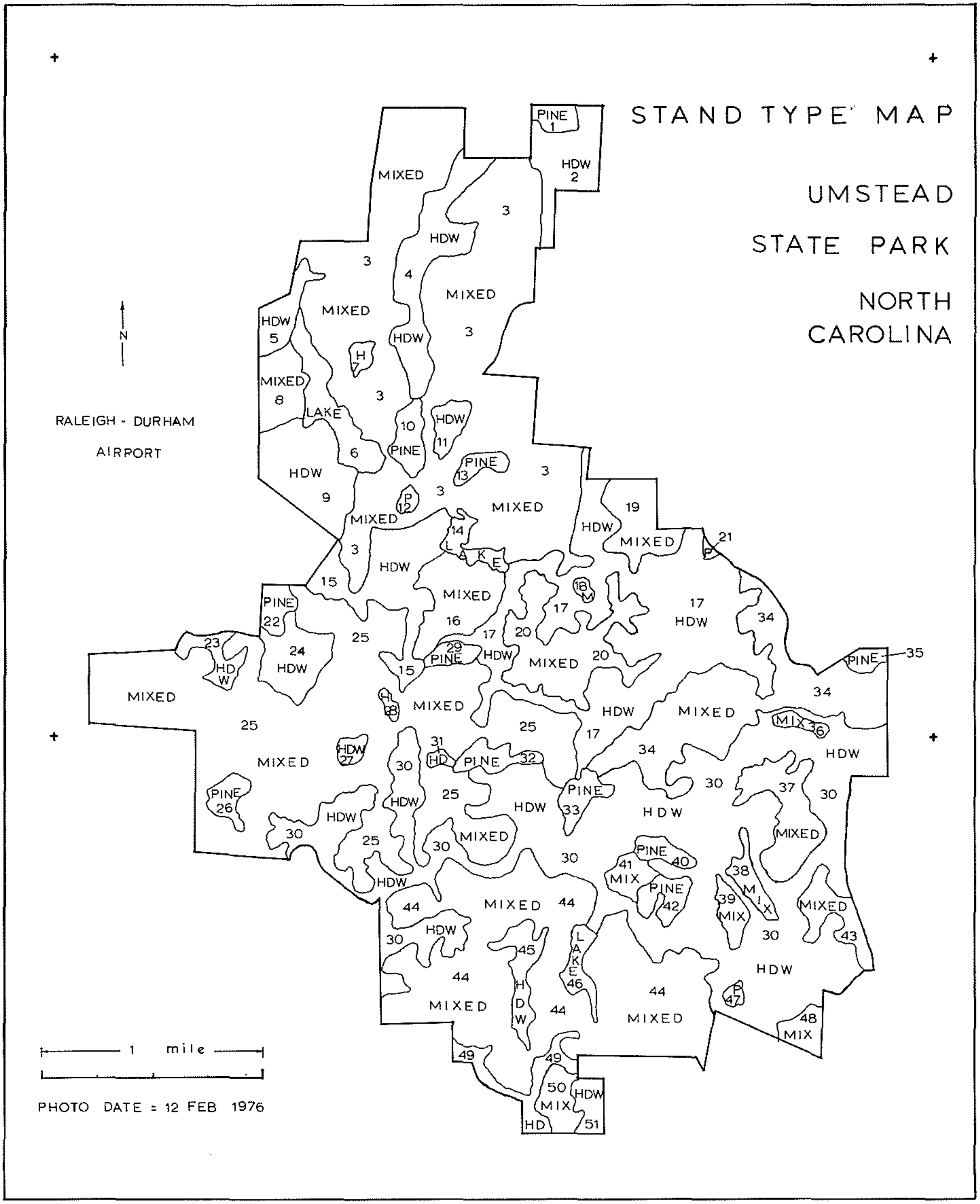

Figure 8—Vegetation type at Umstead State Park in 1976 had changed from that recorded in *figure 7* because of the extensive pine mortality. Scale of map depicted is 1:39,000.

Table 3—*Stand type polygon information, Umstead State Park, North Carolina, 1976*

Polygon	Stand type	Area (ha)	Polygon	Stand type	Area (ha)
1	Pine	6	27	Hardwood	4
2	Hardwood	28	28	Hardwood	2
3	Mixed	358	29	Pine	5
4	Hardwood	43	30	Hardwood	381
5	Hardwood	12	31	Hardwood	2
6	Lake	23	32	Pine	9
7	Hardwood	3	33	Pine	8
8	Mixed	18	34	Mixed	102
9	Hardwood	40	35	Pine	4
10	Pine	10	36	Mixed	4
11	Hardwood	7	37	Mixed	30
12	Pine	2	38	Mixed	8
13	Pine	5	39	Mixed	7
14	Lake	8	40	Pine	6
15	Hardwood	48	41	Mixed	8
16	Mixed	31	42	Pine	9
17	Hardwood	172	43	Mixed	16
18	Mixed	2	44	Mixed	227
19	Mixed	23	45	Hardwood	14
20	Mixed	49	46	Lake	8
21	Pine	1	47	Pine	2
22	Pine	7	48	Mixed	8
23	Hardwood	9	49	Hardwood	17
24	Hardwood	22	50	Mixed	11
25	Mixed	335	51	Hardwood	8
26	Pine	8			

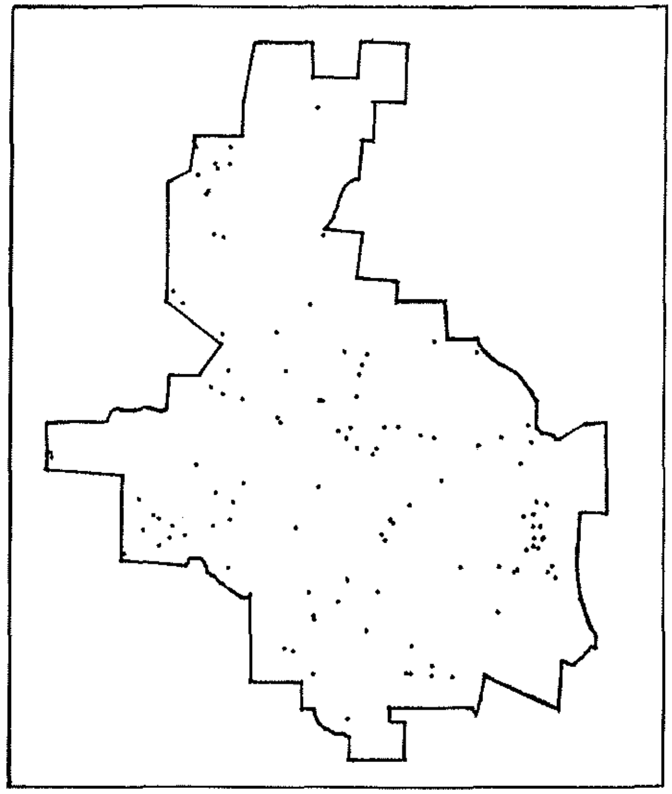

Figure 9—Aerial photography taken on March 17, 1976, shows the extent of pine mortality from southern pine beetle infestations. Scale of map depicted is 1:78,000.

Table 4—*Number and stand type for trees killed by southern pine beetle, Umstead State Park, North Carolina, spring and summer 1976*

Julian date	Spots detected	Trees		Stand type		
		Checked	Killed	Pine	Mixed	Hardwoods
				percent		
76077	120	13	[1]248	8	80	12
76117	13	28	24	0	86	14
76142	5	20	18	0	95	5
76176	2	2	2	0	0	100
76198	6	9	9	11	44	44
Total	146	72	301	—	—	—

[1]Probability proportional to size estimate of 248 ± 187.

March 1976 Photography

Pine trees with crowns fading between 20 October 1975 and 17 March 1976 were recorded on the March photography. We detected 120 separate mortality spots, and counted 225 newly dead pines since the October photos were interpreted. Among these spots, 45 were scheduled to be ground checked, but only 5 were because of a shortage of time and staff. All trees at these spots had been infested by southern pine beetles. We estimated that a total of 248 ± 187 pines had been killed by the southern pine beetle (*table 4, fig. 9*).

Some spots occurred along the margins of large, older mortality spots detected in October, but most of them were small and scattered throughout the study area. This difference suggests that the southern pine beetle populations as well as the size of the pine mortality spots had declined. While there were many spots in excess of 100 dead trees evident in October, the largest spot detected in March contained only 8 trees. This mortality produced negligible effects on the vegetation type, and no type lines on the map were modified.

Spring, Summer 1976 Photography

The spring and summer photo interpretation data for the months of April through July continue to show a drastic decline in newly killed pines associated with southern pine beetle (*table 4*).

A complete ground check of the April photo-detected spots showed 24 beetle-killed trees. A computer plotted map illustrates their distribution. Five spots were detected on the May photos, with 18 beetle-killed trees (*table 5,6*). Only two new spots were found in June, each with one beetle-killed tree. July photos showed six spots with nine beetle-killed trees. The spots were all small (less than 0.08 ha) and scattered, occurring almost entirely in mixed and hardwood type stands. No changes in the vegetation map were required.

Table 5—*Pine mortality at Umstead State Park, North Carolina, mapped from photos taken May 21, 1976*

Spot	Coordinates		Faded crowns[1]				Stand type	Ground check	Beetle-killed trees	Source photos
	X	Y	Total	Yg	Og	Rd				
4101	2.52	4.42	2	—	2	—	Mixed	Yes	4	1-3
4103	2.13	8.57	1	—	—	1	Mixed	Yes	4	1-7
4201	4.05	2.43	1	—	—	1	Hard-wood	Yes	1	2-3
4302	5.40	4.43	1	—	1	—	Mixed	Yes	6	3-4
4303	4.36	6.58	4	—	4	—	Mixed	Yes	3	3-6

[1]Colors: Yg = yellow-green, Og = orange, Rd = red.

Table 6—*Ground check data from tree mortality spots at Umstead State Park, North Carolina detected on photos taken May 21, 1976*

Spot	Tree	D.b.h. (mm)	Height (m)	Crown color		Insect		HBI[2] (m)	Tree species
				Ground	Photo	Species[1]	Stage		
4101	931	311	23	Snag	Orange	SPB	Aban	0.0	Short leaf
4101	932	274	25	Snag	Orange	SPB	Aban	.0	Short leaf
4101	933	285	27	Snag	Orange	SPB	Aban	.3	Short leaf
4101	986	137	16	Snag	Orange	SPB	Aban	.0	Short leaf
4103	916	434	26	Snag	Orange	SPB	Aban	.3	Loblolly
4103	917	370	23	Snag	Orange	SPB	Aban	.3	Loblolly
4103	978	343	20	Snag	Orange	[3]—	—	—	Loblolly
4103	979	250	17	Snag	Orange	SPB	Aban	.6	Loblolly
4103	980	202	17	Snag	Orange	SPB	Aban	.3	Loblolly
4201	915	435	31	Snag	Orange	SPB	Aban	.3	Short leaf
4302	923	338	24	Snag	Orange	SPB	Aban	.0	Short leaf
4302	924	208	18	Snag	Orange	SPB	Aban	.0	Short leaf
4302	925	234	17	Snag	Orange	SPB	Aban	.0	Short leaf
4302	926	265	20	Snag	Orange	SPB	Aban	.0	Short leaf
4302	927	325	22	Snag	Orange	SPB	Aban	.3	Short leaf
4302	975	238	17	Snag	Orange	SPB	Aban	7.2	Short leaf
4303	936	271	16	Snag	Orange	SPB	Aban	.3	Short leaf
4303	937	267	21	Snag	Orange	SPB	Aban	.3	Short leaf
4303	938	250	18	Snag	Orange	SPB	Aban	.3	Short leaf
4303	976	139	13	Snag	Hidden	—	—	—	Short leaf

[1]SPB = Southern pine beetle.
[2]Height to base of infestation.
[3]— = unknown.

Table 7—*Number and dimensions of trees killed by southern pine beetle, Umstead State Park, North Carolina, spring and summer 1976*

Julian date	Killed trees	D.b.h.		HBI[1]		Height[2]		Total[3] volume
		X	SD	X	SD	X	SD	
		mm		*m*				*m*³
76077	248	300	82	0.45	0.49	19.5	3.8	186.00
76117	24	326	100	.30	.25	21.1	3.5	23.28
76142	18	283	77	.28	.36	21.0	4.4	12.96
76176	2	311	12	.60	.00	21.5	2.1	1.54
76198	9	292	90	.91	.93	24.8	8.0	8.37
Total	301							232.15

[1]Height to base of infestation.
[2]Total tree height estimated by regression.
[3]Volume (m^3) = 0.37 × d.b.h.^{2} × HGT × no. trees.

Because of the collapse of the beetle population and the resulting decline in pine mortality at Umstead State Park, we discontinued sequential photographic coverage.

Tree Heights

Estimated tree heights (25.6 ± 5.3 m) did not differ significantly from measured heights (24.0 ± 5.7 m) (*table 7*). The relationship is characterized by the linear regression:

$$Y = 2.08 + 0.86X$$

in which

Y = measured tree height

X = estimated tree height

Volume and Value

To estimate the volume of trees killed, we prorated the 20,550 trees killed in the 3 earlier years (1973-1975) by using the proportion of spots detected by the North Carolina State Forest Service in the surrounding area of Wake County during the infestation period occurring in a given year. On that basis, the estimated number of trees killed, by year, was 4932 in 1973, 7398 in 1974, and 8220 in 1975 (*table 8*). We then estimated the total volume of trees killed each year by applying the average cubic volume per tree killed in 1976 (0.77 m^3). By scaling to obtain round wood equivalents, we computed the volume, in cords, by year: 1785 in 1973, 2677 in 1974, 2975 in 1975, and 109 in 1976 (*table 8*). By applying the average round wood prices for each year (Hutchins 1977), we estimated that the value of trees killed during the outbreak was $240,581.

Mapping Tree Mortality

Predicted map coordinates for tree mortality spots detected on the March through July 1976 photography were plotted on the 1:39,000-scale maps (*fig. 9,10*).

Table 8—*Amount and value of trees killed by southern pine beetle, Umstead State Park, North Carolina, 1973-1976*

Year	Trees killed[1]	Volume killed		Price	Total value
		m^3	[2]*cords*	[3]*dollars/cd*	*dollars*
1973	4,932	3797.6	1784.9	28.20	50,333
1974	7,398	5696.5	2677.4	32.80	87,817
1975	8,220	6329.4	2974.8	33.20	98,764
1976	301	232.2	109.1	33.60	3,667
Total	20,851	16,055.7	7546.2	—	240,581

[1]Prorated by proportion of tree mortality spots detected by the North Carolina Forest Service in Wake County, N.C. for the years 1973-1975 (personal communication from Coleman Doggett, North Carolina State Forest Service, July 12, 1980).
[2]Based upon 76 ft^3/cord of roundwood and 35.61 ft^3/m^3.
[3]Hutchins (1977).

The mapping system performed well, providing tree mortality maps with an average ground accuracy of 12 ± 5 m (40 ± 16 ft) (*table 9*). The accuracy of the fit of tree mortality spots, inferred from the fit of the independent set of control points (ATR), averaged 16 ± 5 m (53 ± 17 ft) and ranged from 1 to 30 m (3 to 99 ft). Mortality spot comparisons between sequential photos were aided by machine comparison of location information rather than solely by the ocular comparisons of the photo interpreter. Analysis of the distance between nearest neighbor trees infested by the southern pine beetle is also possible.

CONCLUSIONS

Tree mortality information from this study provide a coherent data base to relate to the other southern pine beetle studies which have been conducted at Umstead State Park. The original plan was to provide complete tree mortality data for an area to combine with within-tree beetle population estimates, in order to produce estimates of the total beetle population over a wide area. The total beetle population equals the average beetle density per unit of bark × the average number of infested bark units per tree × the number of trees (Stephen and Taha 1979a, 1979b).

Population sampling was discontinued (due to the population decline) at Umstead State Park before sufficient data were collected to make these estimates.

The procedures made available here illustrate the type of data which can be collected with the aid of aerial photography and some of the factors to be considered in planning such an effort. Such products provide the type of information vital in evaluating both natural southern pine beetle populations and the results of experimental controls.

The value of trees lost to beetle infestation was estimated at more than $240,000. The economic meaning of this dollar value may be subject to question. In a strict

Table 9—*Average accuracy of fit of control points (CTR) and test points (ATR) obtained with the PISYS-1 photo information mapping system for Umstead State Park, North Carolina, 1976*

Julian date	CTR				ATR				Units
	X	SD	Range		X	SD	Range		
76077	45	17	80	14	59	20	99	35	(feet)
	14	5	24	4	18	6	30	11	(meters)
76117	35	9	59	28	47	11	30	8	(feet)
	11	3	18	9	14	3	9	2	(meters)
76142	38	8	55	26	40	12	56	19	(feet)
	12	2	17	8	12	4	17	6	(meters)
76176	26	9	39	15	51	12	64	35	(feet)
	8	3	12	5	16	4	20	11	(meters)
76198	51	20	84	26	68	15	59	4	(feet)
	16	6	26	8	21	5	18	1	(meters)
Overall	40	16	84	14	53	17	99	4	(feet)
accuracy	12	5	26	4	16	5	30	1	(meters)

Figure 10—Spots showing trees killed by the southern pine beetle were detected on photographs taken on (*A*) April 26, 1976; (*B*) May 21, 1976; (*C*) June 24, 1976; and (*D*) July 16, 1976. Scale of maps depicted is 1:78,000.

sense, the tree mortality is not an economic loss, because the policy of the Park is to treat the area as an unmanaged "natural forest" and logging green trees, or even the salvage of killed trees, is not a possibility. An alternative view however, is to consider the $240,581 as an investment, or cost, of environmental protection.

The procedures developed to map and compare tree mortality should be applicable to many studies of bark beetle damage assessment and population dynamics. The specifics on impact are more limited, but are probably typical of other parks and natural areas in the Southeast where timber stands are unmanaged.

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In 1975-1976, pine trees killed by the southern pine beetle (*Dendroctonus frontalis* Zimm.) in a 2170-hectare (5362-acre) area at the William B. Umstead State Park in central North Carolina, were monitored by sequential color infrared aerial photography. From 1973 through summer 1975, beetles in 350 infestation spots killed more than 20,500 pines on 137 hectares (339 acres). From October 1975 to July 1976, an additional 301 dead pines were detected at 146 tree mortality centers. Southern pine beetles were associated with 98 percent of these dead trees. Pine mortality dropped rapidly from 248 trees killed in fall and winter at 120 spots to 9 trees killed in July at six spots. The volume of timber killed during the outbreak exceeded 16,000 m^3 (7500 cords) of roundwood valued at more than $240,000. Strictly speaking, this is not an economic loss because the Park's management goal is to maintain a "natural forest."

Retrieval Terms: Dendroctonus frontalis, southern pine beetle, *Pinus*, Coleoptera: Scolytidae, damage surveys, detection, volume losses, economic impact, ecologic impact