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AIRBORNE VIDEOGRAPHY AND GPS FOR ASSESSMENT OF FOREST DAMAGE IN SOUTHERN LOUISIANA FROM HURRICANE ANDREW[1]

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ABSTRACT: One week after Hurricane Andrew made landfall in Louisiana in August 1992, an airborne videography system, with a global positioning system (GPS) receiver, was used to assess timberland damage across a 1.7 million-ha (4.2 million-acre) study area. Ground observations were made to identify different intensities of timber damage and then cross-referenced with the aerial video using GPS coordinates. Flight lines were established at 16-km (10-mile) intervals perpendicular to the storm's path. The nominal flight altitude of 600 m (2,000 feet) above ground level and a 55-mm focal-length camera lens resulted in a ground swath averaging 92 m (300 feet) in width. Video frames were captured digitally from the 8-mm analog videocassette at 800-m (half-mile) intervals along each flight path. Each video frame was interpreted for timber damage and placed into one of four arbitrary categories of bole-volume damage. The video frame locations were grouped into relative damage-zone polygons in a geographic information system (GIS). The polygons were then used to retrieve forest inventory plot information by damage zone and to estimate volumes of damaged timber.

INTRODUCTION

The USDA Forest Service, Southern Forest Experiment Station conducts forest inventories through its Forest Inventory and Analysis unit (SO-FIA) across seven Midsouth States (Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas) and Puerto Rico. Statewide inventories are maintained in computer databases at the SO-FIA office in Starkville, Mississippi. Different methods of updating these periodic inventories are currently being researched (Evans and Beltz 1992) to estimate annual rates of change, location, and extent of timber. Of equal importance is a need for quick evaluation of catastrophic events such as hurricanes, heavy fire seasons, and major insect outbreaks (Evans and Beltz 1991).

Hurricane Andrew made landfall Tuesday, August 25, 1992, on the Louisiana coast of the Gulf of Mexico. The most current Statewide forest inventory of Louisiana was completed by SO-FIA in

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1991 (Vissage *et al.* 1992). Aerial reconnaissance reports from the Louisiana Department of Agriculture and Forestry[3] indicated widespread damage to timberland impacted by the hurricane. Hence, there was a need to assess the timber damage that occurred since the latest forest survey.

HURRICANE-IMPACTED STUDY AREA

After Hurricane Andrew left a devastating wake of destruction in southern Florida, forest resource damage assessment plans were developed for its imminent landfall on the northern coast of the Gulf of Mexico. Predictions were for the hurricane to hit land in Mississippi or Louisiana. Flexible plans were developed for an airborne videography flight to perform a quick assessment of anticipated timber damage. After Andrew's landfall in southern Louisiana, the Atchafalaya River Basin and surrounding bottomland forests were selected as the primary study area.

Maximum sustained winds were recorded at 115 knots when Andrew made landfall in Louisiana. As the hurricane moved northward (Figure 1), it rapidly lost strength and was subsequently downgraded to a tropical storm. The eye of the hurricane traveled along the western edge of the Atchafalaya River Basin. The area immediately to the east of the storm track was thought to have suffered the most severe damage, as is typical of northern gulf coast hurricanes. The affected area not only included the Atchafalaya Basin but also the surrounding swamps and bottomland forests of the Mississippi River floodplain.

Primary timber species in the southern part of the basin include: baldcypress (*Taxodium distichum (L.)* Rich.), water tupelo (*Nyssa aquatica* L.), black willow (*Salix nigra* Marsh.), and eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.). Drier sites in the northern part of the basin and surrounding alluvial flood plains support a wide variety of hardwoods such as: oaks (*Quercus* spp.), ashes (*Fraxinus* spp.), elms (*Ulmus* spp.), boxelder (*Acer negundo* L.), American sycamore (*Platanus occidentalis* L.), sugarberry (*Celtis laevigata* Willd.), red maple (*Acer rubrum* L.), locusts (*Gleditsia spp.*), pecan (*Carya illinoensis* (Wangenh.) K. Koch), and other hickories (*Carya spp.*) (Vissage *et al.* 1992; Beltz and Bertelson 1990).

MISSION PREPARATION

Plans were coordinated with the North Carolina Forest Service to use an aircraft and an experienced aerial photography pilot to fly the video mission. There was a slight delay in beginning the video mission because the storm moved inland over Mississippi, eventually turning eastward toward North Carolina. This presented a problem for the pilot to fly safely from North Carolina to

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[3]Louisiana Department of Agriculture and Forestry. 1992. Unpublished aerial reconnaissance reports. Baton Rouge, LA.

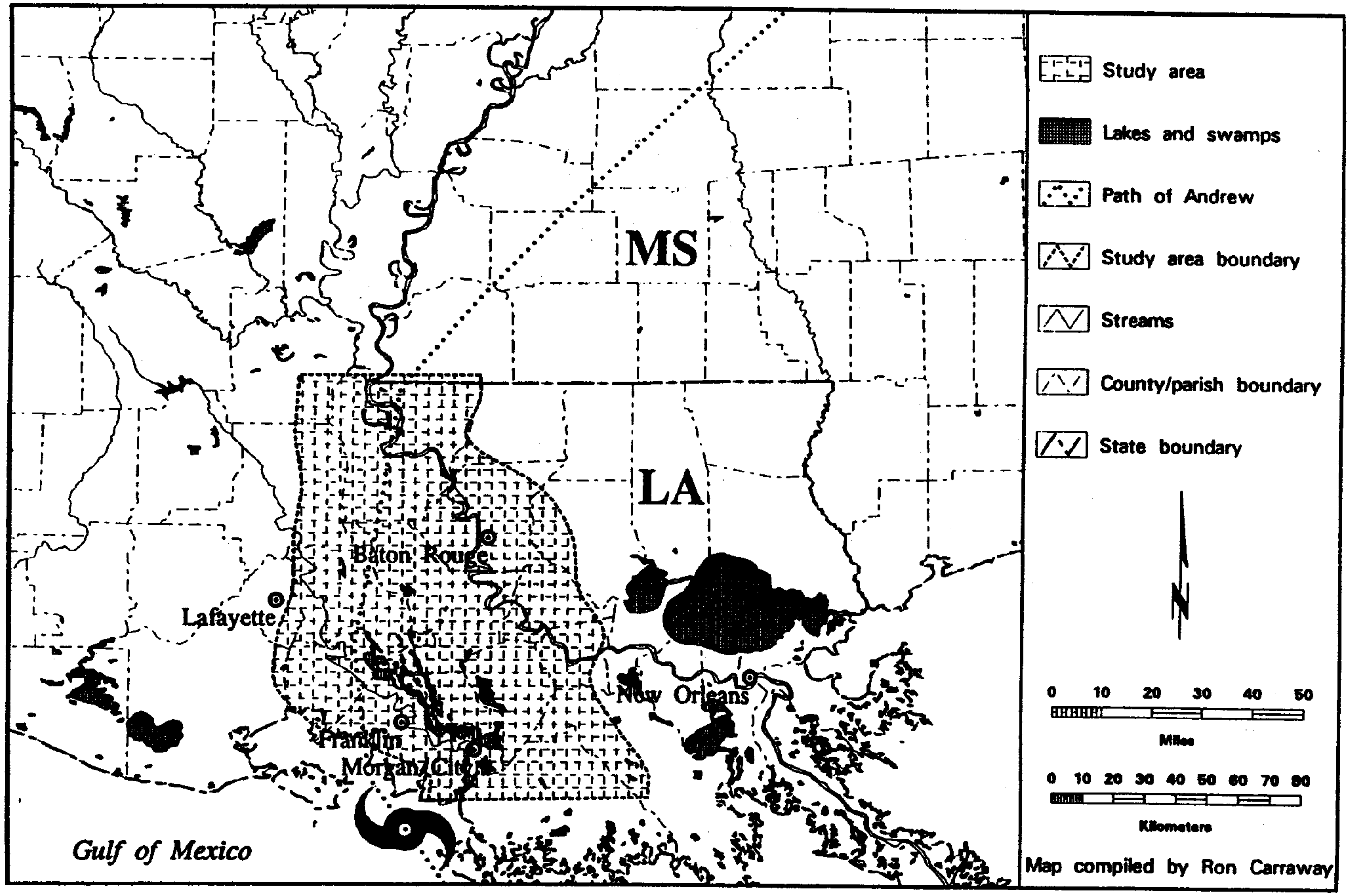

Figure 1. Reference map of Hurricane Andrew study area.

Mississippi for installation of the video equipment. The delay resulted in missing the 2 days of clear weather immediately following the hurricane, August 28 and 29.

The video equipment was installed in a Cessna[4] 185 on Saturday, August 29, and the video mission was flown on Sunday, August 30. The skies were becoming partly cloudy by Sunday, with up to 50-percent cloud cover blowing in from the gulf.

VIDEO EQUIPMENT

The video equipment consisted of an electronically shuttered video camera head, a 55-mm focal-length camera lens, a portable 8-mm videocassette recorder, and a portable color monitor. The color video camera head used a high-resolution, charge-coupled device (CCD) that generated a horizontal resolution of 470 composite television lines. The cassette recorder was installed in a self-contained unit that also housed a small computer, a keyboard, and a slot for a global positioning system (GPS) receiver or loran-C (Long Range Navigation) receiver. The computer generated captions on the video image containing pertinent information such as date, time, and GPS or loran-C coordinates. The keyboard allowed additional entry of observational text as the aerial video was being recorded. There were also inputs for a Trimble Pathfinder™ GPS receiver and audio signals. GPS input was standard for the mission. A detailed description of the system has been provided by Evans and Beltz (1991).

VIDEO MISSION

Flight lines were established at 16-km (10-mile) intervals due to time and budget constraints. The aerial video was flown at 600 m (2,000 feet) above ground level to provide a video swath approximately 92 m (300 feet) in width. Each video frame covered an area of about 0.6 ha (1.5 acres) to ensure a minimum sampling area of 0.4 ha (1.0 acre) per video frame. Autonomous GPS coordinates were superimposed on the video frames in flight. All data were recorded on 8-mm videocassettes for retrieval and interpretation on UNIX®-based computer workstations at a resolution of 0.15 m (6 inches) per picture element.

Field crews visited forest stands that met the damage criteria set out in Table 1. Accordingly, ocular timber damage information, photographs, and GPS coordinates were recorded for each site. The ground locations were flown with aerial videography using the field-gathered GPS ground coordinates. The narrow field-of-view of the 55-mm camera lens and the strong gulf winds made this task cumbersome. Some field points needed second and third overflights to acquire the necessary video imagery. Aerial video was recorded

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[4]Mention of equipment, products or company names is for information only and does not constitute official endorsement by the USDA Forest Service.

over the field locations to verify and cross-reference the video interpretations using the ground-point field information and corresponding aerial video imagery. Low-level videography was also recorded above a heavily damaged area at 100 m above ground level to help distinguish species of downed trees.

Table 1. Forest damage assessment variables for visual interpretation of video frames.

1. Ground use
   a. nonforest
   b. forest

2. Forest type
   a. pine
   b. baldcypress
   c. hardwoods
   d. oak-pine

3. Volume damage (mortality)
   a. no visible damage
   b. 1 to 33 percent of timber volume downed (light)
   c. 34 to 67 percent of timber volume downed (moderate)
   d. over 67 percent of timber volume downed (severe)

4. Predominant timber type affected by volume damage
   a. softwoods (excluding baldcypress)
   b. baldcypress
   c. hardwoods
   d. plot has more than one forest type group, and all are affected more or less equally
   e. indeterminate

5. Live tree damage (form/crown damage)
   a. no visible damage
   b. 1 to 33 percent of canopy damaged or basal area affected by other form damage
   c. 34 to 67 percent of canopy damaged
   d. more than 67 percent of canopy damaged
   e. indeterminate

6. Predominant timber type affected by live tree damage
   a. softwoods (excluding baldcypress)
   b. baldcypress
   c. hardwoods
   d. plot has more than one forest type group, and all are affected more or less equally
   e. indeterminate

VIDEO INTERPRETATION

Video frames were captured in digital form on UNIX-based workstations at an approximate rate of 1 per 800 m (0.5 mile) of flight line. This provided roughly twice the sampling intensity used in current field inventory procedures by SO-FIA. Each digital video frame was labeled as forest or nonforest and stored on the computer for later retrieval and interpretation. Video images containing more than 50-percent forest cover were codified as forested ground use. In addition, contiguous forest area had to be greater than 0.4 ha (1 acre), a minimum for SO-FIA inventory forest area (Vissage *et al.* 1992). Forested locations are indicated in Figure 2.

Each forested video frame was displayed and, utilizing the assessment variables given in Table 1, a determination was made for the predominant timber type group affected by timber damage. Two types of damage were interpreted: volume (bole mortality), indicating probable tree death; and form (bole and crown damage), indicating form damage in live trees. This damage-class information was entered into a GIS of the study area.

Form damage was highly variable and provided insufficient information relating to volume loss or future mortality. It provided only enough information to show that about two-thirds of the study-area forest received some form of foliage or crown damage. Although form damage was entered in the GIS as attribute information, it was not included for this study but may be addressed in a later publication. Therefore, volume damage due to bole mortality (downed timber) is discussed in the remainder of this paper.

Two crews of two persons each interpreted the captured video frames. The video frames paired with ground observations through GPS coordinates were reviewed and studied before aerial video interpretation was accomplished. Ground evaluations of affected basal area showed that the linear features of the fallen trees and the distinct bright spot of the fractured boles with the crowns snapped off were more obvious on the video images than crowns and relatively intact boles of the standing, wind-defoliated timber. Further, the defoliated crowns and boles of the standing small trees were not as evident on the aerial video as the large trees. Hence, both crews frequently worked together to review each crew's interpretations, to compare them with the ground-truth video, and to assure consistency in the video analysis.

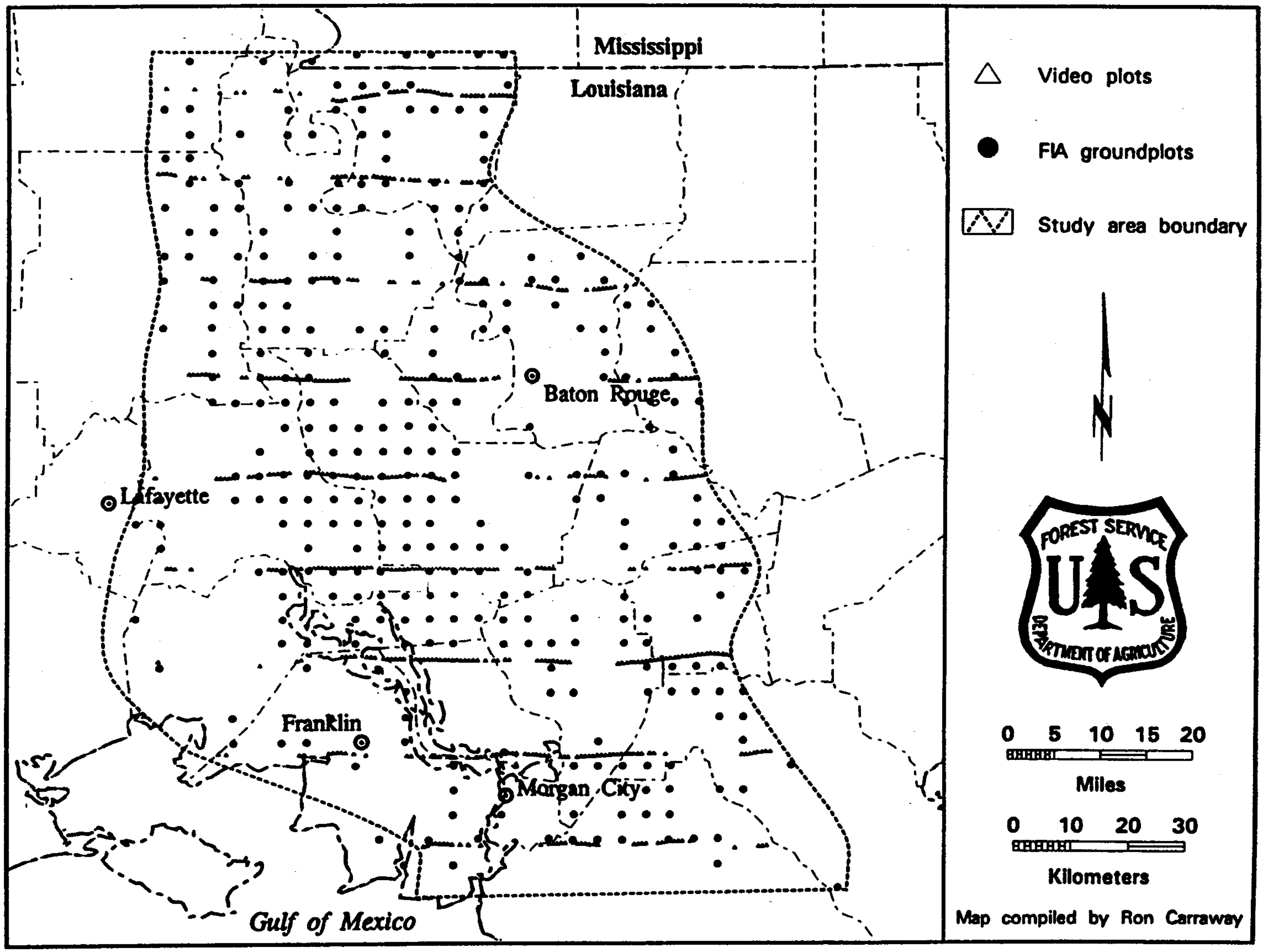

Figure 2. Forested video plots and Forest Inventory and Analysis groundplots.

GEOGRAPHIC INFORMATION SYSTEM (GIS) DEVELOPMENT

GPS coordinates (latitude and longitude) were transcribed from the video images to the GIS database as each image was interpreted visually. These autonomous GPS coordinates, assumed nadir for each video frame, were entered and referenced as ground-point locations in the GIS. Each location was assigned the corresponding damage assessment value as a point attribute. From item number 3 in Table 1, four damage-severity classes were coded to describe the volume damage observed within each video frame: 3 = severe, 2 = moderate, 1 = light, 0 = no damage.

GPS coordinates designating the ends of each video flight line established the study area boundary. Locations for the forested video frames were plotted by damage-class attributes. From the four damage classes, five damage zones were established: 4 = severe, 3 = moderate, 2 = light, 1 = scattered light, 0 = no damage. The following describes the methodology used as the basis for determining damage-class limits along each flight line to create the damage-severity polygons.

Each east-west flight line was treated independently from the other flight lines to identify end-points (limits) for each of the five damage zones. All video frames containing severe damage were located in a cluster to the east of the hurricane path. Extending progressively in both directions from this severe-damage zone were frames classed as moderate damage, then light, and finally, interspersed clusters of light damage and no damage. The midpoint within the heaviest damage per flight line was used as the central axis of concentric lighter damage zones.

To determine the limits of each damage zone, a focal window of average damage values was moved within each range using class weights of: 3 = severe, 2 = moderate, 1 = light, 0 = no damage. Nonforest locations were assigned nearest neighbor values of weighted averages. The window size was adjusted to one-half of the total geographic range of the damage zone under evaluation. Thus, the average damage values within the end-points were: 2.50 to 3.00 for severe, 1.50 to 2.49 for moderate, and 0.50 to 1.49 for light. The severe, moderate, and light damage end-points along each flight line were contoured to form damage-severity polygons for the study area (Figure 3).

A polygon of scattered light damage was delineated to distinguish a transition zone between light damage and no damage. Most storm damage was concentrated in the first three categories of contiguous damage. The scattered light-damage category, however, contained isolated pockets of damage extending beyond the area of concentrated damage. This area included all clustered video interpretations of light damage. Six isolated incidences of light damage were scattered throughout the north end of the 205 frame locations comprising the no-damage zone. The information for forested video frame locations is summarized by damage class and damage zone in Table 2.

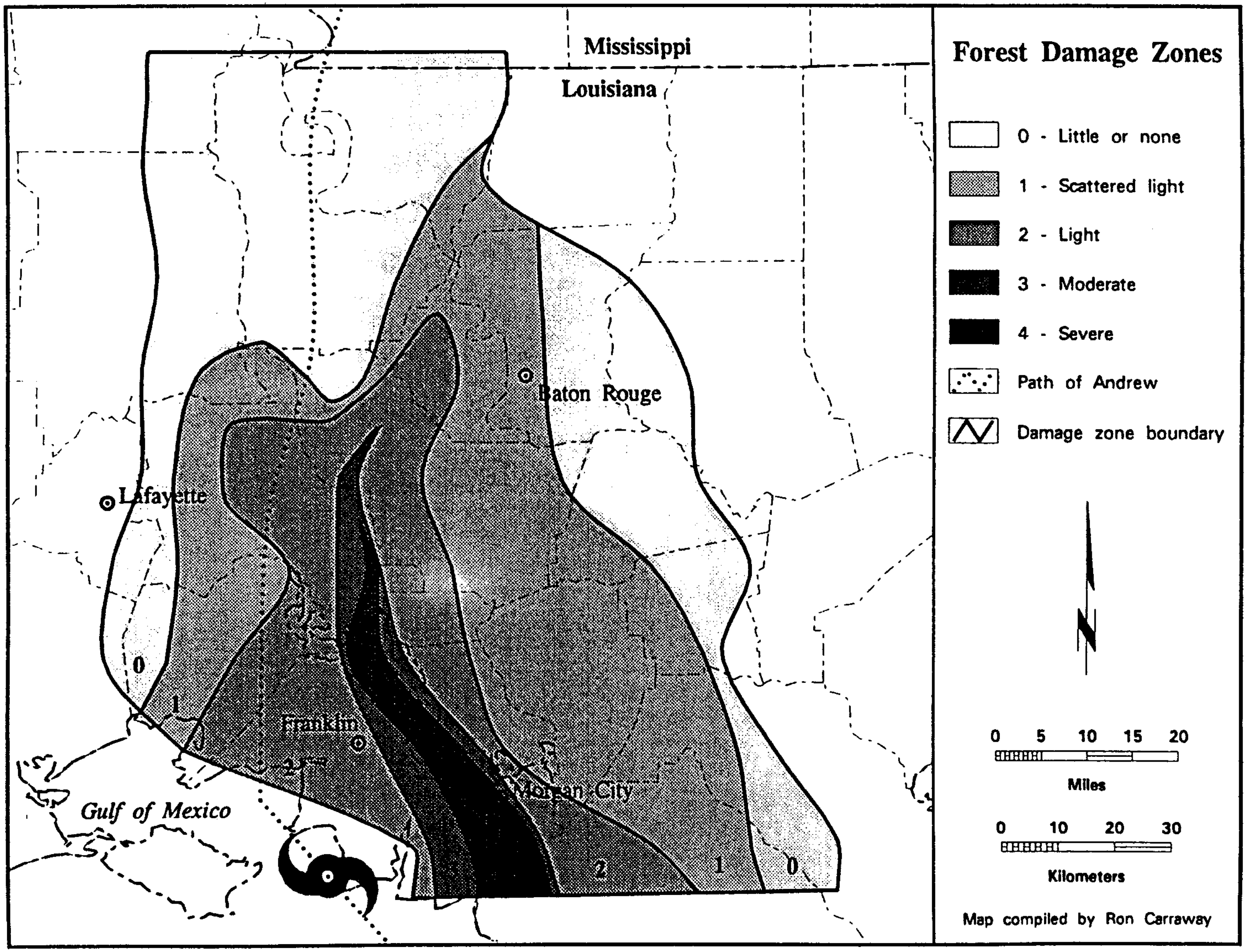

Figure 3. Path of Hurricane Andrew in southern Louisiana and zones of forest damage.

Table 2. Number of forested video frames by damage class and damage zone.

DAMAGE ZONE	No Damage (0%)	Light (1 to 33%)	Moderate (34 to 66%)	Severe (67 to 100%)
	VIDEO FRAME FOREST DAMAGE CLASS			
Severe	0	0	3	13
Moderate	0	12	15	4
Light	20	103	12	0
Scattered light	106	59	1	0
Exterior of damage zones	199	6	0	0

The GIS damage-zone polygons were used to retrieve SO-FIA field inventory data, using the timber survey plot locations within each damage zone for trees 12.7 cm (5.0 inches) in diameter at breast height and larger. Forest volumes were retrieved for each damage zone along with estimates of forest and nonforest area. The video analysis scheme was designed to estimate percentage of volume, not area, of downed timber as displayed on each sampled video frame. Therefore, no attempt was made to estimate area of damaged forest.

RESULTS AND DISCUSSION

The study area covered approximately 1.7 million ha (4.2 million acres). Less than half, about 730,000 ha (1.8 million acres), was determined to be forested ground use, with about 445,000 ha (1.1 million acres) of forested land receiving some volume damage. Table 3 lists approximate area by damage zone. Forest area is derived from SO-FIA sample data, which are subject to statistical error. Refer to Vissage *et al.* (1992) for further information.

Table 3. Approximate area by damage zone.

DAMAGE ZONE	AREA (hectares) TOTAL	FOREST
(4) Severe	57,900	25,740
(3) Moderate	67,600	25,820
(2) Light	338,100	179,850
(1) Scattered light	572,400	210,680
(0) Exterior of damage zones	658,400	286,810
TOTAL	1,694,400	728,900

Over half of the study area was nonforested; either farmland, swampland, or rights-of-way. Consequently, a portion of the damage could be attributed to edge-effect wind damage. The six video frames of light damage observed in the undamaged zone were in close proximity to a nonforest area. Trees adjacent to open areas were more subject to wind damage because the crowns were not protected by a surrounding canopy.

Species composition and terrain also played a part in defining the damage zones. Species composition changed as the terrain varied from coastal plain to river terraces and meander scars to swamp. Black willow and water tupelo were especially susceptible to windthrow in swampy areas with standing water. Young timber in the Atchafalaya Basin also sustained wind breakage. This was noted in areas containing breakage of water tupelo and young baldcypress that had not yet developed extensive amounts of heartwood. Mature baldcypress appeared to weather the storm better than surrounding hardwoods. Resilience to storm damage by mature baldcypress was noted in studies carried out in the Hurricane Hugo-damaged area of South Carolina (Sheffield and Thompson 1992; Putz and Sharitz 1991). The field observations supported the species-group damage interpretations of the video imagery.

The pockets of clustered damage, relating to species composition, resulted in the following examples. First, a 4.5-mile and a 4.0-mile segment of video locations along one flight line containing no video-interpreted damage were included within the scattered light-damage zone. These locations were comprised of storm-resistant baldcypress. Second, a pocket of moderate damage was included near the outer edge of the light-damage zone. This was comprised of black willow (especially susceptible to windthrow) with upturned root mats discernible in the video imagery. This information was verified with ground truth information. Overall, storm damage was less severe in mature baldcypress than in other forest type groups.

CONCLUSION

The use of current airborne videography techniques allowed a rapid assessment of forest resource damage in southern Louisiana caused by Hurricane Andrew. Airborne videography reduced the need for ground analysis of the damaged area. This was especially advantageous due to the reduced ground accessibility in the wake of the hurricane. In addition, GPS coupled with aerial videography provided for quick orientation of the video imagery and allowed the video frame location and corresponding damage class to be entered into a GIS. In turn, the GIS linked the video interpretation schemes with the SO-FIA database to derive estimates for the volume of damaged timber.

A relatively small area was affected by heavy damage. However, a much broader area of scattered light damage occurred around the concentrated area of heavy damage, affecting a large volume of timber. Crown and form damage were also evident on aerial videography. However, an analysis of form damage was not attempted since the effect of damage on future volume and mortality was uncertain. This study concentrated on downed timber having a diameter at breast height of 12.7 cm (5.0 inches) and larger. For information on the storm effects on smaller trees and the volume affected by tree-form damage, a more detailed ground-based study is needed. Landsat Thematic Mapper imagery will be used in another study to investigate a more comprehensive characterization of the spatial distribution of the storm damage.

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