Prescribed Burning and Wildfire Risk in the 1998 Fire Season in Florida

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Abstract—*Measures of understory burning activity in and around FIA plots in northeastern Florida were not significantly associated with reduced burning probability in the extreme fire season of 1998. In this unusual year, burn probability was greatest on ordinarily wetter sites, especially baldcypress stands, and positively associated with understory vegetation. Moderate amounts of lightning also were associated with greater burning probability. Factors associated with reduced burn probability included road density and nearby requests for site preparation or seed tree burns, perhaps a proxy for other intensive forest management practices. Alternative tactics may prove more effective than fuel reduction in extreme years.*

Introduction

While La Niña has previously been associated with dry and fire-prone conditions in Florida (Brenner 1991, Brenner and Barnett 1992), the extremely rapid transition from the Super El Niño of 1997-1998 to La Niña in spring of 1998 brought a transition from heavy rains to extremely dry conditions. Dry conditions were especially severe in the St. Johns River Water Management District (SJRWMD) of northeastern Florida. Based on wildfire records from Florida's Division of Forestry (Jim Brenner, Florida Division of Forestry, personal communication), wildfires typically burn about 0.7% of the northeastern Florida landscape per year, but in 1998 they consumed as much area as in the previous 12 years combined (figure 1).

Those records also highlight the unusual importance of lightning as an ignition source during this period, accounting for 89% of acres burned. In 15 of the past 21 years, the incendiary / arson category has accounted for the largest share of ignitions in this populous state. While this combination of lightning and drought was unusual, it would be foolish to count on it never recurring, sparking debate over whether policies that promote increased prescribed burning would be a prudent means to reduce damages should such severe fire conditions recur. The study reported here seeks to inform that debate by testing whether past prescribed burning as implemented in the years prior to 1998 significantly reduced the area burned during that severe six week fire season in northeastern Florida, when taking into account vegetation type, vertical structure, and fragmentation, plus variables related to ignition sources and accessibility.

To empirically test this hypothesis, we develop in this paper a model of the probability of wildfire as a function of both on-site and neighborhood conditions. The resulting statistical tests should help identify strategies and tactics to prevent or minimize damages from fires in future extreme drought conditions in northeastern Florida.

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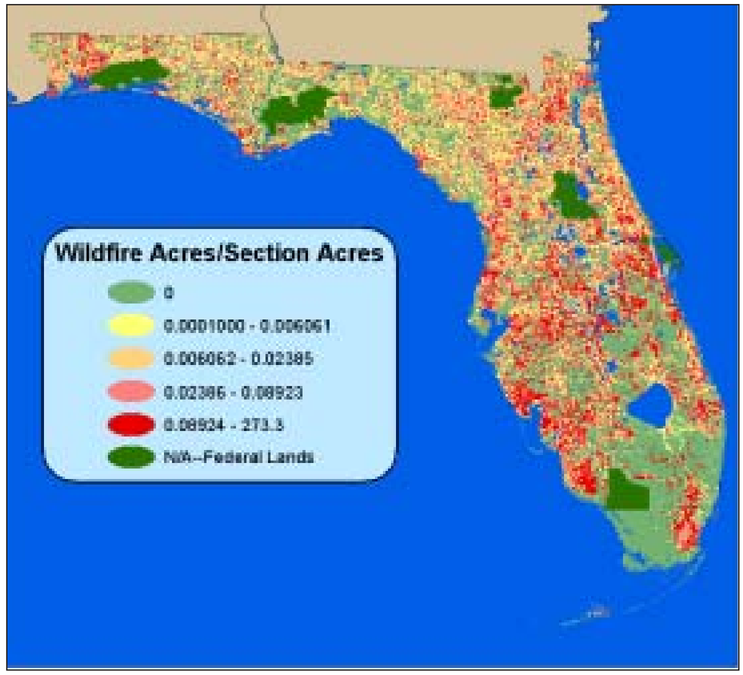

Figure 1—Aggregate historical wildfire risks in Florida 1981–2001.

We assume that stand wildfire risk is related to both on-site and neighborhood vegetation and management conditions, weather / climate, and human factors. Influential site conditions include fuel types and strata, soil moisture content, stand management including prescribed burning, as well as previous wildfires in the stand (which may be considered as a proxy for current aggregate fuel loads). Neighborhood lands can affect wildfire risk through conditions on those lands and by contagion (Chou 1993). Weather affects site wildfire risk through precipitation, evaporation, and wind and by providing a direct ignition source (lightning). Humans affect wildfire risks by (1) development patterns that alter vegetation characteristics and contiguity, thereby affecting wildfire spread and sparking; (2) providing ignition sources, including arson and accidents; (3) suppressing fires once they have begun; and (4) managing fuels and lowering spread rates through vegetation management and building fire breaks.

The SJRWMD includes large areas of actively managed forests, often involving the use of prescribed understory fire to control vegetation and reduce fire hazard, as well as intentional burns to prepare harvested sites for planting or seeding. Recent research suggests that the spatial pattern of these previous burns or treatments may be an important factor in the spread of wildfire (Agee and others 2000, Finney 2001) but these conclusions are based on simulations of fire and management. McKelvey and Busse (1996) had good success stratifying areas at risk based on elevation, slope, and aspect in California's Sierra Nevadas. Nonetheless, they found that some areas reburned more often than expected by chance, notably in areas adjacent to major roadways. As with another Western U.S. analysis (Hyderdahl, Brubaker and Agee 2001), they found statistical relationships between site characteristics and the probability of burning but included little vegetation and no management information in their estimates, and their most important variables of elevation, slope, and aspect are of little relevance in the flat coastal plain of Florida.

In Mississippi, geographically more similar to Florida, Munn, Zhai, and Evans (2003) found that slope was not an important predictor of wildfire.

However, they found that wildfire occurred more often in pine and oak-pine stands than hardwoods, and that wildfire was positively associated with proximity to development. Others have also found human presence to be positively associated with wildfire, increasing the number of ignitions and the number of large fires (Cardille and Ventura 2001; Cardille, Ventura, and Turner 2001). However, Sapsis and others (1996) found that human presence decreased the risk of large fires.

Two studies that may be of particular importance in evaluating fire risk in Florida address riparian areas (Fites-Kaufman 1997) and fuel connectivity (Miller and Urban 2000), although both of these studies evaluated forest fires in the Western U.S. Fites-Kaufman found that riparian areas had an average fire return interval of greater than 20 years, with irregular intervals between fires. Miller and Urban, examining Sierra Nevada forests, found that connectivity in fuels led to increased spread potential. They note, however, that connectivity is likely a minor influence when temperature and fuels are conducive to large fire development.

Other research has focused on identifying the influence of weather and climate, including drought, precipitation, temperature, humidity, and wind. One study (Heyerdahl, Brubaker, and Agee 2001) found that temporal, rather than spatial, climatic variation was the driving force in fires in Oregon. Wind speed was not found significant in predicting large fire development (Potter 1996), though high temperatures and low humidity did contribute to large fires. McKelvey and Busse (1996) found that all of the extreme fire years in the Sierra Nevada occurred during hot, dry seasons, but that not all hot, dry seasons were extreme fire years. The fit from other weather variables was weak.

Model of Wildfire Risk

In light of the previous work on wildfire risk, we specified our model of wildfire risk in this catastrophic season for stand *i* in a population of I stands in year *t*, $R_{i,t}$, as:

$$R_{i,t} = f(S_{i,t}, N_{i,t}, L_{i,t}, H_{i,t}) \qquad [1]$$

where $S_{i,t}$ and $N_{i,t}$ are on-site and neighborhood risk factors, respectively. The $L_{i,t}$ are influences of lightning, and the $H_{i,t}$ are human factors affecting risk in that period. In a particular year, the realization of the risk for stand i is either 0 or 1, so that the occurrence of a wildfire in the stand, $W_{i,t}$, is a binary variable, whose value is influenced by functional (F) relationships between wildfire and influential factors ($x_{i,t}$). Given data on these factors, an empirical representation of this model can be estimated as a binary logit (Greene 1990):

$$P(W_{i,t} = 1 \mid x_{i,t}) = \frac{\exp(x_{i,t}'\beta)}{1+\exp(x_{i,t}'\beta)} = \Lambda(x_{i,t}'\beta) \qquad [2]$$

$$W_{i,t} = \begin{cases} 1 & \text{if burned in year } t \\ 0 & \text{otherwise} \end{cases} \qquad [3]$$

The equation was estimated using quasi-maximum likelihood covariances and standard errors, robust to varying underlying distributions of the dependent variable. Calculations were performed using EViews (Quantitative Microsoftware 1997).

Data

The unit of analysis used in this study was individual Forest Inventory and Analysis (FIA) forested plots in the SJRWMD (figure 2). Plot locations and stand conditions ($S_{i,t}$) were obtained from the FIA records (USDA Forest Service Southern Research Station, Knoxville, TN).

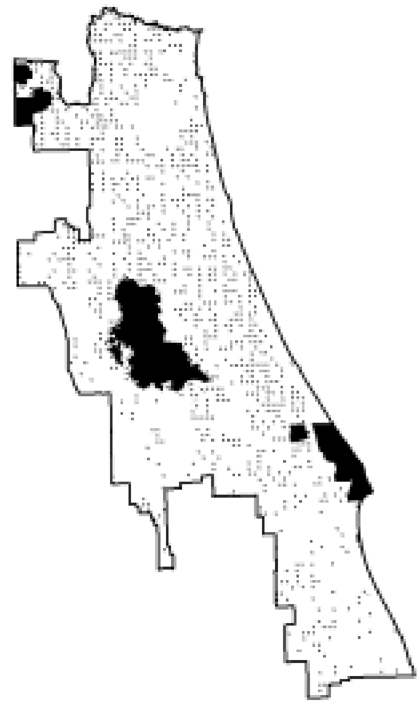

Figure 2—Forested FIA plot locations in the Saint Johns River Water Management District, Florida. Black areas indicate federal lands.

Stand/On-Site Factors

The FIA plot locations in Florida were visited by FIA crews in 1985-86 and reported in the 1987 FIA survey, and visited again in late 1993-1994 and reported in the 1995 FIA survey. From the FIA data, observations of plot conditions for 1993-1994 and observations on activities occurring on the plot between the 1987 and 1995 surveys were used in the model.

FIA field crews reported evidence of wildfire on the plot since the previous survey. They also report evidence of prescribed burning, defined as "the occurrence of fire (excluding wildfire) not used as a site preparation tool." For our analysis, both the wildfire and prescribed burn variables were coded as 1 if reported to have occurred and zero if not. The FIA surveys also reported a measure of forest-nonforest edge as observed at the perimeter of a 20.2 ha (50 acre) circle. This variable ranged from 0 to 9, with 0 indicating no forest edge and 9 indexing considerable forest edge.

Stands were classified by forest type as (1) cypress [*Taxodium distichum* (L.) Rich.], (2) pine [*Pinus* species], (3) oak-pine, and (4) hardwood types.

FIA reports five measures of vegetation strata: counts of the number of trees in three diameter classes per 0.4 ha of forest in the stand (2.5-5 cm, 5-12.7 cm, 12.8 cm dbh and larger), plus measures of the percentage of space occupied by non-tree vegetation at 0-0.90 m and 0.9-2.44 m above the forest floor. These measures are intercorrelated and thus suitable for recoding into a smaller number of independent variables, which we accomplished using principal components analysis. This procedure produced two orthogonal measures that together explained the majority of variation in the five FIA variables as measured on the different plots. The first measure, referred to as ladder fuel index 1, most strongly reflected the two non-tree vegetation variables. The second measure, ladder fuel index 2, reflected variations in the numbers of small and medium trees. In each measure, higher numbers indicate more vegetation on site.

We identified burn status for each plot (W_s) by overlaying a GIS coverage of approximate FIA plot locations (figure 2) with a coverage of polygons representing areas burned in the SJRWMD between June 3 and July 7, 1998 (figure 3) (Barbra Sapp, St. Johns River Water Management District, personal communication).

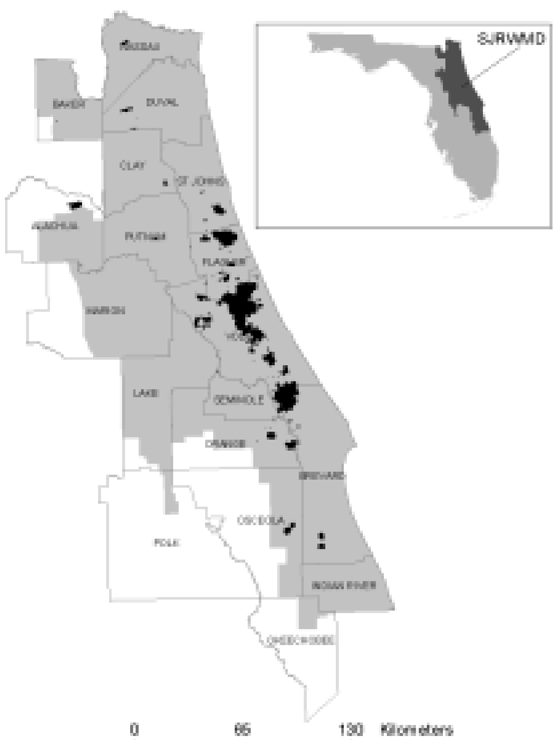

Figure 3—Wildfires in the 1998 wildfire season in the St. Johns River Water Management District.

Neighborhood Factors

To ensure the integrity of the survey process, the locations of plots provided by FIA have been limited to hundredths of a degree. In this region, this corresponds to an accuracy of 1.5 km north-to-south and 1.3 kilometers east-to-west. Unless otherwise noted, this location uncertainty defines the neighborhood size for the following neighborhood variables in this analysis.

Information on wildfire and prescribed burning history was obtained from the Florida Division of Forestry's individual wildfire records, running from 1986 to 1997 in our analysis, and permits for silvicultural burns, which stretched from 1996 to 1998 in our analysis. We chose to focus on the most common types of silvicultural burns: hazard reduction, which we equate with understory burns, and an aggregate of the site preparation and seed preparation burn categories ("regeneration burns"). We omitted wildlife and ecological burns because of their limited use and rangeland burns because they could not be distinguished from burns on croplands. In this paper we refer to both FIA's prescribed burning and Florida's hazard reduction burns as understory burns to avoid confusion with prescribed regeneration burns.

The location of wildfire ignitions and permits for both forms of prescribed burns are reported by Public Land Survey (PLS) section. The wildfire data and permit data were joined to a coverage of PLS sections (David Kelly, Florida Division of Forestry, personal communication) for neighborhood analyses. Wildfire, understory burn, and regeneration burn areas were all expressed relative to forest area in the neighborhood of the FIA plot. These measures were the ratio of the sum of the area of the wildfire or permits issued to the area of forest in a rectangle 1.3 km (east-west) by 1.5 km (north-south) centered around the nominal FIA plot location.

For wildfire, two temporal aggregates were generated: 4 to 12 years (1986-1994), and 1 to 3 years (1995-1997) previous to 1998. These temporal aggregates roughly correspond with the FIA survey cycle and the period between the end of that cycle and the study year. Because the plots with neighborhood regeneration burns in 1997 and 1998 experienced no burning in 1998, only the regeneration burning for 1996 was used in the model.

Two measures of forest surrounding the FIA plots were generated based on Multiple Resource Land Cover data (Riitters 1997). These report the total area of forestland, and the proportion of that forest classified as "woody wetlands" as opposed to "upland forest." Small amounts of forest in the neighborhood provide one indication of fuel fragmentation, along with the FIA measure of forest-nonforest edge.

For information on lightning we used a dataset purchased from WeatherBank, Inc. (Edmond, OK). Originally collected through the National Lightning Detection Network, the dataset contains records of all individual cloud-to-ground strikes covering northern Florida between June 3 and July 7, the most intense period of wildfire activity. Each record reports the location of strike. Converting these into a GIS coverage (figure 4) enabled us to calculate the

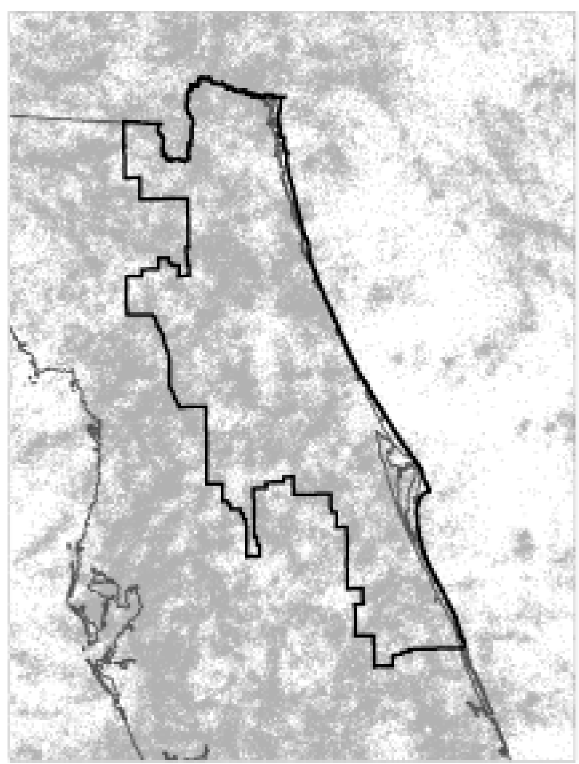

Figure 4—Lightning groundstrikes in northeastern Florida during the subject period, June 3–July 7, 1998.

number of lightning strikes that occurred within 0.833 km of each nominal FIA plot location (1/2 mile).

Road density information was derived from a vector coverage of paved roads (ESRI, Inc., Redmond, CA). The coverage was rasterized to 100 m pixels and the density of pixels containing roads was calculated in the vicinity of each FIA plot using the 1.5 x 1.3 km neighborhood. Population density was calculated for a similar neighborhood based on census block population numbers from the 1990 Census, normalized by census land area.

Observations Included or Excluded

Of the 2,948 FIA plots in the SJRWMD, 46%, or 1,346 were classified as timberland. Of these, 81 burned, and 1,255 did not. Logistic analysis requires that factors perfectly correlated with the left-hand side variable be omitted from the analysis. Three factors in this model showed perfect correlations. None of the plots with the following characteristics were judged to have burned in 1998: (1) all plots with wildfire recorded between surveys (23 plots), (2) all plots with neighborhood regeneration burning in 1997 and 1998 (210 plots), and (3) all plots classed as xeric (280 plots). These plots were thus excluded from the logistic regressions. Also excluded were plots with missing data. Florida State wildfire records do not consistently report wildfires on federal lands, thus wildfire history data was unavailable for the 402 plots either in or near federal lands. Also excluded were 13 plots that lacked non-tree vegetation data. Some of the plots are in more than one of the above classes, resulting in a total of 555 usable observations, 59 of which were burned in 1998.

Table 1 shows the mean values for the various independent variables broken out by forest type. It shows, for example, that the 52 baldcypress stands in the sample predominantly occurred on hydric sites, had less non-tree vegetation than other types on average (ladder fuel 1) but more small trees (ladder fuel 2), were surrounded by more wetland forest, experienced virtually no prescribed burning on site, and had few roads and human residents nearby.

Table 1—Mean values and number of observations for FIA plots used in the logistic model, by forest type.

		Forest type			
Variable	**Units**	**Pine**	**Oakpine**	**Baldcypress**	**Hardwood**
Hydric site	proportion on hydric sites	0.0	0.4	0.9	0.4
Ladder fuel 1	index of ladder fuel 1	-9	-45	-95	-25
Ladder fuel 2	index of ladder fuel 2	203	341	429	248
Upland forest	acres/(1.5x1.3 km)	107	89	84	79
Wetland forest	acres/(1.5x1.3 km)	47	52	70	60
Rx burn	1 if prescribe burn, 0 if not	0.1721	0.0217	0.0000	0.0000
Forest edge	1 if little forest edge, 9 if a great deal	3.7	3.8	3.5	3.3
Under.burn96	proportion of forest area	0.0077	0.0164	0.0065	0.0065
Under.burn97	proportion of forest area	0.0001	0.0000	0.0001	0.0001
Under.burn98	proportion of forest area	0.0063	0.0072	0.0211	0.0044
Regen.burn96	proportion of forest area	0.0012	0.0001	0.0019	0.0056
Road density	proportion of pixels containing a road	0.152	0.159	0.087	0.147
Pop. density	persons per acre	0.089	0.120	0.051	0.161
Prev.wildfire1	proportion of forest area	0.0028	0.0013	0.0071	0.0029
Prev.wildfire2	proportion of forest area	0.0047	0.0061	0.0034	0.0031
Lightning	ground strikes/0.25 mi^2	3.23	2.87	2.02	2.74
Count	number of observations	308	46	52	149

Results

The results of the logistic model estimation of the probability of wildfire are shown in table 2. Overall performance of the models was good, with the chi-squared value significant for the model with variables as compared to the model with only a constant. McFadden's R-squared is 0.20, although interpretation of values between 0 and 1 are difficult with this measure (Greene 1993).

In this multivariate model, which regresses the occurrence of wildfire in 1998 on site and neighborhood variables, stand forest type is mildly predictive of burn probability, with baldcypress stands more at risk than other forest types. Baldcypress stands are typically associated with hydric drainage conditions, and at the other extreme from the perfectly and negatively correlated xeric condition.

Pine stands were no more likely to burn than the intercept hardwoods in this unusually severe drought. This may be due in part to the influence of the two ladder fuel measures, which were highly significant and positively correlated with burning in 1998.

While non-tree and small tree vegetation were positive correlates with burning, and previous evidence of wildfire in 1994 was a perfect negative correlate, evidence of understory burning on the site did not exert a negative influence on burning in 1998.

As with the on-site measure of understory burning, none of the three neighborhood measures of understory burning permits had any significant negative influence on wildfire probability in 1998. The only significant burn permit

Table 2—Logit model estimates of wildfire occurrence as a function of site, neighborhood, lightning, and human variables (St. Johns River Water Management District, 1998, Forest Inventory and Analysis plots). [a]

Variable	Coefficient	Standard error	P value
Intercept	-5.03	1.10	<0.0001
Stand/on-site			
Pine forest	0.12	0.49	0.8109
Oak-pine forest	-0.33	0.74	0.6557
Cypress forest	1.33	0.57	0.0213
Hydric site	0.48	0.48	0.3246
Rx Burn (stand)	0.69	0.44	0.1168
Ladder fuel-1	0.009	0.003	0.0048
Ladder fuel-2	0.002	0.001	0.0084
Forest edge	0.11	0.10	0.2736
Neighborhood			
Total timberland	0.02	0.01	0.0001
Proportion wetland forest	-3.12	0.66	<0.0001
Understory burn-96	0.86	2.83	0.7624
Understory burn-97	-327.14	785.36	0.6770
Understory burn-98	1.95	3.12	0.5321
Regeneration burn-96	-124.49	52.97	0.0188
Previous wildfire (1995-1997)	-2.34	7.36	0.7511
Previous wildfire (1986-1994)	19.24	9.69	0.0472
Lightning strikes (1998)	0.16	0.13	0.2251
Ltng. strikes*ltng strikes	-0.02	0.01	0.0487
Population density	-0.41	2.68	0.8774
Road density	-6.09	1.70	0.0003

[a] McFadden's R-squared: 0.20. Log likelihood: -149.59. Model significance level: <.0001.

measure was regeneration burning in 1996, which had a strongly significant negative effect on the probability of fire in 1998. This is consistent with the perfect correlation and exclusion of the plots with regeneration burning in the neighborhood in 1997 and 1998. Regeneration burning appears to have a negative effect on fire risk. While it is plausible that harvesting a stand and then burning the remaining slash and vegetation would at least temporarily reduce fuels and wildfire risk, it is also likely that some of the influence of this measure arises from other management practices associated with intensive forestry. These may include stocking control, herbicide use, and fire breaks, none of which are directly reflected in this model.

The model includes the neighborhood measures of historical wildfire for 1995-1997 and 1986-1994. The existence of wildfires in the last 3 years is not significantly related to the probability of a plot burning, but wildfires in the previous 9 years are significant and positive. This implies that areas that had experienced wildfires more than 3 years ago were again at higher risk of fire in 1998. The exclusion of all plots with recorded on-site wildfires does not allow direct statistical comparison, but the fact that none of these sites burned in 1998 is at least suggestive of a local and countervailing negative effect of previous wildfires.

The fragmentation measure of forest-nonforest edge was not significant, but the amount of forest surrounding an FIA plot was significant, with more forest associated with increased probability of burning in 1998. However, upland forests increased burn probability more than wetland forests, as reflected in the significant and negative effect of the proportion of wetlands. This is in seeming contrast to the elevated burn probability for baldcypress. One possibility is that the baldcypress stands most likely to burn are those at the drier, more upland margins.

Of the two measures of human influence—population density and road density—only road density is significant, and it shows a negative influence on burn probability. As mentioned in the Introduction, the literature on the influence of human presence is inconsistent, but the differences in results may be related to the dominant ignition sources in the dataset being examined. In most years in northeastern Florida, accidents and arson—sources logically associated with roads and people—dominate natural ignition sources. In the 1998 wildfire season, human-caused ignitions played a minor role, allowing influences of roads on detection and suppression to show increased importance. These potential influences include quicker detection, easier access for suppression resources, and greater fragmentation of fuels, each of which could result in less area burned.

Because severe drought conditions spanned the entire SJRWMD in the spring of 1998, we do not attempt to include site-specific weather data. However, because 1998 was highly unusual in the number of lightning caused fires and acres, we included contemporaneous lightning strikes. Studies in the Southwest and Florida (Gosz and others 1995, Shih 1988), have each shown that, in general, lightning is strongly correlated with rainfall, and yet anecdotally we understand that dry lightning was an important ignition source during this period. We attempted to isolate this influence with linear and second order terms. Our results show that lightning has an increasing then decreasing correlation with increased fire risk, with a maximum positive influence reached at approximately eight strikes per square mile. Taken together they suggest that small and intermediate amounts of lightning, perhaps associated with little precipitation, can raise the probability of fire, while high levels of lightning are correlated with suppressive rain events.

Discussion

Taken together, the results indicate that in the extreme 1998 fire season in northeastern Florida, it was forests ordinarily thought of as wet that were most likely to burn—forests on mesic and especially hydric sites, and baldcypress stands in particular. These locations do not match the general pattern of wildfire indicated in the recent FIA survey nor our casual expectations of areas at risk to wildfire. However, baldcypress is not immune to wildfire. At least one source reports that cypress ponds in north Florida typically burn several times a century (Myers and Ewel 1990). It is noteworthy that in this drought, fire risk areas did not merely expand outward from xeric into mesic locations on the landscape. Fire risk simultaneously moved into hydric sites and out of the more typically fire-prone xeric sites, changing rather than augmenting the areas at risk.

Given the above, it perhaps should not be surprising that understory burning was not found to be a significant reducer of risk in this catastrophic year. Xeric sites, even in areas with no previous understory burning in the area, were apparently at low risk during this extreme period. Instead, it was baldcypress stands that were at greatest risk. Based on the FIA data from 1994, baldcypress stands typically have high densities of small trees but little nontree vegetation in the lower strata. However, conditions when FIA crews visited in 1994 may have differed from those during this extreme drought, when areas ordinarily flooded can dry sufficiently to allow understory fuels to first proliferate and then dry out. Baldcypress on the drier margins of wetland forests might be especially prone to such ephemeral conditions, consistent with the negative correlation with percent wetland forest (but see Myers and Ewel 1990 for a contrary fire pattern). Should this be true, understory vegetation on hydric sites would be minimal in more ordinary years, thus precluding use of fuel reduction treatments, whether through fire, chemical, or mechanical alternatives.

While our results do not support the hypothesis that understory burning affects fire risk in extreme drought years, we did not examine whether controlled burns might reduce wildfire intensity or severity. Such activity could reduce damage to the stand, and wildfires in those areas where it is practiced may be safer to control. Understory burns may also reduce wildfire risk in years with more typical rainfall patterns or for shorter periods of time than tested here.

Management Implications

Our motivation for this study was to identify strategies that would mitigate risk during future catastrophic droughts. However, prescribed understory burns apparently do not help, at least as they have previously been conducted. While some potential may exist to increase the protective effects of such burns through better identification of areas of greatest benefit and spatial arrangement, the feasibility of alternative fuel reduction methods in the important baldcypress forests appears discouraging. This suggests we must look at other tactics beside fuel management to mitigate risk on hydric sites during extreme drought conditions. Possible tactics could include constructing and maintaining firebreaks and ensuring defensible spaces around buildings and other areas of value. Suppression capabilities are also important, but given the rare occurrence of these extreme drought conditions, emphasis should be given to maximizing access to suppression resources that are easily mobilized, including unused aircraft and field crews from distant regions.

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