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FIG. 1. John Wear of the USDA Forest Service's Pacific Southwest Forest and Range Experiment Station prepares the equipment that is to be used to take the temperature of trees. The pod attached to the lower frame of the helicopter contains a heat-sensing unit and a closed circuit TV camera. (*Photo by Gregg Perry.*)

Sick Trees

A helicopter, a TV camera and a heat-sensing radiometer are used in an effort to detect root rot disease in Douglas fir.

JOHN F. WEAR IS A space age *doctor* who takes the temperatures of trees rather than human beings. And he does it hovering 150 feet above the forest in a helicopter, with a faithful assistant familiar to millions of television viewers.

From the results of Wear's research, it is hoped disease centers in Pacific Northwest forests can be located and harvested before they become economically worthless and before they have a chance to infect other trees. Wear, a research forester in remote sensing with the U. S. Forest Service's Pacific Southwest Forest and Range Experiment Station, heads the survey techniques study, which is financed by the National Aeronautics and Space Administration-(NASA).

A major forestry problem is the reduction of growth and extensive loss of timber due to forest diseases. Many richly-wooded areas are far from established roads, and detection of distressed timber is an arduous and impractical task from the ground. Aerial location of disease centers needs some means of reference, both for ground crews to make their way directly to pinpointed locations, and for logging firms to push their roads toward the still salvageable timber.

The problem of detecting and recording these areas is being studied by Wear in his experimental program, which makes use of photographic and infrared sensing techniques. Flying above a forest in a four-seat helicopter, Wear utilizes a heat-sensing device that transmits infrared rays to a digital counter, which in turn combines with two TV cameras and an Ampex videotape recorder to display on a TV monitor both the picture of a tree top and the tree's temperature translated into a series of three digits.

TREES, LIKE HUMANS, seem to have a higher temperatures when *sick*—sometimes as much as 4° F above normal. The sicker a tree gets, the more infrared rays it emits, according to Wear.

By using videotape recording, the familiar *instant replay* of TV sportscasts, it is possible for the first time to locate precisely a disease center with existent aerial maps and provide the information to foresters and forest managers.

"We are still experimenting with the technique," Wear said, "but we believe it has real promise. The accuracy of pinpointing a particular tree or group of trees is critical. I can think of no better way to achieve this accuracy than through the combination of *instant replay* and heat-sensing techniques."

Wear's study is currently focused on Douglas fir in Oregon and Washington. Douglas fir is the most important timber species in the Pacific Northwest, representing 57 percent of the total sawtimber volume in that region. *Poria weirii* root rot is by far the region's most destructive Douglas fir disease, ruining more than 170-million board feet of timber per year. A cure for this organic disease has not yet been found, so diseased trees must be cut down to prevent further infection.

By discovering and harvesting diseased trees, their lumber often can be salvaged commercially. Locating the disease center thus becomes very important financially because almost half of the timber in the United States that is lost to insects, disease, and fire is due to some form of infection. Nearly 50 percent of the root-destroying diseases in the U. S. are attributable to *Poria weirii*.

Poria weirii research was started by Wear in 1966, when branchlet samples from 45 selected dominant trees were clipped by a pole pruner from a hovering helicopter. Old growth, second growth and yough growth samples were taken and spectral reflectance curves from all sample trees were obtained from a General Electric spectrophotometer at the University of California's illumination Laboratory in Berkeley.

The most encouraging preliminary result of the beginning research was that significant differences in infrared emissions occurred between healthy and diseased trees at certain times of the day. Temperature differences taken in the 8.0 to 14.0-micron band of the electromagnetic spectrum were highly significant in the early morning, even if disease symptoms were not always visible in the crowns of the trees.

Before beginning the video and heat-sensing survey, Wear conducted research into remote sensing of tree temperatures through several spectral areas. Aerial photography with color and infrared film was performed on the foliage of healthy and diseased trees in the 0.4 to 1.0-micron band of the electromagnetic spectrum. (Wear, who earned a Master of Science degree in forestry from the University of Michigan, has extensive aerial photography experience dating back to World War II.)

In November 1967 Wear decided the addition of videotape recording would fill out the missing link in his survey—that of providing exact visual references which would lead ground crews to diseased trees. By spring of the following year he had completed project specifications, with welcomed assistance from the Bonneville Power Administration sub-station in Vancouver, Washington. It was decided to rent the necessary equipment, and Oregon Audio/Video Systems in Portland was awarded the contract after open bidding. The first test runs came in July 1968, and the first pilot survey began the next month.

THE EQUIPMENT

A helicopter capable of seating a pilot and three passengers was selected for the program. Housed in a long aluminum pod outside the 'copter near its right skid (Figure 1) is an Ampex CC-6007 closed circuit TV camera with wide-angle lens, and a Barnes Engineering Company PRT-5 infrared heat-sensing radiometer. The pod is attached by a pipe to a mount near the right door.

A cable attachment opens the bottom of the pod in flight, allowing the vidicon TV camera to record video images and the heat-sensing radiometer to measure infrared emissions from trees. The right door of the craft has been removed to facilitate operation of the outside pod's instruments, and to compensate for turbulent atmospheric con-

FIG. 2. Slung beneath the helicopter, an Ampex closed circuit TV camera captures video images for the monitor mounted in the cockpit. The camera provides a view of the trees being examined while the results of that examination—the temperatures of the trees taken by a heat-sensing device—are indicated by the numbers registered on the monitor screen by a second camera. (*Photo by Gregg Perry.*)

ditions which caused the helicopter to bounce about. A clearer video image resulted.

Inside the craft at the pilot's right side is another aluminum pod containing a second Ampex CC-6007 camera focused on a digital readout (voltmeter with lights). Bolted atop this pod is a 9-inch TV monitor and a TV control panel. The digital voltmeter is fed via cable from the heat-sensing device outside.

Infrared rays are electronically transposed into electrical output in the voltmeter, and the TV control panel combined on the monitor's screen to produce the video image of a tree with its digital readout. The composite picture shows the crown of a tree with the readout superimposed to the right of the tree (Figure 2). A black circle at the rear of the outside camera lens superimposes a bullseye on the middle of the screen (Figure 3). This bullseye represents the area covered by the PRT-5 radiometer and aids exact pinpointing of the target tree.

In flight, Wear sits behind the pilot on a bank of three seats. To his left is an Ampex VR-7000 portable videotape recorder, which records on tape the readout and tree visible on the monitor. The video tapes may be replayed immediately in flight or later at the heliport or an office. The tapes may be

FIG. 3. A close-up view of the television monitor shows (circled) the tree being measured for heat generation, and the reading (the number 4) indicated on the counter. A picture of the trees and the temperature information are recorded on an Ampex videotape recorder for later study. (*Photo by Gregg Perry.*)

saved, or erased and reused hundreds of times without loss in quality. A microphone permits Wear to record a verbal commentary on the same tape.

Power for the video and heat-sensing system comes from a portable static inverter which draws 12-volt direct current from the helicopter's generator and converts it into 110-volt alternating current.

The videotape recorder operates continuously while the helicopter follows its predetermined flight pattern. Following this exact line facilitates correlation of the tape with aerial maps. Each reel of tape plays for approximately an hour, and most flights in a survey area may be accomplished with a single reel.

Flights for the experimental developments originate from a heliport on Swan Island, a man-made island in north Portland. After two years of various aerial tests, it has been determined that early morning flights provide the most significant results.

"One hypothesis for the more apparent morning temperature differences between healthy and diseased Douglas firs is the use of moisture accumulated by trees overnight," Wear said. "A tree with a deteriorated root structure has a reduced capacity to absorb moisture and translocate it throughout the tree. Transpiration of moisture from the leaves keeps the tree cool. The diseased tree, therefore, is a *hot* tree because it transpires less (in the morning). Later in the day, the differences between *hot* and normal trees become less significant."

When the initial video and heat-sensing experiment began, specific samples of three known groups of trees were used to test the equipment. There were five healthy trees, five diseased trees with no visible damage, and five diseased trees with visible damage. To facilitate identification, the healthy trees were topped with a yellow streamer, the diseased trees without indications received orange streamers, and the diseased trees with indications were marked with red streamers. The helicopter cruised at about 25 miles an hour so that the heat-sensing device and video picture could capture and record the infrared rays emitted by individual trees.

The marriage of *instant replay* and infrared rays proved successful, and the surveys proceeded. Wear decided to collect data on old growth, young growth and second growth Douglas firs. To establish variations in tree temperature, the forester set up early morning, noon and afternoon surveys. As was previously indicated, the morning surveys proved significant more often, but a full range of data was needed for complete comparisons. Wear was able to collect late summer data and some fall data in 1968.

In the spring, summer and early fall of 1969, Wear hopes to add a third season to his survey. Tree growth in winter is minimal, and tree temperatures are less significant. Gathering information in the late fall also proves difficult, for it is the rainy season in the Pacific Northwest.

Widespread use of videotape recording in forestry is considered possible by Wear.

"Forest pathologists in the past have been limited to working on the ground," he said. "Now it may be possible both for these scientists and the lumber interests to record on tape specific information from the air that can be studied repeatedly on the ground.

"Naturalists also could have an interest in this method. For instance, the video monitoring of wildlife might provide a more efficient means of herd control, as well as provide a visual record of the animals."

NASA is financing Wear's survey research as part of its Natural Resources Program because it wishes to determine whether the method of locating forest disease centers might some day be carried out by satellite. The Natural Resources Program subsidizes surveys in such diverse fields as geology, geography, agriculture, and fire detection because of its interest in generating other possible satellite uses.

"Our survey of temperature differences between healthy and diseased Douglas firs is far from complete," Wear notes, "but the preliminary indications are good. The method of putting infrared rays into a digital readout and combining the readout with a tree's picture on video tape has provided us with valuable data.

"Videotape recording and heat sensing continue to be an integral part of this research."