Fire terminology, behavior, and effects: Principles for archaeologists

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1. Basic fire concepts
2. The fire environment
3. Fire and fuels terminology
4. Fire types and behavior
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Basic fire concepts: Fire triangles

Fire triangle:
Necessary ingredients for fires to ignite and burn

Fire behavior triangle:
Fire behavior depends on the amount and arrangement of fuel, the topography, and weather conditions (fire environment)

Fire regimes:
Role of fire in ecosystems and interactions with dominant vegetation.
Described by fire frequency, extent, intensity, severity, and seasonality

Moritz et al. PNAS 2005;102:50:17912-17917
Fire environment: Fuels

Fuel properties determine fire behavior and effects: how fires heat fuels and how much oxygen is in contact with fuels → how quickly fuels will ignite, how long they will burn, and resulting intensity.

Important fuel properties that influence fire behavior:

• Size and shape – physical properties
• Moisture content – amt. $\text{H}_2\text{O}$ for given temp and RH
• Quantity (loading)
• Spatial arrangement (vertical and horizontal)

<table>
<thead>
<tr>
<th>Dead woody class</th>
<th>Piece diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>inches</td>
</tr>
<tr>
<td>DWD</td>
<td></td>
</tr>
<tr>
<td>FWD 1-hr</td>
<td>0–0.25</td>
</tr>
<tr>
<td>10-hr</td>
<td>0.25–1.0</td>
</tr>
<tr>
<td>100-hr</td>
<td>1.0–3.0</td>
</tr>
<tr>
<td>CWD 1,000-hr and greater</td>
<td>3.0 and greater</td>
</tr>
</tbody>
</table>

Fire environment: Fuels

Aerial fuels
- Foliage & tree branches
- Snags
- Lichens & moss

Surface fuels
- Low vegetation
- Large logs
- Leaves, grass & limbwood
- Duff

Ground fuels
- Roots

Mineral fuels
- Soil
Fire environment: Topography and weather

Slope impacts fuel availability and moisture, thus rate of spread and flame length

Weather defines amount of fuel available to burn

Long-term - “Big picture” conditions – vegetation (fuel) type, amount, arrangement

Short-term – Relative humidity (RH), temperature, winds regulate LIVE AND DEAD fuel moisture

For more information on fire weather -
https://www.nifc.gov/nicc/predictive/predictive.htm
https://gacc.nifc.gov/swcc/predictive/outlooks/outlooks.htm
Fire terminology: Fire characteristics

**Fire regime** - role of fire in ecosystems

**Fire frequency** - mean number of fires per time period

**Fire extent** – size of fire

**Fire rotation** - time required to burn an area equal to a defined area of the landscape.

**Fire intensity** - measure of the heat energy released by a fire

**Fire severity** - net ecological impact

**Seasonal timing** – Occurrence in year

**Source of ignition** – lightning or human

For more definitions: [https://www.nwcg.gov/glossary/a-z](https://www.nwcg.gov/glossary/a-z)

For more info on fire: [https://www.nifc.gov/](https://www.nifc.gov/)

**Fire terminology: Fire behavior and fire types**

**Rate of spread** - rate of forward spread of the fire front, usually in chains or acres per hour

**Flame length** - distance from the ground to the **flame** tip

**Torching** — movement of a surface fire up into tree crowns; the precursor to crowning

**Crowning** — active fire movement through the tree canopy

**Spotting** — glowing embers lofted up and ahead of the main fire front that ignite spot fires

**Ground fire** — Fire that burns in the organic material below the litter layer, mostly by smoldering combustion

**Surface fire** — Fire that burns in litter and other fuels at or near the surface of the ground, mostly by flaming combustion

**Crown fire** - Fire that has ascended from the ground into the forest canopy

For more info on fire behavior and fire ecology –
[https://www.frames.gov/partner-sites/fireworks/fireworks-home/](https://www.frames.gov/partner-sites/fireworks/fireworks-home/)
Ground Fire

If ground fuels are too wet to burn, only top 3cm or so of soil will be heated, even in an intense crown fire.

Burns by smoldering combustion

Low energy release rates, long duration, and often by deep soil heating.

Ground fuels burn after the flaming front passes, with temperatures over 400°C (752°F) for 3 to 30 hours (or more).

Cultural resources in the duff and near the mineral soil surface can be significantly impacted in ground fires with dry duff.

If ground fuels are too wet to burn, only top 3cm or so of soil will be heated, even in an intense crown fire.
Creeping Surface Fire

In forests, smoldering in dry duff keeps fires going.

Temperatures can reach 500°C (932°F).

Because fuel consumption is patchy, effects to cultural resources will be variable.
Active Surface Fire

Few unburned patches, low but continuous rates of spread, moderate flame lengths (1/4m to 1.5m), and short duration (5 minutes or so, except for woody fuel concentrations).

500°C (932°F), can reach 700°C (1292°F) for short periods of time.

Cultural resources in flaming zone will be impacted, and those one meter away will be visibly altered.
Running Active Surface Fire

Rapid rates of spread, very few unburned patches, flame lengths of 1.5 to 4m, and short duration (5 minutes or so, except for wood fuel concentrations).

500ºC (932ºF), but can reach 800ºC (1472ºF) for short periods of time.

Substantial heat effects, with heat damage occurring to resources up to 4 meters beyond the burned area.
Crown Fire

Characterized by very rapid rates of spread, flame lengths over 10m

Flaming in the crown will last about one minute, but residual burning in the order of 5 minutes is common

Temperatures in excess of 1500°C (2732°F) can occur, but more often they hover around 1000°C (1832°F)

Cultural resources as far away as 30 meters from the burned area can suffer heat damage
Fire effects - Temperature and duration

**Ground Fire, Total Duff Consumption**

**Grass Fire, No Duff Consumption**

**Crown Fire, No Duff Consumption**

**Crown Fire, Total Duff Consumption**
Temperature Effects

- **<200**: Hides and fibers destroyed
- **200-300**: Organic matter distilled
- **300-400**: Charring bones, Basalt will fracture, Organic lost, Pollen & grains destroyed, Realignment of magnetic signature
- **400-500**: Chemical alteration to bone, No alteration to cultural inorganics/<1/2 hr exposure, No impact to lithics
- **500-600**: Glass damaged, Flints & cherts will show bound water loss
- **600-700**: Pottery will be structurally changed
- **700-800**: Clay particles destroyed, Ash aggregates

Temperature (C)
Fire effects - Depth of burn

For Duff ≥ 4 cm Deep

- 90% Deep
- Depth of Burn
- Moderate
- Light

Typical Range

Duff Depth Reduction (%)

Moisture Content (%)
Easiest way to protect resources: Control the heat pulse and Reduce fire residence times

(manipulating fuels, burning under particular weather conditions, altering ignition patterns around resources, etc.)

Change any leg of any of the triangles, and the outcome (effect) changes

(* size, shape, material, location above or below ground, associated data, etc.)
Fire: From fuels to fire effects

Fire environment
- Terrain
- Weather

Fuels
- Size, shape
- Moisture content
- Quantity
- Spatial arrangement (vertical and horizontal)

Fire behavior
- Depth of burn
- Residence time
- Temperature
- Combustion byproducts
- Oxidation, reduction

Fire effects