United States
Department of
Agriculture

Forest Service

**Pacific Southwest
Research Station**

General Technical
Report PSW-GTR-131

Measuring Soil and Tree Temperatures During Prescribed Fires With Thermocouple Probes

Stephen S. Sackett **Sally M. Haase**

Sackett, Stephen S.; Haase, Sally M. 1992. **Measuring soil and tree temperatures during prescribed fires with thermocouple probes.** Gen. Tech. Rep. PSW-GTR-131. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 15 p.

Soil and cambium temperatures must be known to ascertain certain effects of prescribed fires on trees. Thermocouple-based systems were devised for measuring soil and cambium temperatures during prescribed fires. The systems, which incorporate both commercially available and custom components, perform three basic functions: data collection, data retrieval, and data translation. Although the systems and procedures for using them were designed for research purposes, they could be adapted for monitoring operational prescribed fires.

Retrieval Terms: soil temperature, tree temperature, prescribed fire, thermocouples, dataloggers, Southwestern ponderosa pine, sugar pine, giant sequoia

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Acknowledgments:

We thank David Carpenter, Robert Pederson, Jan Mitchell, and Barbara Menzel for their help in putting the temperature monitoring systems together.

Cover--Soil and cambium thermocouples in the temperature measuring systems are connected by extension cables to dataloggers located outside the fire perimeter.

Publisher:

Pacific Southwest Research Station
Albany, California

(Mailing address: P.O. Box 245, Berkeley, CA 94701-0245
Telephone: 510-559-6300)

June 1992

GPO 1992-784-387

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In Brief ...

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Various wildland management objectives have been achieved for many years using prescribed fire. Prescribed burning used as a tool must be judged by the effects it produces. Oftentimes these effects, if unseen initially, go unnoticed. Extensive soil heating in the rooting zone of trees can be one of these unseen effects.

To determine the extent of heating in the soil and in the cambium around the base of trees during fires, a thermocouple temperature-measuring system was devised and fabricated. In addition, a similar system was developed to monitor ambient soil temperatures after the insulating properties of the forest floor material had been reduced by prescribed burning.

Three basic functions are performed by the systems: data collection, data retrieval, and data translation.

Data collection is accomplished using chromel/alumel thermocouples and wires. Thermocouple probes for measuring soil temperatures during fires are made of $^3/_{16}$-inch diameter stainless steel tubing with the actual thermocouple wire packed inside mineral insulation and grounded at the tip. The thermocouple wire is strung through 12 inches of flexible conduit to a high-temperature-resistant plastic plug.

Thermocouple probes used for measuring cambium temperatures are made of $^1/_8$-inch diameter stainless steel tubing with mineral insulation-packed wire, grounded at one end and with a ceramic plug attached directly to the probe. Both stainless steel thermocouple probes are made commercially.

Thermocouple probes for measuring ambient soil temperature are made by the authors using solid, 20-gauge chromel/alumel wire with glass braid insulation. The wires are twisted at one end, inserted in a $^1/_8$-inch diameter $2^1/_2$-inch long brass tube, and silver soldered. Six pairs of wires are then encased in plastic tubing and soldered into a common multipin plug. The tubing is sealed to protect the wires when buried underground.

Voltage produced by heated thermocouples is carried through chromel/alumel wire to a datalogger. Six pairs of highly insulated wires make up a cable 150- to 200-feet long that is further encased in flexible aluminum electrical conduit for abrasion protection.

Data retrieval is accomplished using an electronic datalogger, electronic reference junction with a reference junction sensor, and flexible cable. A data quality tape recorder stores data for later retrieval.

Data is translated by playing back the audio cassette tapes through software provided by the datalogger manufacturer. The data is read into a computer and organized, the magnetic signal is converted to millivolt values, and an appropriate format is printed out. In-house programs convert millivolt values to temperatures for producing temperature tables and graphs.

Field tested techniques are used to install thermocouple probes. Installing thermocouple probes in soil prior to a prescribed fire is a delicate, time-consuming operation if done correctly with minimal disturbance of forest floor. Once the forest floor has been carefully cut and extracted, an access hole is dug in the soil. Depending on the subsurface temperature gradient, an appropriate depth is determined. Soil moisture content samples are taken at descending depths to compare with afterburn samples. The 12-inch long thermocouple probes are inserted into the soil wall parallel to the forest floor surface. To develop a relationship between the amount of fuel consumed and soil temperature, six depths are sampled starting at the top with the soil and forest floor interface. When in place, the thermocouple probes are connected to the extension cable, and the hole is carefully filled in. Once the forest floor material is carefully replaced over the filled hole, the extension cable is strung overhead to a location outside the fire and plugged into a datalogger.

Cambium temperature thermocouple probes are inserted vertically through a notch cut in the bark of a sample tree. The temperature-sensing tip is positioned in the cambium at a depth halfway between the soil surface and the top of the forest floor surrounding the tree. Once installed, an extension wire is attached to each thermocouple probe and routed to an extension cable that is also suspended overhead to a location outside the fire where it is plugged into a datalogger. Aluminized insulation is used to protect the thermocouple plug and the cambium where the notch was cut from the bark.

Since sites for measuring ambient soil temperature are not subjected to fire, dataloggers can be plugged into them where they are installed. The brass tube thermocouple probes used for ambient temperatures are inserted at the soil and forest floor interface, and at 1 inch and 2 $^3/_4$ inches in the soil. Six-foot-long extensions on these probes allow the plug-holding bracket and datalogger to be set back from the temperature-sensing site.

These soil and cambium temperature-measuring systems can be constructed with care and understanding. Systems such as these can be used effectively to link fuel consumption and fire behavior to fire effects. With enough information from temperature-measuring systems such as these, it should be feasible to predict an association between the amount of fuel consumed and fire effects.

Introduction

Prescribed burning has been used for many years to achieve a variety of wildland management objectives. Different ecosystems and wildland situations require different levels of fire treatments, but all prescribed fires need to be judged by the effects they produce. Many times the immediate impacts of a given fire go unnoticed initially, but are revealed later.

An extensive prescribed fire research study was established in a ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) stand on the Fort Valley Experimental Forest near Flagstaff, Arizona, in 1976, to investigate the effects of prescribed fire in fall, in heavy, natural fuel conditions (Sackett 1980). The stand was burned at night because of warm, dry, daytime conditions. The fires and conditions under which they were accomplished have been described in detail (Sackett 1980). Many of the smaller overstory trees were severely crown scorched as expected, and they died. The crowns of the large, old-growth trees, however, were not greatly affected. A noteworthy observation was that the forest floor around each of the 405 large trees was completely consumed. Not only was the consumption complete, but also it extended from the bole out to the dripline in practically every case.

About $1^1/_2$ years after the burns, a number of the large pines began to fade and die. None of the same-size trees on control plots was dying. Since the crowns were not affected during the 1976 fires, other parts of the trees--roots and boles--had sustained some kind of damage. This situation prompted the development of temperature-measuring systems for use during prescribed fires.

To determine the extent of heating in the soil and around tree boles at the cambium during fires, a thermocouple system was devised and fabricated. In addition, a similar temperature-measuring system was developed to monitor ambient soil temperatures, which typically change as a result of burning.

This report describes the components, assembly, and use of the temperature-measuring systems. Most of the equipment consists of standard "off the shelf" items, and other parts are custom made.

Temperature-Measuring Systems

The complete temperature-measuring systems perform three basic functions: (1) data collection, (2) data retrieval, and (3) data translation. These three functions are handled by three basic parts of the temperature-measuring systems *(fig. 1)*. Each part is standardized so that all pieces of equipment are compatible.

Data Collection

Thermocouples

A thermocouple is the junction of two dissimilar metals, which produces a voltage output proportional to the difference in temperature between the hot junction and the lead end wires.

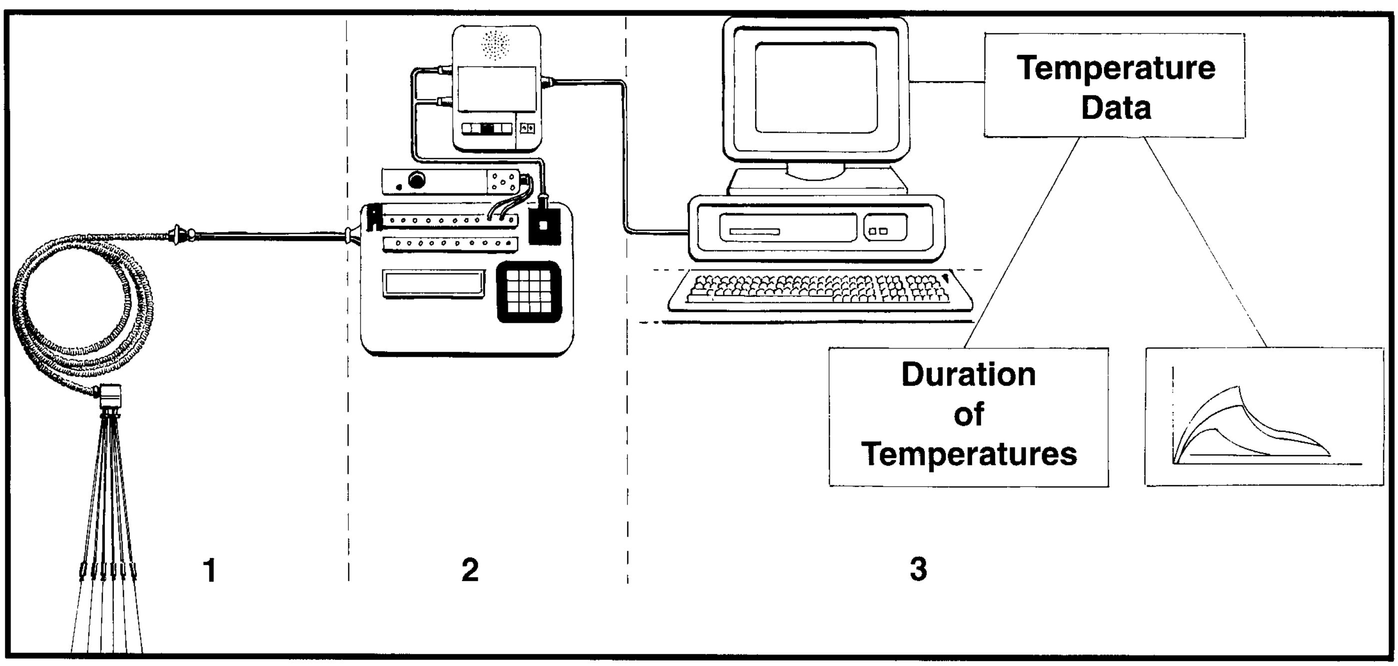

Figure 1--The temperature measuring systems have three basic parts: (1) thermocouples and extension cables; (2) datalogger, reference junction, and recorder; and (3) data translation hardware.

The temperature measuring systems. using chromel/alumel (type K) thermocouples and thermocouple wire, can measure temperatures ranging from -418 °F to 2300 °F (-250 °C to 1260, °C), and are very resistant to oxidation. If requirements demanded another temperature range or sensitivity, other types could be used, and only minor changes in the system would be required. Custom thermocouples measure ambient soil temperatures, while commercially made thermocouples measure soil and cambium temperatures. Grounded thermocouples are used because they provide a faster response than ungrounded thermocouples and are more rugged than exposed thermocouples when used repeatedly.

To measure ambient soil temperatures in burned and unburned forest soils, we construct thermocouples with 20-gauge, type K solid wire with glass fiber braid insulation on both conductors or wires and glass fiber braid overall. The two wires are bared ($^1/_2$ inch) at one end and twisted together making a thermocouple. Next, the thermocouple is inserted into a $^1/_8$-inch diameter brass tube $2^1/_2$-inches long. The end with the thermocouple is squeezed tight with a pliers, and the wires are grounded to the brass tube with silver solder. Shrink tubing is shrunk over the open end of the brass tube and about 4 inches of the wire. Multiples of six thermocouple probes are prepared in this way.

Three thermocouple probes are grouped into each of two, $^3/_{16}$-inch pieces of clear flexible plastic tubing and sealed with silicone sealant, which protects the thermocouple wires while they are buried underground. The opposite ends of the six thermocouple probes are then soldered into a 24-socket Amphenol connector to complete the system for sensing ambient soil temperature (*fig. 2*).[1] It is important to establish a standard wiring pattern for the connector so that the system parts are compatible.

[1]Trade names and commercial enterprises or products are mentioned only for information. No endorsement by the U.S. Department of Agriculture is implied.

Stainless steel, mineral insulated, thermocouple probes used to measure soil temperatures are $^3/_{16}$-inch diameter and 12-inches long. This length seems to be sufficient in extending the point of measurement past any disturbance caused by digging the insertion hole. Each probe has flexible stainless steel conduit covering 18 inches of extension wire and is attached to a high temperature, two-conductor, plastic connector with sockets (*fig. 3*).

Thermocouple probes for sensing cambium temperature are mineral insulated and sheathed with $^1/_8$-inch diameter stainless steel tubing, 18-inches long. A two-conductor, ceramic connector with pins is attached directly to the end of the thermocouple tubing by means of an "L" bracket (*fig. 4*). Pin connectors are used on cambium probes to keep them from being confused with soil probes, which have socket connectors (*fig. 3*), in rushed circumstances common during fires.

Extension Wires

Extension wires are a vital part of temperature sensing. Voltage from thermocouples must be carried to a measuring device via the same type of wire as the thermocouple itself. A coaxial cable of six pairs of chromel/alumel wire transmits the current. The multiple shield thermocouple extension cable is 20 AWG solid wire, 150- to 200-feet long, with insulation protecting each conductor, each thermocouple pair, and the bundle. The whole unit is jacketed with thermoplastic elastomer protected to 257 °F (125 °C). The coaxial cable is inserted into $^1/_2$-inch flexible electrical conduit made of aluminum for additional thermal and abrasion protection.

An exterior grade, cast aluminum conduit box with a 12-pin panel (6 pairs) is attached to the thermocouple end of the extension cable. Socket connectors on soil thermocouple probes plug

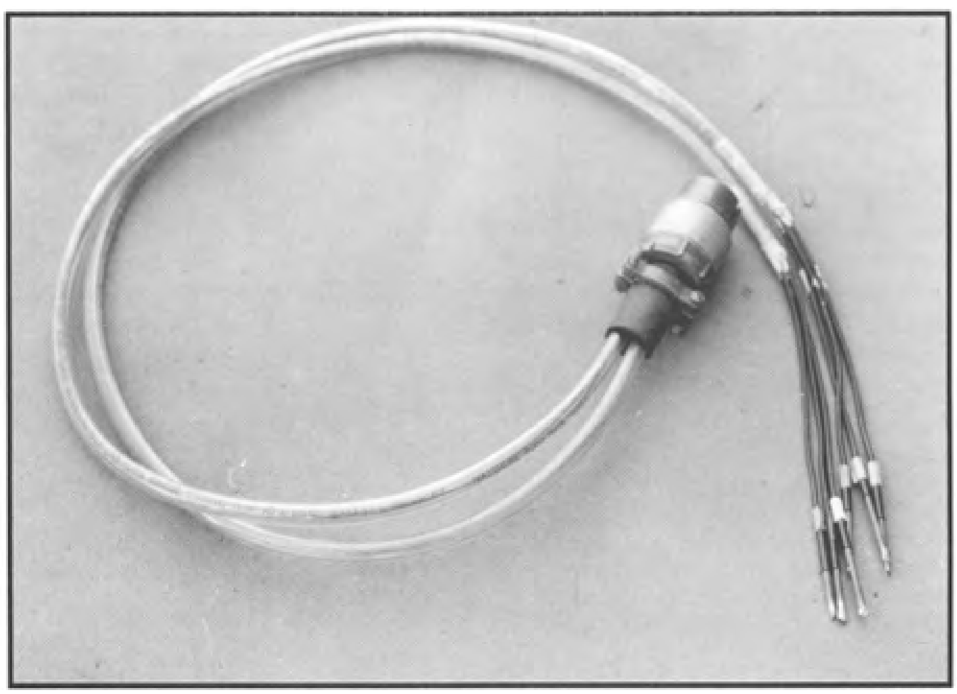

Figure 2--Custom brass thermocouples are used to measure ambient soil temperatures.

directly into the panel pins. At the other end of the cable, which leads to the datalogger, is a 24-pin socket connector (*fig. 5*).

Sensing cambium temperatures requires an extension wire link, in addition to the 150- to 200-foot extension cables. Between the coaxial cable conduit box and cambium thermocouple probes are six pairs of wires making up an "octopus" connection. A conduit box with a 12-socket panel (6 pairs) plugs directly into the coaxial cable conduit box with the 12-pin panel conduit box. Each of the six pairs of CEFIR clad (fireproof insulation) wires 10-feet long coming out of the back of the conduit box is shielded by flexible stainless steel conduit and has a ceramic, two-conductor socket connector that plugs directly into a

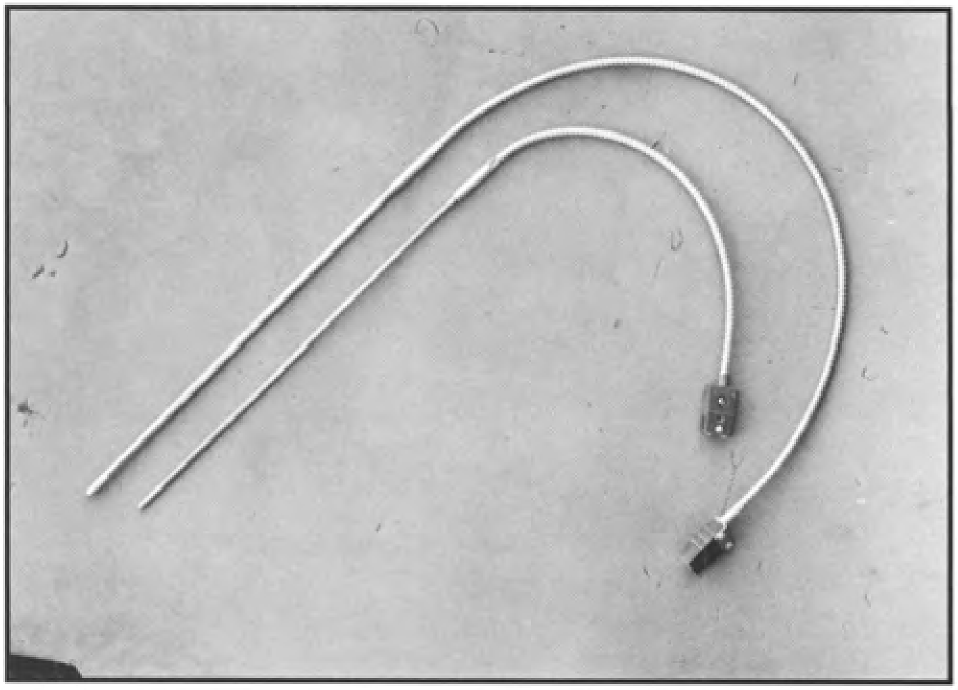

Figure 3--Stainless steel thermocouples with flexible extensions and plastic socket connectors are used to measure soil temperatures during prescribed fire.

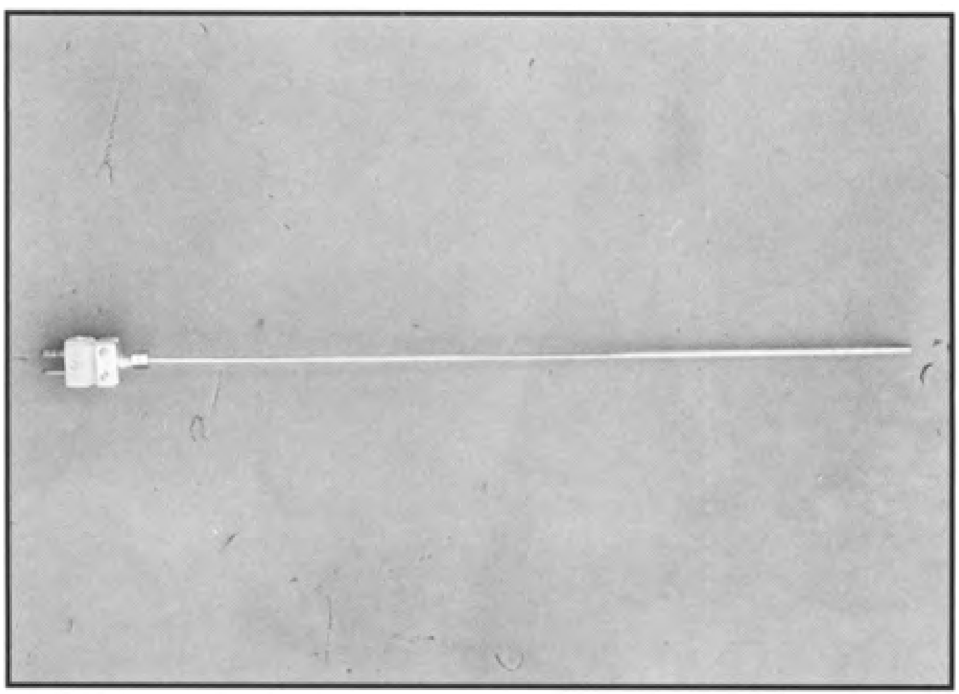

Figure 4--Stainless steel thermocouples with ceramic pin connectors are used to measure cambium temperatures.

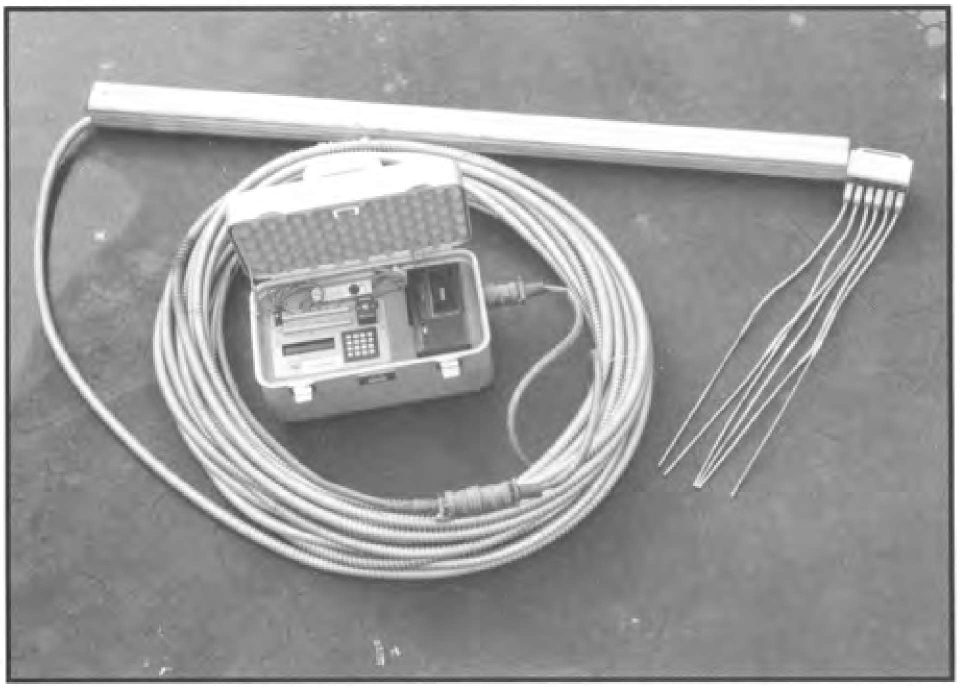

Figure 5--Soil thermocouples are plugged to a conduit box with a 12-pin panel at one end of the extension cable. The other end of the extension cable is plugged to the pigtail and datalogger.

cambium thermocouple probe (*fig. 6a*). This length of wire allows positioning of the cable and extension box connection away from flames on the forest floor surface. Often a flame column can form on the leeward side of a tree during a surface fire, and can damage the octopus and junction box when they are anchored to the tree. To correct the problem, an "A-frame" bracket was constructed to hold the octopus and extension cable $2^1/_2$ feet from the tree (*fig. 6b*). The A-frame has spikes welded to its two base legs as does the lower support arm that holds the bracket perpendicular to the tree. A separate chain is attached to each of the base legs. The chains are positioned around the tree and clamped together and tightened with a small load binder.

Data Retrieval

Three components are used in the data retrieval process: datalogger, electronic reference junction, and reference junction thermocouple sensor and flexible cable.

Datalogger

Campbell Scientific Models CR21 and 21X microloggers are used to measure voltage changes occurring in the thermocouples. These battery-powered instruments, which can be programmed to sample readings as often as necessary, convert the sensor signal to a digital value, store the data, and output it to a long-term storage medium, such as audio cassette tapes, with a connector interface cable. In addition, the date, time, and appropriate identification number become part of each data point measurement.

Electronic Reference Junction and Flexible Connection

When using thermocouples, it is necessary to use an ice point reference junction since a second thermocouple is formed where the thermocouple wire attaches to the datalogger voltmeter. To correct the millivolt reading at each thermocouple, one leg of the thermocouple would normally be forced to a known temperature, usually 32 °F (0 °C), by running it through an ice bath. The process can also be accomplished and--more efficiently--by an electronic ice point, because the ice bath is cumbersome and awkward for field work. Electronic ice points are expensive, however, if one has to be inserted on each thermocouple channel, and many points are being monitored at one time. One solution to the problem is to use one of the seven available channels on each datalogger to sense the voltage (temperature) at the point where the chromel/alumel thermocouple wires join the copper voltmeter wires.

So that the datalogger can be quickly disconnected from the 150- to 200-foot extension cable, a 3-foot flexible cable (pigtail) is used (*fig. 5*). Six pairs of copper wires and one pair of chromel/alumel wires are stretched inside $^3/_4$-inch diameter plastic tubing. The copper wires are soldered into a 24-pin Amphenol connector in the same configuration as in the socket connector on the extension cable. In the center pin of the pigtail connector the chromel/alumel wire is grounded to measure the voltage (temperature) of the connectors joining the two wire types (*fig.* 7). An Omega Model MCJ-K miniature electronic ice point is connected inline between the copper wires running from channel 7 on the datalogger to the pigtail with the chromel/alumel wire extending from it. Only 13 of the 24 points in the Amphenol connectors are used. This larger connector is used to maintain a more constant temperature with its greater mass. In the field, insulation is wrapped around the joined connectors to further maintain a constant temperature at all 12 contacts in the connector. A computer program adds the reference junction millivolt reading to each of the six unreferenced thermocouple readings and converts the compensated millivolt readings into degrees (Fahrenheit or Celsius).

Data quality tape recorders are used to record data on tape when dataloggers are left in the field for extended periods of time. When the buffer in the datalogger interface is full, it automatically starts the tape recorder and dumps the data onto

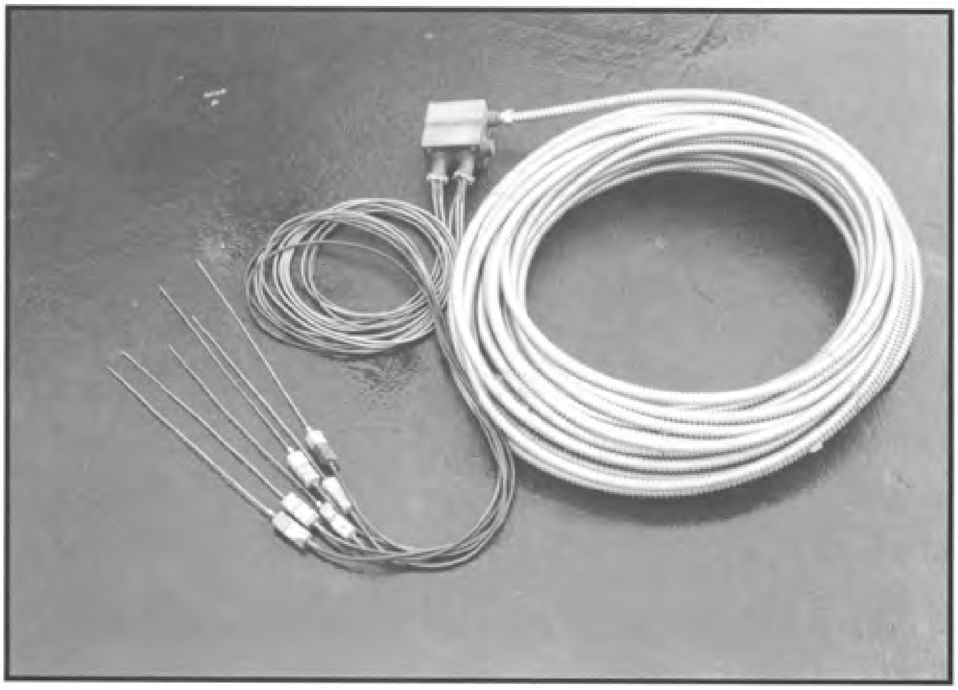

Figure 6--(a) Octopus connection attaches cambium thermocouples to the coaxial extension cable.

Figure 6--(b) An "A" frame bracket on the tree holds the octopus and extension cable junction boxes away from the tree surface.

the tape. Newer model dataloggers have high density data handling capacity so that 60-minute cassette tapes hold many days of continuous data, even when data is taken at short intervals (5 minutes). Although cassette tapes are preferred by some for storing data, storage/data modules can store data from dataloggers for later translation and analysis.

Each datalogger, including reference junction and tape recorder, are encased in static-resistant polyfoam in an aluminum carrying case (*fig. 8*) for easy field transport and use.

Data Translation

The millivolt values stored on audio cassette tapes are retrieved by playback through hardware supplied by the datalogger manufacturer. The Campbell Scientific PC201 clock, tape, and serial I/O card are controlled by PC201 software. Data are translated on an IBM compatible personal computer (*fig. 9*). Complete instructions are provided by the manufacturer, but simply, the data is read into the computer and organized; the magnetic signal is converted to millivolt values; and an appropriate format is printed out. This format includes identification number, date, time of sample, and millivolt values for seven datalogger channels. The in-house program, as mentioned before, adds the millivolt readings from the thermocouple with the reference junction to each of the six channel readings, and converts millivolt values to degrees (Fahrenheit or Celsius) providing an accurate soil or cambium temperature. Additional software has been written to graph the data and define the length of time a sensor was over a specific temperature. Plotting the data graphically provides a good overall view of the soil and cambium heating process *(fig. 10)*.

Techniques for Using the Temperature-Measuring Systems

In this section, we discuss specific applications of our equipment. You may find that they apply as is to your own research objectives or that they need to be modified.

Measuring Ambient Soil Temperature

Prescribed burning and other forest disturbances create microclimate changes that may affect many different systems in the environment. Monitoring soil temperatures can provide insight into how elevated temperatures might affect plant parts above and below ground as well as physical, chemical, and biological soil components.

Brass tube thermocouple probes have been placed in the soils under a variety of ponderosa pine overstory situations to monitor the changes caused by removing forest floor material from the soil surface by burning. Not only is the insulation of the soil affected, but also the color changes affect solar radiation heating. Changes in soil moisture may also influence soil temperature.

Six brass tube thermocouple probes are placed at each sample site--three each at two locations 6 feet apart, providing

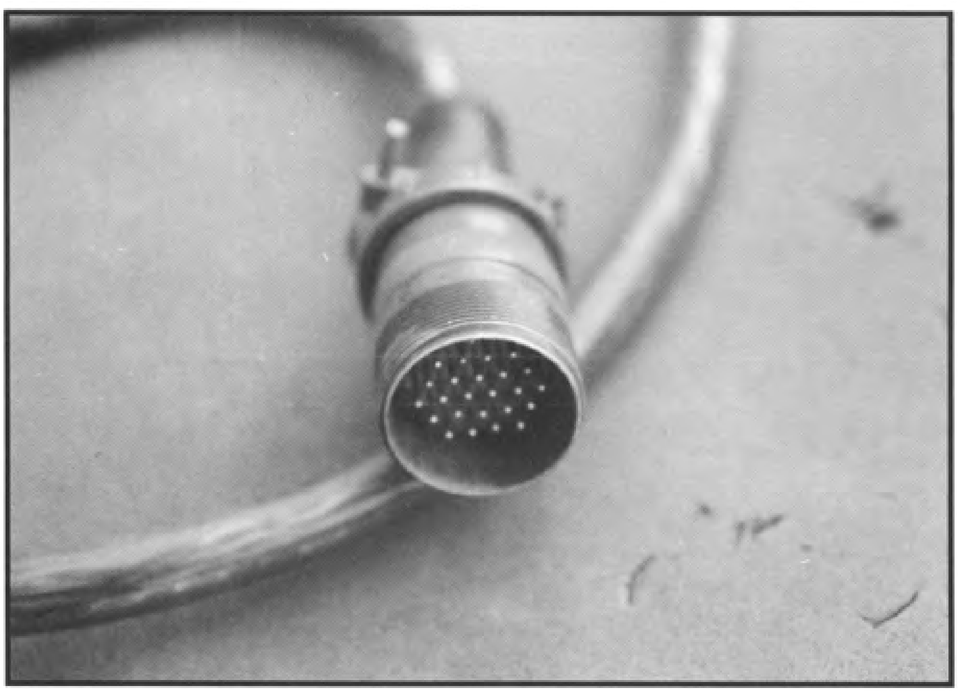

Figure 7--Chromel and alumel wires in the flexible pigtail cable are inserted into the center pin of the 24-pin Amphenol connector and soldered in place.

two replications. At each location thermocouple probes are placed at the soil surface and duff interface, and at 1 inch and $2^3/_4$ inches below the soil surface. Other depths can be sampled depending on circumstances.

A small hole (2 inches by 4 inches) is dug north of the proposed sample point avoiding disturbing the surface at the sample point as much as possible. Thermocouple probes are inserted into the soil horizontally at the appropriate depths (*fig. 11*). The hole is filled in. and the forest floor is replaced on top of it. A shallow trench is cut from the insertion hole to a thermocouple connector stand, and the 24-socket connector is clamped to the stand for easy acceptance of the pigtail connector (*fig. 12*).

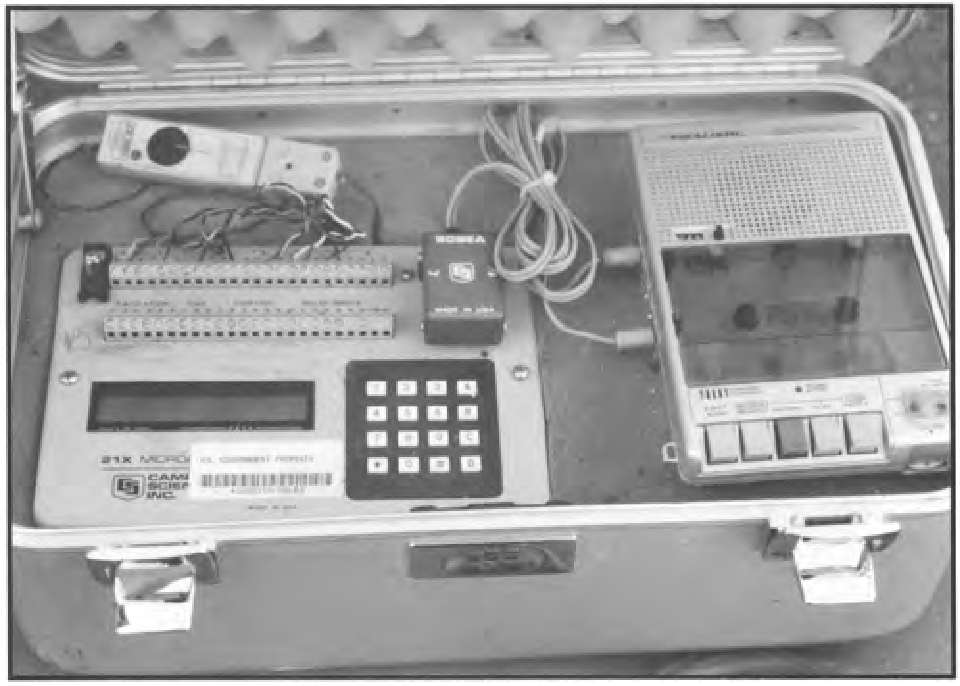

Figure 8--A polyfoam-lined aluminum carrying case is used to transport and protect the datalogger, reference junction, and tape recorder in the field.

Figure 9--Data collected by the datalogger and stored on the tape recorder are translated using an IBM-compatible computer.

Thermocouple connector stands are located north of the sample sites to avoid any sun angle interference. Inverted, insulated cans are placed over the connections to protect them from weather and solar heating since the reference junction temperature is taken inside the connectors.

The ruggedness of the entire system allows it to be left outside for extended periods. Curious animals such as elk and deer have been known to "throw" instrument boxes with their antlers. When such animals are known to frequent a study site, it is wise to secure the instruments to a concrete reinforcing rod driven deep into the ground.

Measuring Soil and Cambium Temperatures During Prescribed Fire

Installing Thermocouple Probes in Soil

To develop a relationship between the amount of fuel consumed and soil temperature, soil temperature is sampled under various amounts of forest floor. In old-growth ponderosa pine it is easy to place thermocouples under different depths of forest floor, since depth is a function of distance from the tree. The forest floor depth around a large tree increases from the bole to a distance of about 3 feet from the bole, then tapers off to the dripline. In sequoia and mixed-conifer stands placing thermocouples under different amounts of forest floor is difficult, since the overstory is virtually closed and forest floor depth is relatively uniform. Determining forest floor depth ahead of time would disturb the site, which could affect the resulting fire. Therefore, sample points are selected based on the stand arrangement, heavy fuel locations, and other objectives stated by the cooperating manager. Also sites are avoided where there has been excessive disturbance by wildlife and people.

Installing thermocouple probes in soil before a prescribed fire is a delicate time-consuming operation. Once sample points have been selected, the person digging the holes and installing the thermocouples kneels on a piece of plywood (about 4- by 4-feet) to protect the site. A heavy plastic sheet placed next to the sample point provides a place to put forest floor and soil from the hole so that it will not mix with the adjacent forest floor material. First the forest floor is excised by cutting a 6- by 18-inch rectangle down to the soil. A cutting trowel designed for forest

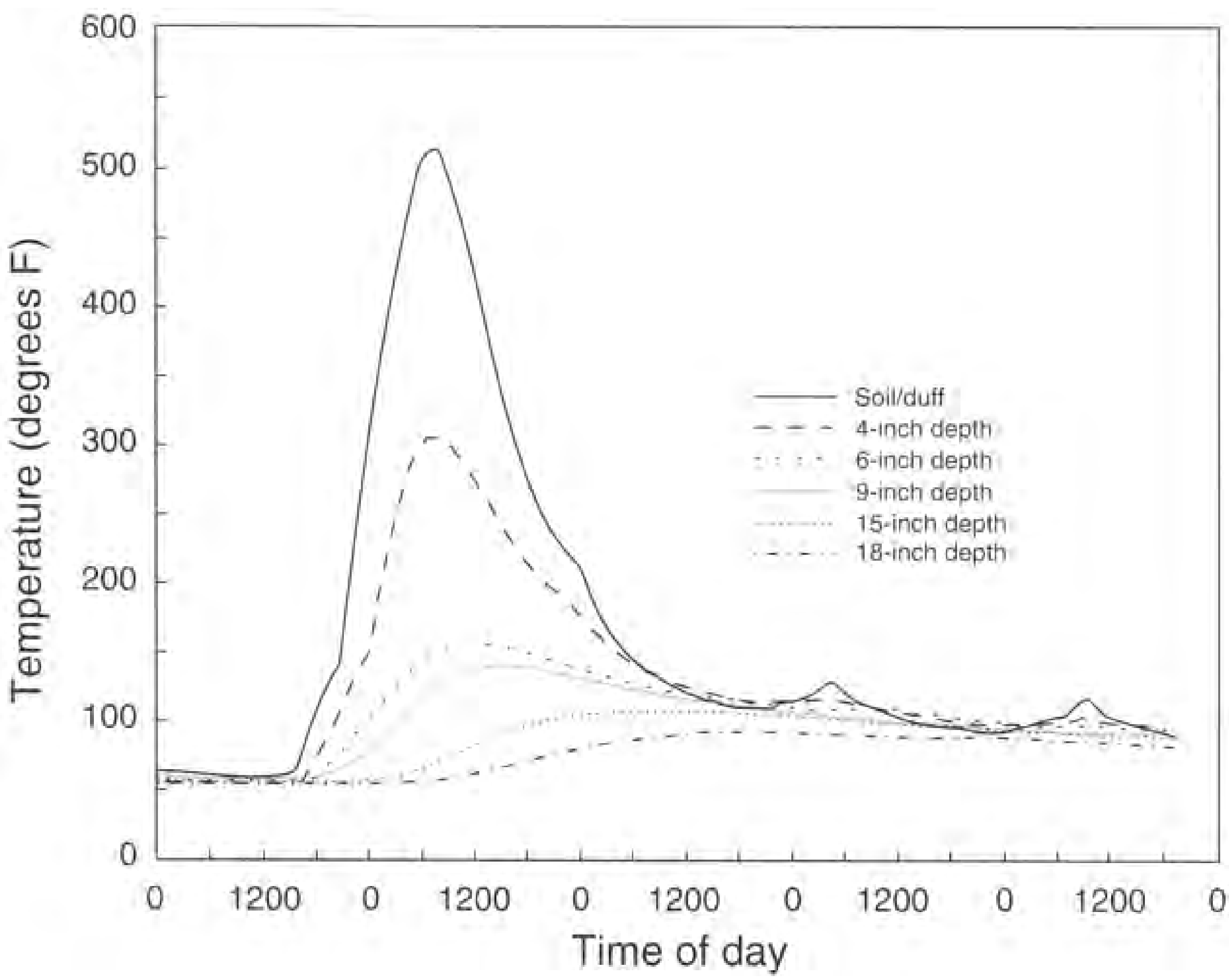

Figure 10--Soil temperature data obtained with the temperature-measuring system during a prescribed burn are plotted on a graph.

Figure 11--Brass tube thermocouples are installed horizontally to measure ambient soil temperatures.

Figure 12--Thermocouple wire socket connector is mounted on a field stand and attached to the pigtail and datalogger when measuring ambient soil temperature.

floor sampling and made in-house is used for this task (*fig. 13*). The forest floor material is kept intact as a solid piece and is replaced once the hole is filled in.

Using the same trowel and other tools, a hole is dug a couple of inches deeper than the deepest thermocouple will be placed. Thermocouple probes are installed as deep as 24 inches in sequoia stands, but only 12 to 14 inches in ponderosa pine stands. Preliminary sampling, experience, and need-to-know will dictate the depths of the samples.

Normally soil moisture samples are taken in 2-inch increments from the top to the bottom. Care is needed in taking the samples so that the different depths are not mixed and that they are taken as quickly as possible to avoid drying of the soils. The soil sample is sieved (2 mm), capped and sealed, identified, and saved for processing. The afterburn soil moisture samples are taken in the undisturbed probe sampling area, in 2-inch increments.

Next the thermocouple probes are inserted. On the facing wall of the hole determine the depths where probes are to be installed. The soil and duff interface and soil depths at 2-, 4-, 8-, 16-, and 24-inches are sampled in the sequoia and mixed-conifer ecosystem; the lowest depth may be a function of the length of the installer's arm. Soil and duff interface and soil depths at 1-, 2-, 4-, 8-, and 12-inches are sampled in the ponderosa pine ecosystem. The probe is inserted horizontally so that the heat penetrating the soil reaches the length of the probe equally if any conduction occurs from along the probe to the sensing tip. Each consecutive probe should be staggered somewhat so that the vertical heat flux is not disrupted by the probe above (*fig. 14*). The angle of insertion is dependent upon the angle of the ground. Often soil mounds caused by large root growth or other natural disturbances are hidden from view by the forest floor material. Also, roots and rocks may deflect the probe either pushing the probe deeper or shallower making the actual depth of the probe tip different from the intended depth. Because of these unforeseen problems, the depth of each probe tip is measured after the burn.

Once the thermocouple probes are installed to satisfaction. each thermocouple is joined to the connector pins on the extension cable conduit box, and the millivolt values on the micrologger are checked to confirm the system's integrity. The millivolt reading should convert to around 50 °F (10 °C) for ambient forest soil temperature.

The next step is to drive a 6-foot steel fence post into the bottom of the hole to support the extension cable. For additional protection from the fire, 4 to 5 feet of extension cable at the thermocouple end is covered with fiberglass insulation and inserted in a section of galvanized metal downspout (*fig. 5*). This section of the extension cable is secured to the upright fence post with wire (*fig. 14*).

The hole is filled in to the original soil depth. Soil is added to reach the top of the existing forest floor around the downspout to further protect the cable from heat. The removed forest floor is then carefully placed back on the lower soil surface in reversed order so that it resembles the natural condition (*fig. 15*). Since the thermocouple junctions are almost 12 inches from the insertion site, minimal site disturbance should not affect fire behavior at the sampling point. Extension cables are then strung above and out of the fire area. Six-foot steel fence posts are installed

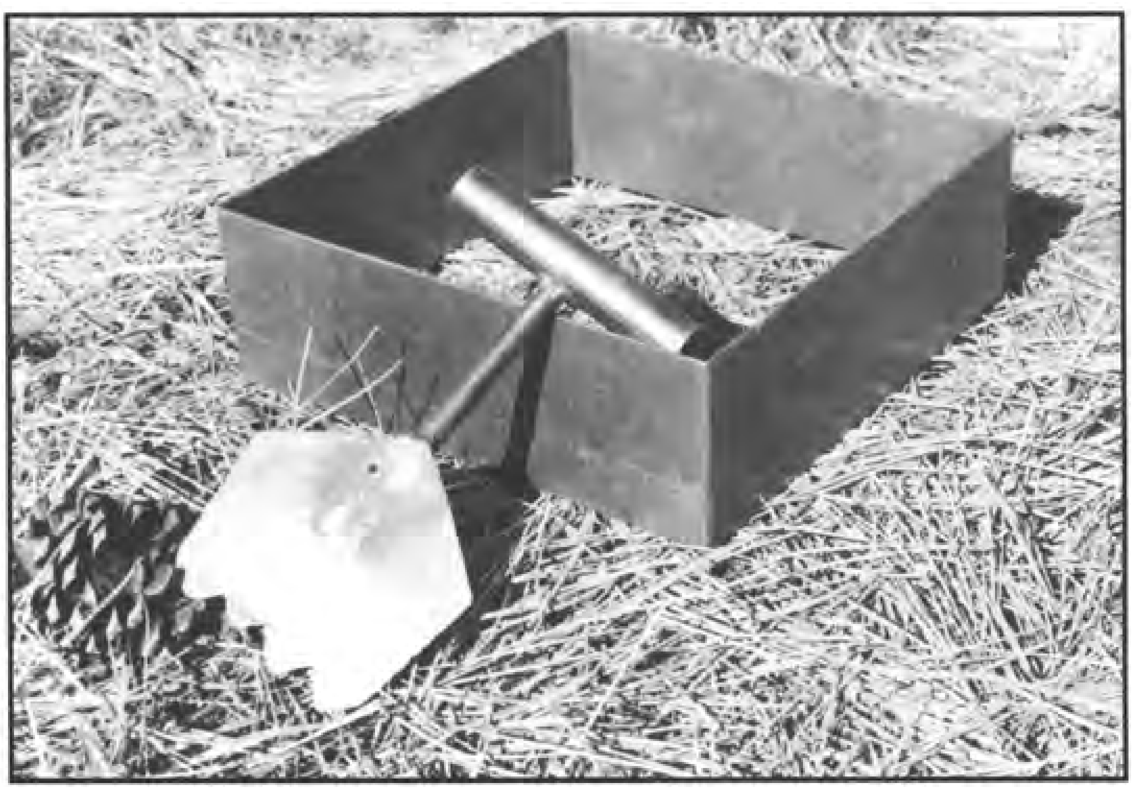

Figure 13--A specially designed trowel is used to cut the forest floor.

at 10- to 20-foot intervals (depending on cable weight). Then an 8-foot section of 2-inch diameter steel conduit is slid over the posts. An "S" shaped piece of concrete reinforcing rod is hooked on top of the conduit, and the extension cable is hung on the hook.

To define fuel consumption at each soil temperature sample site, five, $^3/_8$-inch diameter concrete reinforcing rods 18-inches long are installed in an arc around the thermocouple tip area. An extra soil thermocouple is placed on the surface to show the approximate location of the six measuring thermocouples, making sure there is adequate distances between them and the rods. A notch made ahead of time in each reinforcing rod is positioned level with the top of the forest floor (*fig. 16*). After the fire, total forest floor depth and depth of forest floor consumed are measured at each of the five rods. Measurements are then averaged. Prediction equations from previous samplings of forest floor

Figure 14--Thermocouples are inserted horizontally into soil in a staggered configuration, and the portion of the extension cable protected by galvanized metal downspout is secured to a fence post.

Figure 15--Completed soil temperature monitoring site should resemble natural conditions.

depth and weight relations are used to estimate fuel loading and consumption at each temperature sample point and on transects extending from each tree being sampled.

Inserting Thermocouple Probes Into Tree Cambium

Effects of prescribed fire on the boles of trees can be assessed by monitoring temperatures at the cambium. In a series of ongoing studies, cambium temperatures in ponderosa pine, sugar pine (*Pinus lambertiana* Dougl.), and giant sequoia (*Sequoiadendrom giganteum* [Lindl.] Buchholz) were ascertained during operational prescribed fires. The purpose of monitoring cambium temperature is merely to get an understanding of the heating that occurs, and after a large data base is developed, to try to relate bark and fuel variables to cambial death.

Selecting the appropriate sample point on each tree is difficult, since bark thickness--a good criterion for heat resistance--cannot be determined easily ahead of time without damaging the tree. Also, the portion of the bole that is subjected to the highest temperatures is within the forest floor mat, and accessing the bark at that point would only disturb the site. Experience eventually allows one to locate areas of thick bark (plates) and thinner bark (fissures). In giant sequoia they are more difficult to locate since bark thickness ranges from less than 1 inch to more than 18 inches.

Figure 16--Notched concrete reinforcing rods measure depth of the forest floor to determine the amount consumed by fire.

After a sample point on the bole is selected, it is best to place a piece of plywood (about 4- by 4-feet) down next to the bole to minimize disturbance of the forest floor. Changing burning conditions by disturbing the fuel can drastically affect the accuracy of temperature measurements. Plastic sheets placed around the tree keep chain saw shavings from mixing with forest floor material. Although a chain saw appears to be a gross way of making an incision on a tree, a little experience allows the operator to develop a keen sense of how deep to cut. The inner bark is usually white and spongy. Exerting slight pressure on the saw so that the cutting tip penetrates the bark slowly makes it easy for the operator to see the color change in the chain saw shavings. Once white shavings from the inner bark appear, steady hands can guide the saw at the same relative depth by keeping an eye on the shavings.

Using all safety equipment, especially chain saw chaps, is imperative when making precision cuts in the bark of a tree. Extreme care should be taken while cutting with the tip of the saw bar.

Two vertical, parallel incisions are made 8- to 10- inches or more above where the thermocouple tip ultimately should be positioned. The cuts should be 2- to 3-inches apart, and 4- to 5-inches long in ponderosa and sugar pine, and 8- to 10-inches long in sequoia (*fig. 17a*). Two horizontal cuts, perpendicular to and making a rectangle with the vertical cuts, can be cut with either a chain saw or a wide (1 $^1/_2$-inch) wood chisel (*fig. 17b*). Once the rectangle has been cut in the bark, a large wood chisel is used to knock the section out (*fig. 17c*). Keeping the bark section intact is important because it will be replaced once the thermocouple has been inserted.

Next, the $^1/_8$-inch diameter cambium thermocouple probe is inserted down along the cambium. First, determine how much of the upper end of the thermocouple probe should be exposed when the tip is at the appropriate location. A mark on the probe with a felt-tip marker will help. A good position is where the tip is halfway between the soil surface and the forest floor surface.

Most pines have spongy inner bark which makes for relatively easy probe insertion. A sheet metal type Visegrip can be used to grip the probe, and a hammer can be used to pound the thermocouple probe gently and progressively down the cambium if the probe cannot be pushed in by hand (*fig. 17d*). Care should be taken not to collapse the probe.

The extension cable is then plugged into the thermocouple. If the bark is more than 4-inches thick, the bark section is notched as needed to get it back into place around the protruding thermocouple. Thermocouple probes can be bent slightly to conform to the shape of the tree. When the entire system is in place and before the burn, each thermocouple needs to be tested. During the fire, it is too late for testing.

When the system continuity has been verified by appropriate temperature readings, a patch of aluminized fabric insulated with fiberglass is nailed with aluminum nails over the replaced bark section and thermocouple connector (*fig. 17e*). Fire shelters used for training, or discarded shelters, work well over the fiberglass insulation. Heavy aluminum foil works also. The edges of the aluminum should be folded around the edges of the rectangular fiberglass section to protect it from flames. The bottom edge of the insulation patch is placed at the top of the forest floor to serve as a reference point for fuel consumption measurements.

Figure 17--Thermocouples are inserted into the cambium in a step-by-step procedure. (a) Two vertical cuts are made in the bark with a chain saw.

The octopus extension from each thermocouple to the extension cable junction box is wired to the A-frame bracket attached to the tree (*fig. 6b*). The junction box connection must be covered with fiberglass insulation and aluminum also. From the bracket fastened to the tree, extension cables should be strung above the burn area to a secure spot, such as a fireline or other safe area away from the fire (*cover*). Outside the fire perimeter, the extension cable is connected to the pigtail, and the connection is wrapped with a piece of $^3/_8$-inch-thick Ensolite.

Figure 17--(b) Completed cuts form a rectangular bark section where the thermocouple will be inserted.

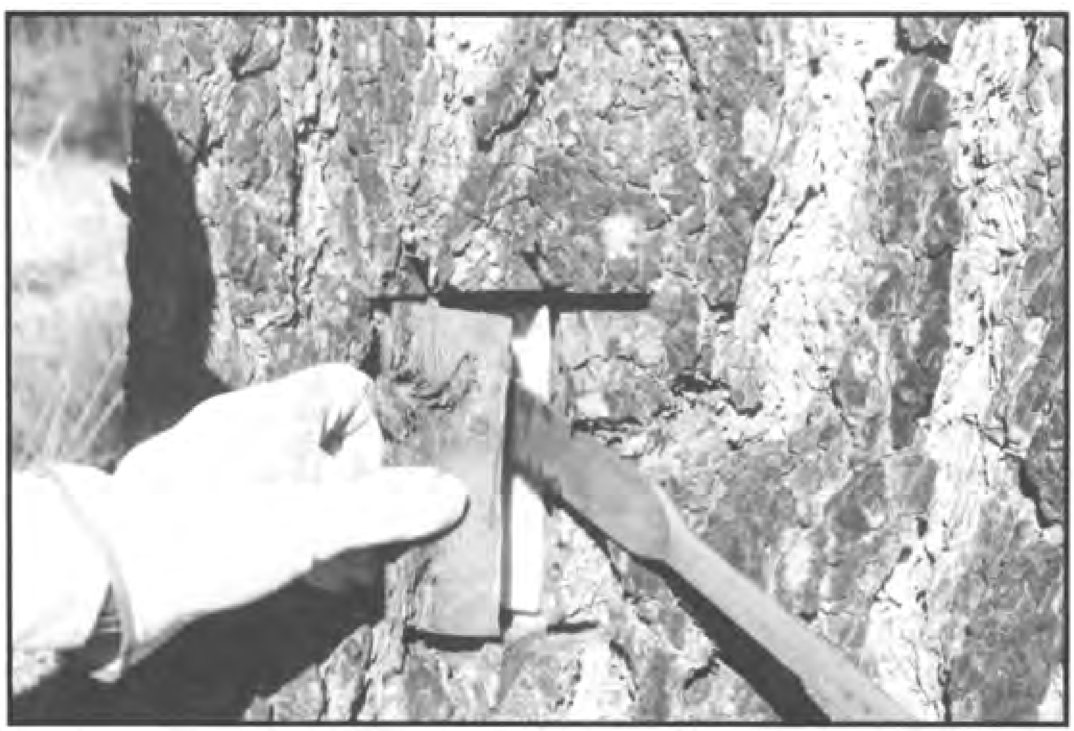

Figure 17--(c) The rectangular bark section is removed from the bole with a wood chisel.

Conclusions

The soil and cambium temperature-measuring systems described here can be constructed and used with care and understanding. Although somewhat complex, this type of instrumentation is necessary to define the temperature regimes during and after prescribed fires. In many cases mortality occurs so much later that the real cause of death (bole girdling, soil heating, and root mortality) may be mistakenly attributed to some other more visual and secondary cause such as insects. It is systems like those described here that can link fuel consumption and fire behavior to fire effects. With enough information on temperature range and duration, it should be feasible to predict fire effects on trees and soil from the amount of fuel consumed.

Reference

Sackett. S.S. 1980. **Reducing natural ponderosa pine fuels using prescribed fire: two case studies.** Res. Note RM-392. Fort Collins. CO: Rocky Mountain Forest and Range Experiment Station. Forest Service, U.S. Department of Agriculture: 6 p.

Figure 17--(d) With Visegrip applied, a hammer can be used to tap the thermocouple probe so that the tip is about halfway between the soil surface and the forest floor surface.

Figure 17--(e) Aluminized fabric and fiberglass insulation are attached to the tree with aluminum nails over the rectangular bark segment and thermocouple-extension wire connection.

Appendix: Materials List

Ambient Soil Temperature-Measuring System

Thermocouples
- brass tubing
- 20-gauge, type K, parallel duplex thermocouple wire
- shrink tubing
- clear flexible plastic tubing $^3/_8$-inch od
- silicone sealant
- silver solder
- 24-socket connector with locking ring
- field mounting bracket

Flexible Connection and Electronic Reference
- Junction 24-pin threaded connector
- single length of 20-gauge, type K, parallel duplex thermocouple wire
- 12 lengths of copper wire, color
- coded miniature electronic ice point
- clear flexible plastic tubing $^5/_8$-inch od
- 24-socket connector with locking ring

Datalogger and Data Translation Equipment
- aluminum carrying case, 9 inches by 16 inches by $7^3/_4$ inches
- static resistant polyfoam
- 24-pin threaded receptacle
- Campbell Scientific-21X datalogger
- SC92 cable connectors
- data quality cassette recorder
- 60-minute cassette tape
- PC201 hardware and software
- IBM-compatible personal computer
- graphics software

Soil Temperature-Measuring System

Thermocouples
- $^3/_{16}$-inch diameter stainless steel, mineral insulation-packed, grounded thermocouples--12 inches long; with 12- or 16-inch flexible stainless steel conduit extension and a high temperature socket connector

Extension Cable
- six pairs coaxial thermocouple extension cable - type K
- two conduit junction boxes
- 12-pin panel (6 pairs) to fit junction boxes
- 12-socket panel (6 pairs) to fit junction boxes
- aluminum flexible electrical conduit --$^1/_2$ inch id
- glass fiber insulation
- galvanized metal downspout
- 18-gauge wire to secure insulation to cable
- 24-socket connector with locking ring

Flexible Connection and Electronic Reference Junction
- (See Ambient Soil Temperature-Measuring System)

Datalogger and Data Translation Equipment
- (See Ambient Soil Temperature-Measuring System)

Cambium Temperature-Measuring System

Thermocouples
- $^1/_8$-inch diameter stainless steel, mineral insulation packed, grounded thermocouple 18-inches long; with 2 pins, very high temperature connector

Octopus Connection and Extension Wires
- six 10-foot lengths of CEFIR insulated type K wire with flexible stainless steel conduit--each with very high temperature 2-socket connector
- conduit junction box 12-
- socket panel (6 pairs)

Extension Cable
- (See Soil Temperature-Measuring System)

Flexible Connection and Electronic Reference Junction
- (See Ambient Soil Temperature-Measuring System)

Datalogger and Data Translation Equipment
- (See Ambient Soil Temperature-Measuring System)

Forest Service

Pacific Southwest Research Station

General Technical Report PSW-GTR-131

Measuring Soil and Tree Temperatures During Prescribed Fires With Thermocouple Probes

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