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The Role of Fire in Wildlands



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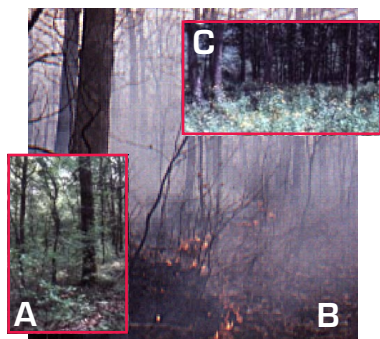
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On the Cover:



Before European settlement, frequent fires maintained the biological diversity of the oak-dominated forests of the Midwest. But post-settlement fire suppression has helped cause the open oak forest to decline. (A) Dense understory, considerable leaf litter, and sparse herbaceous growth now characterize dry upland forest communities on Indiana's Hoosier National Forest. (B) Low-intensity burning in these communities top kills understory vegetation and reduces leaf litter. (C) After a burn, more sunlight reaches the forest floor, promoting abundant herbaceous growth, especially in open areas. Photos: Steve Olson, USDA Forest Service, Hoosier National Forest, Tell City Ranger District, Tell City, IN, 1991–93. (See related article by Steve Olson beginning on p. 4.)

The FIRE 21 symbol (shown below and on the cover) stands for the safe and effective use of wildland fire, now and in the 21st century. Its shape represents the fire triangle (oxygen, heat, and fuel). The three outer red triangles represent the basic functions of wildland fire organizations (planning, operations, and aviation management), and the three critical aspects of wildland fire management (prevention, suppression, and prescription). The black interior represents land affected by fire; the emerging green points symbolize the growth, restoration, and sustainability associated with fire-adapted ecosystems. The flame represents fire itself as an ever-present force in nature. For more information on FIRE 21 and the science, research, and innovative thinking behind it, contact Mike Apicello, National Interagency Fire Center, 208-387-5460.



Firefighter and public safety is our first priority.

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THE HISTORICAL OCCURRENCE OF FIRE IN THE CENTRAL HARDWOODS*



Steven D. Olson

What did the forests of the Midwest look like at the time of European settlement? What ecological processes were at work on the landscape? And just how important was fire—how much of the land burned and how often? Answers to these questions can be found in the writings of early European visitors and settlers.

Early Fire History

The two sources of fire prior to European settlement were Native Americans and lightning. Anthropogenic (human-caused) fires generally do not coincide with the timing of natural fires (Martin 1991). In the Midwest, lightning fires are most likely to occur in late summer, whereas anthropogenic fires before the arrival of Europeans usually occurred in spring or fall.

Native Americans set many fires to keep areas clear for villages and agriculture (Noss 1985). Parts of the Midwest were known for their smokiness at certain times of the year. In 1796, an early surveyor of the Ohio River, Andrew Ellicot, noted daylong fog and smoke near Gallipolis, OH, due to “the effect of fires extending over the vast forests

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* This article summarizes an article published in 1996 by the author under the title “The Historical Occurrence of Fire in the Central Hardwoods, With Emphasis on Southcentral Indiana” in *Natural Areas Journal*, 16(3):248–256.

Since fire suppression began, the open oak forests and woodlands have become closed forest stands, and the canopy oaks are declining in some regions.

of our country” (Gordon 1969). In his 1823 journal, the traveler William Faux mentioned the daylong smoke of “Indian Summer” near Princeton, IN (Faux 1823). Ladd (1991) cites numerous authors during the period of early European settlement who discuss the occurrence of fires in Missouri.

Fire explains the frequent observation by European travelers that many forests in the Eastern United States lacked undergrowth. In his review of the literature concerning the Native American influence on the landscape of the Northeast, Day (1953) cites authors as far back as 1670 who attributed the open character of the forests to annual burning. Low-intensity surface fires kept woodlands open in the Ozarks as well (Guyette and Cutter 1991).

The brushy character of many areas can also be attributed to frequent fire (Marks et al. 1992). If short-return-interval fires are interrupted for several years, oak and hickory can regenerate, increasing woody fuels and reducing herbaceous fine fuels. Fire then no longer passes through a stand except under severe conditions. When those conditions occur, fire top kills seedlings and

saplings in the understory but not their well-established roots, which quickly send up new shoots (fig. 1). A low, brushy growth can result and persist for many years. Early travelers in the Midwest described the resulting pattern of woody undergrowth often dominated by “grub-forming” oaks in dense thickets (Ladd 1991).

Early travelers also left many accounts of large stands of trees killed by fire (Williams 1994). However, Day (1953) notes “that there is no evidence in the early authorities for the wholesale conflagration of southern New England . . . but only burning ‘in those places where Indians inhabit,’ and outside the swamps.” Similarly, there is scant evidence of widespread, all-consuming fires in the Midwest.

In the survey notes left by the USDI General Land Office (GLO—predecessor to the USDI Bureau of Land Management), references to fire-killed trees are rare, probably because catastrophic fire was indeed quite infrequent, whereas the effects of low-intensity fires were so common that the surveyors considered them unworthy of note. On what is now the Hoosier National Forest in Indiana, the



Figure 1—Dry upland forest community in the first summer following a prescribed fire on Boone Creek Barrens, Tell City Ranger District, Hoosier National Forest. Note plentiful sunlight on the forest floor and abundant sprouting by shrubs and saplings after being top killed by fire. If fire is again excluded from the area, this woody growth might form a dense understory. Photo: Steven D. Olson, USDA Forest Service, Hoosier National Forest, Tell City Ranger District, Tell City, IN, 1992.

GLO mentions three areas of fire-killed timber:

- Surveyors found “poor brushy hills; timber dead by fire” on one survey section line about 5 miles (8 km) east of Tell City, IN.
- At the opposite end of the forest, about 2 miles (3 km) west of Waymansville, surveyors found the area “hilly and poor; w&b [probably white and black] oak; mostly killed by fire.” An adjacent line outside what is now the Hoosier National Forest also had fire-killed timber.
- The largest burned area mentioned in the GLO notes was 5 miles (8 km) east of Shoals, where surveyors on three contiguous lines inside the forest and three more outside found the timber “all” or “mostly killed by fire.”

Fire history of a given site varies with its physiographic character (Kline and Cottam 1979). Exposed ridges and dry south- to west-

facing slopes would burn more frequently than protected slopes and mesic sites. Deep ravines protected by high cliffs would burn only rarely.

Ecosystem Fire Dependence

Physiologically, upland oaks such as white oak and chestnut oak have several adaptations to frequent fire, including thick bark, resistance to rotting, sprouting ability, fire-created seedbeds, deep roots, xeromorphic leaves, and high photosynthetic rates during drought (Abrams 1992). These characteristics give them greater resistance to fire than late-successional species such as beech and sugar maple.

Fire suppression favors oaks over grasses because the growing point of the grasses is below the surface of the ground, whereas that of oaks is exposed to flames. By removing heavy amounts of combustible materials in the form of grasses,

fire suppression reduces the loading of fine fuels and the intensity of fire (Guyette and Cutter 1991). Suppression also favors sugar maple and beech over the upland oaks (Packard 1991). Beech and sugar maple lack the adaptations of oaks, making them more susceptible to damage from fire. Additionally, the shade produced by an oak canopy moderates the temperature and moisture conditions at a site. Without fire, the mesophytic sugar maple and beech can gain a foothold at such sites.

The occurrence of fire in the uplands appears “to be the common denominator for the development of oak forests” (Abrams 1992). Even though many upland oak forests appear to be relatively stable communities showing little sign of succession to forests dominated by more mesophytic species, most upland oaks require occasional disturbance to reduce competition (Johnson 1993). Many forest trees other than oaks are also fire tolerant or require exposed soil—such as occurs with fire—for seed germination (Martin 1991). Eastern hemlock, for example, easily invades burned ground.

Prairie and forest species often overlap in midwestern oak forests, depending on drought cycles and on fire and other disturbances, such as grazing animals and storms (Bronny 1989, Packard 1991). Fire enhances habitat for ground- and brush-foraging birds (Martin 1991). Woodpeckers, especially the common flicker, are well adapted to open forests. Many other birds take advantage of woodpecker-created cavities for nesting, including Bewick’s wren, eastern bluebird, and eastern screech-owl. Several species of

migratory birds with declining populations could be fire dependent, including prairie warbler and Bachman's sparrow.

Fire Suppression and Biodiversity Loss

In the Great Lakes region, canopy oaks are already declining, and regeneration is poor in the dense shade of the beech and maples (Apfelbaum and Haney 1991). The situation is much the same on the Hoosier National Forest (USDA Forest Service, Hoosier National Forest 1990). Since fire suppression began, the open oak forests and woodlands have become closed forest stands, without a concurrent change in the herbaceous flora towards shade-tolerant species (Packard 1991 and 1993). The remaining plants appear to be debilitated by shade (fig. 2).

Based on the numerous early accounts of fire in the Midwest, the prevalent trees and herbs in the

region, and the character of existing forests, it can be said that catastrophic fire was quite rare but that low-intensity fires were common and widespread. The vegetation of the Midwest, including all of the organisms comprising its woodland systems, has evolved under a regime of frequent low-intensity fires since the glacial period. Recent attempts at woodland preservation—including fire suppression—have created what could be the first prolonged fire-free interval in the history of the central hardwoods. Such an abrupt change is bound to bring major structural and compositional alterations (Ladd 1991).

Abrupt changes in the abiotic factors influencing natural systems appear to result in a loss of native species. Moreover, no rich association of mesophytic organisms from the eastern cove forests is likely to migrate into the midwestern oak woodlands across today's fragmented landscape. Because there

are no longer adequate mechanisms for recolonization by conservative species adapted to the new environmental parameters, the overall effect of fire removal from the fire-dependent central hardwoods will be decline and loss (Ladd 1991).

Implications for Fire Management

Reintroduction of fire to the central hardwoods is not a panacea for full ecosystem recovery. Many other equally important factors are vital to the ecological health of a woodland system, including hydrology, soils, plant-soil reactions, erosion, area size, and other often poorly understood criteria (Ladd 1991).

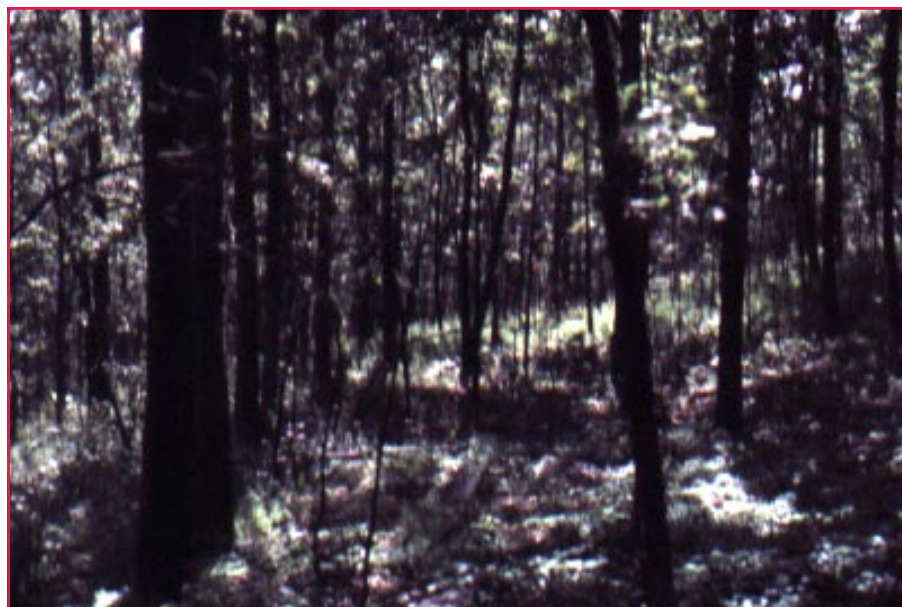
There are frequent calls for studies on an area before considering the use of prescribed fire, but there are no corresponding calls for studies to justify the exclusion of fire from an area. This approach has a fundamental flaw: the decision not to burn is a management action with at least as many ramifications and potential pitfalls as the decision to burn. In light of available evidence about the pervasiveness of fires in the pre-European settlement woodland systems, a case can be made that stronger justification should be required for fire exclusion from a site (Ladd 1991).

If preservation of biodiversity is a worthwhile goal, then steps should be taken to ensure that representative examples of midwestern woodlands are managed to sustain their diversity (Ladd 1991). Fire is an important tool for managing the landscape (fig. 3). As Heinselman (1973) said, "To understand the dynamics of fire-dependent ecosystems, fire must be studied as an integral part of the system. The



Figure 2—Dry upland forest on Boone Creek Barrens, Tell City Ranger District, Hoosier National Forest, looking across a recent fireline into forest unburned for 50 years. Note dense shade, leaf litter, abundant understory trees and shrubs, and little herbaceous growth beyond fireline. Photo: Steven D. Olson, USDA Forest Service, Hoosier National Forest, Tell City Ranger District, Tell City, IN, 1992.

Figure 3—Upland forest community after a 375-acre (152-ha) prescribed landscape burn on Boone Creek Barrens, Tell City Ranger District, Hoosier National Forest. Right: Dry-mesic site in spring (2–3 weeks after burn). Note top-killed shrubs and saplings, remnants of burned leaf litter, and emerging herbs. Below: Dry site in first summer after burn. Note standing top-killed understory shrubs and saplings, abundant herbaceous growth, and little leaf litter. Also note apparent sunlight in understory. Photos: Steve Olson, USDA Forest Service, Hoosier National Forest, Tell City Ranger District, Tell City, IN, 1992.



search for stable communities that might develop without fire is futile and avoids the real challenge of understanding nature on her own terms.” To be able to use fire effectively, as Mutch (1992) put it, “[f]ire history and fire regime information [are] not just ‘nice to know’ reference data, but rather [are] absolutely essential background data for the appropriate design and implementation of resource management projects at the ecosystem and landscape level of organization.”

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HAINES INDEX CLIMATOLOGY FOR THE WESTERN UNITED STATES



John Werth and Paul Werth

For years, atmospheric instability and dry air have been associated with the development of large wildland fires in the United States. Brotak and Reifsnyder (1977) analyzed characteristic values of low-level atmospheric lapse rates on a number of large wildland fires in the Eastern United States. (See sidebar for definitions of special terms used in this article.) They found that most of the major fire runs occurred on days when the atmospheric lapse rate in the vicinity of the fire exceeded the standard atmospheric lapse rate. Haines (1988) conducted a rudimentary comparison of atmospheric lapse rates and dry air during or immediately before large wildland fires with the values expected climatologically for these factors. Results from his study provided further evidence of a strong relationship of environmental lapse rates and dry air to large fire growth. More recently, Potter (1996) conducted a detailed statistical analysis on a number of atmospheric properties, concluding that surface temperature, surface dewpoint depression, and surface relative humidity differed significantly from climatology on days with large wildfire growth.

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SPECIAL TERMS USED IN FIRE WEATHER RESEARCH

Atmospheric lapse rate or *environmental lapse rate* refers to how slowly or quickly temperature changes with height in the Earth's atmosphere. Normally, temperature falls the higher one rises in the Earth's atmosphere. However, under certain conditions, temperature can remain constant or even rise with increasing height in the atmosphere.

Climatology describes the typical or expected values for a particular weather element (such as temperature, humidity, or wind) for a given region.

Foehn-type winds are warm, dry winds that blow down from mountains (the term derives from the German word "Föhn" for a seasonal wind that blows north from the Alps across southern Germany).

Radiosonde data are collected using a miniature radio transmitter that is carried aloft (attached to balloons) with instruments for broadcasting atmospheric humidity, temperature, and pressure.

The *standard atmospheric lapse rate* is the average atmospheric lapse rate for the entire Earth. It is often used in comparison with the actual atmospheric lapse rate to determine relative atmospheric stability.

Subsidence is the slow, sinking motion of air within high-pressure systems covering thousands of square miles. The air mass warms and dries due to compression.

Synoptic-scale refers to atmospheric, weather, or other conditions that exist simultaneously over a broad area (often thousands of square miles).

The Haines Index

However, Haines (1988) was the first researcher to devise a national fire weather index based on the stability and moisture content of the lower atmosphere. Originally called the Lower Atmospheric Severity Index, it is now commonly referred to as the Haines Index, as a tribute to the pioneering work done by Haines in the field of fire and forest meteorology.

Due to large differences in elevation across the United States, three combinations of atmospheric layers were used to construct the Index. The layer chosen for each region was thought to be high enough above the surface to avoid major diurnal changes in temperature and relative humidity caused by heating of the Earth's surface due to exposure to the sun, and to preclude the effects of surface-based inversions on temperature

and humidity. Figure 1 shows a map of the United States divided into three regions based on surface elevation. In the mountainous region of the Western United States, the Haines Index uses the difference in temperature at 70 kilopascals of atmospheric pressure (about 10,000 feet (3,050 m)) and at 50 kilopascals of atmospheric pressure (about 18,000 feet (5,500 m)), and the temperature–dewpoint spread at 70 kilopascals of atmospheric pressure (about 10,000 feet (3,050 m)).

The Haines Index is calculated by adding a temperature term (A) to a moisture term (B). The temperature term is broken into categories 1 to 3, depending on the magnitude of the temperature difference within the predefined layer for each region. The moisture term is also broken into categories 1 to 3, depending on the dryness of the layer's lower level. The resulting Haines Index varies from 2 to 6: a 2 indicates moist, stable air, whereas a 6 indicates dry, unstable air. The potential for large fire growth or extreme fire behavior is very low when the Index is 2 and high when the Index is 6. Table 1 shows the temperature and moisture limits used to compute the high-elevation Haines Index.

Land management agencies and fire weather meteorologists have used the Haines Index operationally since the early 1990's as an indicator of the potential for extreme fire behavior, such as high rates of spread, extensive spotting, prolific "crowning," and the development of large convection columns. Werth and Ochoa (1993) found a correlation between a Haines Index of 5 or 6 and large wildfire growth in central Idaho. Other fire weather meteorologists and fire

managers in the Western United States have also associated a Haines Index of 5 or 6 with extreme fire behavior.

Haines developed a Haines Index climatology for the high-elevation West using radiosonde data from Winslow, AZ, for the 1981 fire season. He concluded that atmospheric conditions during the 1981 fire season were representative of the long-term climate, because

fire activity (number of fires and acres burned) on national forests in the United States was near normal that year. Preliminary results from his study indicated that 6 percent of all fire season days are "Haines 6 days" (that is, days with the highest Haines Index of 6), and 62 percent are "Haines 2 and 3 days" (that is, days with the very low Haines Indices of 2 and 3).

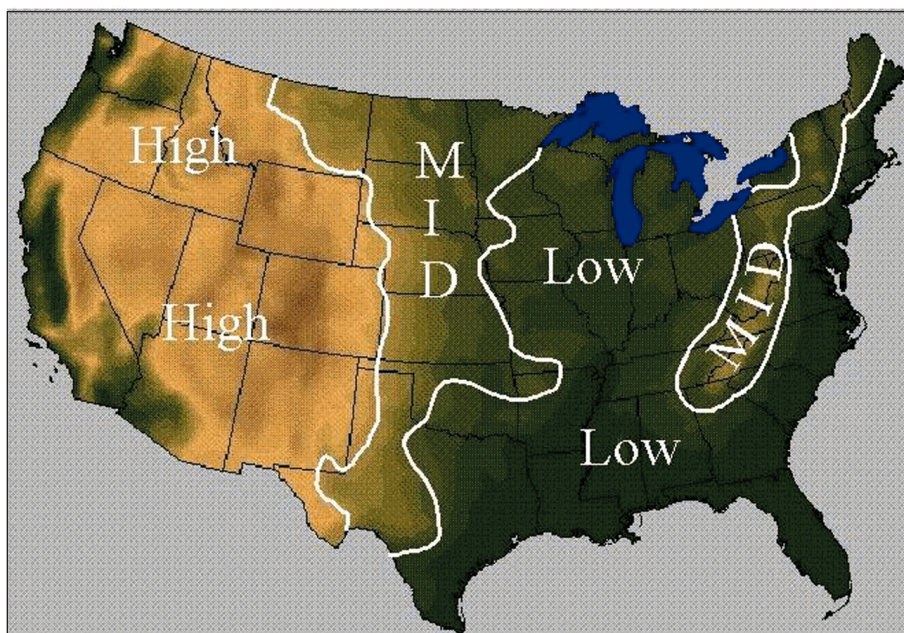


Figure 1—Haines Index elevation map. Due to large differences in elevation across the United States, three combinations of atmospheric layers were used to construct the Haines Index. The high-elevation Haines Index is in the Western United States.

Table 1—Limits for high-elevation Haines Index (Haines Index = category for temperature term (A) + category for moisture term (B)).

Temperature term (A)		Moisture term (B)	
70 kPa T – 50 kPa T ^a	Category	70 kPa T – 70 kPa Td ^b	Category
< 32 °F (18 °C)	1	< 27 °F (15 °C)	1
32–38 °F (18–21 °C)	2	27–37 °F (15–20 °C)	2
≥ 39 °F (22 °C)	3	≥ 38 °F (21 °C)	3

^a Difference in temperature (T) at 70 kPa of atmospheric pressure (about 10,000 feet (3,050 m)) and at 50 kPa of atmospheric pressure (about 18,000 feet (5,500 m)).

^b Difference between the temperature (T) and the dewpoint temperature (Td) at 70 kPa of atmospheric pressure (about 10,000 feet (3,050 m)).

Refining the Haines Index Climatology

This study establishes a more detailed high-elevation Haines Index climatology for the Western United States based on upper air data for 1990 to 1995 from the 20 radiosonde sites located in the Western United States. National figures for both the number of fires and the number of acres burned were near normal during this period, with an average of 74,963 fires and 2,891,966 acres (1,170,350 ha) burned per year. This compares with the 10-year (1987 to 1996) average of 73,914 fires and 3,270,669 acres (1,323,607 ha) burned per year. Nationwide, fire activity was near normal in 1991 and 1992, below normal in 1993 and 1995, and above normal in 1990 and 1994.

For this study, we constructed maps and frequency tables for the observed Haines Index for June through October, 1990 to 1995, for upper air soundings at 1200 coordinated universal time (UTC) (0500 Pacific daylight time (PDT) or 0600 mountain daylight time (MDT)) and 0000 UTC (1700 PDT or 1800 MDT). Questions we addressed include:

- How frequent are Haines 5 and 6 days in the Western United States?
- Does the frequency of these days vary by location?
- Is there a significant diurnal difference in the frequency of the Haines Index between 1200 UTC and 0000 UTC?
- Are there monthly variations in the Haines Index?
- Is the frequency of Haines 5 and 6 days unusually high in California, as many California fire weather meteorologists say?

The Haines Index is useful in predicting large wildfire growth and extreme fire behavior, although further refinement is needed.

Methods

Daily upper air data were collected for the 20 radiosonde sites located in the Western United States (fig. 2) for June through October, 1990 to 1995. For each station, the Haines Index was calculated using the high-elevation limits described in table 1. Separate data sets were constructed for 1200 UTC and 0000 UTC. Each data set included 600 to 700 days of Haines Index values for each site. Seasonal (June through October) frequency distributions were calculated for each radiosonde site (table 2).

Individual data sets were developed for each station using 0000 UTC Haines Index data for the same time period. Data for each station were further stratified by month to show monthly trends in the Haines Index. Table 3 summarizes the

monthly frequency distribution of Haines Index 2 through 6 for each radiosonde site. Afternoon upper air data were used in this portion of the study because 0000 UTC is either during or just after the most active burning period (usually mid- to late afternoon) for nonwind-driven fires in the Western United States. The use of afternoon upper air data was also consistent with Haines' study.

Additional data sets were created for a smaller subset of stations using 0000 UTC data for June through September 1994. For each site, calculated values of the Haines Index were separated into their individual components (moisture and stability). The data were then entered onto spreadsheets for further statistical analysis.

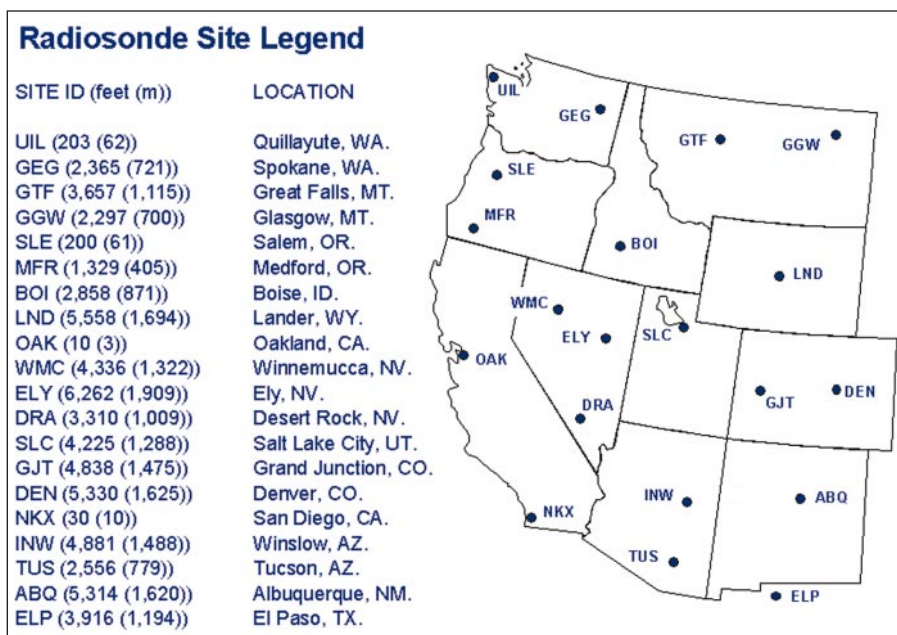


Figure 2—Twenty radiosonde sites in the Western United States, by location and elevation. Daily upper air data collected at these sites for June through October, 1990 to 1995, were used in this study.

Table 2—Seasonal frequencies for Haines Index 2 through 6 at 1200 UTC and 0000 UTC, 1990–95 (percent of days, June through October).^a

	<i>Haines 2</i>		<i>Haines 3</i>		<i>Haines 4</i>		<i>Haines 5</i>		<i>Haines 6</i>		<i>Haines 5 & 6</i>	
<i>Site</i>	<i>1200 UTC</i>	<i>0000 UTC</i>	<i>1200 UTC</i>	<i>0000 UTC</i>	<i>1200 UTC</i>	<i>0000 UTC</i>	<i>1200 UTC</i>	<i>0000 UTC</i>	<i>1200 UTC</i>	<i>0000 UTC</i>	<i>1200 UTC</i>	<i>0000 UTC</i>
UIL	46	44	14	20	28	24	12	12	1	1	13	13
GEG	50	49	26	27	16	16	8	9	1	1	9	10
GTF	49	41	29	35	12	13	9	10	2	2	11	12
GGW	51	48	31	29	12	13	6	9	1	1	7	10
SLE	36	35	24	22	27	26	12	17	1	1	13	18
MFR	29	30	27	26	27	26	16	17	1	2	17	19
BOI	31	23	28	24	22	25	14	23	5	5	19	28
LND	30	16	33	27	17	21	15	25	6	11	21	36
OAK	10	10	13	17	34	33	41	38	2	2	43	40
WMC	21	14	22	19	23	22	27	27	7	19	34	46
ELY	15	9	29	16	27	16	21	29	8	31	29	60
DRA	11	10	27	23	24	22	28	33	9	12	37	45
SLC	19	14	24	25	23	24	24	27	10	10	34	37
GJT	19	10	23	26	18	18	23	26	11	19	34	45
DEN	22	17	32	30	16	19	19	18	11	16	30	34
NKX	10	17	19	26	33	31	33	24	4	2	37	26
INW	22	12	36	32	17	21	16	20	9	15	25	35
TUS	34	37	39	38	12	15	12	9	3	2	15	11
ABQ	26	12	40	37	15	17	13	20	6	14	19	34
ELP	43	37	33	39	12	11	8	8	5	4	13	12

^a Percent might not add to 100 across columns due to rounding.

Table 3—Monthly frequencies for Haines Index 2 through 6 at 0000 UTC, 1990–95 (percent of days per month).^a

MO.	2/3	4	5	6	2/3	4	5	6	2/3	4	5	6	2/3	4	5	6	2/3	4	5	6
	<i>UIL</i>				<i>GEG</i>				<i>GTF</i>				<i>GGW</i>				<i>SLE</i>			
JUN	77	19	4	1	88	6	5	1	82	13	5	0	84	11	6	0	77	10	13	0
JUL	66	23	11	0	87	9	4	0	86	6	9	0	87	7	4	2	53	29	18	1
AUG	68	21	11	0	76	15	10	0	67	16	15	2	73	14	12	1	60	24	16	0
SEP	46	32	21	1	58	25	16	1	66	18	13	3	65	19	13	3	42	32	24	2
OCT	68	24	7	1	75	19	6	0	85	9	5	1	78	12	10	0	65	27	8	0
	<i>MFR</i>				<i>BOI</i>				<i>LND</i>				<i>OAK</i>				<i>WMC</i>			
JUN	73	17	8	2	67	17	12	5	39	17	28	17	27	30	40	4	47	19	14	19
JUL	53	22	24	2	42	26	26	6	33	22	32	13	23	32	43	2	15	23	29	34
AUG	60	28	11	1	31	31	29	10	32	20	31	17	23	37	39	2	24	16	37	23
SEP	44	29	23	4	40	25	32	2	51	22	20	7	27	31	42	1	34	24	30	13
OCT	53	32	16	0	68	23	8	1	63	24	11	3	38	34	27	2	54	29	13	4
	<i>ELY</i>				<i>DRA</i>				<i>SLC</i>				<i>GJT</i>				<i>DEN</i>			
JUN	20	15	31	35	21	16	38	25	38	20	31	11	29	17	25	33	36	20	15	29
JUL	7	8	32	53	18	19	43	21	23	23	35	19	12	17	34	32	50	13	16	21
AUG	15	12	36	38	32	23	31	15	33	26	29	13	37	19	27	17	49	15	24	12
SEP	28	20	27	25	39	29	27	5	43	25	27	6	40	21	25	13	51	20	16	13
OCT	55	25	20	1	53	17	28	2	62	22	15	2	60	20	17	3	43	26	18	13
	<i>NKX</i>				<i>INW</i>				<i>TUS</i>				<i>ABQ</i>				<i>ELP</i>			
JUN	21	32	44	4	17	13	27	43	32	19	37	12	11	15	31	43	29	25	20	27
JUL	33	36	24	6	34	19	19	29	72	11	11	3	43	13	19	25	76	9	11	5
AUG	61	26	14	0	49	22	21	8	91	7	2	0	64	16	17	3	91	7	2	0
SEP	52	30	17	1	53	27	17	3	77	19	4	0	66	21	12	1	90	4	5	1
OCT	38	33	28	2	58	20	19	3	61	18	11	0	45	19	28	7	64	25	11	0

^a Percent might not add to 100 across columns due to rounding.

Results

Haines Index Frequency by Site.

Haines' original research indicated that a high-elevation Haines Index of 6 should occur on about 6 percent of the fire season days in the Western United States. However, our study found large differences in the frequency of Haines 6 days at 0000 UTC across the Western United States. The frequency of Haines 6 days varied from less than 1 percent at Quillayute, WA; Spokane, WA; Glasgow, MT; and Salem, OR, to more than 30 percent at Ely, NV (fig. 3). A statistical analysis of the 0000 UTC data showed a correlation of 0.83 between radiosonde site surface elevation and the frequency of Haines 6 days at 0000 UTC (fig. 4).

Diurnal Variation of the Haines

Index. Haines speculated that indices calculated from upper air soundings in the morning (at 0500 PDT or 0600 MDT) might be more useful in predicting large wildfire growth later in the day during the most active burning period.

Are there significant differences between Haines Index frequencies calculated from morning upper air

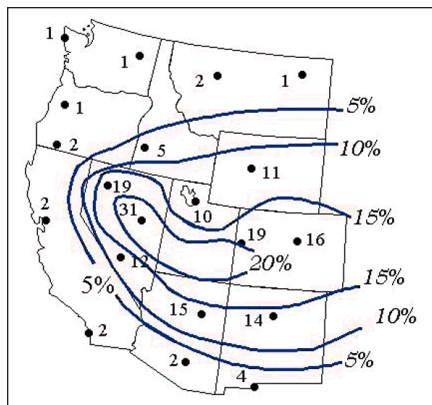


Figure 3—Seasonal (June through October) frequency of Haines 6 days at 0000 UTC (percent).

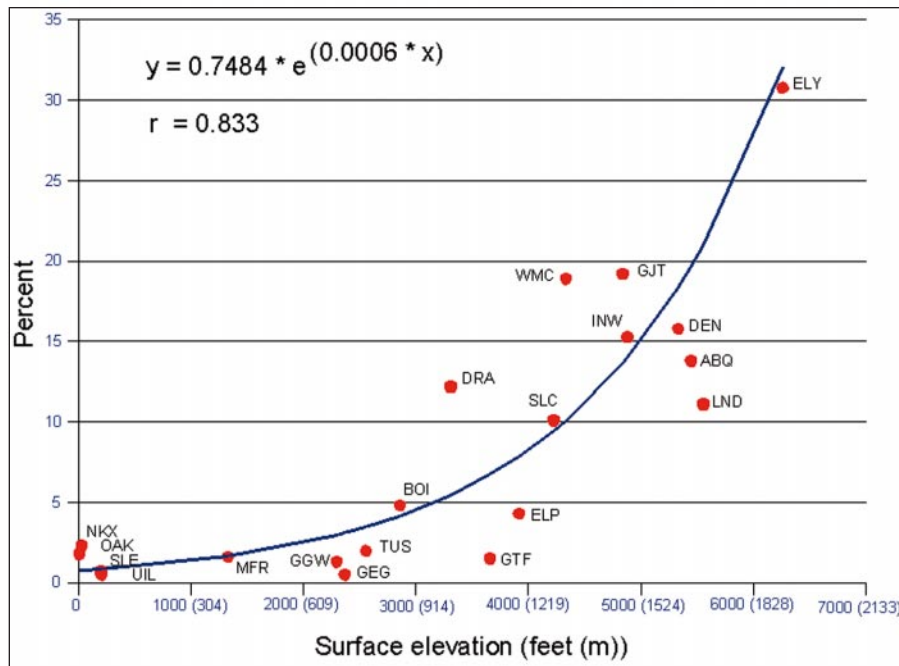


Figure 4—Surface elevation for 20 stations plotted against frequency of Haines 6 days at 0000 UTC in feet (m).

soundings and late afternoon or evening soundings? We found that the frequency of Haines 6 days at 1200 UTC varied from less than 1 percent at Quillayute, WA; Spokane, WA; Glasgow, MT; Salem, OR; and Medford, OR, to more than 10 percent at Salt Lake City, UT; Denver, CO; and Grand Junction, CO (fig. 5). Large increases in the frequency of Haines 6 days were noted in the Great Basin and the Rocky Mountains south of Montana, whereas little or no change was noted elsewhere (fig. 6). The increase was most pronounced in Nevada, Utah, Colorado, Wyoming, northern Arizona, and northern New Mexico, where surface elevations generally exceeded 3,280 feet (1,000 m).

Holtzworth (1972) found that afternoon mixing heights in this area of the United States are climatologically between 13,000 and 18,000 feet (4,000 and 5,500 m) during the summer (fig. 7). On

summer afternoons at these sites, convectively driven thermals of buoyant surface air rise to great heights in the atmosphere, transporting sensible heat throughout the depth of the mixed layer. Figure 7 shows that at most of the high-elevation sites in the West, the depth of the mixed layer encompasses most, if not all, of the layer used to calculate the high-elevation Haines Index. Therefore, as the day progresses, the temperature difference within this layer increases, eventually equaling or surpassing 39 °F (22 °C), the limit defined by Haines for unstable air (category 3—see table 1). Diurnal increases in the temperature at 70 kPa (about 10,000 feet (3,050 m)) would also modify the dewpoint depression, resulting in a higher frequency of days with very dry air (category 3) at these sites.

Figures 8, 9, and 10 illustrate this principle by showing the frequency distribution of the 70-to-50-kPa

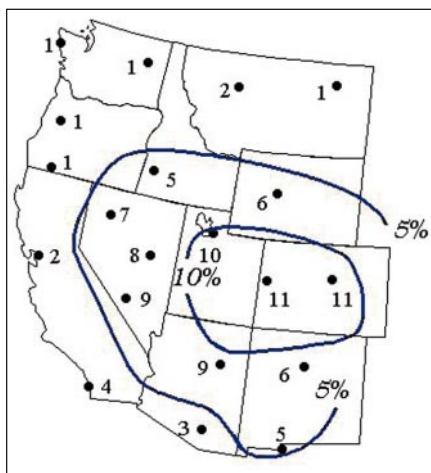


Figure 5—Seasonal (June through October) frequency of Haines 6 days at 1200 UTC (percent).

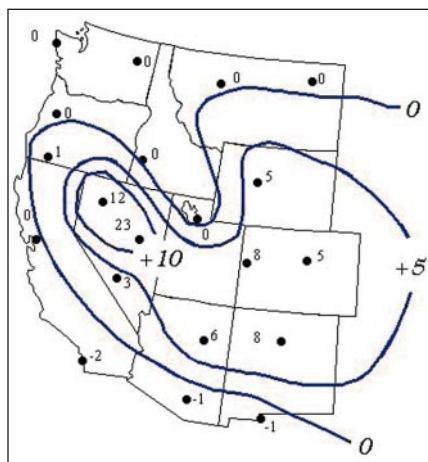


Figure 6—Change in seasonal frequency of Haines 6 days, 1200 UTC to 0000 UTC (percent).

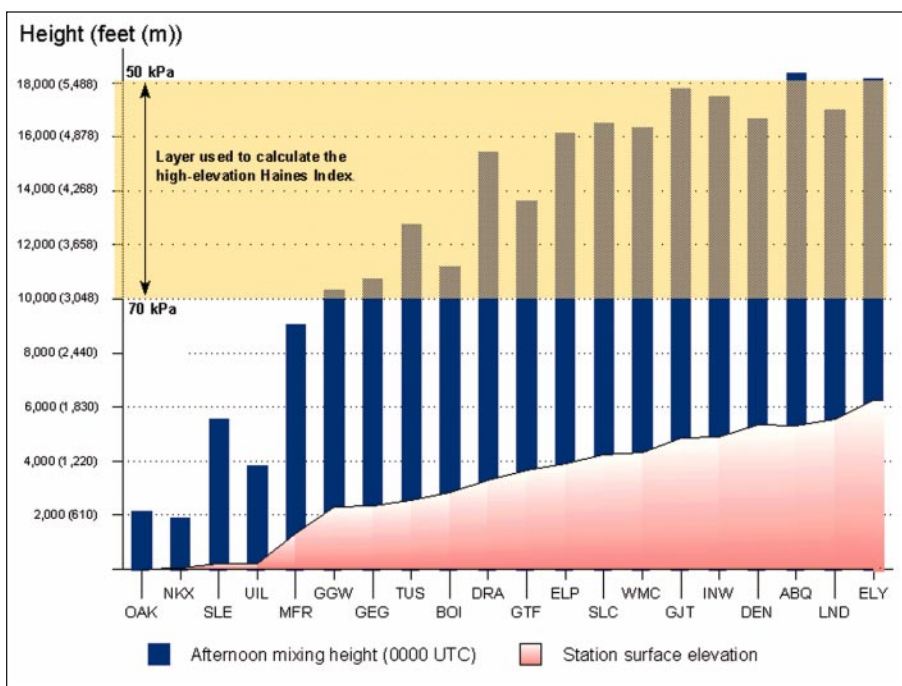


Figure 7—Surface elevation and mean summer afternoon mixing heights of Western U.S. radiosonde sites in feet (m).

temperature difference at three radiosonde sites in the Western United States for the summer of 1994. Each graph plots both the 1200 UTC and the 0000 UTC frequency distribution curves. Vertical double arrows mark the temperature difference limits defined by Haines for high-elevation stations.

The frequency distribution for the low-elevation site of Quillayute, WA, approached a normal distribution curve, with equal tails to the right and left of intermediate values (fig. 8). There was little change in the frequency distribution from morning (0500 PDT) to afternoon (1700 PDT). On most days, the temperature difference fell into category 1, indicating stable air

that would tend to restrict large-scale, vertical motion. There were no days with category 3 temperature differences at Quillayute during the summer of 1994.

The frequency distribution for the mid-elevation site of Boise, ID, also approached a normal distribution (fig. 9). However, in this sample, most days fell into category 2, with smaller percentages in categories 1 and 3. Again, there was no significant change in the frequency distribution between morning (0600 MDT) and late afternoon (1800 MDT).

At the high-elevation site of Ely, NV, there were large changes in the frequency distribution from morning to afternoon (fig. 10). The graph approached a normal distribution curve for the morning soundings (0500 PDT), but was highly skewed towards category 3 temperature differences for the late afternoon (1700 PDT) soundings. The average temperature difference increased from 36.7 °F (20.4 °C) in the morning to 41 °F (22.8 °C) in the afternoon.

Sites with average afternoon mixing heights below 13,000 feet (4,000 m) showed only minor changes in the 70-to-50-kPa temperature difference from morning to afternoon, and little or no change in the frequency of Haines 6 days from morning to afternoon. Figures 7, 8, 9, and 10 provide strong evidence that the diurnal increase in the frequency of Haines 6 days at high-elevation radiosonde sites in the West was the result of diurnal increases in the frequency of category 3 temperature differences, caused by very high afternoon mixing heights during the summer.

Monthly Variations in the Haines Index. During June 1994, the frequency of Haines 5 and 6 days was 70 percent in northern Arizona and northern New Mexico, but only 5 or 6 percent along the United States–Canadian border (fig. 11). The low occurrence of

Haines 5 and 6 days in the north was primarily due to the location of the polar jetstream and the occasional passage of Pacific frontal systems or closed, upper level low-pressure systems over the Pacific Northwest and the northern Rockies.

In July, the minimum frequency of Haines 5 and 6 days still occurred along the United States–Canadian border, whereas the maximum now shifted north into Nevada, Utah, and western Colorado (fig. 12). Farther south, over southern Arizona and southern New Mexico, the frequency of Haines 5 and 6 days dropped dramatically, from nearly 50 percent in June to around 15 percent in July. The influx of monsoonal moisture from Mexico was responsible for the large July decrease at El Paso, TX; Tucson, AZ; Winslow, AZ; and Albuquerque, NM.

Idaho and Wyoming had their highest frequency of Haines 5 and 6 days in August (fig. 13). The maximum frequency now extended from central Nevada into western Wyoming. Frequencies in the southern Great Basin continued to be high but were much lower than in July, due to the occasional northward surge of monsoonal moisture. The minimum frequency (2 percent) extended across southern Arizona and southern New Mexico as the southwest monsoon intensified and pushed farther north (see figure 14 for El Paso, TX (ELP); Albuquerque, NM (ABQ); and Winslow, AZ (INW)).

Data showed that Oregon, Washington, and northern California had their highest frequency of Haines 5 and 6 days during September (fig. 15), resulting from the high frequency of days with large dewpoint depressions (very dry air) associated with foehn-type winds in the Cascades and Sierra Nevada. The maximum frequency still extended across central California and central Nevada, with the minimum frequency (less than 5 percent) still across southern Arizona and southern New Mexico.

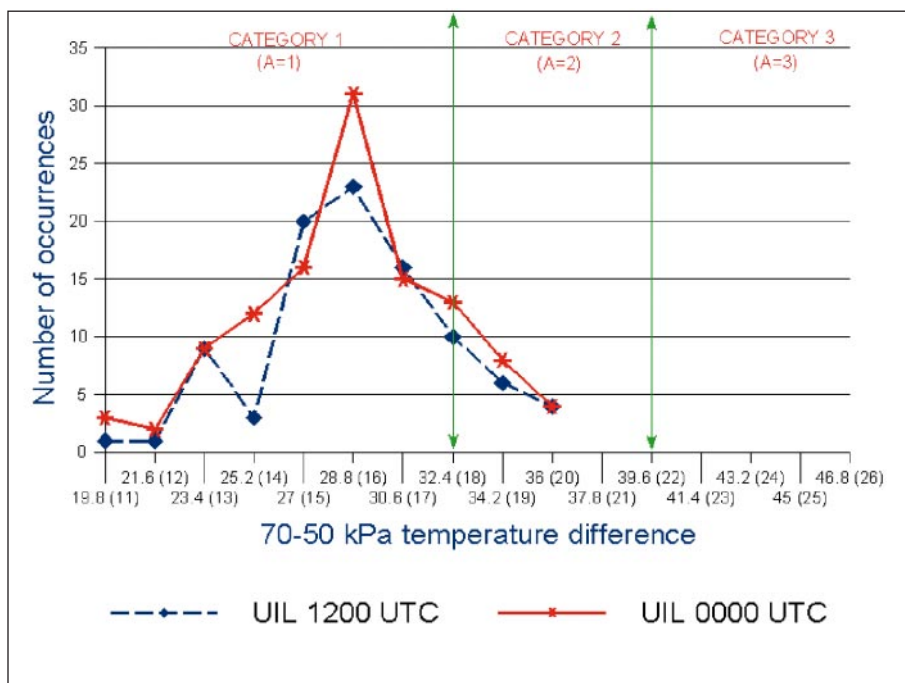


Figure 8—Frequency distribution of 70-to-50-kPa temperature differences (in °F (°C)) for Quillayute, WA.

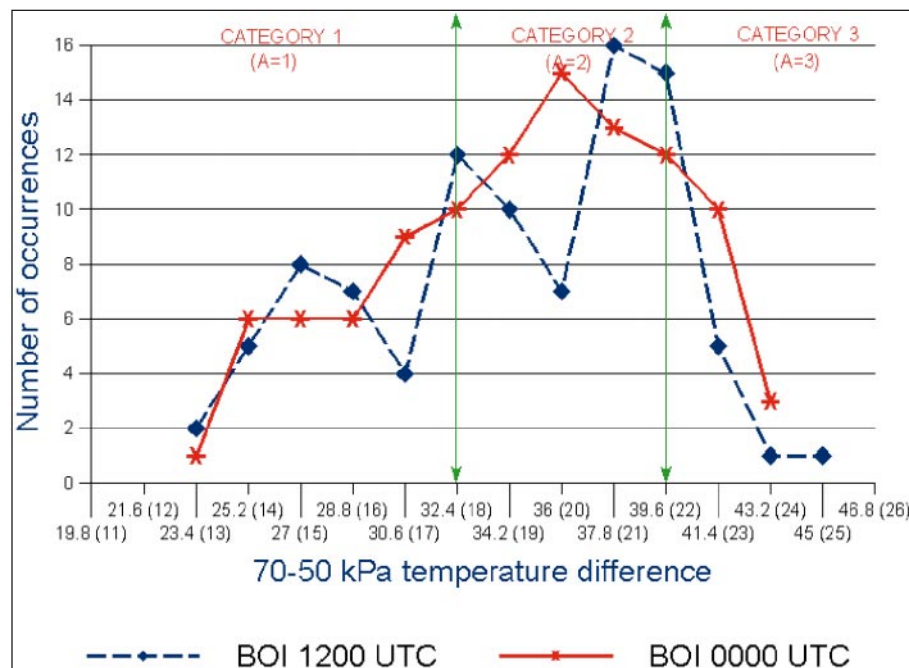


Figure 9—Frequency distribution of 70-to-50-kPa temperature differences (in °F (°C)) for Boise, ID.

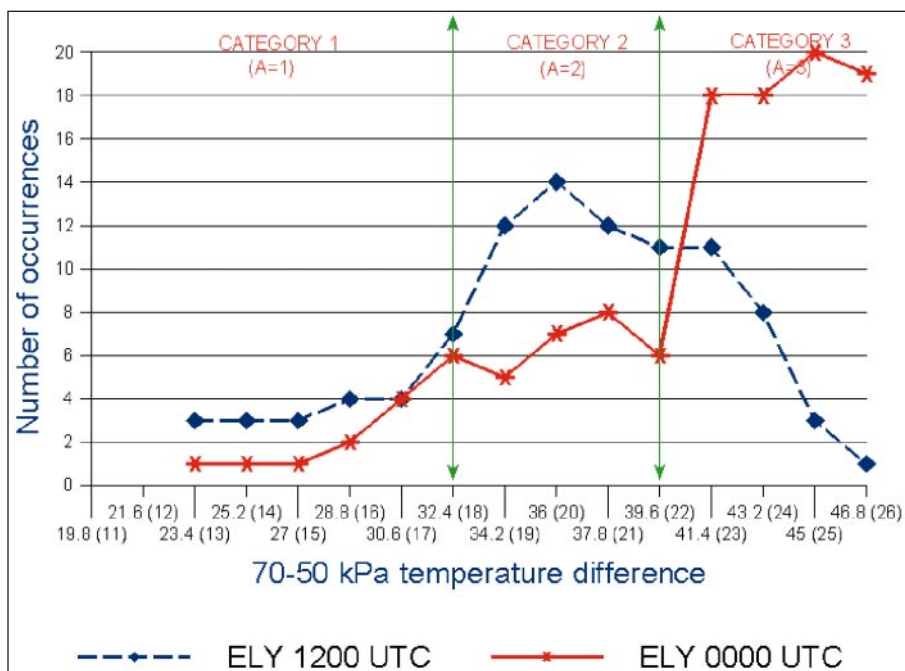


Figure 10—Frequency distribution of 70-to-50-kPa temperature differences (in °F (°C)) for Ely, NV.

In October, the frequency of days with a Haines Index of 5 or 6 diminished significantly in most of the West (fig. 16). At this time of the year, jetstream winds again begin to dip farther south, allowing moist Pacific frontal systems to move farther inland across the northern-tier States. However, the frequency of Haines 5 and 6 days increased again over the desert Southwest as the effects of the summertime monsoon ended. In southern California, there was a marked increase in the frequency of Haines 5 and 6 days due to the drying effects of strong Santa Ana winds associated with the occasional development of high-pressure systems over the Great Basin.

When the seasonal frequency of the Haines Index was stratified by month, large variations by area became readily apparent. Monthly variations in the index resulted from changes in the location and strength of the polar jetstream, the onset of the desert Southwest

monsoon, and the occurrence of foehn-type winds in the Pacific Northwest and California in the late summer and early fall.

California Haines Index. The final question answered by this study is whether or not California experiences an unusually high frequency of Haines 5 and 6 days. Both Oakland and San Diego, CA, have less than 4 percent Haines 6 days (figs. 3 and 5). However, these sites have the highest frequency of Haines 5 days for both morning and afternoon (fig. 17). A look at the individual components of the Haines Index for Oakland (figs. 14 and 18) revealed that low moisture values, not temperature differences, were responsible for the high number of Haines 5 days in California. The high frequency of dry air resulted from the synoptic-scale subsidence associated with subtropical high-pressure systems that usually lie off the California coast during the summer months.

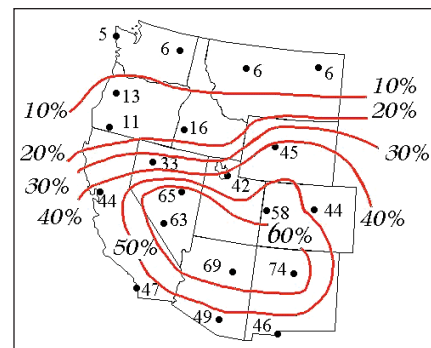


Figure 11—Frequency of Haines 5 and 6 days in the Western United States in June 1994.

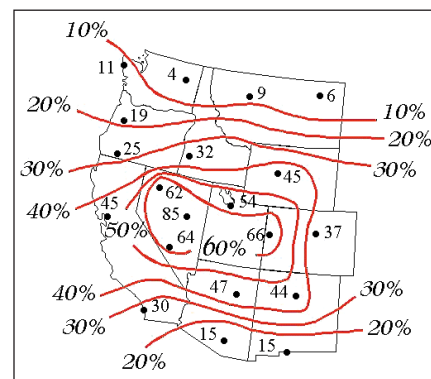


Figure 12—Frequency of Haines 5 and 6 days in the Western United States in July 1994.

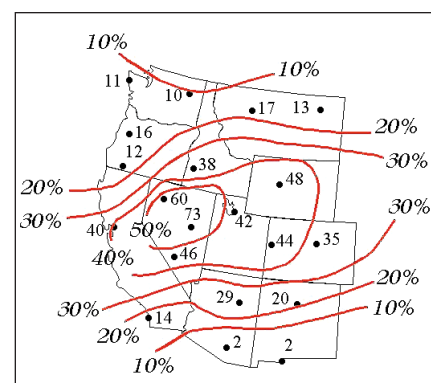


Figure 13—Frequency of Haines 5 and 6 days in the Western United States in August 1994.

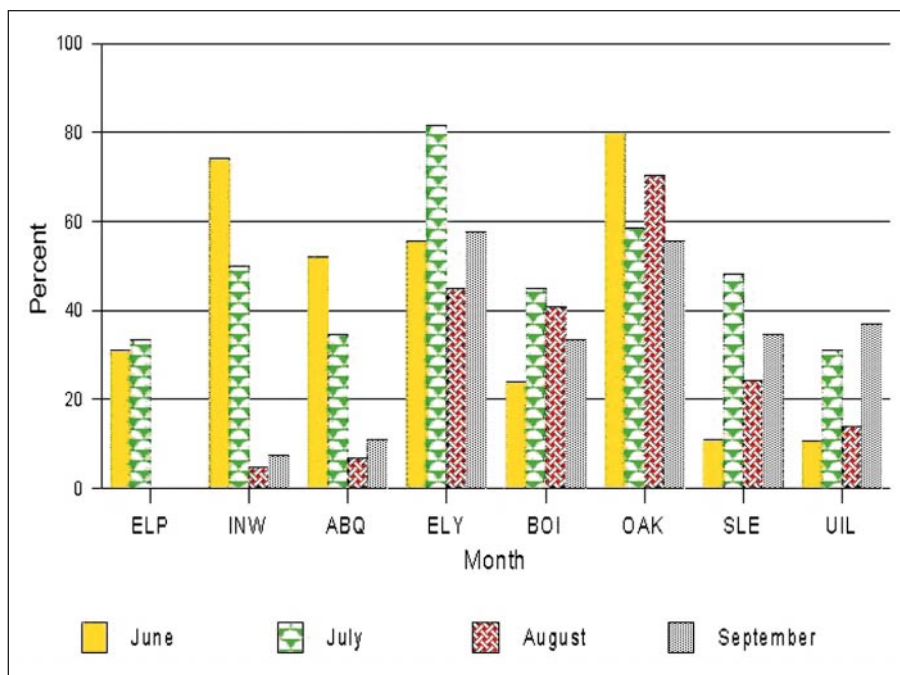


Figure 14—Frequency of category 3 moisture days ($B = 3$) at selected upper air stations from June through September 1994.

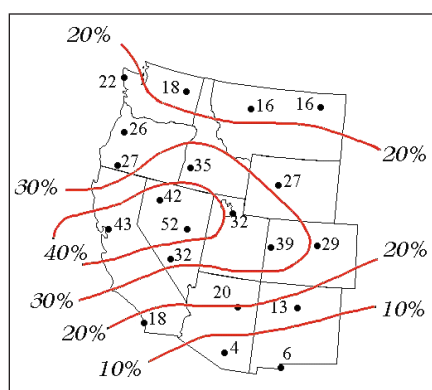


Figure 15—Frequency of Haines 5 and 6 days in the Western United States in September 1994.

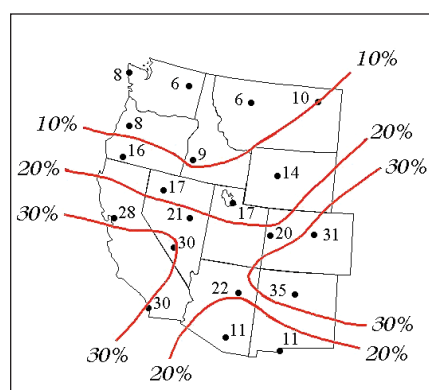


Figure 16—Frequency of Haines 5 and 6 days in October 1994.

Conclusions

We found that the frequency of days with a Haines Index of 5 or 6 differs significantly from what Haines observed in his original study. It is much higher in the Great Basin and the central and southern Rockies, and much lower in the Pacific Northwest, the northern Rockies, and the California coast.

We also noted large monthly variations in the Haines Index, resulting from changes in the location and strength of jetstream winds, the development and decay of the desert Southwest monsoon, and the occurrence of foehn-type winds in the Pacific Northwest and California. Monthly charts and tables included in this study should aid fire weather meteorologists and fire managers in assessing when

their districts are climatologically most susceptible to days with a high Haines Index value.

The data show a significant diurnal increase in the frequency of Haines 6 days from 1200 UTC to 0000 UTC, especially at high-elevation radiosonde sites in the Great Basin, and in the central and southern Rocky Mountains. Table 2 shows similar increases in the frequency of Haines 5 days. Thus, Haines Index values calculated from 1200 UTC soundings appear to be a better measure of synoptic-scale atmospheric stability and moisture conditions in the Western United States.

High-elevation Haines Index values measured at the coastal lowland sites of Oakland and San Diego, CA, show that the climatological frequency of Haines 6 days is very low in California but that Haines 5 days are quite frequent. This suggests that low- or mid-elevation Haines Index values might better reflect the potential for large fire growth in the coastal lowland and interior lowland areas of California, Washington, and Oregon. However, high-elevation Haines Index values measured at Quillayute, WA; Salem, OR; Oakland, CA; and San Diego, CA, might still be appropriate for high-elevation areas of the Cascades, Sierra Nevada, and coastal mountain ranges of Washington, Oregon, and California.

The Haines Index has shown more usefulness than traditional stability indices in predicting large wildfire growth and extreme fire behavior. However, this study indicates the need for further refinement to better identify from climatology the days that have a high potential for extreme fire behavior or large wild-

fire growth in the Western United States. The authors are researching modifications to the Haines Index in preparation for a second paper on this topic.

Acknowledgments

The authors would like to thank Donald Haines (retired research meteorologist, formerly with the USDA Forest Service's North Central Forest Experiment Station, East Lansing, MI); Brian Potter (USDA Forest Service, North Central Forest Experiment Station, East Lansing, MI); Bob Walker (Mt. Hood National Forest Supervisor's Office, Portland, OR); and David Billingsly (science and operations officer, National Oceanic and Atmospheric Administration, National Weather Service, Boise, ID) for reviewing the manuscript. Their comments and suggestions were greatly appreciated.

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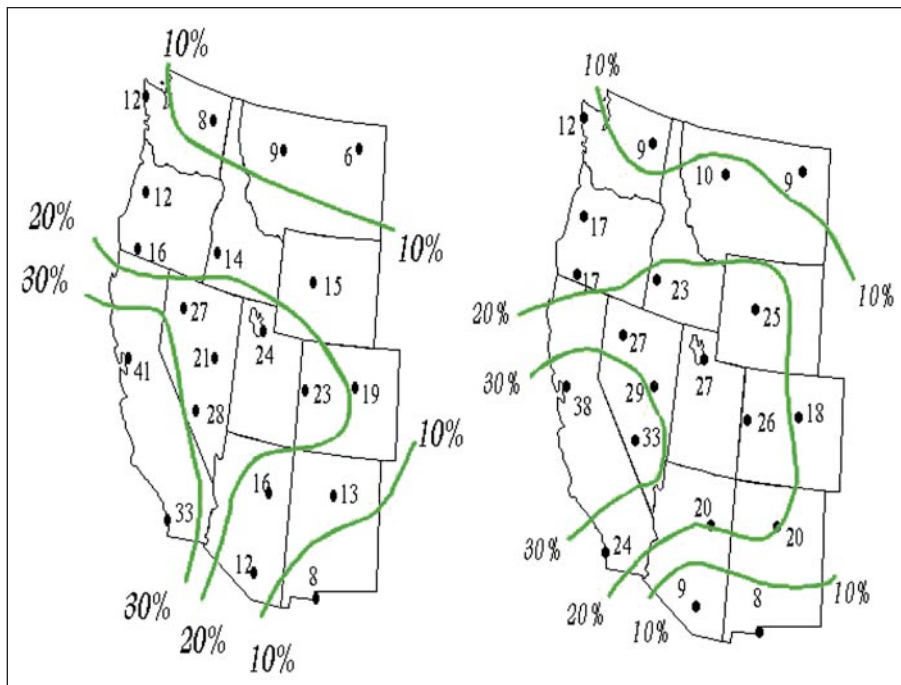


Figure 17—Frequency of Haines 5 days at 1200 UTC (left) and 0000 UTC (right).

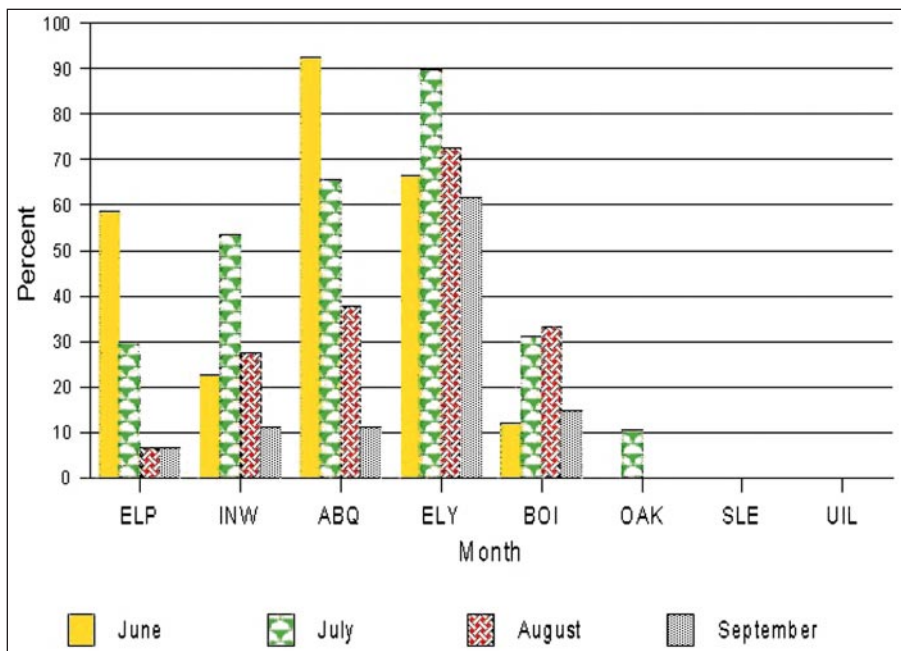


Figure 18—Frequency of category 3 temperature differences ($A = 3$) at selected upper air stations from June through September 1994.

SPARK ARRESTER GUIDE UPDATE

Sig Palm

The Spark Arrester Guide (SAG) has been updated to include qualified general-purpose, locomotive, and multiposition small-engine (MSE) spark arresters approved since the June 1997 SAG for MSE's and the April 1996 SAG for general-purpose and locomotive engines. MSE spark arresters include those for chain saws, trimmers, and brush cutters.

A new edition of the "General Purpose and Locomotive Spark Arrester Guide" (vol. 1, April 1998) and the latest edition of the "Multiposition Small Engine Spark Arrester Guide" (vol. 2, June 1997) are available from the National Interagency Fire Center (NIFC). A videotape, "Spark Arresters and the Prevention of Wildland Fires," is also

available for use as a supplemental instructional tool. The videotape has five modules ("Introduction," "Multiposition Small Engine," "General Purpose," "Off Highway," and "Railroad").

Only local, State, and Federal co-operators may order the guides and videotape. To order, send a requisition or purchase order showing the following NFES number(s):

NFES #1363—"General Purpose and Locomotive Spark Arrester Guide," vol. 1, April 1998, \$3.67 per copy.

NFES #2363—"Multiposition Small Engine Spark Arrester Guide," vol. 2, June 1997, \$4.70 per copy.

NFES #2237—"Spark Arresters and the Prevention of Wildland Fires," 1992, 68-minute videotape, VHS size, \$3.68 per copy.

Send your order to National Interagency Fire Center, Attn: BLM Warehouse, Supply Office, 3833 S. Development Avenue, Boise, ID 83705. Please do not phone in your order, and do not send cash, checks, or money orders. Allow 4 weeks for delivery.

Questions regarding ordering procedures may be addressed to the NIFC Great Basin Cache Supply Office, tel. 208-387-5104. Billing questions may be directed to NIFC Finance Office, tel. 208-987-5566.

For answers to technical questions or to obtain the updated list of approved spark arresters, contact Ralph Gonzales, USDA Forest Service, San Dimas Technology and Development Center, 444 E. Bonita Avenue, San Dimas, CA 91733, tel. 909-599-1267, ext. 212. ■

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BUSHFIRE '97

Dick Mangan



The city of Darwin, located in Australia's "Top End," hosted the "Bushfire '97" conference from July 8 to July 11, 1997. The sixth in a series of biennial conferences, this event—with its theme of "Fire as a Land Management Tool"—drew more than 150 fire managers, researchers, and firefighters from across Australia and from Brazil, France, New Zealand, the United States, and Venezuela.

Major Areas of Discussion

The purpose of the Bushfire conferences is to "provide a forum for members of the Australian fire community to discuss the latest concepts, research findings, and technologies in bushfire-related research and development." The 1997 conference gave an excellent overview of the role of fire in the North Australian ecosystem, affording a historical perspective on traditional Aboriginal burning as a natural and cultural resource management tool for the Yolngu people of the Northern Territory's Eastern Arnhem region. Other major areas of discussion included:

- The ecological responses of flora and fauna to bushfires;
- Operational and planning aspects of bushfires, including a study by the Missoula Technology and Development Center on the survivability of entrapments

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The items discussed during "Bushfire '97" sounded amazingly similar to issues that arise at American fire conferences.

- in engines versus fire shelters (which are not used in Australia);
- Landscape-scale mosaic burning, its fire dynamics, and its impact on wildlife;
- The positive impact of fire on pastoral operations when used to improve farmlands;
- Remote sensing, monitoring, and modeling; and
- The Kapalga fire experiments conducted by Australian fire researchers on Kakadu National Park.

After the formal conference presentations, attendees had the opportunity to join a daylong field trip into the Northern Territory bush. The trip addressed urban-rural interface issues in the Darwin area; provided an overview of "Top End" landscapes; introduced participants to the Australian savannas; and provided a discussion of the management program for both wildfire and prescribed fire on Kakadu National Park, where 30 to 40 percent of the bush burns annually from all types of fire. The



Field trips during the "Bushfire '97" conference showed local fuel conditions in Australia's Northern Territory. Photo: Dick Mangan, USDA Forest Service, Missoula Technology and Development Center, Missoula, MT, 1997.



A recently burned area in the Kapalga area of Kakadu National Park in Australia's Northern Territory. Experimental burns are designed to evaluate the impact of fires at different intensities on water, fauna, flora, soils, and fire behavior. Photo: Dick Mangan, USDA Forest Service, Missoula Technology and Development Center, Missoula, MT, 1997.



Several years of regrowth after an experimental burn in the Kapalga area of Kakadu National Park in Australia's Northern Territory. Photo: Dick Mangan, USDA Forest Service, Missoula Technology and Development Center, Missoula, MT, 1997.

trip concluded with a detailed explanation and discussion of fire experiments in the Kapalga area of the park. These experimental burns, conducted annually since 1990 during both wet and dry seasons, are designed to evaluate the impact of fires at different intensities on water, fauna, flora, soils, and fire behavior.

An American Perspective

The items discussed and the problems that surfaced during “Bushfire ‘97” sounded amazingly similar to issues that arise at American fire conferences: the need to reintroduce more fire into the landscape, the uncertainty about short-term versus long-term effects of prescribed burning, the failure of planning commissions to address fire problems before approving new homesites, and the loss of expertise among fire managers and practitioners as the work force shrinks.

Although the Australian Bush Fire Brigades are able to mobilize large numbers of volunteers for fire suppression, personnel resources for applying prescribed fire in these heavily fire-dependent ecosystems are stretched to the limit. Increased concern about the air quality impacts of prescribed burning, especially in areas of wildland–urban interface and heavy tourist use, is also limiting opportunities to apply large-scale fire to the landscape. ■

CAN FIRE SHELTERS PROTECT FIREFIGHTERS FROM BEE AND YELLOWJACKET STINGS?*



Richard S. Vetter, Brandy T. Parker, and P. Kirk Visscher

Forest firefighting is inherently dangerous, rife with unpredictable threats to life. As if the fire itself were not sufficiently treacherous, a firefighter who is constructing line or performing mop-up could agitate a colony of stinging insects and be exposed to stings as the insects emerge to defend their colony. The use of chain saws and heavy machinery adds to the problem, first by causing vibrations that irritate honey bees or yellowjacket wasps, and second by preventing the operator from hearing the buzzing insects so stings are the first warning.

Although serious stinging incidents from bees or wasps are rare, this is little consolation to a firefighter surrounded by a tornado of stinging insects. Furthermore, stinging incidents could become more common and dangerous now that Africanized honey bees have become established in southern portions of Texas, New Mexico, Arizona, and California (Visscher et al. 1997). Merrill and Visscher (1995) recently reviewed the significance of Africanized honey bees for fire managers.

Rick Vetter is a staff research associate, Brandy Parker is a laboratory assistant, and Kirk Visscher is an associate professor in the Department of Entomology at the University of California–Riverside.

* The views expressed in this article are those of the authors. Readers should not construe them to be advice from the U.S. Department of Agriculture (USDA) or the Forest Service. Those individuals who anticipate being close to hymenoptera should seek advice from their physician. In addition, the naming of products is for the convenience of the reader and should not be misconstrued as an official endorsement by the USDA or the Forest Service.

When honey bees are aroused defensively, they seek targets that evolution has programmed them to pursue: upright, dark, moving, hirsute mammalian predators.

We were interested in determining the degree of protection offered by firefighter clothing and, in particular, the fire shelter. The best defense when attacked by stinging bees is to run from the area of the nest as rapidly as possible. Any shelter available, such as a building or an enclosed vehicle, can provide protection. However, injury or circumstances such as topography or fire behavior might make it impossible to run away. Therefore, we tested the efficacy of firefighter clothing and the fire shelter in protecting from stings.

Methods

We conducted two types of experiments. In both, we agitated bee colonies to the point where bees emerged in large numbers to defend their nests. In the first set of experiments, we wore Nomex firefighter clothing and sought cover under a fire shelter near the agitated colonies to test the degree of protection this provided from the bees. In the second experiment, we covered bare skin with the fire shelter to test whether it would protect exposed flesh from stings.

In these tests, one of us served (with obvious double entendre) as the “Sting Test Dummy” (SD). At

the University of California–Riverside, we maintain research colonies of honey bees, and the person who volunteered as SD is stung about 200 times annually in the course of normal beekeeping operations. Aside from pain, he has only minor reactions to bee stings. As a precaution, several emergency epinephrine kits (EpiPens®) were made available, and before the experiments, an observer was instructed on their use. As figure 1

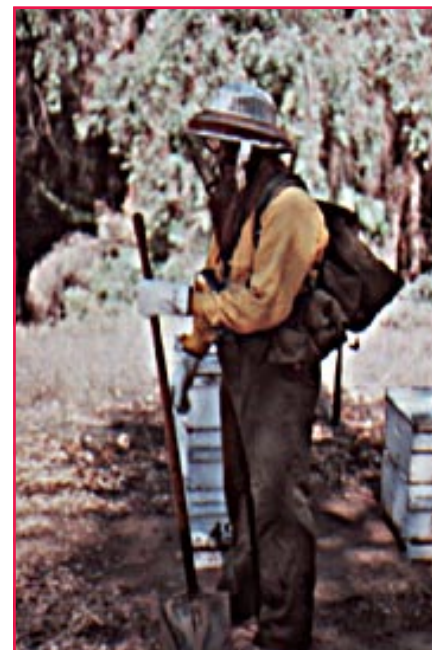


Figure 1—The Sting Test Dummy wearing firefighter gear and pith helmet/bee veil. Photo: P. Kirk Visscher, University of California–Riverside, Department of Entomology, 1997.

shows, the SD wore Nomex clothing, leather gloves, web gear, and a hose pack. In addition, he wore a conventional beekeeper's pith helmet/bee veil to protect his face and neck, the most dangerous sites for stings.

In the first experiment, we deployed the fire shelter before initiating each test. Although pre-deployment did not truly mimic field conditions, we chose it to limit the number of stings to the SD, because several colonies were tested in a single day. We judged efficacy by the behavior of the bees before and after the SD was under the fire shelter and not by the total number of stings received before getting under the shelter.

We tested colonies consisting of at least two 10-frame Langstroth honey supers, with an estimated population of between 20,000 and 40,000 honey bees each. Four colonies were tested on one day and a fifth 2 weeks later. We began the test by prying loose the cover of a beehive, but leaving it in place. Then the SD beat vigorously three times on top of the hive cover with a long-handled shovel (fig. 2) and flipped the hive cover off to allow more defending bees to emerge from the colony in a short time. Next, the SD shook the hive by inserting the shovel beneath it and pumping up and down vigorously 10 times (fig. 3). This was typically sufficient to irritate the bees.

After 10 pumpings of the shovel or when the SD felt the first sting, he quickly got under the fire shelter located about 3 feet (0.9 m) from the hive entrance (fig. 4). Inside the shelter, he lay prone on the ground and attempted to get the edges of the shelter flat against the ground to prevent bees from enter-



Figure 2—Beating on the top of the hive to agitate the bees. The fire shelter is already deployed and out of the picture. Photo: P. Kirk Visscher, University of California–Riverside, Department of Entomology, Riverside, CA, 1997.



Figure 3—After removing the lid, the whole hive is rocked to agitate the bees. Photo: P. Kirk Visscher, University of California–Riverside, Department of Entomology, Riverside, CA, 1997.

ing (fig. 5). In some tests, the SD thrashed about under the shelter to emulate the movements of a firefighter trying to remove stings or kill bees inside the shelter. This action tested whether such movements drew more defensive attacks by the bees (since movement is one of the cues that defending bees

use to locate an intruder). If not much stinging had occurred, the SD lifted a small edge of the shelter to see whether defending bees would fly into the darkened interior of the shelter.

An observer garbed in beekeeper's protective clothing watched the



Figure 4—The Sting Test Dummy getting under the fire shelter. Note that there are many bees coming out of the hive, and several bees are stinging the left arm through the Nomex shirt. Photo: P. Kirk Visscher, University of California–Riverside, Department of Entomology, Riverside, CA, 1997.



Figure 5—The Sting Test Dummy is safely under the fire shelter. Note that bees are still flying around the area, but none are attacking the fire shelter. Photo: P. Kirk Visscher, University of California–Riverside, Department of Entomology, Riverside, CA, 1997.

test from about 30 feet (9 m) away, making observations of the bees on the outside of the shelter and timing the experiment. The observer signaled to the SD when the bees were no longer defensive and the hive appeared to have settled down. Timing of the test started with the first shovel attack

and ended when the bees were no longer flying around in an agitated manner. Inside the shelter, the SD observed the behavior of bees that entered the shelter.

Where possible, we recorded the number of stings felt by the SD before getting under the shelter. At

the completion of the test, the SD moved away from the colony and removed the firefighter gear. Then we recorded the number of stings detectable as welts on his skin (fig. 6).

A second experiment tested whether bees could or would sting through the material of the fire shelter. Two weeks after first testing colony 4, we agitated it again, and the SD stood nearby with beekeeper protective clothing on his upper body and with the shelter wrapped in a single layer around his bare legs (fig. 7). We recorded the behavior of the bees toward the shelter material and compared it with their behavior toward the veil and jacket. The test lasted 11-1/2 minutes, until the colony's defensive response decreased to near zero.

Results

In the first set of tests, colonies 1, 2, and 3 were not very defensive. The SD received no stings during the agitation phase, and only one, two, and zero stings, respectively, while under the shelter. These were from bees that crawled under the shelter or were brought in when the SD initially got under the shelter. The stings resulted because the bees were trapped between the ground and the body, and not because they actively pursued the SD inside the shelter. All three colonies returned to normal in 3 to 5 minutes.

Colony 4 was the most demonstrative and most convincingly showed the efficacy of the shelter. During the agitation phase, nine stings were delivered (four to the left biceps, two to the right wrist, one to the thigh, and one to each knee), all within about 10 seconds. While under the shelter, one bee crawled



Figure 6—Two sting welts inflicted on the arm (the raised weals with red centers). Photo: P. Kirk Visscher, University of California–Riverside, Department of Entomology, Riverside, CA, 1997.

under a glove and stung the wrist, and another got under the veil and delivered a sting to the pinna of the ear. This colony settled back to normal within 3-1/2 minutes.

Colony 5 was very defensive, delivering 19 stings: 7 to the forearms (6 to the left forearm, 1 to the right); 8 to the upper arms (6 to the left arm, 2 to the right); 2 to the left thorax; 1 to the left rib cage; and 1 to the buttocks. Unfortunately, due to the large number of stings and the distraction of getting under the shelter, we could not determine precisely how many stings were delivered before and after the SD entered the shelter. In fact, the SD initially believed that he had been stung no more than 6 to 8 times in all, and was surprised to discover 19 welts on his body after emerging from the shelter. Although several stings did occur when the bees landed on the Nomex shirt after the SD got under the shelter, stinging inside the shelter stopped precipitously. This colony settled back to normal in 4-3/4 minutes.

In the first experiment with the five colonies, the observer noticed bees outside the shelter flying about looking for the offending stimulus. They mostly searched the dark edge of the shelter shadow and did not attack the silver surface of the shelter. This was also evident to the SD inside the shelter, who heard no sound of bees colliding with the shelter from the outside. Bees inside the shelter spent much of their time at the top, attracted to the light coming through the pinholes; they were apparently trying to escape. Otherwise, they mostly crawled on the SD's clothing. Bees made little attempt to sting the SD in the dark interior of the shelter unless they were trapped.

In the second experiment, with the shelter wrapped around the SD's legs, the bees emerged from the hive and readily attacked the upper half of the SD's body. They made virtually no defensive attacks on the legs covered by the shelter. No stings were inflicted during this experiment, and the bees settled down after 11-1/2 minutes.



Figure 7—The Sting Test Dummy is wearing shorts and pressing bare legs against the fire shelter to test its ability to ward off stings. Notice that the bees are concentrated on the head area and ignore the silver fire shelter. Photo: P. Kirk Visscher, University of California–Riverside, Department of Entomology, Riverside, CA, 1997.

Discussion

In the rare event that a firefighter is attacked by honey bees and cannot retreat from the area, the fire shelter can provide useful, potentially life-saving protection from additional stings. The shelter removes the firefighter from the view of agitated bees, and they do not respond to the shelter itself as an object to be attacked. Bees brought under the shelter during deployment mostly change their behavior from attack to escape.

Shelter Deployment. The most important protective feature of the fire shelter is its coloration, not its thickness. When honey bees are aroused defensively, they seek targets that evolution has programmed them to pursue: upright, dark, moving, hirsute mammalian predators. Because its color and texture do not match this profile,

In the rare event that a firefighter is attacked by bees and cannot flee, the fire shelter can provide useful, potentially life-saving protection from additional stings.

the shelter is largely ignored by defending bees. The white clothing worn by beekeepers provides protection for a similar reason.

The bees searched the dark shadow of the shelter and entered the shelter when the margin was breached. However, after entering the shelter, most bees aborted their attacks and went to the top of the shelter to escape. This parallels our experience of fleeing into a dark shed to escape harassing bees and seeing many of the bees cease attack and fly out the door.

This suggests that the shelter is most effective against stings when it is fully deployed to minimize crevices and shadows, and when it is horizontal (rather than wrapped around an erect firefighter). Our experiments showed this in two ways. First, colonies 4 and 5 delivered 24 stings through the yellow shirt (possibly because defending bees were attracted to the dark straps of the web gear) and only 4 through the darker green pants. Second, when the SD was lying flat under the shelter, the bees settled down in about 4 minutes. But when the SD stood upright with the shelter wrapped around his legs, bees continued to harass him after 11 minutes (although they focused on his head, not on his shelter-wrapped legs).

Sting Treatment. One trait peculiar to honey bees is that their sting is designed to detach in mammalian flesh, where it emits

an alarm pheromone (isopentyl acetate, which smells like bananas). This signals other bees to join the attack and marks the area of the sting as vulnerable. The detached sting also continues to pump venom into the flesh. After entering the shelter, a firefighter should attempt to remove any stings to minimize the quantity of venom injected. Contrary to conventional medical wisdom, the method used to remove a sting does not affect the venom injected, but even seconds of delay can be harmful (Visscher et al. 1996). Therefore, rubbing the area of the sting (through the clothing if necessary), pinching the sting out, and scraping it off with a fingernail are all effective methods of removal.

Many of the bees that enter the shelter as it is deployed might already have stung and offer no further threat. Others will mostly attempt to escape, but will sting if trapped against skin or clothing. The bees can be safely crushed with a gloved hand, but should not be struck at, because this could lift the shelter off the ground and allow more bees to enter.

Attacks from honey bees will always be rare, and death from bee stings even rarer. The number of honey bee stings necessary to kill half of those who die from bee stings (the median lethal dose, or LD_{50} —a commonly used measure for the toxicity of all types of venom, pesticides, and other chemical substances) has been

estimated to be from 500 to 1,200 (Merrill and Visscher 1995, Vetter and Visscher [In press]). Because the initial stings would probably be enough to alert even the most focused firefighter, most would be able to flee the area before receiving a life-threatening number of stings. However, for incapacitated firefighters, protection is necessary to prevent large numbers of stings. Fortunately, the fire shelters carried by wildland firefighters are quite effective in this regard, and—if promptly deployed—can make the difference between survival and death.

For those allergic to bee venom, even one sting can set off an anaphylactic response. In the minority of these cases, death can result (usually within 1 hour) from swelling of respiratory passages or a precipitous drop in blood pressure. Hypersensitive people typically understand their vulnerability and should always carry anaphylaxis emergency treatment kits (such as Ana-kits® or EpiPens®), both on the firelines and off. Injection of epinephrine can usually reverse the life-threatening symptoms.

Africanized Honey Bees and Yellowjacket Wasps. In our experiments, we used European honey bees to simulate defensive attacks against a firefighter. With Africanized honey bees, a firefighter should expect the defensive attack to involve more defenders and last longer, and the bees to chase a fleeing firefighter farther. If a fire shelter were deployed to protect from Africanized bees, we would expect it to be effective. However, the bees would be more likely to enter if there were openings between the shelter and the ground, and to continue their defensive attacks after having

entered the shelter when it was first deployed.

Yellowjacket wasps are also a potential problem for firefighters. Wasp stings—unlike honey bee stings—do not normally detach. Therefore, each wasp can sting several times (possibly in rapid succession), fly off, and return for another attack. As with bees, some people are dangerously sensitive to yellowjacket stings (Flanagan and Fadich 1996). Because the venom components and allergens in wasp venom are different from those in honey bee venom, people who are hypersensitive to bees are not necessarily hypersensitive to wasps (and vice versa). Wasps are potentially more dangerous than bees because fewer stings are capable of causing death through kidney damage (Levick and Braitberg 1996).

Yellowjackets, unlike honey bees, do not store provisions for winter. They appear to be more active late in the warm season because the populations in their annual nests peak at this time of year, not because they are collecting food for winter. Even though yellowjackets searching for food might be drawn to the color yellow, the yellow Nomex shirts worn by firefighters are not likely to provoke attack, because both yellowjackets and bees target the upright, moving mammalian form when defending their nests, not objects that are yellow. Yellowjackets use their venom only to defend themselves or their homes; they subdue their

prey by mauling with their mandibles, not by stinging. People can be stung regardless of shirt color, and those wearing dark objects (such as the pack straps in this study) are more likely to be stung than those wearing lighter colors (Visscher and Vetter 1995).

Recommendations for Firefighters

When attacked by honey bees or yellowjacket wasps:

1. If at all possible, run away from the nest as quickly as you can.
2. If running away is impossible due to injury, fire conditions, or topography, then deploy a fire shelter to drastically reduce the number of stings. Get your head and neck under the shelter as quickly as possible, and try to lie flat. Then cover the rest of your body.
3. Flatten down the edges of the shelter along the ground to prevent additional insects from entering.
4. If stung by honey bees, remove stings by rubbing your hands over exposed skin. Remove stings in clothing by rubbing or pulling on the cloth.
5. Use gloved hands to crush any insects inside the shelter.
6. After the bees or yellowjackets settle down (which will take several minutes to an hour, depending on the degree of their agitation), move away from the nest, using the shelter as protection from any remaining defenders.

As always, knowledge of how to respond correctly in an emergency is the best insurance of survival. In most circumstances, timely escape is best; but when escape is impossible, the fire shelter can provide significant protection from stings. The fire shelter now has a new, potentially life-saving application.

Acknowledgments

We would like to thank the following current or former Forest Service personnel for supplying us with equipment, information, and contacts: Dr. Laura Merrill, Russ Johnson, and Dean Ryans.

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PRESCRIBED FIRE AND PUBLIC EDUCATION

Jim Thorsen and Earle Kirkbride



From 1991 through 1995, more than 250,000 acres (101,175 ha) per year were burned in Florida using prescribed fire. Total acreage burned during this 5-year period ranged from a low of 252,139 acres (102,040 ha) in 1992 to a high of 311,728 acres (126,157 ha) in 1993. These figures are likely to grow as land managers recognize the benefits of using prescribed fire.

Still, many Floridians continue to believe that all fires are bad. The widespread presumption that all fires should be suppressed poses a challenge to Florida's fire managers. How we have met this challenge in Florida could be of interest to fire managers in other parts of the country who face similar problems in educating the public on the value of prescribed fire.

The Central Florida Prescribed Fire Council

The Central Florida Prescribed Fire Council was established in 1993. Membership is open to any agency, organization, corporation, or institution that uses prescribed fire as a land management tool. The Council's first chair was Bill Korn, a manager for the Florida Division of Forestry at the Withlacoochee Forestry Center in Brooksville, FL.

Jim Thorsen is the district ranger for the USDA Forest Service, Ocala National Forest, Seminole Ranger District, Umatilla, FL; and Earle Kirkbride is a volunteer for the USDA Forest Service, Vero Beach, FL.

We are succeeding in spreading the message that prescribed fire carries social as well as ecological benefits.

Council Objectives. Soon after its establishment, the Council decided that the most immediate need was to educate the public on the value of prescribed burns. In effect, the Council decided to overcome the widespread belief that all fires are bad.

"Establishment of the Council was timely," says Korn. "Every land manager is affected by every other land manager who uses fire. Before the Council, we had no way to reach out to others in State, Federal, or private areas. With the Council, we can share information

and support each other in dealing with the public. The educational program conducted by the Council has raised public awareness, I believe."

Council Actions. The Council produced and distributed more than 30,000 copies of a brochure (figs. 1 and 2) explaining the historic nature of fire and why burning was needed, and succinctly listing the benefits of fire management. Each member of the Council made presentations to various groups. Council members personally contacted civic groups,



Typical prescribed burn in central Florida during late winter. Photo: Jim Thorsen, USDA Forest Service, Ocala National Forest, Seminole Ranger District, Umatilla, FL, 1990.

government leaders, adjacent landowners, public schools, and volunteer fire departments to explain the importance of prescribed fire. Since 1995, we have made more than 45 presentations reaching more than 3,000 people. This effort is continuing, and the number of programs is increasing.

Council members invited representatives of various news media to observe prescribed burns. In addition, the Council observed “Media Day” with a demonstration of a prescribed fire and an explanation of why we burn in Florida, challenging journalists to report positively on prescribed burning. The Council also created an eye-catching poster (fig. 3) and distrib-

uted more than 10,000 copies to schools, community facilities, and recreation areas. Council members even mounted the posters at sites where prescribed burns had been completed.

The film “Fire in the Southland,” produced by Tall Timbers of Tallahassee, FL, was shown on public television in Orlando, FL, and seen by a large number of Floridians. The 18-minute film shows the history and effects of prescribed fire in southern Florida. Tall Timbers has given the Council permission to use the film in its presentations as an educational tool.

Impact and Outlook

It is very difficult to determine how much the Council’s actions have changed public attitudes toward prescribed fire. However, the public and the news media now appear to be somewhat more aware of the need for prescribed burns. One letter to the editor in “The Daily Commercial,” a central Florida newspaper, defended the USDA Forest Service from criticism by summarizing very well the

reasons for prescribed fire. It is doubtful that such a letter would have been written before the Council’s public education program.

Council members recognize that they must continue the education program. Many long-term Florida residents still do not understand the importance of prescribed fires, nor do many of Florida’s newcomers (about 1,000 people per day). However, with the cooperation of individuals and organizations in both the public and the private sector, and with support from environmental groups, we are making progress in spreading the message that prescribed fire

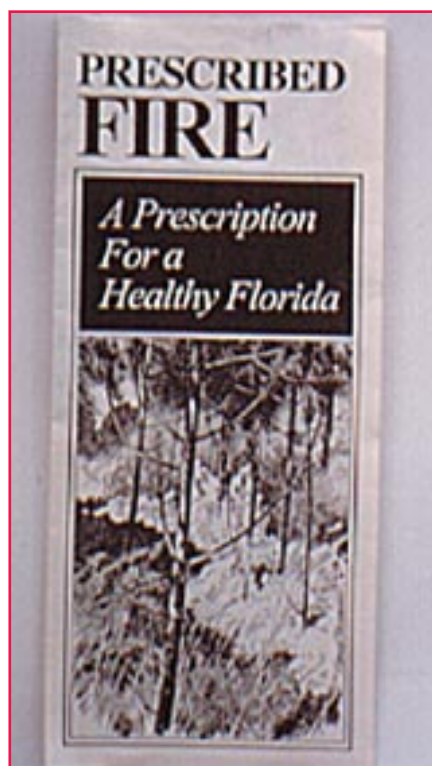
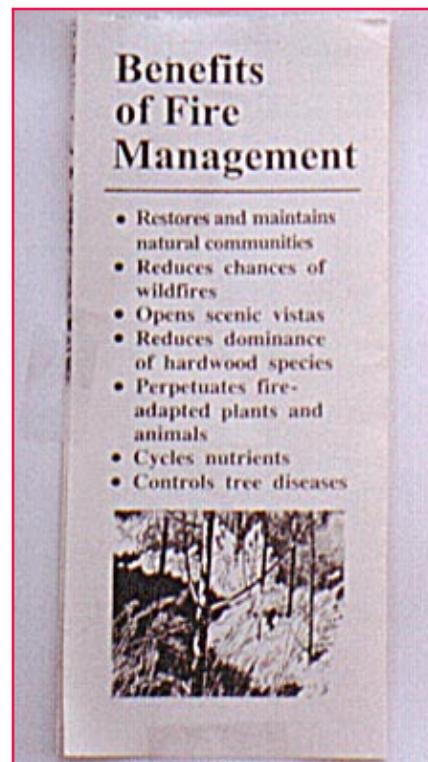


Figure 1—Educational brochure on prescribed fire, illustrated by Gene Packwood, a freelance artist and volunteer for the USDA Forest Service. The Central Florida Prescribed Fire Council has produced and distributed more than 30,000 copies since the brochure was first published in 1996. Photo: Jim Thorsen, USDA Forest Service, Ocala National Forest, Seminole Ranger District, Umatilla, FL, 1990.



Figure 2—Pages from the brochure “Prescribed Fire: A Prescription For a Healthy Florida,” showing illustrations by Gene Packwood, a freelance artist and volunteer for the USDA Forest Service. Photos: Jim Thorsen, USDA Forest Service, Ocala National Forest, Seminole Ranger District, Umatilla, FL, 1990.



carries social as well as ecological benefits. Public sector involvement is increasingly needed to support this effort.

For additional information on the Council, or to obtain the Council's brochure or poster, contact The Central Florida Prescribed Fire Council, 40929 State Road 19, Umatilla, FL 32784. ■

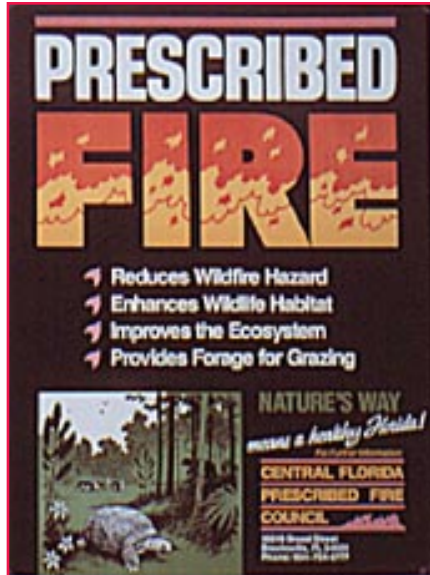


Figure 3—Poster on the benefits of prescribed fire featuring artwork by Gene Packwood, a freelance artist and volunteer for the USDA Forest Service. The Central Florida Prescribed Fire Council has posted more than 10,000 copies throughout central Florida at locations including the sites of prescribed burns. Photo: Jim Thorsen, USDA Forest Service, Ocala National Forest, Seminole Ranger District, Umatilla, FL, 1990.

CONGRESS FUNDS JOINT FIRE SCIENCE PROGRAM

Bob Clark

Congress has approved \$8 million in funding for a new program to address the growing problem of wildland fuels buildup. In the 1998 Appropriations Act for Interior and Related Agencies, Congress earmarked funding for fuels buildup study and treatment. House Committee Report 105–163 outlines specific fuels-related issues and calls for a plan to address those issues.

The Joint Fire Science Plan, forwarded for approval to Congress, identifies four purposes:

1. Fuels inventory and mapping,
2. Evaluation of fuels treatments,
3. Scheduling of treatments, and
4. Monitoring and evaluation.

The program is being managed by a governing board with five representatives from the USDA Forest Service and five from the U.S. Department of the Interior

(one each from the Bureau of Indian Affairs, Bureau of Land Management, U.S. Fish and Wildlife Service, National Park Service, and U.S. Geological Survey). A program manager will supervise day-to-day operations. Until the permanent program manager and location of the program office are selected by the Board, these duties are being filled by Bob Clark at the National Interagency Fire Center (NIFC) in Boise, ID.

The Joint Fire Science Program Governing Board will seek public input to assist it in setting priorities. After priorities are determined, the Board will publish requests for proposals for research into questions related to the Joint Fire Science Plan's four purposes and into development of tools to help local decisionmakers.

The Plan is posted on the NIFC Web site at <www.nifc.gov>. Additional information will be made available as the program evolves. The program office can be reached at 208-387-5349. ■

Bob Clark is the interim program manager for the Joint Fire Science Program, U.S. Department of the Interior, Bureau of Land Management, National Interagency Fire Center, Boise, ID.

DOES RYEGRASS SEEDING CONTROL POSTFIRE EROSION IN CHAPARRAL?



Jan L. Beyers, Peter M. Wohlgemuth, Carla D. Wakeman, and Susan G. Conard

A thick blanket of fire-prone brush known as chaparral covers most of the steep, dry hills at low to middle elevations in southern California. Composed almost entirely of evergreen shrubs, stands of chaparral burn every 20 to 70 years on average. Chaparral plants are well adapted to periodic fires (Barro and Conard 1991). Many common chaparral shrubs, such as chamise (*Adenostoma fasciculatum*) and scrub oak (*Quercus* spp.), sprout vigorously after burning. Others, including many species of California lilac (*Ceanothus*), are killed by fire but are soon replaced by seedlings that germinate from seeds stored in the soil. Herbaceous plants, such as lupines (*Lupinus* spp.), phacelias (*Phacelia* spp.), and wild morning glories (*Calystegia* spp.), also quickly sprout from the soil “seed bank.” Given adequate rainfall, a burned chaparral slope will be carpeted with flowering plants within 1 to 2 years after the fire.

Postfire Erosion Problems

In the critical period after the fire and before the regrowth of plant life, bare hills are vulnerable to greatly accelerated erosion. During a fire, chaparral vegetation and organic debris are burned away. As

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In southern California's chaparral-covered uplands, fire can increase hillslope erosion by up to 1,000 times the prefire rates.

plants and ground litter are consumed, barriers to sediment movement are destroyed. Loose surface soil is destabilized and moves down the steep hillslopes during and immediately after a fire, creating a pulse of dry erosion by the process known as “ravel.” Without plant cover and organic litter to hold the soil in place and promote infiltration, rain falling on burned hillslopes can wash additional soil material downhill. The development of a water-repellent layer in the soil as a result of heating by fire increases surface runoff by drastically reducing infiltration (DeBano 1981). This accelerated hillslope runoff can mobilize the dry ravel material that has accumulated at the base of slopes, creating flooding and debris flows (Wells 1987).

In heavily populated southern California, urban development has encroached on chaparral wildlands so that fire in the chaparral now threatens nearby human communities. Wind-driven fires can sweep through housing tracts: the Panorama Fire of 1980 burned 250 homes in San Bernardino, and a 2-week series of wildfires in the fall of 1993 burned more than 1,100 homes in the greater Los Angeles area. But after the fire is

out, the danger continues—in the form of catastrophic erosion. Even after moderate rainfall, roads, buildings, communications and utility lines, and water storage reservoirs downstream from burned wildlands can be inundated by runoff and debris flows. Property damage, severed utility lines, and lost reservoir capacity can be extensive.

Postfire Ryegrass Seeding

To address the threat of postfire erosion, agencies such as the California Department of Forestry and Fire Protection and the USDA Forest Service have explored ways of rapidly reestablishing plant cover on burned hillslopes. By the 1940's, land managers were routinely seeding burned chaparral stands with annual ryegrass (*Lolium multiflorum*). Ryegrass was believed to provide effective postfire erosion control because it germinates quickly and produces an extensive root system. Ryegrass is also inexpensive and readily available, and can easily be applied to large areas from the air (Barro and Conard 1987). However, annual ryegrass is not native to California; it is indigenous to temperate Europe and Asia.

Although ryegrass has been used for decades to attempt to control postfire erosion in chaparral, research has been scant on whether seeded ryegrass effectively reduces erosion. Similarly, few studies have been done on the impacts of ryegrass on the native chaparral plant community. Some studies suggested that the introduction of ryegrass to burned chaparral could interfere with the survival and growth of sprouting shrubs or shrub seedlings, or could displace native postfire herbaceous plants (Nadkarni and Odion 1986, Taskey et al. 1989). Since 1986, researchers at the Forest Service's Pacific Southwest Research Station in Riverside, CA, have been investigating the effects of this introduced grass on postfire erosion and on the regeneration of native chaparral plant communities in southern California.

Impact on Erosion

In southern California, precipitation patterns are strongly seasonal. Most rainfall occurs during the winter and early spring, from November to April; a dry season follows from May to October. At each of four study sites in southern California's coastal mountain ranges, we established replicated experimental plots in mature chaparral and measured both wet- and dry-season hillslope erosion for 1 to 4 years before burning.

After prefire sampling was complete, some experimental plots on each site were set aside as controls (unburned). The rest of each study site was burned in a hot prescribed fire, and only completely burned plots were used for subsequent measurements. After each prescribed fire, half of the plots on each study site were randomly



Chaparral grows on steep slopes throughout southern California. Here, a helicopter uses a drip-torch to ignite the prescribed fire at one of the study sites. Photo: Jan Beyers, USDA Forest Service, Pacific Southwest Research Station, Riverside, CA, 1994.

selected for seeding with annual ryegrass. Erosion data from the control plots were used in conjunction with prefire data from the burned plots to calculate a baseline level of erosion for each plot. This baseline is an estimate of the amount of erosion that a plot would have produced during a particular time interval had it not been burned. The baseline varies over time, generally increasing with greater rainfall, but the magnitude of the fluctuations is very small compared to the change in erosion rate after fire. Postfire erosion rates were measured for up to 5 years at each site and compared to the calculated baseline erosion rates to quantify the effects of both fire and the ryegrass seeding treatment on hillslope sediment movement.

Measurement of the initial postfire dry ravel at each of the four study sites revealed an erosion rate from 10 to 100 times greater than baseline dry-season erosion, increases similar to or greater than

previously reported (Krammes 1965). In the first wet season after fire, hillslope erosion rates at the four sites varied from slightly less than baseline at one site to more than 1,000 times greater at another. Erosion rates in the subsequent dry season were usually less than three times greater than the baseline rate. Postfire erosion at all four sites decreased over time, returning to or dropping below the calculated baseline within 2 to 4 years after the fire, similar to the pattern observed at the San Dimas Experimental Forest in southern California (Wells 1981).

Average erosion rates were not significantly different between seeded and unseeded plots until after erosion was at or below the baseline level. After that time, experimental plots that were seeded with annual ryegrass produced significantly less erosion than plots that were not seeded on two of the four study sites. On the other two sites, there was no significant reduction in erosion on seeded plots.



During the first wet season after fire, greatly increased hillslope erosion filled the boxes used to quantify sediment movement at one of the sites in this study. Photo: USDA Forest Service, Pacific Southwest Research Station, Riverside, CA, 1991.

A generalized pattern of erosion response was determined on the basis of data from our four study sites and the results of other studies (fig. 1):

- An initial postfire pulse of dry erosion during and immediately after the fire and before the application of ryegrass seed.
- An increase in erosion during the first wet season after fire, which is not reduced by the presence of ryegrass.
- A decrease in erosion over time as the site returns to and decreases below the baseline. During this time, seeded plots sometimes produce significantly less erosion than unseeded plots.

Although this general trend (fig. 1) was observed in our study and is consistent with results of previous studies (Krammes 1965, Wells 1981), the results from our

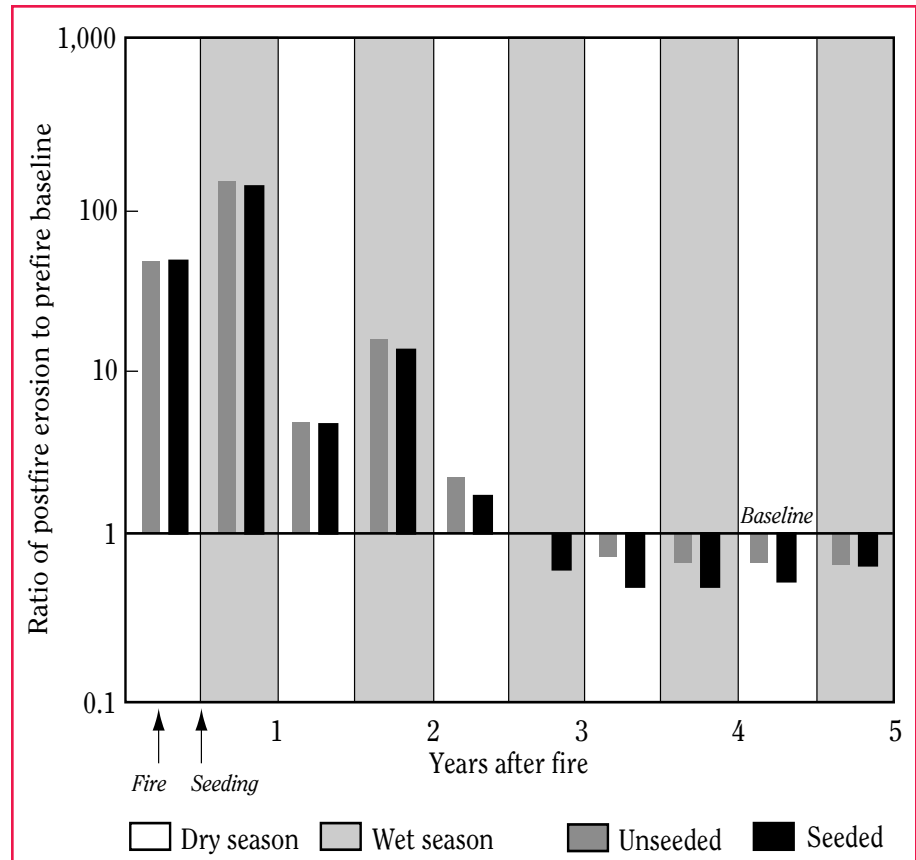


Figure 1—Generalized pattern of postfire hillslope erosion in chaparral and the impact of postfire ryegrass seeding. The baseline is the prefire erosion rate. The ratio of postfire erosion to baseline erosion is plotted on a log scale. (Values shown are indicative only and do not represent an actual site.)

experimental plots showed a great deal of variability in erosion response from site to site. This variability results from site-specific factors such as topography, soil type, prefire vegetation characteristics, fire severity and timing, and (particularly) postfire weather patterns. For these same reasons, the actual magnitude of postfire erosion at other chaparral sites could deviate substantially from the general pattern we found.

Impact on Vegetation

Detailed vegetation data were collected on experimental plots before each prescribed fire and for up to 5 years afterwards. Information was recorded on the number and size of sprouting shrubs, the number of shrub seedlings, and

the percent cover of herbaceous plant species. Data analysis did not reveal statistically significant differences in the number and size of sprouting shrubs between experimental plots seeded with ryegrass and plots that were not seeded. Similarly, no significant differences were found in the density of shrub seedlings between seeded and unseeded plots. The results suggest that, as these chaparral stands mature, ryegrass seeding will not affect shrub composition.

The rationale for grass seeding is that it rapidly provides a ground cover that will retain the soil on the hillslopes until the native vegetation is reestablished. However, chaparral ecosystems have a dormant soil seed bank of herbaceous species that are stimulated to

germinate by fire, appearing during the first postfire growing season (Keeley et al. 1981). Therefore, to provide any additional measure of erosion protection, seeded grasses would either have to begin growth sooner than native species, supplement the natural regrowth, or hold soil more tenaciously than native plants during the first wet seasons after a fire. Of these three possibilities, we evaluated the impact of seeded grass on total herbaceous plant growth (ground cover).

Statistically significant differences in total herbaceous plant cover were not found on seeded compared to unseeded plots except at one site, where natural postfire herbaceous cover was extremely low during the first wet season after fire (less than 5 percent cover). At that site, ryegrass seeding resulted in a small increase in herbaceous cover, which persisted for 3 years. At the other study sites, ryegrass appeared to replace some portion of the native herbaceous plants on the seeded plots without increasing total plant cover. This effect was greatest during the second year after fire. Average species richness (number of species per plot), a measure of biodiversity, was lower on seeded plots in some years and at some sites as well. Our results are similar to those obtained by other researchers (Nadkarni and Odion 1986, Taskey et al. 1989). At all sites, ryegrass effectively disappeared from the ecosystem by the fourth year after fire.

Does Postfire Ryegrass Seeding Work?

In southern California's chaparral-covered uplands, fire can increase hillslope erosion by up to 1,000

times the prefire rates. The amplitude of this fire effect is influenced by burn characteristics (timing and severity), postfire rainfall (amounts and intensities), and site characteristics (topography, soil types, and vegetation). Grass seeding as a postfire emergency rehabilitation measure does not reduce the amount of dry ravel that accumulates downslope immediately after a fire. Similarly, seeding will not affect the magnitude of the debris flows or runoff that occurs with the first winter rain, because the grass will not yet have germinated. Our data suggest that grass seeding has no significant impact on hillslope erosion at any time during the first wet season after fire.

In subsequent wet seasons, grass seeding might increase plant cover and reduce erosion where natural regeneration is low, but it does little to supplement native regrowth where a viable seed bank exists. In our study, most of the measured reduction in sediment movement occurred after erosion rates had returned to the prefire baseline rate.

Seeded ryegrass can displace native vegetation, especially in the second growing season after a fire, but we found the impact limited to the herbaceous flora. Because growth of native postfire herbaceous species is essentially restricted to the first year or two after fire (Keeley et al. 1981), reduction in their abundance by seeded ryegrass could reduce their contributions to the soil seed bank, and negatively affect future populations of these plants and the measure of erosion protection that they provide to the soil. The long-term impact of ryegrass seeding on native herbaceous plants is unknown, but if an

area contains rare species that germinate only after fire, seeding with ryegrass would not be advisable. Unlike other investigators (Griffin 1982, Taskey et al. 1989), we did not detect a significant decrease in the average chaparral shrub seedling density or survival in seeded compared to unseeded plots. However, none of our sites averaged more than 25 percent ryegrass cover during the first growing season after fire, when shrub seedlings germinate and become established. Ryegrass might be more detrimental to chaparral shrub seedlings in areas where seeding results in very high ryegrass cover (e.g., the Sierra Nevada foothills (Schultz et al. 1955)).

A key result is that both vegetation and erosion responses varied from site to site. Each burn site consisted of a unique combination of



Growth of annual ryegrass was greatest in the second year after fire at three of the four study sites. Where ryegrass was abundant, fewer native herbaceous plants were found. The pole in the center of the photo is about 3 feet (1 m) high. Photo: Jan Beyers, USDA Forest Service, Pacific Southwest Research Station, Riverside, CA, 1992.

site characteristics, fire characteristics, and postfire rainfall that governed vegetation regrowth, erosion response, and seeding treatment effectiveness. Thus, examination of more study sites with better replication will be necessary before postfire hill-slope erosion patterns are fully understood.

Tradeoffs and Alternatives

Fire and postfire management is growing in importance as more people choose to build at the wildland–urban interface. Demands on Federal, State, and local land management agencies have increased dramatically. Managers are under conflicting pressures to seed postfire slopes to protect life and property, and to avoid seeding to protect native ecosystems and rare plants.

In southern California, land managers are using the results of this and other studies to weigh the tradeoffs associated with postfire grass seeding. They must carefully balance the potential for property damage from the inevitable post-fire sediment pulse against the need to protect other ecosystem values in a burn area, such as rare species. Seeding is no longer routinely applied to every burned slope—only to areas where even a small reduction in erosion will outweigh the seeding cost and where natural seed banks are believed to be inadequate.

Instead of seeding, land managers often use mechanical methods for trapping or diverting sediment to protect critical resources. Where seeding is used, grass species other than annual ryegrass are being tested to attempt to reduce potential damage to native plant communities. Continued monitoring and research will be needed to determine whether alternate grass species actually reduce erosion or affect native plant recovery.

For more information about these research results and for copies of other publications on this study, please contact Jan Beyers or Peter Wohlgenuth, Prescribed Fire and Fire Effects Research Work Unit, USDA Forest Service, Pacific Southwest Research Station, 4955 Canyon Crest Drive, Riverside, CA 92507, tel. 909-680-1500, fax 909-680-1501, e-mail jbeyers@psw_rfl@fs.fed.us; pwohlgem@psw_rfl@fs.fed.us.

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