Jackson Demonstration State Forest
State of California Dept. of Forestry P.O. Box 1185 Fort Bragg, CA. 95437

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TEMPERATURE REGIMES OF SMALL STREAMS ALONG THE MENDOCINO COAST

Peter Cafferata

Stream temperature measurements have been collected in the Caspar Creek drainage on Jackson Demonstration State Forest periodically over the past 25 years. Review of this data and other recently collected data from western Mendocino County illustrates much about the temperature regimes of small coastal drainages, and how they are impacted by timber harvesting. This article gives a synopsis of these studies and summarizes reasons for concern. Additionally, it presents a model currently in use by the U.S. Forest Service to predict changes in maximum summer temperatures resulting from canopy reductions.

INTRODUCTION AND BASIC PRINCIPLES

Concern over elevated stream temperatures resulting from logging have generally centered around impacts on the fisheries resource. Field and laboratory studies done in many areas show that high water temperatures increase the metabolic rate of fish, increase their susceptibility to pathogens, and decrease the dissolved oxygen content of the water. Temperature changes that can result from logging may have indirect or sub-lethal effects on salmonid fish populations. Examples of these impacts include: decreases in the emergence time of fry from gravels; earlier, less favorable smolt migration to the sea; and lowered abundance and diversity of food organisms (Holtby 1988).

Various species of salmonids respond differently to elevated stream temperatures. Water temperatures for good survival and growth of juvenile coho salmon range from 50° to 59° F, with 55° appearing to be the optimum. Growth is slowed considerably at 64° and ceases at 68°. The upper lethal limit has been reported to be 78° from laboratory studies (Bell 1973). Young steelhead trout prefer temperatures between 45° and 68° F, with the optimum about 56°. The upper lethal limit is considered to be 82° (W. Jones, CDF&G, pers. comm.). Both species are stressed at temperatures over 68° F. Chinook salmon juveniles rarely over-summer in freshwater, so they are the least affected.

Researchers have documented that slight temperature increases in small headwater streams following harvesting sometimes increases fish biomass. This results from greater primary production, and subsequently higher production throughout the food chain for these fishes. The cumulative or additive effect resulting from harvesting many areas in a sizable watershed on mid-order (i.e., larger) streams usually has not been addressed. It is likely that moderate stream temperature increases are a significant problem for streams inland from the buffered coastal environment.

Stream temperatures increase after logging largely because of the increased exposure of the stream surface to solar radiation. Higher air temperatures resulting from harvesting are not the reason for higher water temperatures (Brown 1969). The key factors to consider are the surface area of the stream exposed to sunlight, and its discharge (i.e., amount of streamflow at a given time).

CALIFORNIA DEPARTMENT OF FORESTRY AND FIRE PROTECTION
Harold R. Walt, Director

George Deukmejian
Governor
State of California

Gordon K. Van Vleck
Secretary for Resources
The Resources Agency

Buffer strips have been required along all streams bearing fish since 1973 in California. One of the reasons for this requirement was to reduce the potential adverse impacts of increased stream temperatures due to logging. These protection zones vary in width based on the steepness of the ground, and require half of the initial shade-producing canopy to remain following harvest. Effective buffer strips for temperature control are those which leave the trees and shrubs that actually shade the stream during the critical summer months of the year. The size of a stream, its orientation (east-west vs north-south), surrounding topography, and type and density of vegetation need to be considered when designing a buffer strip. In addition, attention must be given to stability during windstorms and damage from logging and slash burning.

TWO CASE STUDIES OF COASTAL STREAMS

A. Caspar Creek

As part of the Caspar Creek Watershed Study, stream temperatures were measured in the North and South Forks from 1965 to 1969, and again from 1988 to the present. When the first data was collected, the second- growth redwood and Douglas-fir forest was 60 to 80 years old. The entire 5,000-acre basin extends inland only six miles and empties directly into the ocean. Periods of summer fog exist, but often burns off before mid-day beyond three miles inland. Both gauged tributaries are slightly more than 1,000 acres.

Most observed summer maximum stream temperatures (i.e., the highest temperature during a 24-hour period) in both forks before disturbance were slightly below 60° F. Absolute maximums of 62° F were recorded several times. Road building in the South Fork in 1967 left 3,000 feet of the channel with greatly decreased shading. Maximum water temperatures were frequently near 70° F, and most were above 60°. The highest single temperature observed after roading was 78° F. Two years after the road was built, temperature increases of 3° to 4° F were documented for water flowing from shaded to open areas. No data was collected after selective harvesting was done in the South Fork.

Figure 1. Aerial view of the North Fork of Caspar Creek.

In 1988, electronic data loggers were installed to record water temperatures at two locations in the South Fork and five locations in the North Fork, prior to clearcut harvesting. Small, totally uncut tributary basins in the North Fork show summer maximum temperatures of about 56° F. Average daily highs are about 54° F. Diurnal fluctuations are slight, with daytime highs usually only about 1.3° F higher than nighttime lows. A temperature station on the mainstem below recent clearcut harvests with buffer strips on both sides of the channel shows summer maximums of 61° F (see Figure 1). Average daily highs are approximately 59° F. Diurnal fluctuations here are commonly 4° F (see Figure 2). Large masses of filamentous algae now grow in most of the open stretches, probably due to the increased light. Further down the mainstem, summer maximums are 60° F; this site is slightly diluted with cooler water from three uncut tributaries below the clearcuts. The highest stream temperatures in the North Fork are found just above the large weir pond. Shading is very poor and summer peaks reached 65° F.

Winter low temperatures on these streams have dropped down to 36° F, but usually are no lower than 37.5° F. High temperatures for winter days are around 46° F. During cloudy, rainy conditions, temperatures show little fluctuation and may be considerably warmer (e.g., 50° F).

B. Railroad Gulch

Railroad Gulch is a 2000-acre tributary of the Albion River, located about seven miles south of Caspar Creek. This drainage is owned by Louisiana-Pacific Corporation and ex-

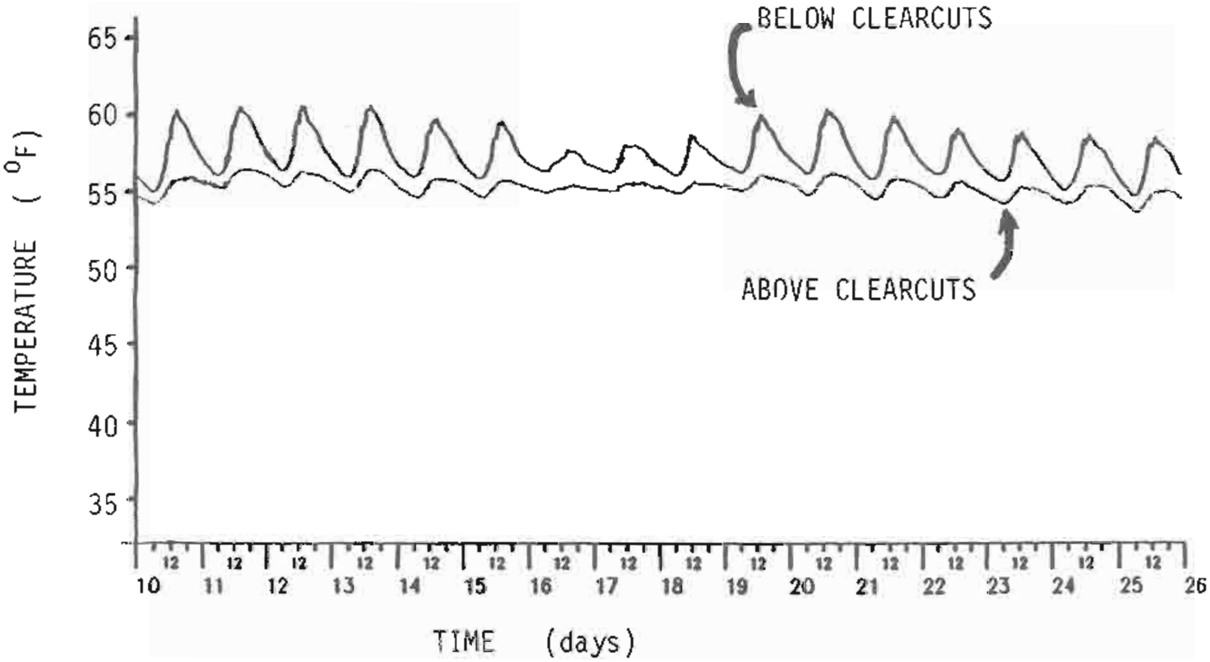

Figure 2. Plot of stream temperature, North Fork of Caspar Creek, July 10 - 25, 1990.

tends inland five miles from the ocean. Electronic data loggers were installed at two locations prior to harvesting. The first site is an uncut fork of the gulch (800 acres) with a measured shade canopy of 93 percent (see Figure 3). A device called a solar pathfinder was used to determine the canopy shading the water; it has proven to be an excellent tool for this job (see Figure 4). Maximum summer temperatures were found to be 58.5° F, with daily highs averaging 54.5° F. The lower site was used to document the impacts of clearcut harvesting a 40-acre block, with a buffer strip on both sides. A high water table through this reach had partially killed shade producing trees prior to harvest, and pre-logging maximums were 61.5° F. Daily highs averaged about 57° F. Following harvest, the effective shade for the stream was measured at 62 percent, and maximum water temperatures were 63° F. Average daily highs were 57.5° F.

PREDICTING STREAM TEMPERATURE INCREASES

In order to predict stream temperature increases, several parameters must be measured or estimated. These include: discharge, stream length impacted by logging, average stream width, travel time for the water to move through the harvested area, the effective shade before harvest, and estimated shade after harvest. Using an equation developed by Brown (1969) and modified by Amaranthus (1983), it is possible to calculate what the maximum increase in stream temperature will be.

The recent clearcuts in the North Fork of Caspar Creek were used to test this equation (see Figure 1). We measured the parameters on July 17, 1990. The North Fork example is shown in Table 1.

The observed increase is about 4° F, based on measurements taken above and below the clearcut reach (see Figure 2). Incomplete information was available to test the equation for Railroad Gulch. No estimate of shade before logging was made, and no measurement of travel time through the logged reach was done.

Table 1. A method to predict maximum stream temperature increase.

discharge = 0.20 cfs
length of flowing stream impacted by harvesting = 1800 feet
average stream width = 3.4 feet
travel time for the water through the unit = 6 hours
heat input, based on latitude and travel time = 4.19 BTU/ft^2-min (from published data)
shade before logging = 93 percent
shade after logging = 80 percent

The equation to predict temperature change (Δ T) is:

$$\Delta T = \frac{\text{Area x Heat x Percent Shade Lost}}{\text{Discharge}} \text{ x conversion factor}$$

$$\Delta T = \frac{\text{1800 feet x 3.4 feet x 4.19 BTU/ft}^2\text{-min x 0.13}}{\text{0.20 cfs}} \text{ x 0.000267}$$

$$\Delta T = 4.5^{\circ} F$$

SUMMARY

Small coastal streams in Mendocino County provide valuable anadromous fish habitat. Prior to timber harvest operations in second-growth forests, maximum stream temperatures are generally below 60° F. Full exposure to solar radiation, as was permitted before modern Forest Practice Rules went into effect, sometimes allowed unacceptable temperature increases to occur. For the two case studies presented here, large temperature increases did not occur from clearcut harvesting with buffer strips. The predictive equation can be used to estimate what the maximum temperature increase will be from logging. The California Department of Forestry and Fire Protection (CDF) will soon provide foresters in California with a guidebook on watercourse temperature prediction.

ACKNOWLEDGMENTS

The Caspar Creek data was collected as part of a joint watershed study being conducted by CDF and the USFS's Pacific Southwest Research Station. The Railroad Gulch data was supplied by Lee Susan of Louisiana-Pacific Corporation.

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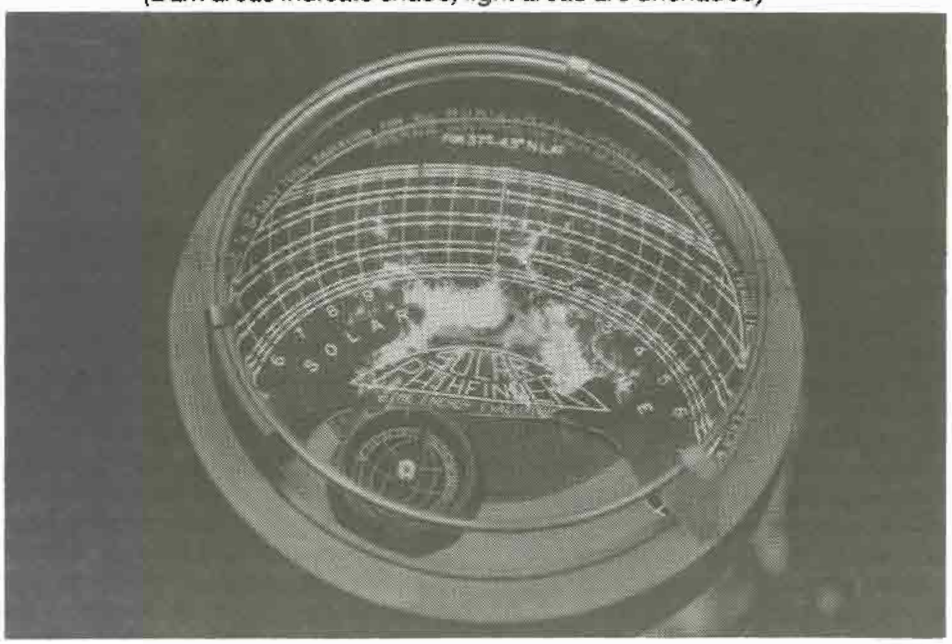
Figure 3. Measuring canopy shade at Railroad Gulch. (Above)

Figure 4. Top view of a solar pathfinder. (Below)
(Dark areas indicate shade, light areas are unshaded)



JDSF PARTICIPATES IN A SATELLITE IMAGERY STUDY TO EVALUATE REMOTE SENSING OF FUEL MOISTURES

Norm Henry, Forester II

The California Department of Forestry and Fire Protection (CDF) participated in a cooperative study evaluating the use of satellite remote sensing to monitor live fuel moistures for several vegetation types in 1989. This information is to be used to improve current models that determine fire danger and behavior. CDF joined the US Forest Service, Bureau of Land Management, National Park Service, Montana Department of State Lands, the EROS Data Center, and the Intermountain Fire Sciences Lab in collecting data for this study. The latter facility served as the collection point for the data gathered. Additionally, it is responsible for developing an integrated fire danger rating/fire behavior prediction system, which may be used for many fire management planning purposes.

Several state forests in California were involved in the field portion of the study during the summer of 1989. The Jackson Demonstration State Forest staff was asked to collect fuel moisture data at a site representing one area within the redwood vegetation type. The fuel samples collected were used to "ground truth" the data from the satellite.

Basic Concepts of the Research

Measurements of surface reflectance are taken by satellite in the visible and near infrared parts of the spectrum. The study is based on the principle that leaf surface reflectance of solar radiation varies with chlorophyll content and vegetation density. Chlorophyll absorbs much of the visible portion of solar radiation. Since leaf water content and chlorophyll content are fairly proportional, total reflectance can serve as an accurate analog for fuel moisture content. Vegetation density also contributes to the reflectance values in the visible portion of the spectrum. Less vegetation means less chlorophyll, which in turn means greater total reflectance in this part of the spectrum. Also, as vegetation dries, reflectance in the near infrared portion of the spectrum is reduced, for reasons not clearly understood.

The current system uses an Advanced Very High Resolution Radiometer (AVHRR) installed on a National Oceanic and Atmospheric Administration (NOAA) satellite. This polar orbiting satellite passes over a given site each day near 2 pm in the west on a shifting orbit. The AVHRR uses two channels to monitor the visible and near infrared reflectance values. These values are ultimately combined in an equation to calculate an index called the Normalized Difference Vegetation Index (NDVI), and produce "greenness" maps of the western United States. The numerical value of the index increases with increasing greenness and density. It is "normalized" to reduce the effect of oblique angles of view from the satellite, which changes the length of atmosphere through which reflectance radiation must travel from day to day. This procedure also reduces the problem of soil color differences from site to site.

Site Description and Field Procedure

The field sampling site specifications called for a four-square-mile area of similar vegetation. The actual sampling itself was done near the center of .7 x .7 mile square, itself centered within the larger square. This sample size is based on the resolution limitations of the sensors on the satellite. Each pixel, or unit of digitized data, represents one square kilometer from which an NDVI index value is calculated. The larger area serves as a buffer from other dissimilar vegetation patterns. As with most other large managed forested ownerships, finding a large area of similar forested cover was difficult on JDSF. Past and current harvesting plus natural site variation create a mosaic of forest conditions. However, near the center of the Forest in the South Fork Noyo drainage, a large enough area was found which closely fit this criteria. This site has an elevation of 600 feet, with approximately equal stocking of 70-year-old redwood and Douglas-fir in the overstory. The understory consists of scattered tanoak and shrub species.

The samples taken at the Noyo site consisted of: freshly picked redwood needles, fresh tanoak leaves, duff (dead needles and leaves), and mineral soil from the surface horizon. Each sample was placed in a sealed can, weighed prior to being oven dried, and then reweighed. The percent moisture content was calculated and the results sent to CDF study coordinator Steve Sayers, Forest Manager at Boggs Mountain State Forest. Three staff foresters were involved in collecting and processing the samples from April to October 1989. Samples were taken at least once every two weeks.

Results

A progress report was prepared in the fall of 1989 for the field cooperators. The results from the analysis of the 50 sampling sites throughout the western United States indicate that all the vegetation types show a seasonal trend in the NDVI index consistent with the measured fuel moistures (see Figure 1). "Greenness" maps were produced from the index for each two-week period to show drying throughout the west from April to October. Different vegetation types, however, do show significantly different index values. Conifer areas show much higher values than grass or shrub areas. It was difficult to predict the moisture content for mixed vegetation types from the index due to several limitations of the system. One problem is the averaging effect of the system resolution, when compared to a point sample on the ground. This effect occurs both from sensing reflectance values from all species, and from both live and dead fuels. Another difficultly is that the dates of field collection and satellite imagery may have differed. Only the

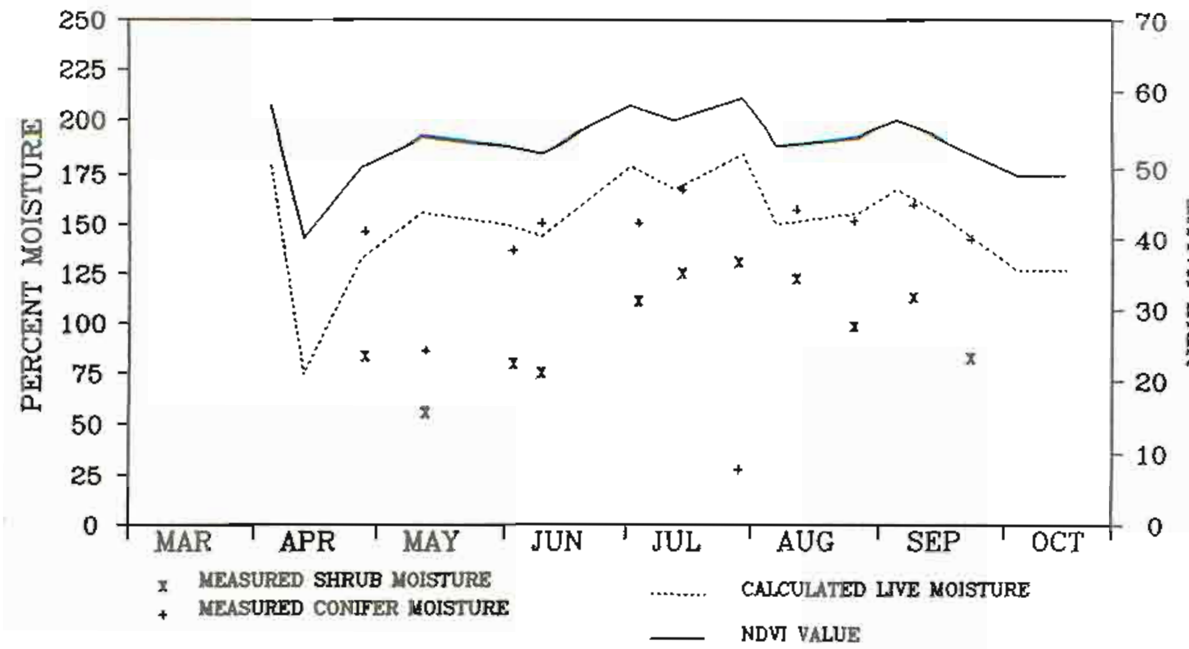


Figure 1. Fluctuations in NDVI values for vegetation on JDSF, 1989.

single highest NDVI index value was used in any bi-weekly period and it is probable that the ground sampling was done on a different day. To overcome these problems, approaches other than direct statistical relationships are being tried.

Future plans include developing live fuel moisture maps for other vegetation types. Additionally, the researchers hope to produce a map showing current "greenness" levels in relation to the maximum greenness that can be expected for a given area. The use of this technology in an integrated fire danger/behavior system will require mating this with the current National Fire Danger Rating System (NFDRS). The project leaders point out that continuation of this project is essential to develop a historical data base and improve the initial procedures developed from the first year's work.

If this system proves reliable, fuel moistures can be "measured" by satellite and the information fed into computers. Once automated, the numbers can replace the modeled values currently used in the fire danger rating and fire behavior systems. There may be many other applications, such as fire season start-up and shut-down dates, that can be developed with this data.

NATIVE AUSTRALIAN FORESTS

Walt Decker

[EDITOR'S NOTE: Walt Decker, Forester I on JDSF, spent the past year with his family in Benalla, Victoria. He exchanged positions with Malcolm Tonkin, an Australian forester, who has just left our staff to head back home. We enjoyed working with Malcolm very much. Walt sent this letter to me on Australian forestry a few months ago. Note some of the interesting similarities between eucalyptus and coast redwood.]

The forests of Australia are dominated by Eucalypts. Blue Gum Eucalyptus, commonly planted in California, is but one of over 600 species native to this island continent. The old geologic landscape is very flat and weathered, producing generally infertile soils. As little rainfall reaches the interior regions, most forests are located along the moist coastal belts. Much of the continental rainfall occurs along the East Coast. This zone stretches over 4000 miles from tropical mangrove forests within 10 degrees of the equator to the ash and gum forests of Tasmania in the roaring 40's (latitudes comparable to the Oregon-California border).

Southeastern Australia has been our home this year, permitting us to travel through parts of New South Wales, the Australian Capital Territory, South Australia, Tasmania, and much of Victoria. This area has some of the best native eucalypt forest in the world. Mountain ash (Eucalyptus regnans) is the world's largest flowering plant. It reaches heights of 100 meters (328 ft.) or more and diameters of 2.5 meters (8 ft.) in Victoria. The Great Dividing Range paralleling the southeast coast is called the Australian Alps and reaches its maximum height of 2228 meters (7308 ft.) at Mt. Kosciusko, the Nation's highest peak. The summit is actually just a low rise on a long ridge above the timberline at the headwaters of the Snowy River.

Very few species of conifer are native to Australia and their distribution is quite restricted. Coming from the

Figure 1. Example of fire in the red gum forest. The Australian forester is illustrating a sapling killed by fire several years ago. It produced two sprouts from its lignotuber.

Northern Hemisphere, it seems a bit unusual to be able to ascend Victoria's highest peak, Mt. Bogong (6514 ft.), on foot in just over two hours from the river valley below. Nearly a thousand feet above timberline I had to remind myself that this really is an alpine environment in spite of its moderate altitude and the round topped eucalyptus trees in the forest below. In winter the snow level often extends well into the subalpine forests below timberline, as the Alps become a winter playground for hordes of skiers from Melbourne and Sydney. Numerous resorts featuring groomed slopes and lifts cater to the downhill enthusiasts. The summit of Mt. Bogong is an almost imperceptible rise along one of a series of bare interconnecting alpine ridges that appeal to the nordic skiers.

Eucalypts are well adapted to the infertile soils. They grow in association with wattles, usually understory plants, of the genus Acacia. As members of the legume family, wattles provide nitrogen to the soil. The hot dry summers here often result in drought conditions which would destroy less hardy species. As sclerophyll type vegetation, similar to many chaparral plants in California, their adaptations to droughty conditions also permit them to flourish on relatively poor soils. In order to minimize water loss, mature eucalypt foliage hangs pendulously to avoid the direct rays of the sun. Leaves have a strong lignified structure which prevent collapse under moisture stress. They are coated and impregnated with oils which further reduce water loss, but make them very flammable. Many species shed their outer bark annually.

Lightning fires, common throughout Australia, frequently burn the flammable bark, leaves and understory wattles, releasing the nutrients stored in this material back into the soil as ash. Alpine eucalypt species rely on fire for regeneration, with hot fires killing the mature trees, but releasing large quantities of seed which germinate readily in the ash beds created by the fire. Lignotubers are large masses of dormant buds, usually at or below ground level, common to many eucalypts. When intense fires or other agents destroy the aerial portion of the tree, these buds are stimulated to produce new shoots vital to the regeneration of the species (see Figure 1). Many eucalypts and wattles produce juvenile foliage for several years after sprouting or germination. The large juvenile leaves are oriented toward the sun, in order to maximize photosynthesis during seedling establishment. This often occurs under limited light conditions near the forest floor.

As one proceeds inland from the coastal mountains, conditions become progressively more arid. Eucalypts adopt more stunted forms and are less dense. Acacias become more abundant and eventually dominate the interior vegetation types. Between these two extremes, river red gum (_Eucalyptus camaldulensis_) occurs near almost all seasonal watercourses in the arid and semi-arid areas and along many streams and rivers. River red gum is the most widely distributed of all eucalypts and is now planted on flood plains and arid regions of many third world countries. The hard, durable, deep red heartwood of this species is used for heavy construction, railway sleepers (ties), flooring, framing, fencing, plywood and veneer manufacture, turnery, firewood, and charcoal. One of my most enjoyable duties as hardwood production planning officer for the Benalla region in Victoria is to coordinate management of the river red gum forest along the Murray River.

JACKSON DEMONSTRATION STATE FOREST
802 N. MAIN STREET
P.O. BOX 1185
FORT BRAGG, CA 95437