RELATIONSHIP BETWEEN PALMER'S DROUGHT SEVERITY INDEX AND THE MOISTURE INDEX OF WOODY DEBRIS IN THE SOUTHERN COASTAL PLAIN

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Abstract—After the 1998 through 2000 drought in Louisiana, some prescribed burns had uncommonly severe fire behavior. A significant portion of the consumed fuels most likely were larger material normally unavailable for burning. Therefore at sites in Louisiana, Mississippi, and Texas, we studied the relationship between Palmer's Drought Severity Index (PDSI) and the drying rate of 3- to 12-inch-diameter woody fuels, expressed as resistance of fuel moisture to electrical current in kiloPascals. Woody fuels dried as drought severity increased. Once the drought abated in November 2000, fuel moisture indexes rose but not as quickly as PDSI. Although there is a general relationship between drought condition and drying of large-diameter fuels 1 year after the drought ended, large fuels had not sufficiently rewetted and remained available for burning in the event of a wildfire or prescribed burn.

INTRODUCTION

After the 1998 through 2000 drought in Louisiana, some prescribed burns became uncommonly severe and monitoring techniques, such as the Keetch-Byram Drought Index (KBDI), normally used to predict fuel moisture conditions did not predict this behavior (Keetch and Byram 1968). We suspected that a significant portion of the consumed fuels came from fuel classes not normally ignited in prescribed burns. For example, in April 2001, a prescribed burn within a natural longleaf pine (*Pinus palustris* Mill.) forest generated a Byram's fire intensity (from Brown and Davis 1973) of 447 Btu per second per foot. This fire consumed 650 pounds per acre of living herbage; 540 pounds per acre of living stems < 0.25 inches in diameter; 9,410 pounds per acre of dead fuels < 0.25 inches in diameter; 720 pounds per acre of dead fuels between 0.25 and 1 inch in diameter; and 1,130 pounds per acre of dead fuels between 1 and 3 inches in diameter. Although the conditions were within prescribed KBDI values, this fire intensity was nearly nine times the recommended level of 50 Btu per second per foot and approached uncontrollable intensities (Deeming and others 1977).

Palmer's Drought Severity Index (PDSI) identifies extended periods of unusual moisture conditions compared with seasonal norms and serves as a generalized indicator of the total environmental moisture supply (Louisiana Office of State Climatology 2001). It reflects the overall hydrologic status of a region and is particularly useful for evaluating the potential for development of prolonged regional droughts. PDSI may, therefore, be a better predictor of moisture trends in large-diameter fuels because these fuels do not gain and lose moisture with daily changes in moisture conditions (Deeming and others 1977). PDSI measurements, calculated continuously by the State Climatology Services, are also readily available.

We decided to test prediction of moisture trends for 3- to 12-inch-diameter woody fuels based on trends in PDSI. We plotted PDSI against fuel moisture to determine if such a relationship existed on three sites in the Lower Coastal Plain of Louisiana, Mississippi, and Texas.

MATERIALS AND METHODS

Study Areas

The National Long-Term Soil Productivity (LTSP) study is a joint effort between the U.S. Department of Agriculture, Forest Service, National Forest System and Forest Service Research (Powers and others 1990). We used three LTSP installations on the Palustris Experimental Forest, Rapides Parish, LA; DeSoto National Forest, Jones County, MS; and Davy Crockett National Forest, Trinity County, TX. The Texas site has the driest long-term climate and the Louisiana and Mississippi sites have similar annual precipitation.

Wood Samples

A 43-year-old loblolly pine (*P. taeda* L.) stand on the Palustris Experimental Forest, Rapides Parish, LA, was the wood source. This stand was planted at 6- by 6-foot spacing in 1955. The stand was never thinned, so mortality was high in recent years. Because of dense spacing, the trees had little taper, and the live crown ratio was 25 to 30 percent. At age 40, the average diameter at breast height (d.b.h.) (diameter at 4.5 feet above ground line) of all live trees in the stand was 9 inches, and the average height was 74 feet.

There were 21 trees in the 12- to 14-inch d.b.h. class, and the first live limb was usually > 49 feet above the ground. From this group, three trees with straight boles and few dead limbs below 39 feet were randomly selected as source material. After felling, 3.2-foot long, 12-inch-diameter logs were cut from the main stem of each of the three trees (table 1); a 12-inch-diameter log exceeds the size for 1,000-hour time-lag dead fuels (Deeming and others 1977). Limb material was simultaneously collected from the same trees. The limb samples averaged 3.3 feet long and 4 inches in diameter and were taken from a primary limb. Limb sizes fell in both the 100-hour and 1,000-hour time-lag dead fuel classes (table 1).

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Table 1—Limb and log weights and dimensions for the three study sites in Louisiana, Mississippi, and Texas.

Classes	Location	Weight	Inside-bark diameter at the upper end of the section[a]	Inside-bark diameter at the lower end of the section[a]	Length
		pounds	- - - - - - - -	*inches*	- - - - - - - -
Limbs	Louisiana[b]	9.7	2.9	2.6	39.8
	Mississippi[c]	23.6	4.6	4.2	39.4
	Texas[c]	37.8	5.6	5.2	39.2
Logs[d]	Louisiana	171.5	11.7	11.8	38.1
	Mississippi	158.7	11.6	11.5	39.1
	Texas	162.8	11.7	11.7	39.0

[a] The upper and lower ends of the logs were also the upper and lower ends in the standing tree. The lower end of the limb was the one closest to the tree bole.
[b] The limbs in Louisiana are within the 100-hour time-lag dead fuel class (Deeming and others 1977).
[c] The limbs in Mississippi and Texas are within the 1,000-hour time-lag dead fuel class (Deeming and others 1977).
[d] All logs exceed the 1,000-hour time-lag dead fuel class in size (Deeming and others 1977).

Placement of Wood Samples at Field Sites

Both a limb and log from the same tree were randomly selected, transported from the 43-year-old loblolly pine stand, and placed within the adjacent mature pine stand at each LTSP installation. In Louisiana, the mature stand was a 45-year-old loblolly pine plantation that originated from direct seeding in 1953. At age 37, it was thinned to a residual basal area of 65 square feet per acre. In Mississippi, the mature pine stand was a 63-year-old mixed stand of slash pine (*P. elliottii* Engelm.) and longleaf pine. The slash pines had been planted in 1935. The longleaf pines were residual trees or postplant volunteers. In Texas, this was a natural mixed stand of loblolly, longleaf, and shortleaf pine (*P. echinata* Mill.) between 60 and 80 years old.

Measurements

At each location, a Watermark™ sensor was embedded in the middle of each limb and log to eliminate edge effects on moisture conditions (fig. 1). The sensors are designed to estimate soil water tension by measuring the resistance to electrical current. Using the calibration curve for soil, the measurements were converted to kiloPascals (kPa) as an index of the water content of the log. While not calibrated for measuring water content of wood, the sensors have the advantage of being relatively stable over the course of the experiment. In addition, calibration curves between measurement parameter and water content of wood would have continually changed because wood decays rapidly in the southern environment. An Easylogger automatically recorded the data, which ranged from 14 kPa (wet) to 170 kPa (dry).

Resistance readings were taken from April 1998 through December 2001 at the Louisiana and Texas sites. At the Mississippi site the EasyLogger was not working from

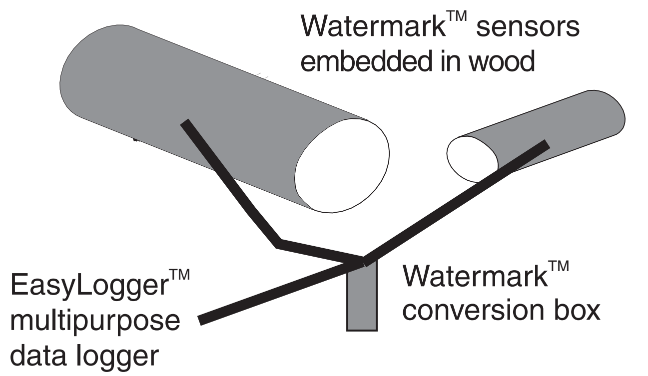

Figure 1—Schematic of the limb and log in the field; a Watermark™ sensor is embedded in the center of each piece of wood.

September through December 2001. For each site, numerical PDSI values were taken from the Southern Regional Climate Center databases for April 1998 through December 2001. The climate divisions for the LTSP sites are Division 5 – Central Louisiana, Division 9 – Southeast Mississippi, and Division 4 – Northeast Texas (Louisiana Office of State Climatology 2001).

Data Presentation and Analysis

For each site, the PDSI data were graphed alone (fig. 2) and in combination with the resistance readings for each limb and log (figs. 3 and 4). To align the data so the x,y intercept would be the driest value for both the PDSI and the moisture index, the resistance data were inverted (1/kPa) in figures 3 and 4. Regression equations were developed to examine the relationship between 1/kPa and time and PDSI ($\alpha = 0.05$).

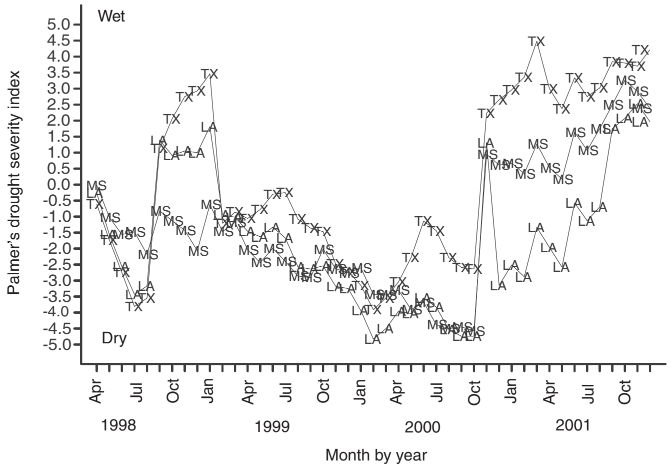

Figure 2—Changes in Palmer's Drought Severity Index for the Louisiana, Mississippi, and Texas sites over a 45-month period from April 1998 through December 2001.

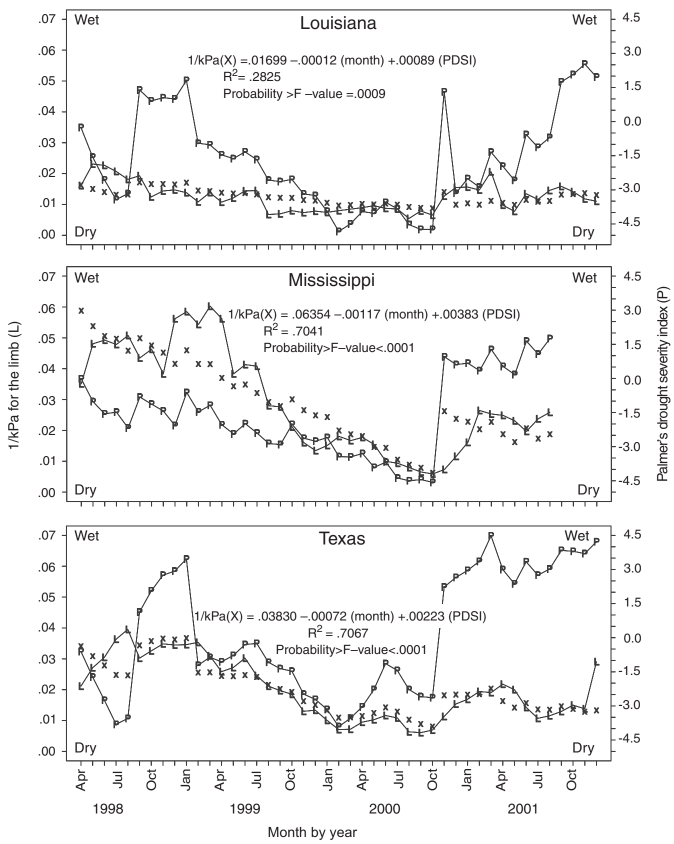

Figure 3—For each limb, monthly changes in 1/kPa (L), predicted 1/kPa (X), and Palmer's Drought Severity Index (P). In the prediction equation for 1/kPa, month is expressed as a numerical value from 4 (April 1998) through 48 (December 2001). Numerical Palmer's Drought Severity Index values were taken from the Southern Regional Climate Center databases.

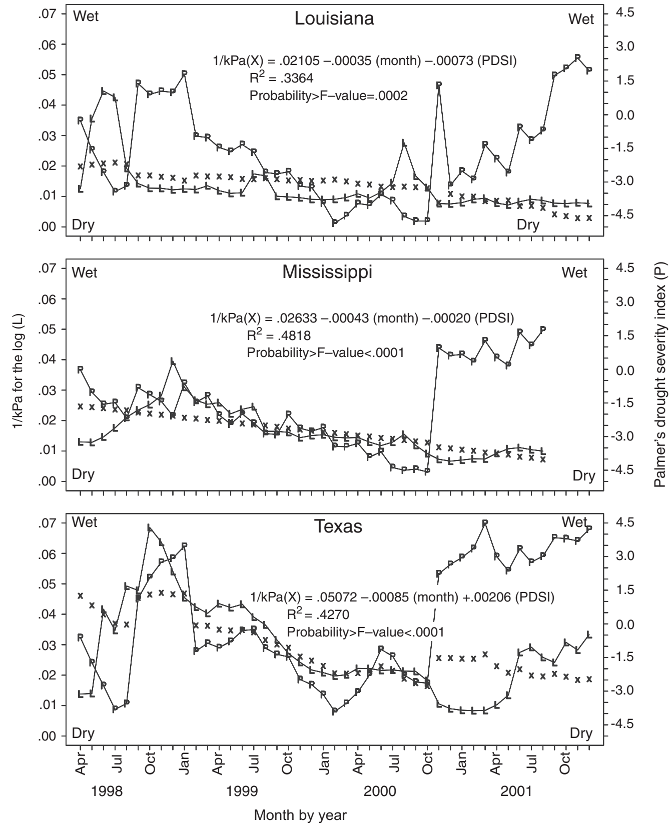

Figure 4—For each log, monthly changes in 1/kPa (L), predicted 1/kPa (X), and Palmer's Drought Severity Index (P). In the prediction equation for 1/kPa, month is expressed as a numerical value from 4 (April 1998) through 48 (December 2001). Numerical Palmer Drought Severity Index values were taken from the Southern Regional Climate Center databases.

RESULTS

At all three sites, a drought developed in early 1998 (fig. 2). The drought steadily worsened through October 2000 at the Mississippi site. In Louisiana and Texas, the drought was relieved by fall 1998 but reintensified in early 1999. From early 1999 it continued to worsen through October 2000 at the Louisiana site. In Texas, a second reversal in the drought began in April 2000, but this reversal was not sustained. On all sites, true drought recovery began in November 2000. The rate of recovery was quickest at the Texas site and slowest at the Louisiana site.

The limb dried in the field in Louisiana from May 1998 through October 2000 and in Texas from September 1998 through October 2000 (fig. 3). The limb dried from May 1998 through October 2000 in Mississippi, but rewetting of the limb in December 1998 interrupted the pattern. The drying pattern was less obvious in Louisiana, where the smallest limb was located (table 1).

We superimposed PDSI and 1/kPa values in figure 3, and there appeared to be a relationship between moisture index (1/kPa) of the drying limb and drought severity. Once the drought began to end in November 2000, the limb moisture index rose and fell with the PDSI value in Mississippi and Texas, although not as quickly as the PDSI value. The amount of rewetting was less in Louisiana than in Mississippi and Texas, and the Louisiana limb was the only 100-hour time-lag fuel in the study (table 1). We suspect this limb, which was also the driest limb at the beginning of the study, failed to respond measurably to environmental conditions.

In fact, there were significant relationships between the moisture index of the limb and time and PDSI at each study site and for all sites combined (fig. 3). The predicted 1/kPa values for Mississippi and Texas responded more to changes in PDSI than in Louisiana, but for all three sites, none of the changes in predicted moisture was greater than the actual moisture index (table 2). The R^2 values ranged from 0.37 to 0.64.

The log initially became wetter at all three sites (fig. 4). Beginning in July 1998, the log dried rapidly in Louisiana. After October 1998, the moisture level remained fairly constant until it rose temporarily in July and August 2000. In Mississippi, the log dried steadily from December 1998 through March 2001, with some moisture gain thereafter. In Texas, the log dried steadily from October 1998 through March 2001. The log gained moisture after March 2001, and this gain was more obvious than at the Mississippi site.

There appeared to be little relationship between the 1/kPa value of the logs and PDSI in Louisiana and Mississippi, because the log did not rewet after the drought was broken in either State (fig. 4). For Texas, a small gain in moisture occurred 6 months after the drought was broken, a response that would be expected in fuels of this size.

Based on the regression equations, a decreasing, negative PDSI predicted a greater 1/kPa value in Louisiana and Mississippi (table 2). This prediction was counterintuitive, because it would mean the log wetted as the drought worsened, which did not happen (fig. 4). In fact, PDSI had little to do with the drying pattern in either State, because the PDSI values were insignificant in both relationships. The important factor was time in the field. In contrast, the predicted value in Texas responded positively to an increasing PDSI, but still the most important variable was time in the field.

DISCUSSION AND CONCLUSIONS

Wildfires are costly. They place people at risk and destroy wildlife habitat, watersheds, recreational areas, and structural property. Although there is a relationship between drought conditions and moisture of 3- to 12-inch-diameter fuels, these fuels do not sufficiently rewet after drying and may be available for burning in a wildfire or prescribed burn long after droughts end.

While there is a significant relationship between the moisture index and PDSI as the log dried during the drought, there is little relationship after the drought ends. This outcome is not surprising, as PDSI is soil based. Increased rainfall would rapidly infiltrate into the dry soil, increasing the amount of water stored in the ecosystem. However, water is readily shed from a conically shaped log, and so the rewetting cycle of wood is often very slow. Because of this lag in rewetting for many months after the return of normal rainfall, we need to consider the presence and moisture status of large-diameter fuels when fighting wildfires and planning prescribed burns. Also, retention of coarse woody debris is ecologically desirable (Loeb 1999, Spetich and others 2002). To allow time for woody debris to reabsorb water, prescribed burns should be delayed for several years after a prolonged extreme drought.

Large-diameter fuels may accumulate in forests where fire has been absent for decades, in chemically injected stands, and in site-preparation areas where tons of residue woody debris have time to cure. Ways to avoid fuel accumulation

Table 2—Relationship between moisture index, measured by a Watermark™ sensor and expressed in kiloPascals, time,[a] and Palmer's Drought Severity Index[b] for limbs and logs at each of the study sites (Louisiana, Mississippi, and Texas) and for all sites combined

Classes	Study sites	Equation	Root mean square error	R^2	Probability of a greater F-value
Limbs	Louisiana	kPa = 59.949 + 0.646(MO) - 8.892(P)	27.53	0.3663	< 0.0001
	Mississippi	kPa = -19.271 + 2.175(MO) - 11.829(P)	26.32	0.5671	< 0.0001
	Texas	kPa = 4.674 + 2.419(MO) - 10.655(P)	23.13	0.6423	< 0.0001
	Combined	kPa = 17.219 + 1.747(MO) - 8.712(P)	31.46	0.4136	< 0.0001
Logs	Louisiana	kPa = 7.255 + 0.232(MO) + 1.421(P)	20.15	0.5849	< 0.0001
	Mississippi	kPa = 37.445 + 1.834(MO) + 4.860(P)	20.64	0.6195	< 0.0001
	Texas	kPa = 23.983 + 0.868(MO) + 0.803(P)	26.85	0.1885	0.0125
	Combined	kPa = 28.631 + 1.657(MO) - 0.651(P)	29.18	0.3325	< 0.0001

kPa = kiloPascals; MO = time; P = Palmer's Drought Severity Index.

[a] Time is the month (MO) of measurement expressed as a numeric value from 4 (April 1998) through 48 (December 2001).

[b] Numerical *P* values were taken from the Southern Regional Climate Center databases from April 1998 through December 2001 for each of the State's climate divisions where the sites are located: Division 9 - Southeast Mississippi, Division 5 - Central Louisiana, and Division 4 - Northeast Texas.

include repeated prescribed burning or mechanical or chemical treatments to arrest woody plant development.

In our preliminary study, moisture measurements were taken with a soil moisture instrument and with only one limb and log per location. To get a true moisture value for these larger fuel classes, we need to refine this technique and to increase the sample size. Also, we need to study the flammability of larger cured fuels under different moisture regimes.

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