nificantly related to susceptibility to weevil injury, more so than d.b.h. Trees with thin bark were less susceptible than trees with thick bark, although there was considerable variation due to other unknown factors.

Bark thickness is considered to be important because of the relation of the thickness of phloem in the terminal shoot to weevil attraction, oviposition, and larval development. Bark thickness at breast height is a cumulative measure of annual phloem production over the period of exposure of the tree to weevil injury.

In even-aged stands, among trees of equal diameter and height, those with the thinnest bark may be expected to be least injured by the white pine weevil. In forest genetics research, this may be used as a guide in the selection of trees to be tested for inherited resistance to weevil injury.

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Lightning Fire Research in the Rocky Mountains

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LIGHTNING is the major cause of fires in Rocky Mountain forests. The lightning fire problem is the prime target of a broad research program now known as Project Skyfire.

The aims of Project Skyfire are broad in character. First, it hopes to gain a better understanding of the occurrence, behavior, and control of lightning fires. Eventually, after fundamental studies provide necessary background, Skyfire expects to test the possibility of preventing or reducing the severity of lightning fires through cloud-modification operations.

Accomplishment of these aims is expected to be achieved through a cooperative research program which capitalizes on the special talents and facilities of a score of private, state, and federal agencies. Skyfire has been initiated as a cooperative enterprise of the Intermountain Forest and Range Experiment Station and the Munitalp Foundation, a private research organization dedicated to the advancement of basic studies of meteorology. Also assisting in the project are Region 1 of the U. S. Forest Service, the National Park Service, the U. S. Weather Bureau, and the General Electric Research Laboratory. Future assistance is anticipated from other forest protection organizations and several colleges and universities.

An active field program is underway on two of the six research tasks now charted for Project Skyfire. During the 1953 fire season a cloud survey was initiated in the northern Rocky Mountains. Throughout each day of the fire season observers at 25 national forest fire lookout stations have been reporting on the development, movement, and action of clouds associated with lightning storms.

A second major task now underway is observation and analysis of the jet stream—a zone of globe-circling winds in the substratosphere which may be related to lightning occurrence and fire weather patterns. Attempts are being made to map the jet stream through observation of certain cirrus and altocumulus clouds often associated with this river of high-velocity air. In both the jet stream study and the cloud survey, time-lapse motion-picture cameras are being used to record the action of clouds.

Future research tasks will include analysis of fire-weather records obtained from some 150 fire danger rating stations, study of a cloud-breeding area to gain a better understanding of the origin and action of lightning in mountainous country, and atmospheric research where a mobile field laboratory will be used to explore the relationship of such factors as incoming and outgoing radiation, soil and air moisture, and atmospheric nuclei and electricity to lightning and fire behavior. Finally, after these tasks have provided a foundation of basic knowledge, field tests will be made of methods for preventing or reducing the severity of lightning fires.

The Lightning Fire Problem

The reasons for a research undertaking of the scope of Project Skyfire are written across vast burned areas in the 120 million acres of Rocky Mountain forests requiring protection from lightning fires. During the 5-year period 1948—1952 over 17,000 lightning fires occurred in the ten Rocky Mountain states. The average annual load of 3,500 lightning fires amounts to 63 percent of the total number of fires occurring in the rugged mountain country ranging northward from Arizona and New Mexico through Idaho and Montana.

In the 40 odd years of organized forest protection in the Rocky Mountains many advancements have been made in lightning fire control. Fire danger rating systems originated here. Fire weather forecasting, better transportation to back-country areas, improvements in fire equipment, and systematic fire control planning have all contributed to more effective protection. More recently the smokejumper program and widespread use of aircraft are spectacular examples of continued progress.

The increasing demands upon the forest resources of this region point to the need for still greater assurance that lightning fire control will be generally effective. The very nature of widespread dry lightning storms over rugged forested country indicates the great potential for conflagrations. Since the three-million-acre burn of 1910 in the northern Rockies, it has been evident that superbly organized and executed fire control programs are essential[1]. No less an effort can assure the safety of the region's resources or the lives and property of its people.

Foresters who have engaged in lightning fire control programs recognize that many of the advancements made to date have been the obvious things to do. To a large degree the cream has been skimmed and in the future, needed progress will be more difficult. The road ahead depends heavily upon research progress in still unsolved lightning fire problems.

Lightning fires have certain characteristics indicating requirements for successful fire fighting and focussing attention on research priorities. One of the most important of these characteristics is the tendency for a great number of lightning fires to occur in a short period. Northern Rocky Mountain forests have been seized by some 400 lightning fires in 24 hours and over 1,500 in ten days. Over a span of 15 fire seasons there have been 76 days when 50 or more lightning fires started in Montana and northern Idaho national forests. Under critical conditions individual forests in the southwest and the northern Rockies have been hit by nearly 200 fires from a single storm.

The bunching of a large number of fires in a short period places great stress on fire-control forces. Economic factors prevent the design of fire-control organizations that are constantly mobilized to meet these overloads. Economical and effective fire control in lightning country calls for great flexibility to rapidly expand or contract detection and suppression forces and great mobility to move these forces to zones of intensive activity. These principles of lightning fire control have long been recognized. However, their full application requires knowledge of when and where lightning fires may start, how many may start, how they will behave once started, and what factors will influence ease or difficulty of control. Project Skyfire is directed at these basic questions and in addition will investigate methods for reducing great overloads of lightning fires.

Recent developments point to possibilities of achieving a better understanding of the lightning phenomena and of the basic meteorological factors influencing the cause and subsequent behavior of lightning fires. Advances in the science of meteorology are providing new information on cloud formations, cloud physics, atmospheric nuclei, and air movements. Meteorologists have only recently begun intensive study of the jet stream and of the relation of this zone of high-velocity air to weather conditions. Of special significance with respect to possible lightning prevention is the recent work of Langmuir, Schaefer, and others of the Project Cirrus group in weather modification and treatment of cumulus clouds[2].

Cloud Survey

The first major field activity of Project Skyfire has been a cloud survey designed to find out when and where cumulus clouds form and to chart their life cycle from initial formation to the lightning stage. A special objective is to identify cloud-breeding areas where more detailed studies can be made of lightning and lightning fires.

The cloud survey being made in the Northern Rocky Mountains utilizes existing facilities at forest fire lookout stations to obtain data for research purposes. Prior to the 1953 fire season, lookout-firemen from the 25 stations in the observation network attended a special training school to receive instruction in cloud identification and general survey techniques. Each day during the fire season a special form filled out at cloud-survey stations recorded the story of clouds and lightning. In addition, during especially interesting days a brief flash report transmitted by radio from each survey station enabled the Project Skyfire staff to obtain a quick picture of cloud action and potential lightning danger over an area of 30 million acres.

The Project Skyfire cloud survey is in a pioneer stage, but already there are indications of its value. Clouds are dynamic indicators of weather and lightning conditions. Results to date show that it is feasible to chart the action of clouds and lightning from fire lookout stations. The information thus obtained provides research workers with a new tool for exploring the lightning fire phenomenon. Furthermore, it is being demonstrated that a network of cloud-survey stations can provide fire-control organizations with useful information for advance location of fire occurrence zones, dispatching fire fighters and evaluating probable fire behavior.

Jet Stream Study

A second major activity of Project Skyfire is study of the jet stream. The great high-altitude winds now known commonly as the jet stream may be visualized as a river of air flowing around the world on a meandering course from west to east and varying in width

[1]Barrows, J. S. Forest fires in the Northern Rocky Mountains. Northern Rocky Mountain Forest & Range Experiment Station Paper No. 28, 251 pp., illus. 1951.

[2]Schaefer, Vincent J. Final report Project Cirrus, Part I, Laboratory, Field, and Flight Experiments. General Electric Research Laboratory Report No. RL-785. 170 pp., illus. 1953.

from ten miles to several hundred. The altitude of the main axis of the jet stream may vary from 20,000 to 40,000 feet. During the fire season months, two or more jet streams may be present over the western United States and Canada, although from meager information now available it appears that the usual pattern is for only one particular path of air to form the true main axis.

While specific knowledge of the jet stream is still very limited, indications are that these great winds may be closely related to many lightning and fire behavior factors. Under some jet-stream conditions lightning may possibly be prevented or reduced by wind action shearing off the tops of towering cumulus clouds. Under other jet stream conditions the lightning storm may possibly become more severe. Of great interest to foresters is the apparent relationship between the jet stream and periods of extremely dry and windy weather. There are strong possibilities that knowledge of the jet stream may answer some of the major problems of predicting fire behavior in Rocky Mountain forests.

Observations made by Schaefer show that certain cloud types are often associated with the jet stream.[3] This association between cloud formations and high-altitude winds points to the exciting possibility of observing and mapping the jet stream by visual methods. In turn, foresters may find that jet-stream clouds serve as indicators of fire weather and lightning conditions and signal some of the probable patterns of fire behavior.

Cloud forms of the jet stream appear to be of four types. The two high cloud types are long streamers of cirrus moving at high velocity and great patches of cirrocumulus made up of cells showing small waves and ripples. The middle cloud types are the altocumulus lenticular tapered like a lens, and often layered in the sky like a stack of leaning flapjacks, and altocumulus billows appearing as parallel bands of clouds showing waves or billows at right angles to their motion.

As an additional phase of the cloud survey, the 25 fire lookouts have been recording daily observations of jet stream clouds. This information will provide the basis for making generalized jet-stream maps which in turn will be compared with the daily high-altitude wind maps furnished by the Weather Bureau. The jet stream is also being studied in relation to lightning occurrence, wind velocity at ground level, air and fuel moisture, and burning index.

Time-lapse Photography

As an important part of both the cloud survey and the jet-stream study, time-lapse motion-picture cameras are being used to record cloud phenomena. The time-lapse motion-picture camera enables cloud action, which is difficult to appreciate with the naked eye, to be speeded up and witnessed as a spectacular series of events. The special cameras provided by the Munitalp Foundation enable an hour of cloud action to be compressed into two minutes of film time. A battery-operated electric solenoid automatically opens the camera shutter every two seconds.

During the summers of 1952 and 1953 over 5,000 feet of time-lapse color motion-picture film has been exposed at fire lookout stations in Rocky Mountain national forests and parks. These motion pictures provide a useful means for studying cloud, lightning, and jet stream activity. This program is expected to provide a film library documenting significant events in Rocky Mountain skies.

Future Studies

The cloud survey and the jet-stream study are the first efforts of Project Skyfire. Additional phases of the planned research program including fire weather analyses, atmospheric research, and study of a cloud-breeding area will be initiated as soon as the necessary facilities and research staff become available. Each of these research tasks should yield segments of the fundamental knowledge needed before work begins on the ultimate goal of attempting to answer the key question—can lightning fires be prevented?

The possibility that lightning fires may be prevented or reduced in severity stems from the pioneer work of Langmuir and Schaefer and from the operational experiences of many others in the cloud-seeding field. It has been demonstrated in the laboratory and the natural atmosphere that cumulus cloud structures may be modified through the introduction of such nuclei as dry ice and silver iodide. These demonstrations point to the desirability of testing cloud modification as a means of reducing lightning occurrence. Experience in experimental meteorology indicates that it may be possible to overseed mature storms in an effort to eliminate the super-cooled clouds associated with lightning, or to initiate the precipitation cycle in growing clouds before they become large enough to produce lightning.

The exact course of events and the results of the research of Project Skyfire remain largely unknown. Recent advances in meteorology and forestry, and the continuing problem of lightning fires make this program a timely undertaking. The possibilities for lightning prevention are worthy of full investigation. Whatever may be the results of these tests, it appears that the very nature of the required research may yield new knowledge of lightning fire occurence, behavior, and control. Future protection of Rocky Mountain forests depends in part on this knowledge.

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[3]Schaefer, Vincent J. Cloud forms of the jet stream. Tellus V. Stockholm, Sweden. 1953.