EFFECTS OF WEATHER, LANDSCAPE STRUCTURE, AND HARVESTING ON FIRE SPREAD IN NORTHERN WISCONSIN HARDWOODS AND NEW JERSEY PINELANDS LANDSCAPES, USA.

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We examined the relationships between fire spread and weather, landscape structure (e.g. fuel types), and harvesting methods within two landscapes: hardwood dominated Chequamegon National Forest (CNF) in northern Wisconsin and northern New Jersey pinelands (NJP) using the FARSITE model for simulations over a 15-day period. Selection of ignition points was base on considerations of fuel type, landscape structure, and evenness of distribution across the landscapes. Two types of harvesting methods (clustered vs. dispersed) at 4% harvesting intensity were implemented using the HARVEST model to link the fire spread with management practices. FRAGSTATS was used for quantifying landscape characteristics.

The paper is designed to answer four specific questions from a landscape perspective: 1) what is the relationship between patterns of fire spread and landscape characteristics? 2) Does harvest increase or decrease surface fire spread across the landscapes? 3) Is there significant difference in harvesting methods on fire spread? And 4) does the above influence on fire spread vary seasonally?

1. METHOD & MATERIALS

Two temperate forest landscapes in the eastern USA (Fig. 1) were selected for examining landscape-level effects on fire spread and behaviors because both are fire-prone ecosystems with major contrasts in vegetation (hardwoods dominated ecosystem in CNF vs. conifer dominated ecosystems in NJP) and land-use history (much more fragmented landscape in CNF vs. the NJP landscape, within a big national reserve with almost no logging in the last 100 years or so).

Study design

In each landscape, we ran the model for the 24 randomly selected fire ignition points (Fig. 1) that were stratified by major fuel types of the landscape with a 15-day fire duration, following the 13 nationally established fuel categories for the U.S. (Anderson 1982). There were 3 to 6 replicates for each fuel type depending on its weighted area of total landscape. The fuel maps in the CNF and New

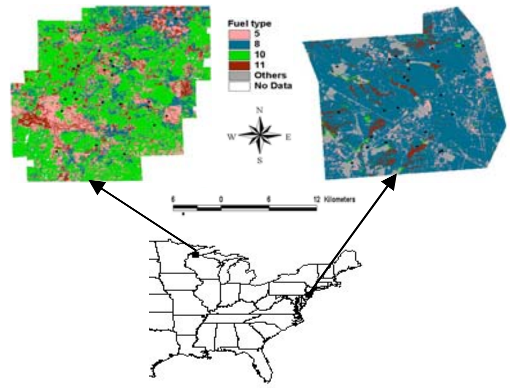

Figure 1. Spatial distribution of 24 fire ignition points in relation to fuel types in New Jersey and Wisconsin landscapes, USA. 5 = Brush < 0.8 m with scattered trees, 8 = Litter layer without under story, 10 = Litter layer with under story, and 11 = light logging/Swamps, Others = grasslands and urban.

Jersey pinelands were developed using the 2001 land-cover map from Bresee et al. (2004) and the 2001 land-cover map provided by the Grant F. Walton Center for Remote Sensing and Spatial Analysis (CRSSA), Rutgers University, respectively. The four major fuel types, based on Anderson (1982), in the two landscapes include: 1) Brush < 0.8 m with scattered trees, 2) litter layer without under story vegetation, 3) litter layer with under story vegetation, and 4) light logging slash/Swamps. In NJP, four additional fuel types (grouped as others) existed which accounted for about 10% of the landscape area (Fig. 1).

To address sole effects of landscape structure on fire spread (e.g. question 1), we conducted hypothetic simulations by applying 15-day weather data collected from CNF in August 2002 in both CNF and NJ landscapes. In other words, we kept the weather constant while varying the landscape.

To illustrate how forest practices can affect fire spread across the landscapes (e.g. questions 2 and 3), we used the HARVEST (Gustafson & Crow 1996) model to generate hypothetically harvested landscapes imposing 4% cutting with two different methods, clustered and dispersed, in both CNF and NJP.

To examine seasonal variation of fire spread (e.g. question 4), two periods of daily weather data with a 15-day duration were selected, one from spring and the other from summer in each landscape. We used daily weather data in August of 2002 (8/2-8/17) and April of 2004 (4/3-4/18, April data in 2002 and 2003 were unavailable or with missing days) in the CNF taken from meteorological equipment mounted on an eddy covariance flux tower. The meteorological equipment made observations every 20 seconds and output the means every 30 minutes to a data logger for download (Noormets et al. 2004). In the NJP, daily weather data in April (4/3-4/18) and June/July of 2004 (6/25-7/10) recorded from the Silas Little tower were applied. The selections of data periods (thereafter refer to spring and summer, respectively) were determined using our best judgment on usefulness and availability of data. For example, August of 2004 in NJP was affected by the hurricane season and there was a 1000-year storm event on 7/12 (21.7 cm rain on one day), so June to July data were used instead.

Both with and without roads as fire barriers were simulated using the FARSITE model to illustrate the road effects on fire spread. Most reported simulation results are with road effects if not specified, which is closer to the real-world situation.

Model applications

We used FARSITE, a fire growth model, to simulate fire spread across the landscapes (Finney 1998). The model can predict both surface and crown fires but this study focuses on surface fire spread only because most fires in CNF area are low-intensity surface fires (Sturtevant et al. 2004) and both landscapes are relatively flat. The required inputs for the model including two ASCII files for weather conditions and five gridded layers representing vegetative and topographic characteristics: 1) elevation, 2) slope, 3) aspect, 4) fuel type, and 5) degree of canopy closure. The topographic files were derived from 3-arc DEM data. The canopy closure file was developed and rescaled to 0-100 (%) based on the Normalized Difference vegetation Index (NDVI) values (0-1) that was calculated from the red and infrared channels of the Landsat 7 data (Rouse et al. 1973). We converted the land-cover maps derived from Landsat TM imagery into fuel maps based on Anderson's classification. The model outputs include: 1) time of arrival (TOA, hours), 2) fire line intensity (FLI, KW.m-1), 3) flame length (FML, m), 4) rate of spread (ROS, m.s-1), 5) heat per area (HPA, KJ.m-2), and 6) area of spread (AOS, ha). Our analyses were focused on area of spread.

For each landscape, we used the HARVEST model to create two additional fuel maps at cutting level of 4% with different harvesting methods, clustered vs. dispersed. The model is primarily a landscape-level, harvesting allocation simulator designed to evaluate alternative strategies of forest management and timber harvests and provide comparable predictions of the spatial pattern consequences of these alternative strategies (Gustafson & Crow 1996). When forests were harvested, the fuel type was simply changed from categories 8 and 10 (forest types) to category 11 (logging slash/swamp).

We used FRAGSTATS (McGarical & Mark 1995), a spatial pattern analysis program, to quantify the landscape structures in the CNF and NJP landscapes. The characteristics of quantified landscape structures were then linked to fire spread and behaviors across the landscapes.

2. RESULTS

Landscape structure (e.g. fuel type) has significant influence on fire spread. The mean fire spread area (MFSA, without road effects) in NJP with less fragmented landscape was about 58% smaller (1630 ha) than that in CNF hardwoods dominated landscape (3867 ha) that was more fragmented after a 15-day burning duration using the August data (Fig. 2). Although the fire-spread areas in NJP were generally smaller than those in CNF, the spatial variation across the landscape of NJP (930 ha) was much larger than those in CNF (795 ha), especially when the MFSA sizes were considered.

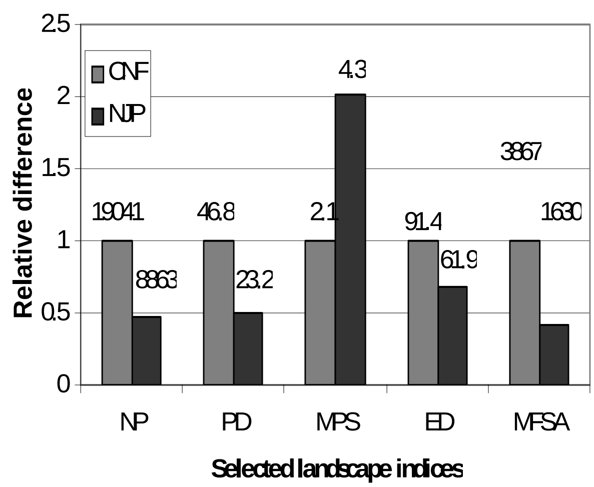

Figure 2. Relative differences of the four selected landscape indices between WI and NJ landscapes, calculated as $VALUE_{NJP}$ / $VALUE_{CNF}$. The indices and the MFSA in CNF landscape are always expressed as 1. NP = number of patches, PD = patch density (No./100 ha), MPS = mean patch size (ha), ED = edge density (m/ha), and MFSA = mean spread area of the 24 fires across the landscapes (ha).

When roads were considered as fire barriers, the MFSA varied from 564 to 586 ha and 374 ha to 511 ha among control and harvested landscapes for CNF and NJP, respectively, depending on weather conditions. Road effects on fire spread areas (FSA) across landscape are positively related to road density and enhanced when weather condition is more favorable to fire spread (Table 1).

In the CNF, MFSAs only differed by 1.4% between spring and summer because the overall effects of whether conditions in spring (dry but cool) and in summer (warm but wet) on fire spread cancelled out each other (Table 1, Fig. 3). In the NJP there was a 37% difference in MFSA between spring

Table 1. Characteristics of weather conditions during the periods used for FARSITE model simulations, road density, and mean fire spread areas (MFSA) of the 24 fires (considering roads as fire barriers). Numbers in the parentheses are the MFSA without road effects and the reduction of size in %.

	WI		NJ	
	Spr04	Sum02	Spr04	Sum04
Tmean (°C)	4.6	18.1	10.4	23.1
Prec. (mm)	0	48	93	15
MFSA (ha)	586	578	$374	@511
	(4561,87)	(3867,85)	(487,23)	(727,30)
Road density (km/km^2)	2.7		0.33	

$ From 6 locations that encountered the roads.
@ From 11 locations that encountered the roads.

and summer because the weather conditions were different (cool and wet vs. warm and dry), which enhanced seasonal effects of weather on fire spread. In the CNF high road density could also be a factor to diminish seasonal weather influences on fire spread. In the NJP the smaller road density allowed most fires to spread without limitation and reinforce the weather effects on fire spread (Table 1, Fig. 3).

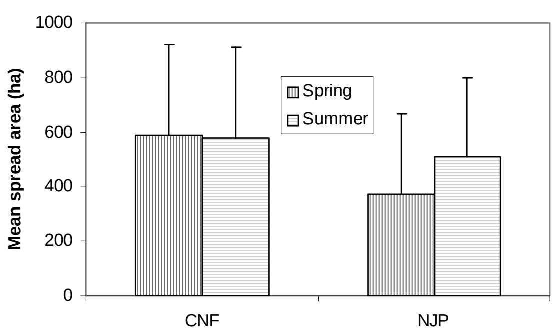

Figure 3. Seasonal changes of mean fire spread areas (road effects were considered) across the landscapes in Chequamegon National Forest and New Jersey Pinelands. Vertical bars represent one standard deviation. The statistics were calculated from 23 fires in CNF; 6 and 11 fires for spring and summer, respectively, in NJP due to much smaller road density.

Harvesting in general reduced FSA in the CNF while it increased FSA during spring in NJP, possibly because differences in composition of the fuel types (hardwood vs. conifer and absence of grasslands, easily burned fuel type, in CNF) between the 2 landscapes. In NJP, higher wind speed (136% than the summer period) and a more consistent wind direction from the NW (47% vs. 27% of 3-direction tie in the summer) were observed; both could contribute to a larger MFSA in the NJ C4 harvested landscape and the smaller area seen in the NJ D4 harvested landscape (Fig. 4). At the 4% level of harvesting, both harvesting methods showed no significant effects (a=0.01) on FSA compared to the control landscape in CNF but were significant in NJP. Evaluation of harvesting methods on FSA was complicated because of varying weather conditions.

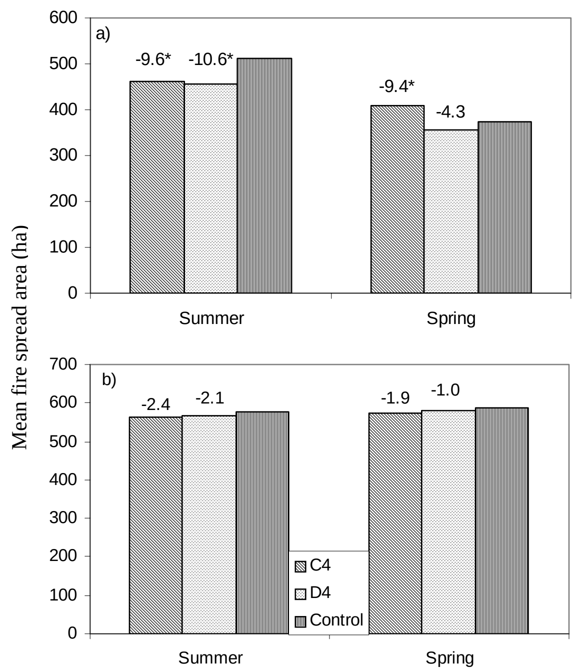

Figure 4. Effects of harvesting methods on mean fire spread area (MFSA) in a) New Jersey Pinelands; and b) Chequamegon National Forest, WI. Numbers above the bars indicate relative changes of MFSA in %, compared to control landscape. The numbers donated with* = significant level of 0.01.

3. CONCLUSIONS

Results from this study suggest that compositions of fuel type and their spatial arrangements showed significant effects on fire spread areas between the New Jersey Pinelands and the Chequamegon National Forest, WI. The landscape that is more fragmented tends to generate larger surface fires. The mature pine dominated landscape produced smaller fires than that of hardwoods dominated landscape. Harvest practice (at the 4% cutting level imposed in this study) could either decrease or increase fire-spread areas compared to that in the control landscape, heavily depending on how seasonal weather factors (temperature, moisture, and wind) interacted with fuel structure during the simulation period. The impacts of harvesting and the methods (clustered vs. dispersed) on fire spread were not significant (a = 0.01) in the landscape experiencing greater fragmentation but could be significant in the landscape with less fragmentation. Thus, our study supports the basic conclusion that fire spread areas could be reduced through planting certain fire resistant species across the landscape and avoiding intensive harvesting at any given one time.

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5. BIOSKETCH

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