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Using NDVI to Assess Departure From Average Greenness and its Relation to Fire Business

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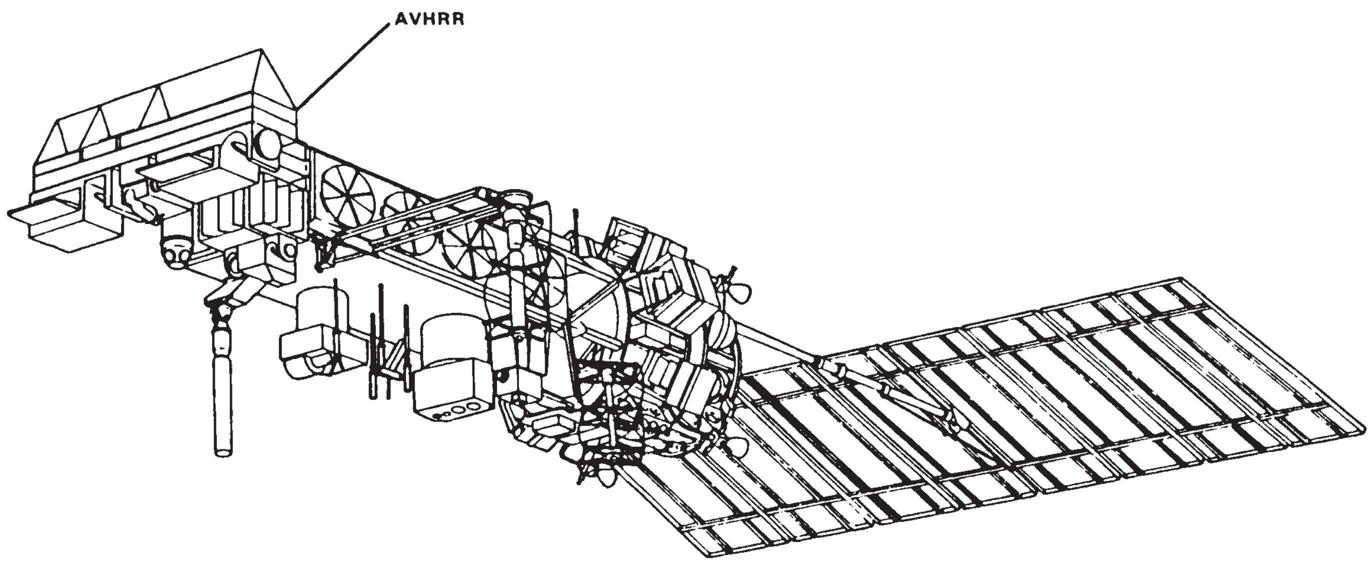

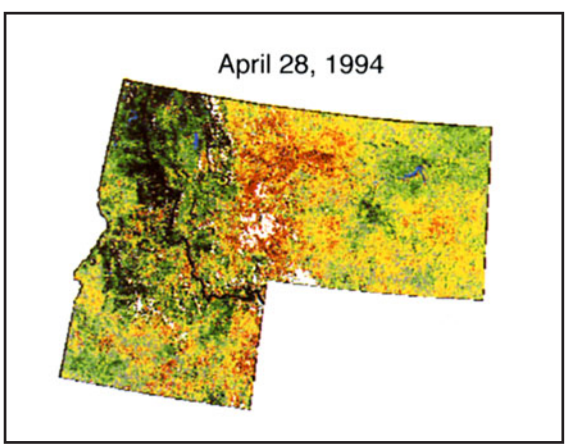

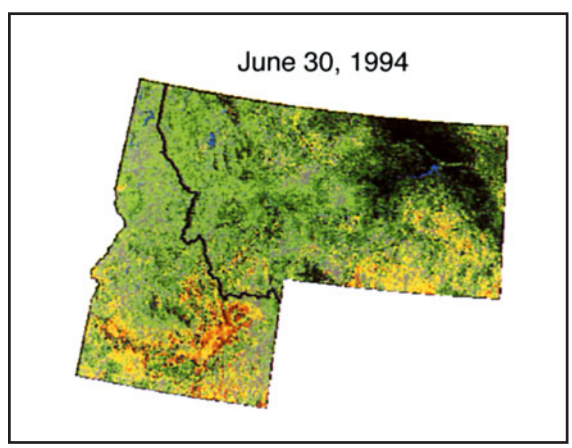

The Authors

Robert E. Burgan, Research Forester, received his bachelor's degree in forest engineering in 1963 and his master's degree in forest fire control in 1966 from the University of Montana. From 1963 to 1969, he served on the timber management staff of the Union and Bear-Sleds Districts, Wallowa-Whitman National Forest. From 1969 to 1975, he was a research forester on the staff of the Institute of Pacific Islands Forestry, Honolulu, HI. From 1975 to 1987, he was at the Intermountain Fire Sciences Laboratory, Missoula, MT, first as a member of the National Fire-Danger Rating Research Work Unit, and then as a research forester in the Fire Behavior Research Work Unit. From 1987 to 1989, he was in Macon, GA, at the Eastern Fire Management Research Work Unit, a part of the Southeastern Forest Experiment Station. In 1989 he returned to the Fire Behavior Research Work Unit in Missoula.

Roberta A. Hartford, Forester, began working at the Intermountain Fire Sciences Laboratory in Missoula, MT, in 1968 assisting with research of chemical and physical properties of forest and range fuels. In the early 1970's, she taught high school sciences and did seasonal work on the Lolo National Forest in fuel inventory. Since 1970, she has remained at the Fire Lab involved in analysis of fuel and fuel bed properties, smoldering combustion, and fire behavior of laboratory and wildland fires. Recent and current work include studies in the use of satellite remote sensing to assess fire potential in wildland vegetation, collecting fire behavior documentation, and using geographical information system technology to document wildfire growth. Roberta received her undergraduate degree in zoology in 1970 and a master's degree in forestry with soils and fire management emphasis in 1993 from the University of Montana.

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Research Summary

Satellite-derived vegetation greenness maps of the contiguous United States have been available to fire managers since 1989. These maps portray vegetation greenness on a weekly basis compared to a very green reference and to the maximum historical greenness range. This report describes a new map, departure from average, which is designed to compare current-year vegetation greenness to average greenness for the same time of year and describes its relationship to fire business.

Comparisons of the departure from average greenness and calculated 1,000-hour fuel moisture trends to fire business were made for the 1993 and 1994 fire seasons in Montana and Idaho. The 1,000-hour fuel moisture value relates to the moisture content of large-diameter dead fuel and duff. In 1993, vegetation was much greener than average as the fire season progressed and high 1,000-hour fuel moisture values were maintained. Fire occurrence and area burned were low. In 1994, fire occurrence and area burned increased dramatically as vegetation greenness decreased below average and 1,000-hour fuel moistures declined.

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Introduction

Satellite-derived vegetation index maps of the contiguous United States have been available to fire managers since 1989. In early 1994, the data were also available through the Weather Information Management System (WIMS), which is a Forest Service, U.S. Department of Agriculture, system for collection and dissemination of land management-related data and software. The basic data source for these maps is the Advanced Very High Resolution Radiometer (AVHRR). The U.S. Geological Survey, Earth Resources Observations Systems (EROS) Data Center (EDC) retrieves the satellite data daily, processes it, and produces normalized difference vegetation index (NDVI) maps that indicate the quantity of actively photosynthesizing biomass on the landscape (Eidenshink 1992). Currently EDC provides weekly updated maps. These maps are sent electronically to WIMS where the contiguous United States data are divided into smaller, more manageable regional datasets that can be downloaded to personal computers or workstations at individual sites (Burgan and Hartford 1993).

To make the NDVI more useful to fire managers, software has been developed to produce two additional maps from the NDVI data: visual greenness and relative greenness.

Visual greenness maps portray current NDVI compared to a very green reference such as an alfalfa field. On visual greenness maps, dry areas typically have low visual greenness values because their NDVI values are usually low, and lush areas typically have high visual greenness values because their NDVI is generally high. These maps provide a standard comparison used to portray regional differences in vegetation greenness across the entire United States. Visual greenness values range from 0 to 100.

Relative greenness maps indicate current vegetation greenness compared to a historically observed NDVI range. On relative greenness maps, any pixel appears fully green when the NDVI for that pixel reaches its maximum value, and fully cured when the NDVI reaches its minimum value. Thus, both dry (Nevada) and lush (western Washington) areas can reach relative greenness values of 0 and 100 percent even though Nevada has much sparser vegetation than western Washington.

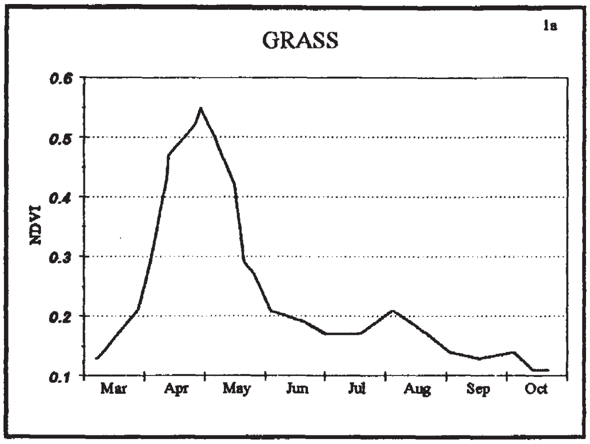
Both maps are useful when assessing seasonal changes in vegetation condition. However, this report describes a new map, departure from average, that is designed to compare current-year vegetation greenness with average vegetation greenness for the same time of year.

Concept

The NDVI profile shows annual patterns of vegetation development from green-up to senescence (Reed and others 1994). For grasslands of the Northern Plains, green-up begins with the onset of warm temperatures and spring rains and terminates with the dry conditions and colder temperatures of autumn (fig. 1a). For a northern forest, green-up begins after snowmelt and terminates in late summer and fall along with drier conditions and senescence (fig. 1b). The EROS Data Center is accumulating an annual series of NDVI maps and data, beginning with 1989.

Clouds, haze, off-nadir view angles, and other factors reduce NDVI data values below what would be obtained under ideal viewing conditions. These problems are minimized by compositing several daily NDVI images, keeping only the highest NDVI value observed for each pixel.

The standard compositing period is 14 days. Although this long compositing period greatly reduces cloud contamination and other problems, it also delays recognition of vegetation senescence. Therefore, beginning in 1996 EROS will also provide 7-day composites that can be used to produce visual greenness, relative greenness, and departure from average greenness maps for wildland fire management use. The shorter compositing period will permit better monitoring of current vegetation condition. The



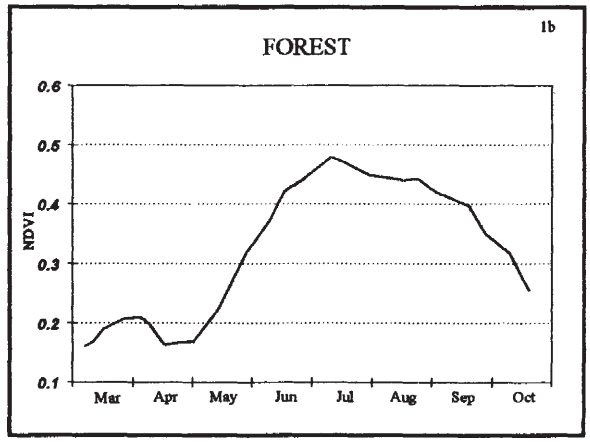


Figure 1—Different vegetation types produce different seasonal NDVI profiles.

NDVI data and the greenness maps derived from it have a ground resolution of 1 km.

Over the 6 years of recorded data (1989-1994), the approximately 30 weekly NDVI updates per year (March through October) generally represent similar time frames, plus or minus 3 days. Table 1 shows the weekly update periods. By analyzing the time frames for each weekly update period it is possible to calculate the mean NDVI for each 1-km pixel. Before calculating the mean, each image is carefully screened for clouds and snow to prevent inclusion of abnormally low NDVI values in the mean. As a result not all means for each pixel will include six observations. The mean NDVI maps are updated annually.

Figure 2 illustrates how, for a single pixel, the current year's NDVI can vary around the seasonal mean profile. At different times of the fire season, the 1989 NDVI values are both above and below the 6-year average. The departure from average calculation provides a meaningful representation of these deviations around seasonal mean NDVI values.

The specific algorithm for producing departure from average maps is:

$$DA_t = NDVI_t/NDVI_{mt}*100$$

where:

$NDVI_t$ = NDVI for the current time period

$NDVI_{mt}$ = mean NDVI for the current time period

DA_t = departure from average NDVI for the current period

The multiplier of 100 is used to scale the current period departure from average values so that average greenness is represented by a value of 100. Thus, the departure from average map can also be thought of as a percent of average greenness map.

Computation of the departure from average maps consists of processing the current year's weekly updated NDVI composite maps with the mean NDVI map for the associated period. This is accomplished on a work station with a software program that implements the described algorithm.

Figure 3 shows the 1989 and 1991 departure from average for the pixel near Red River, ID. A value of 100 represents 100 percent of the mean NDVI, a value of 96 indicates current NDVI is 96 percent of average. The departure from average profile for these 2 years is considerably different. Until late June of that year, 1989 was greener than average, then more cured than average until mid-September, while 1991 shows a different seasonal trace for the same 1-km pixel.

Table 1—Approximate NDVI weekly update periods.

NDVI period	Calendar date	NDVI period	Calendar date
1	Mar 03 - Mar 09	18	Jun 30 - Jul 06
2	Mar 10 - Mar 16	19	Jul 07 - Jul 13
3	Mar 17 - Mar 23	20	Jul 14 - Jul 20
4	Mar 24 - Mar 30	21	Jul 21 - Jul 27
5	Mar 31 - Apr 06	22	Jul 28 - Aug 03
6	Apr 07 - Apr 13	23	Aug 04 - Aug 10
7	Apr 14 - Apr 20	24	Aug 11 - Aug 17
8	Apr 21 - Apr 27	25	Aug 18 - Aug 24
9	Apr 28 - May 04	26	Aug 25 - Aug 31
10	May 05 - May 11	27	Sep 01 - Sep 07
11	May 12 - May 18	28	Sep 08 - Sep 14
12	May 19 - May 25	29	Sep 15 - Sep 21
13	May 26 - Jun 01	30	Sep 22 - Sep 28
14	Jun 02 - Jun 08	31	Sep 29 - Oct 05
15	Jun 09 - Jun 15	32	Oct 06 - Oct 12
16	Jun 16 - Jun 22	33	Oct 13 - Oct 19
17	Jun 23 - Jun 29	34	Oct 20 - Oct 26
		35	Oct 27 - Nov 02

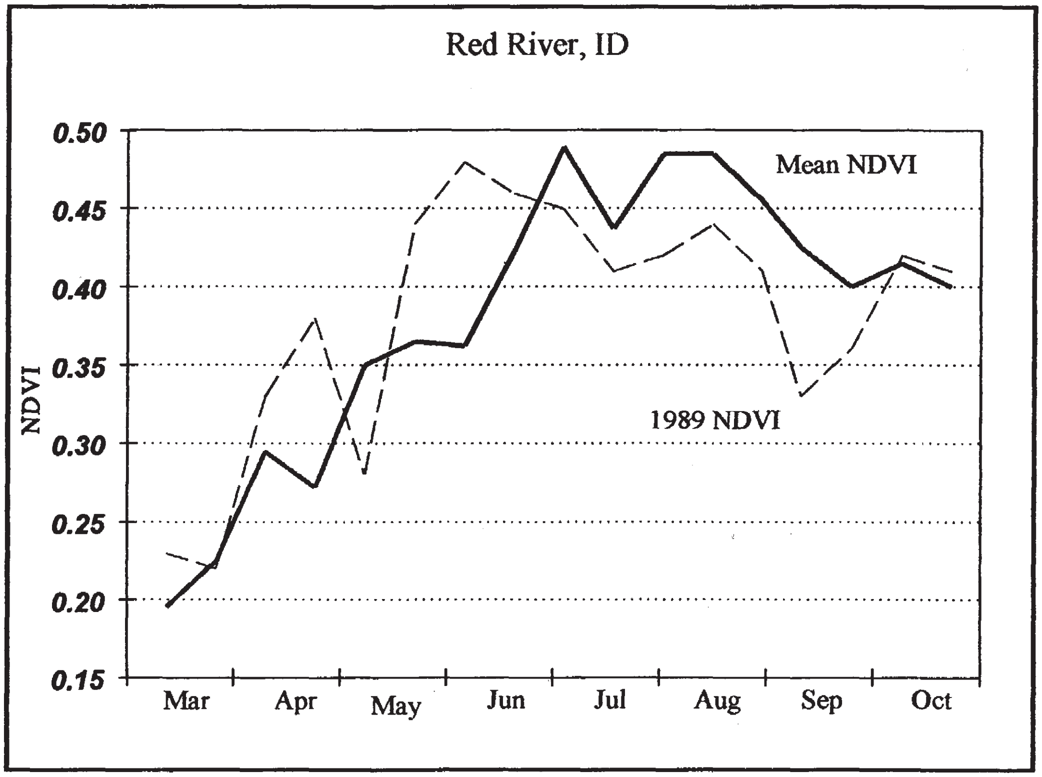


Figure 2—For a pixel near Red River, ID, 1989, NDVI is generally above average until mid-June, then it is below average.

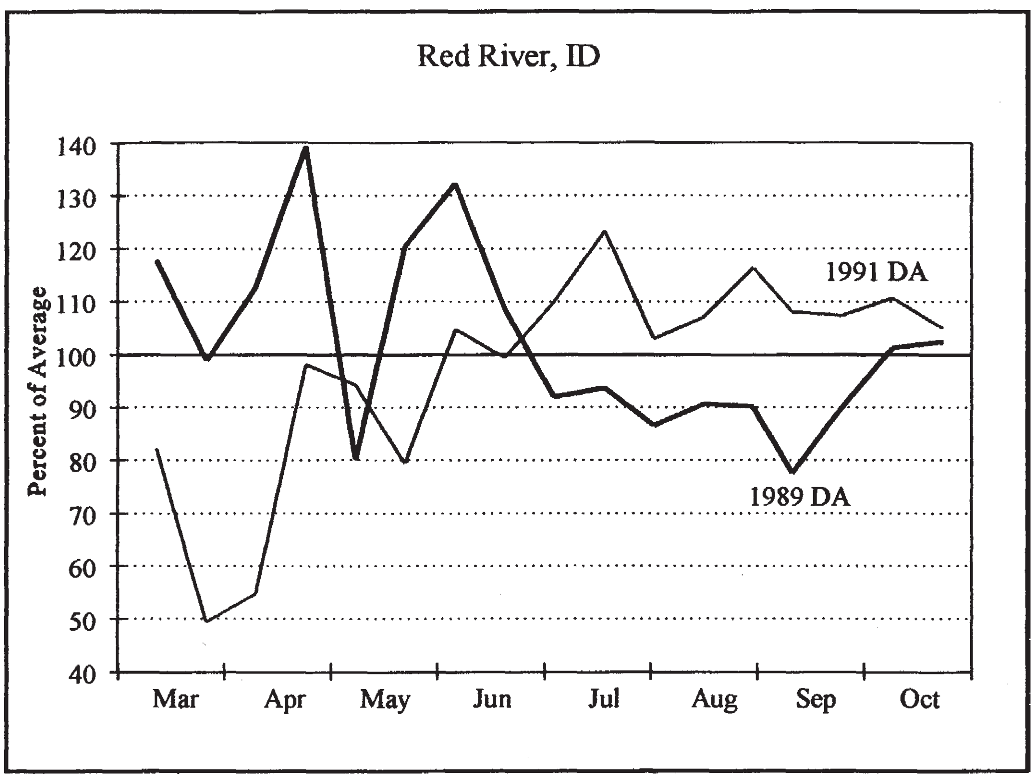


Figure 3—The 1989 and 1991 departure from average values show reverse trends for the Red River pixel.

Departure from average maps of Idaho and Montana for April, July, August, and September 1993 and 1994 are in figure 4. Pixels indicating clouds or snow (white) were not used in any analysis.

The spring of 1993 was cool and wet, resulting in a delayed green-up. The April 29 and July 1 maps show below-average greenness due both to the cool weather and to consistent cloud cover, which reduces NDVI values. The remainder of 1993 continued wetter than normal and the vegetation condition reflected this with above average greenness as shown in the August 12 and September 16 maps.

Overall, early greenness was average for 1994, as the equal areas above and below average greenness indicate on the April 28 map. May and June were warm and sunny resulting in an exceptionally green condition for Idaho and Montana on June 30, before the plants were water stressed. Continuation of the hot, dry weather soon caused much of the vegetation to cure, resulting in the considerably cured conditions on the August 11 map. These conditions continued into September.

Data Analysis

For the departure from average maps to be useful for fire potential assessments, they must relate to fire size and number of fires. We expect fire activity will be lower than normal when vegetation is greener than average and higher when vegetation is less green than average; however, dead fuel moisture is another factor. The 1,000-hour fuels (Fosberg and others 1981) (3- to 8-inch dead roundwood) respond to wetting and drying conditions on a time scale similar to living vegetation. Thus, if the departure from average maps indicate below average vegetation greenness and large dead-fuel moistures are low, significant fire activity is expected. Low fire activity is expected if both values are high. To test this concept, 1,000-hour fuel moisture, number of fires, acres burned, and NDVI data were collected for Idaho and Montana for 1993 and 1994.

Data Collection

We calculated 25 departure from average maps for the contiguous United States at weekly intervals from March 25 to September 15 for 1993 and 1994; however, just Idaho and Montana were used for this analysis. We used the Geographic Resources Analysis Support System (GRASS) (U.S. Army Corps of Engineers 1993) to count the number of pixels at each departure from average value. The values of all pixels within Idaho and Montana were also averaged for each weekly interval for production of graphs showing overall trends of the departure from average.

Daily fire reports were used to collect statistics on numbers of fires and acres burned by date. Weather data stored for all Montana and Idaho fire weather stations reporting to the WIMS were used to calculate 1,000-hour fuel moistures for 1993 and 1994.

A Comparison of Seasons

Figure 5 shows a seasonal profile of the 1989 through 1994 mean NDVI from March to September, averaged for all pixels in Idaho and Montana, as compared to NDVI averages over all Idaho and Montana pixels for 1993 and 1994. In the Pacific Northwest, 1993 was an exceptionally cool, wet year while 1994 was a hot, dry year. Thus, these 2 years provide greater contrasts than expected between more typical years.

The departure from average maps for 1993 showed NDVI values below average until early May (fig. 5). The rest of May, June, and the first half of July vegetation greenness approximated average. From mid-July into September, continuation of cool, rainy weather produced above average vegetation greenness.

The spring of 1994 was warm, with below normal snowpack, resulting in an approximately average green-up in March and April, then greener than average vegetation in May and June. From this point on, 1994 was unusually hot and dry and the NDVI profile reflects this.

These trends are also shown in figure 6. In these plots, an *X*-axis value of 100 represents 100 percent of average greenness. The plot for April 29 (fig. 6a) shows that about 90 percent of Idaho and Montana had below average greenness for that date in 1993, while about 55 percent had below average greenness in 1994. On July 1 (fig. 6b) about 60 percent of Idaho and Montana remained below average greenness in 1993 due to the cool, cloudy weather. However, only about 25 percent of the area had below average greenness in 1994. Up to this point, the vegetation maps did not indicate that 1994 would be an exceptionally active fire year, but the warmth and lack of rain was beginning to concern fire managers. By early August 1994 (fig. 6c), the lack of rain definitely had its effect on vegetation. About 90 percent of Idaho and Montana had below average greenness and the fire season was very active.

In contrast, only 10 percent of the area was below average greenness in 1993 and the fire season was unusually quiet. By September 15 (fig. 6d) the situation in 1994 was worse, with about 95 percent of Idaho and Montana experiencing below average greenness and the fire season continuing. However, 1993 continued to show record low fire activity with only 20 percent of the area at below average greenness.

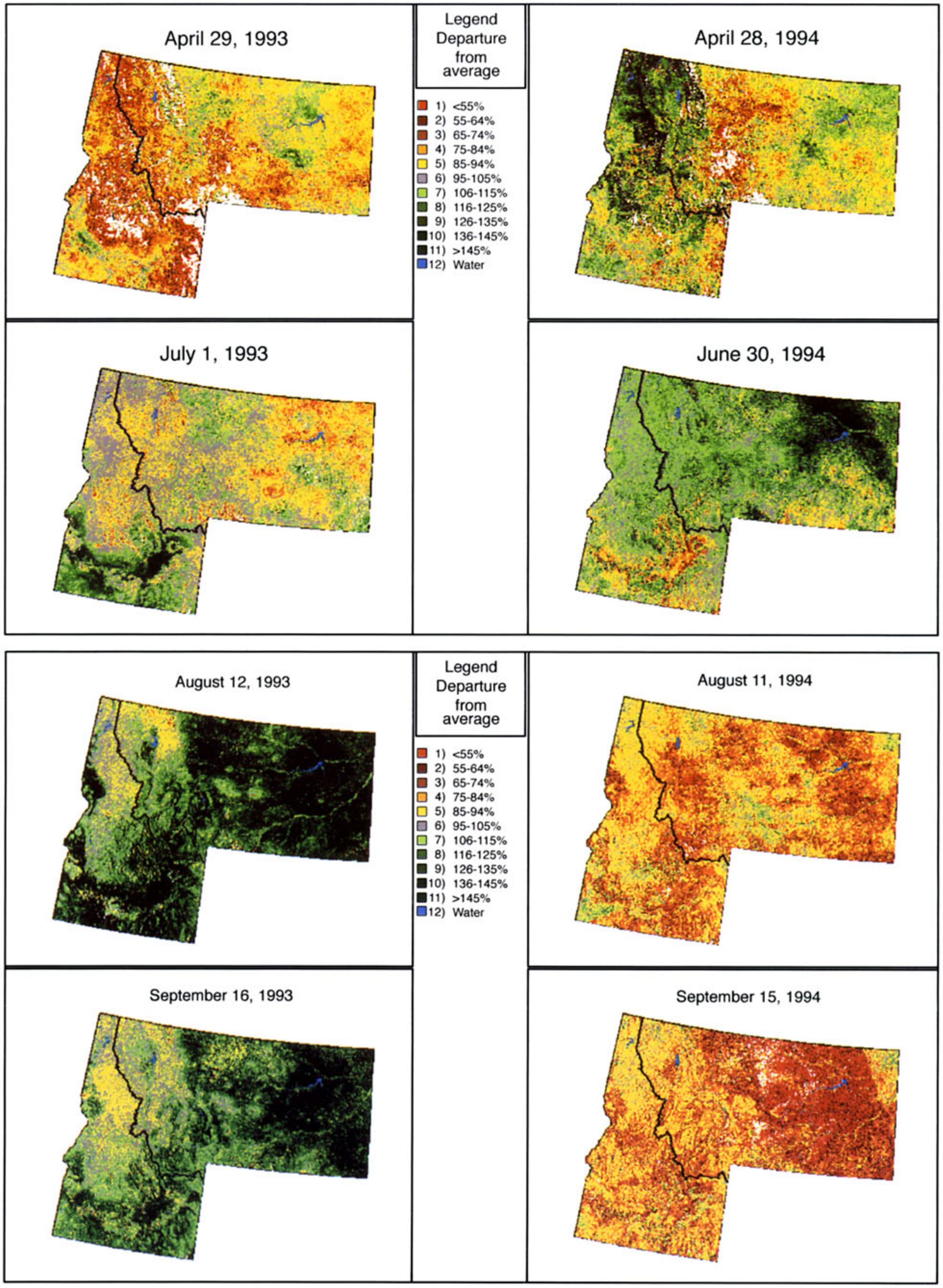


Figure 4—Departure from average greenness for Idaho and Montana was considerably different between 1993 and 1994.

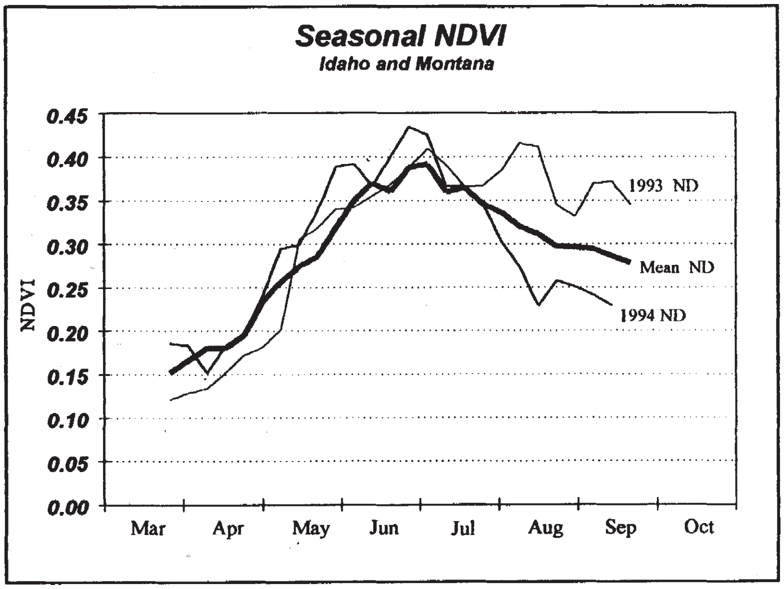


Figure 5—Vegetation greenness, as indicated by NDVI, was above average from mid-summer to fall 1993 and below average for that period in 1994.

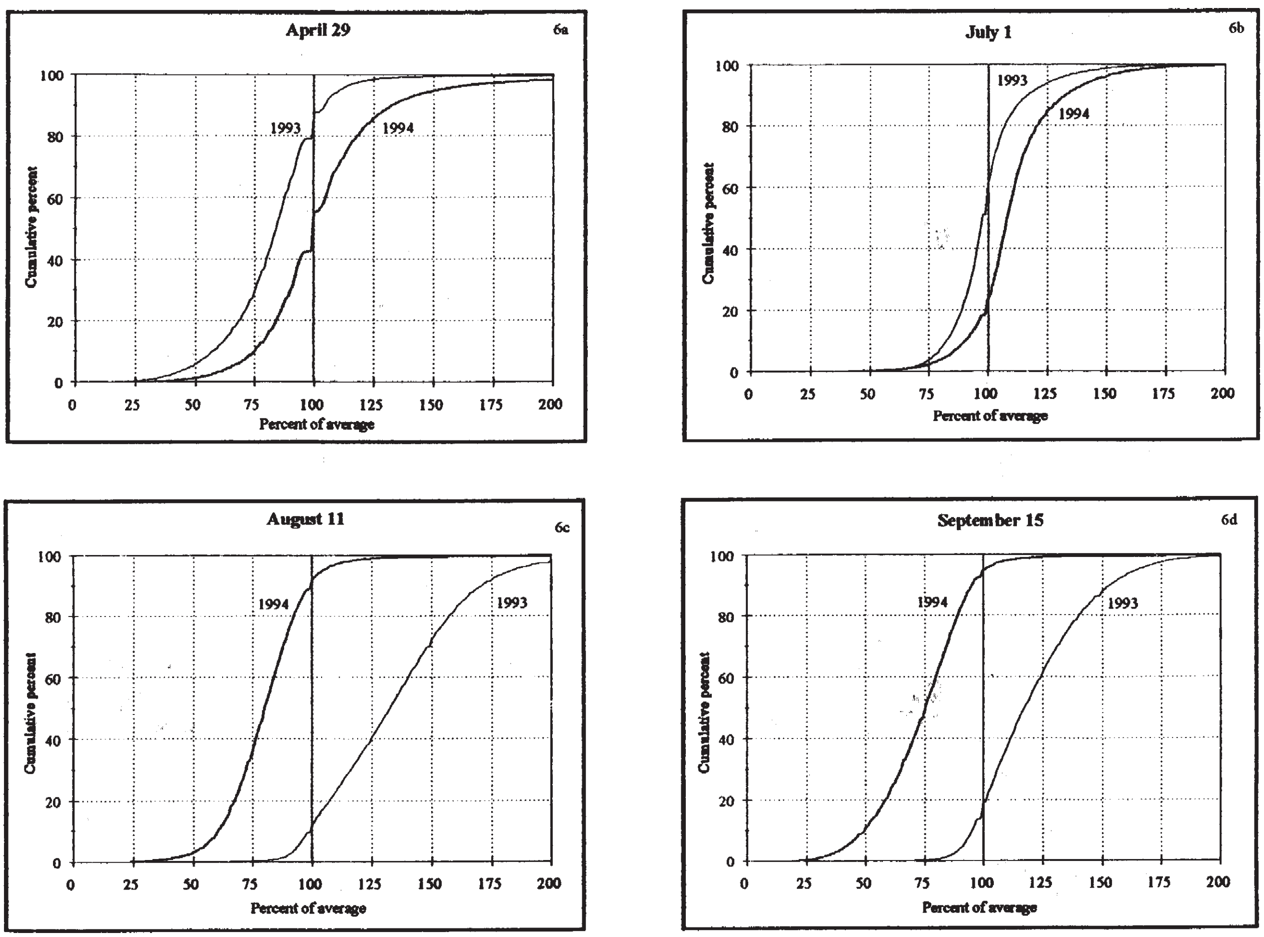


Figure 6—Vegetation greenness was below average (*X*-axis value of 100) in spring and early summer 1993 due to cool, wet weather then above average in late summer and early fall for the same reason. The year 1994 showed an opposite trend due to continuing warm and dry weather all growing season.

A more complete picture of fire potential is accomplished with inclusion of 1,000-hour fuel moisture than with just vegetation greenness. Figure 7 compares both departure from average greenness and 1,000-hour fuel moisture with number of fires and acres burned. The 1,000-hour fuel moisture is calculated for each fire danger weather station from 2:00 p.m. observations of dry bulb temperature, relative humidity, and rainfall.

The 1,000-hour fuel moisture average for all fire weather stations in Idaho and Montana was higher in 1993 (15 to 23 percent) than 1994 (10 to 18 percent) (fig. 7a). The 1,000-hour fuel moisture was generally lower in 1994, with the lowest average value 10 percent. This is a dry average for such a large area, and some weather stations reported even lower values. The 1,000-hour fuel moisture values below about 15 percent indicate onset of significant fire potential for this geographic area.

A comparison of fire activity during 1993 and 1994 with 1,000-hour fuel moisture and greenness indicates that fire potential is inversely related to these values. The number of fires and acres burned is low throughout 1993 (fig. 7c,d), with the number of fires increasing slowly from June through September. There was slightly more activity during August as the 1,000-hour fuel moisture declined; however, with more than average green vegetation (fig. 7b), fire activity was minimal all year.

The picture in 1994 was considerably different. While the number of fires increased modestly during most of June, the rate of fire occurrence increased significantly near the end of June, when 1,000-hour fuel moisture dropped below 15 percent (fig. 7a,c). At the end of July, when the greenness approached 90 percent of average (fig. 7b), the fire occurrence increased dramatically (fig. 7c), although acreage burned did not dramatically increase until mid-August (fig. 7d).

As 1,000-hour fuel moisture and vegetation greenness continued to decrease, acres burned increased dramatically and fire problems continued as 1,000-hour fuel moisture and vegetation greenness remained very

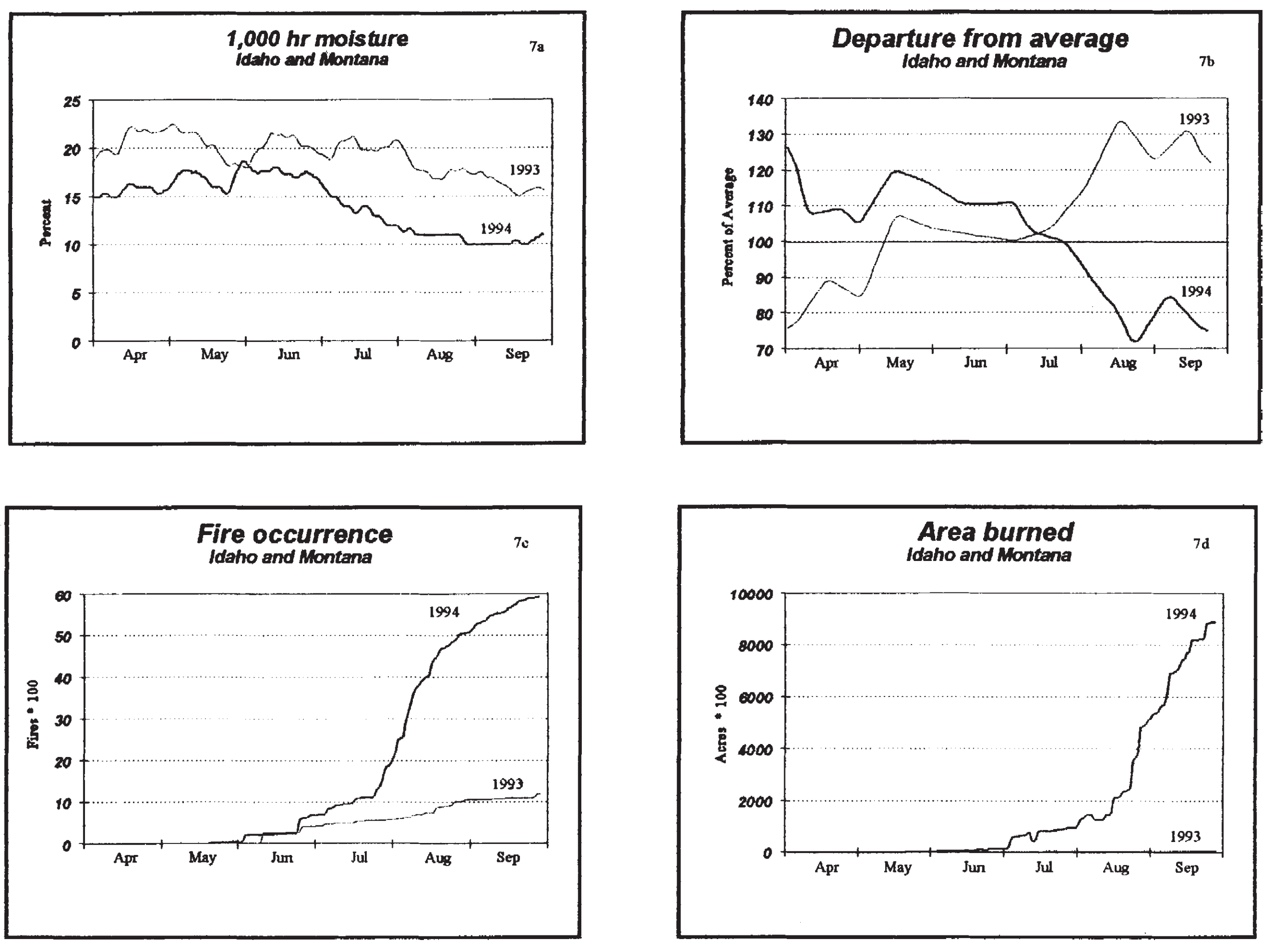


Figure 7—Fire activity remained low in 1993, a year in which 1,000-hour fuel moisture and vegetation greenness both remained high. Number of fires and area burned increased significantly in 1994 when the 1,000-hour fuel moisture was low and vegetation greenness was below average.

low. Thus, these indexes appear to be good indicators of fire activity. The first year that no smokejumpers were dispatched from the Missoula Jump Base was 1993, when fire activity was at a record low. Conversely, 1994 was one of the most active fire years on record, rivaled only by other major fire years such as 1988.

Conclusions

The departure from average map relates current-year vegetative greenness to average vegetative greenness for the same time of year. While this is useful information, it relates only to the quantity of live vegetation that has a relatively high moisture content. The moisture content of dead vegetation is also critical and is represented for large dead fuels by the 1,000-hour fuel moisture. A combined assessment of both departure from average and 1,000-hour fuel moisture may be useful for broad-scale fire potential assessment, although additional research is required to determine the strength of such a relationship.

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A new satellite-derived vegetation greenness map, departure from average, is designed to compare current-year vegetation greenness with average greenness for the same time of year. Live-fuel condition as portrayed on this map, and the calculated 1,000-hour fuel moistures, are compared to fire occurrence and area burned in Montana and Idaho during the 1993 and 1994 fire seasons.

Keywords: satellites, fuels, vegetation condition, moisture, fire

INTERMOUNTAIN RESEARCH STATION

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