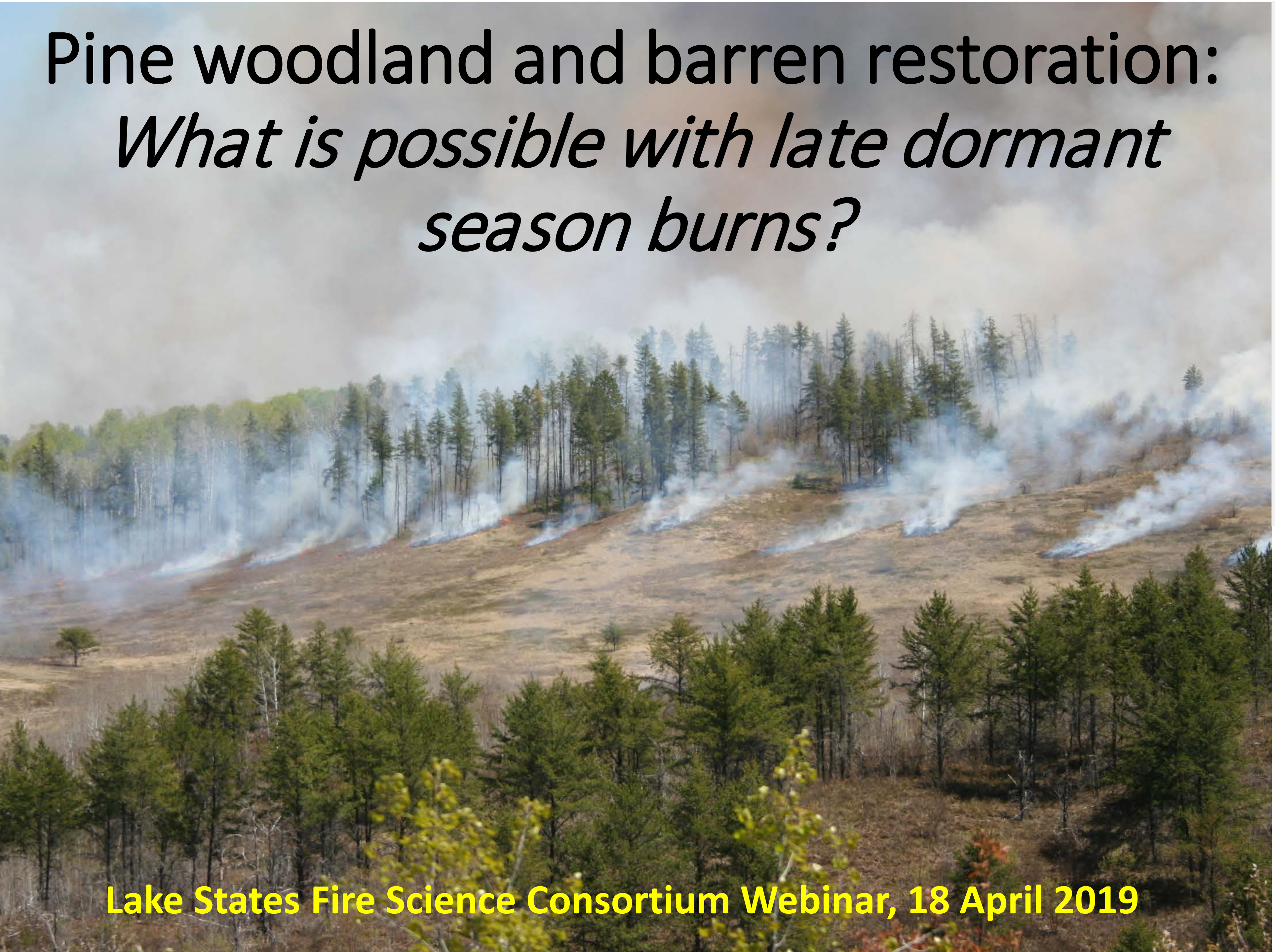
Pine woodland and barren restoration: *What is possible with late dormant season burns?*



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North Carolina NF: Matt Bushman

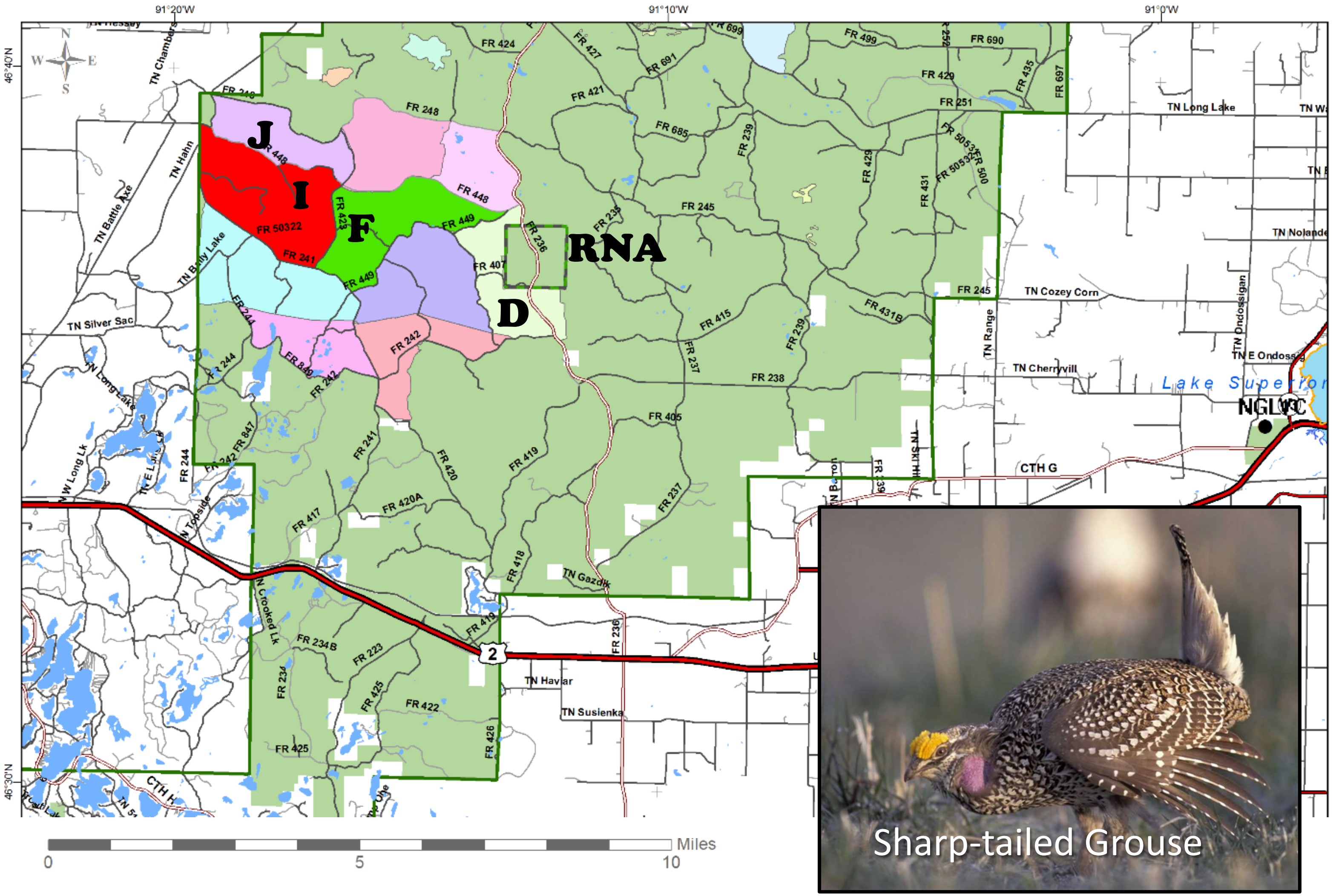
Lake States Fire Science Consortium Webinar, 18 April 2019

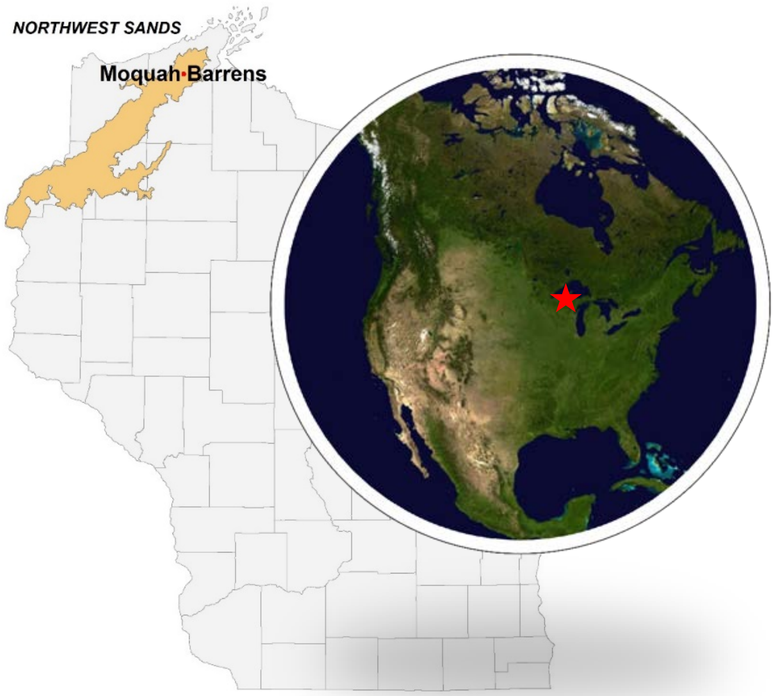
FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

MICHIGAN STATE UNIVERSITY

Joint Fire Science Program

Moquah Barrens Restoration Area





https://www.fs.usda.gov/detail/cnnf/landmanagement/resourcemanagement/?cid=fseprd577751

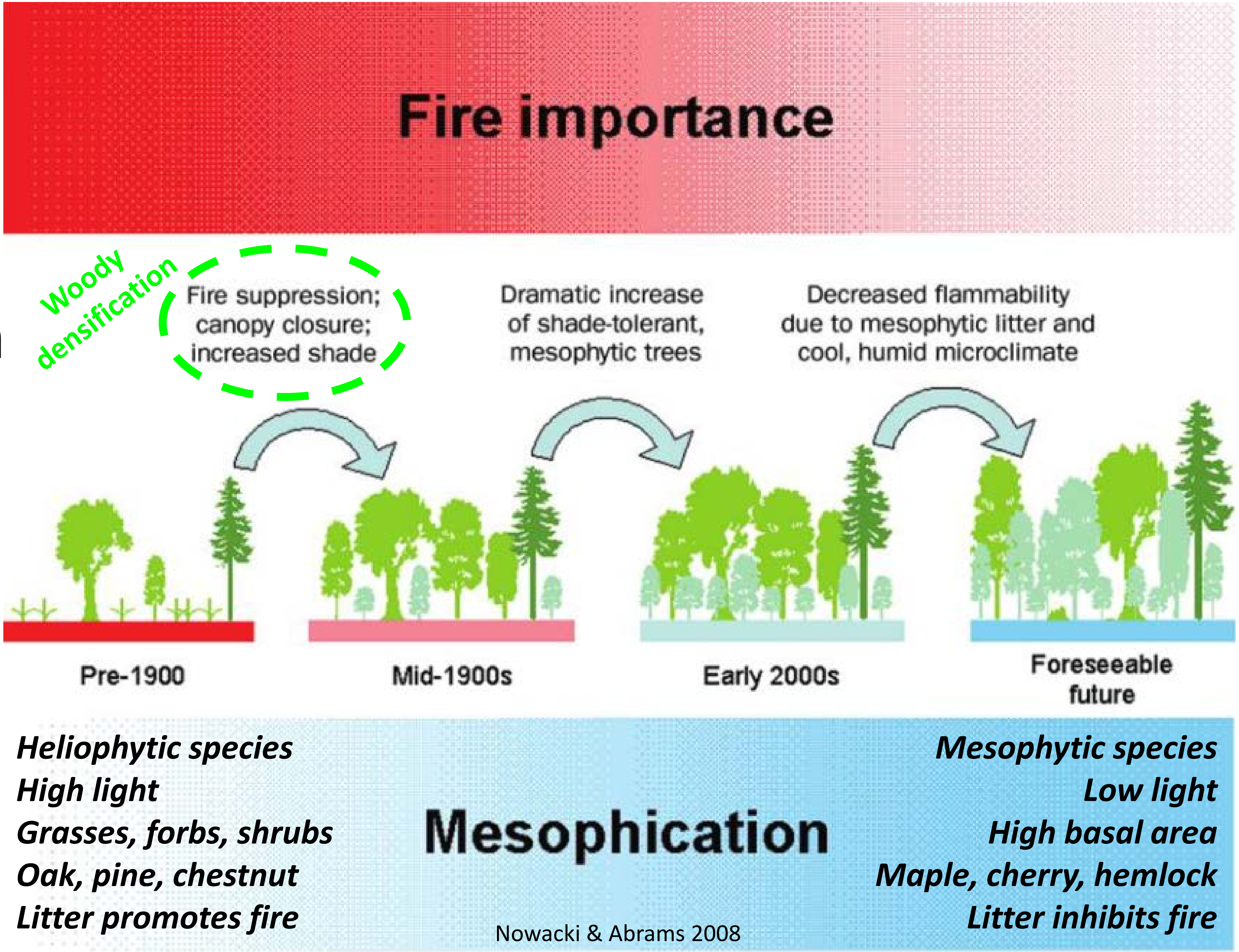
Moqauh Restoration Goals

A mosaic of pine savanna, woodlands, and grasslands

Barrens vegetation consists of grasses, herbs, and low shrubs

Barrens were historically viewed as unproductive, and were commonly converted to pine plantations

A century of fire suppression is threatening fire-adapted ecosystems

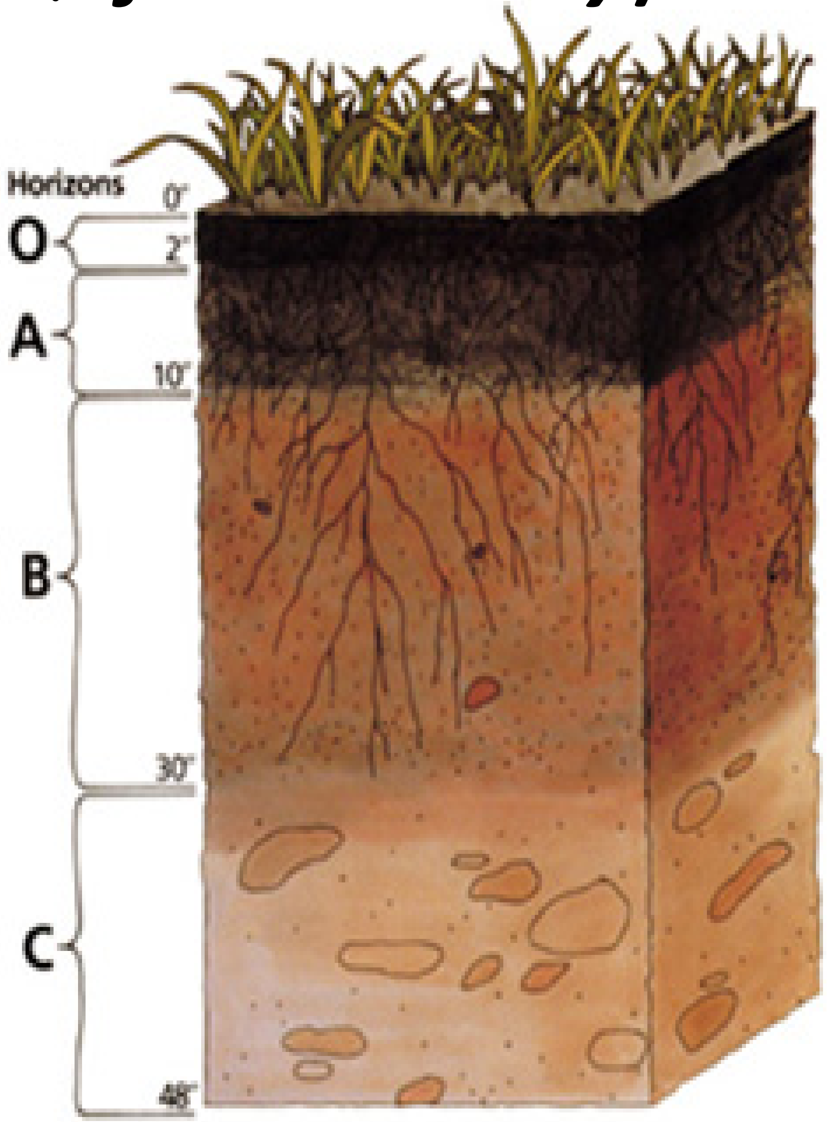


Conversion from grassland to forest increases organic layer (↑ *water & nutrient retention*, ↓ *flammability*)

O *– forest floor (Litter and duff)*

A *– organic matter mixed with minerals*

https://nsrcforest.org/project/forest-floor-remains-major-source-lead-northern-forest



USDA/NRCS

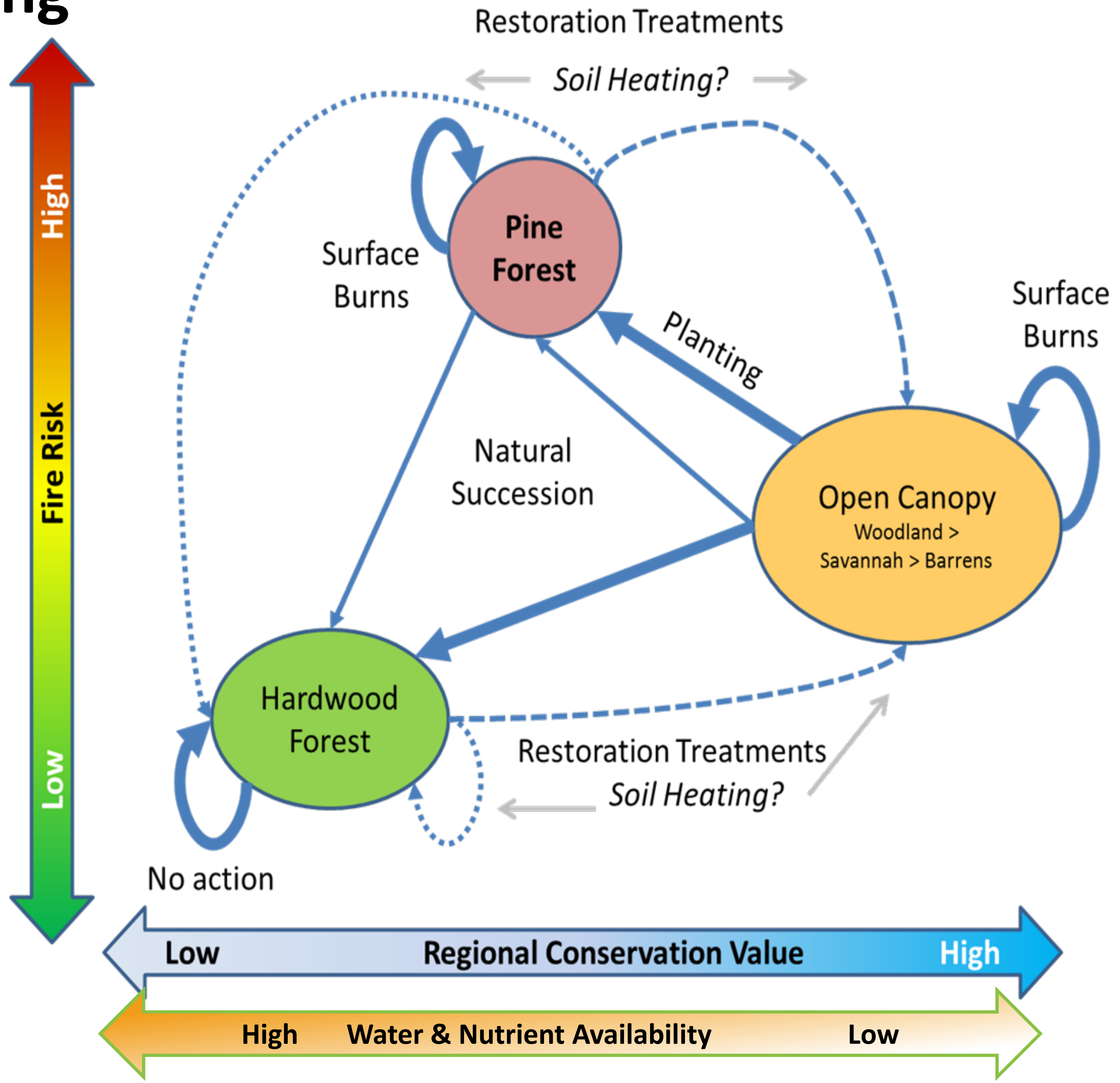
Woody Encroachment Management

- Prescribed Fire
- Brush Cutting
- Brush Cutting + Prescribed Fire
- Other

Can increased soil heating during prescribed burns enhance restoration success?

Intense soil heating can:

- Decrease duff thickness (consumption)
- Decrease soil moisture & nutrients
- Damage belowground woody tissues
- Favor fire-adapted species in the seedbank



Project Objectives

- **Provide field validation of the Campbell soil heating model** within sandy soils underlying fire-prone forest and open barren systems of the Lake States region.

- **Investigate second-order relationships between critical ecosystem processes relevant to pine barrens restoration and soil heating,** including:
  - Hardwood stem mortality and re-sprouting response
  - Seed abundance, diversity, and vitality
  - Soil fertility (total carbon, black carbon, nitrogen, cations, pH)

- **Validate and/or adapt existing field-based estimates of post-burn soil impacts** to determine relationships between predicted vs actual second-order effects.

Study Design *(sample size = 112)*

Historic State (Circa 1951)	Current State: *Woodland*	*Brush*	*Grassland*
Pine	*8 + 8 (A)*	*8 + 8 (C&L) + 8 (C&R)*	*8 + 8 (A)*
Deciduous	*8*	*8 + 8 (C&L) + 8 (C&R)*	*8 + 8 (A)*
Grassland			*8*

Fuel treatments:

A = Addition

C&L = Cut & Leave

C&R = Cut & Remove.

Four burn units ~ 2 years;

> 4000 acres total

Cover type definitions:
forest & woodland

Deciduous forest:

- Deciduous forest history
- At least pole-sized trees (>4.5” DBH)
- Closed-canopy forest

Pine woodland treatment

- Pine plantation history
- Semi-open canopy
  - Minimum tree density = 40 trees/ac
  - Basal Area Target: 30 - 60 ft^2/ac
- Recent harvest (2010 – 2015)
  - Biomass Removal

Cover type definitions: *brush & grassland*

Brush – *A transitional stage*

- Target ≥ 70% woody shrub/sapling cover (Min 50%), excluding short shrub species (e.g., sweetfern & blueberry)
- Stem size ≤ 4.5 in DBH

Grassland Tree Density < 50 trees/acre

- Basal Area < 30 ft2 per ac
- Shrub/sapling cover < 30%, excluding short shrub species

Fuel Treatments (*heating contrasts*)

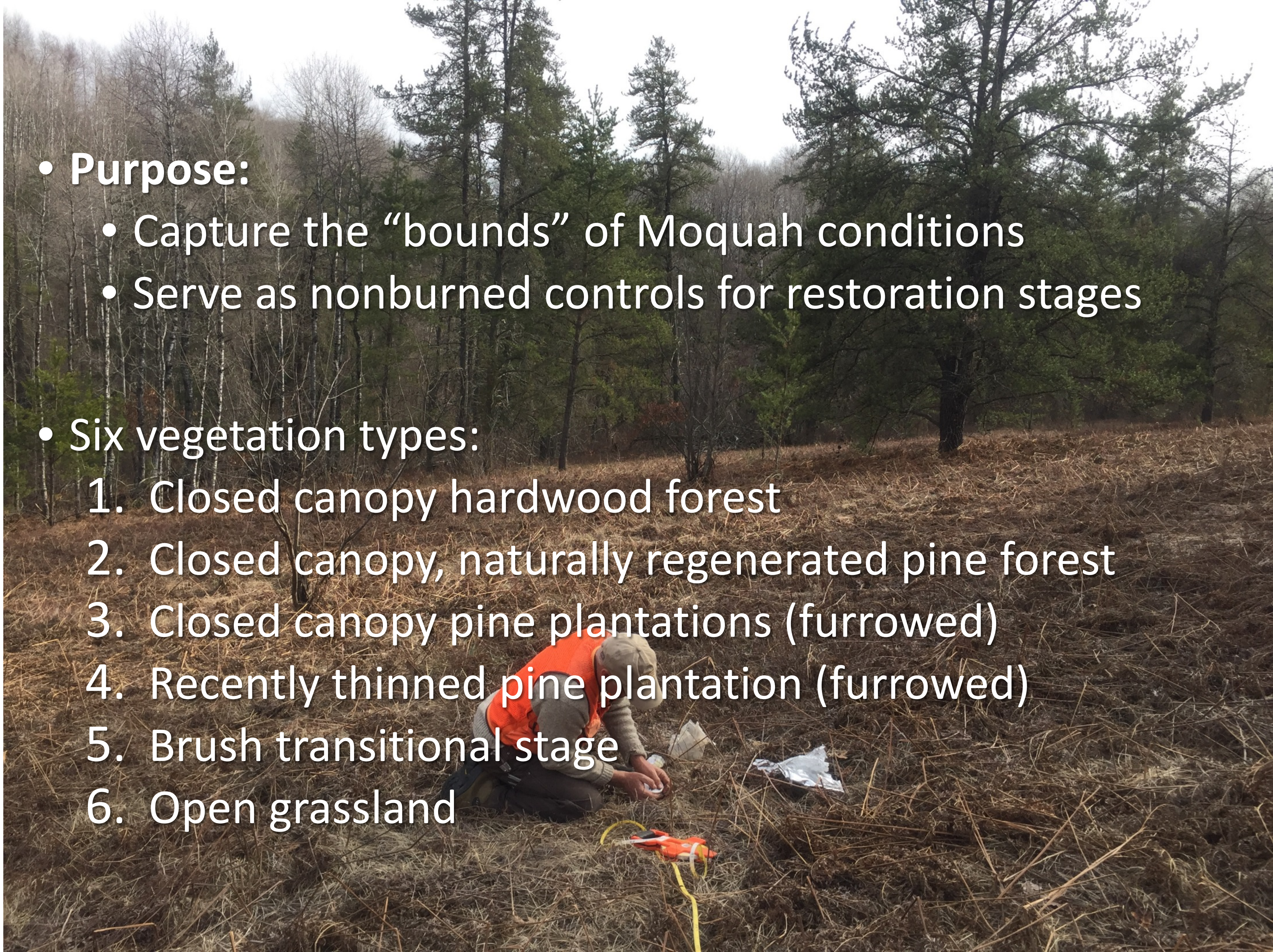
Brush sites
- Brush **cut and leave (high)**
- Brush **cut and remove (low)**
- Standing brush (low)

Pine Woodland
- Existing (low)
- Fuel **addition (high)**

Grassland
- Existing (low)
- Fuel **addition (high)**

Scale: 20-meter (1 chain) radius plots = 1/3 acre

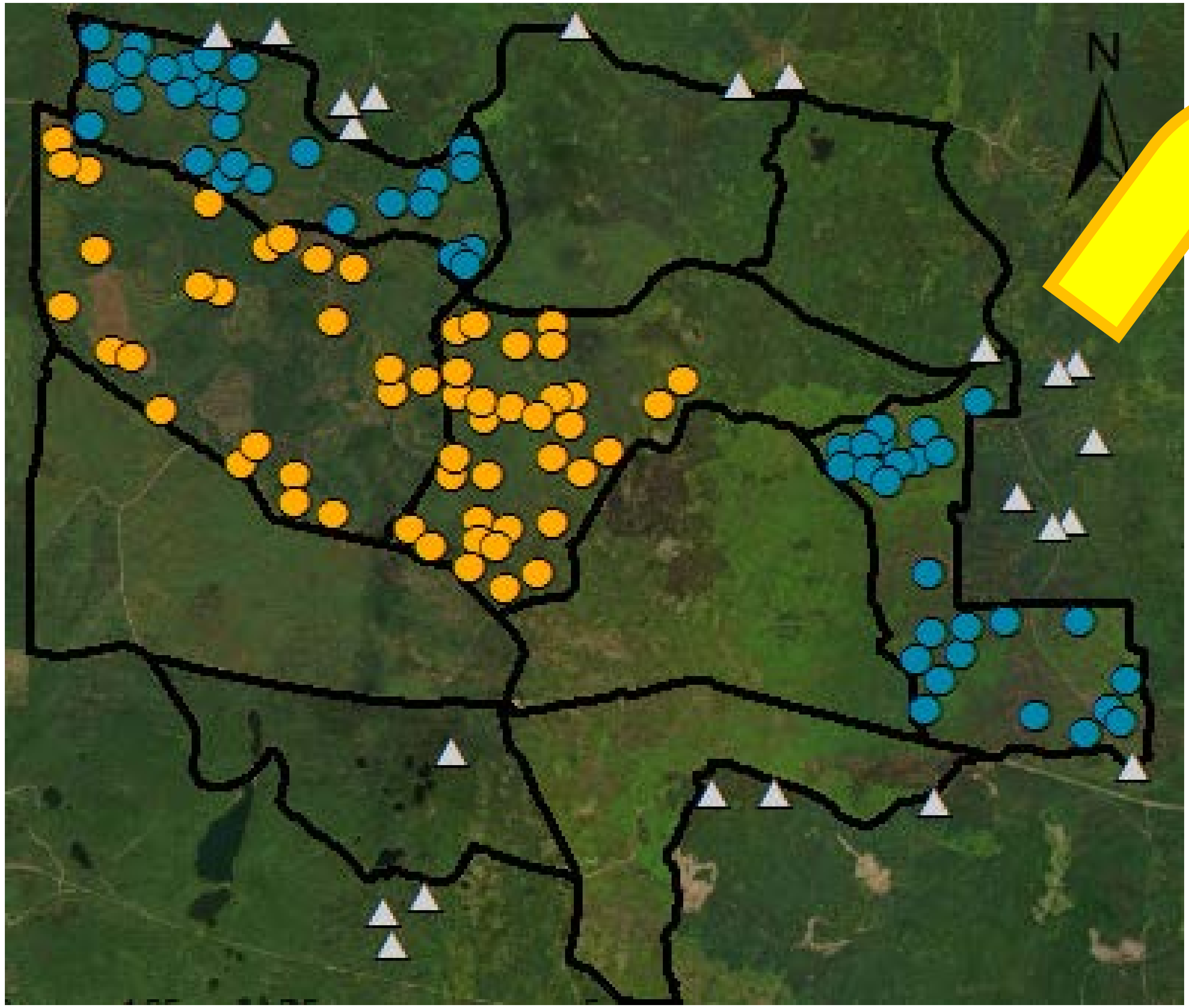
Reference Plots



- **Purpose:**
  - Capture the "bounds" of Moquah conditions
  - Serve as nonburned controls for restoration stages

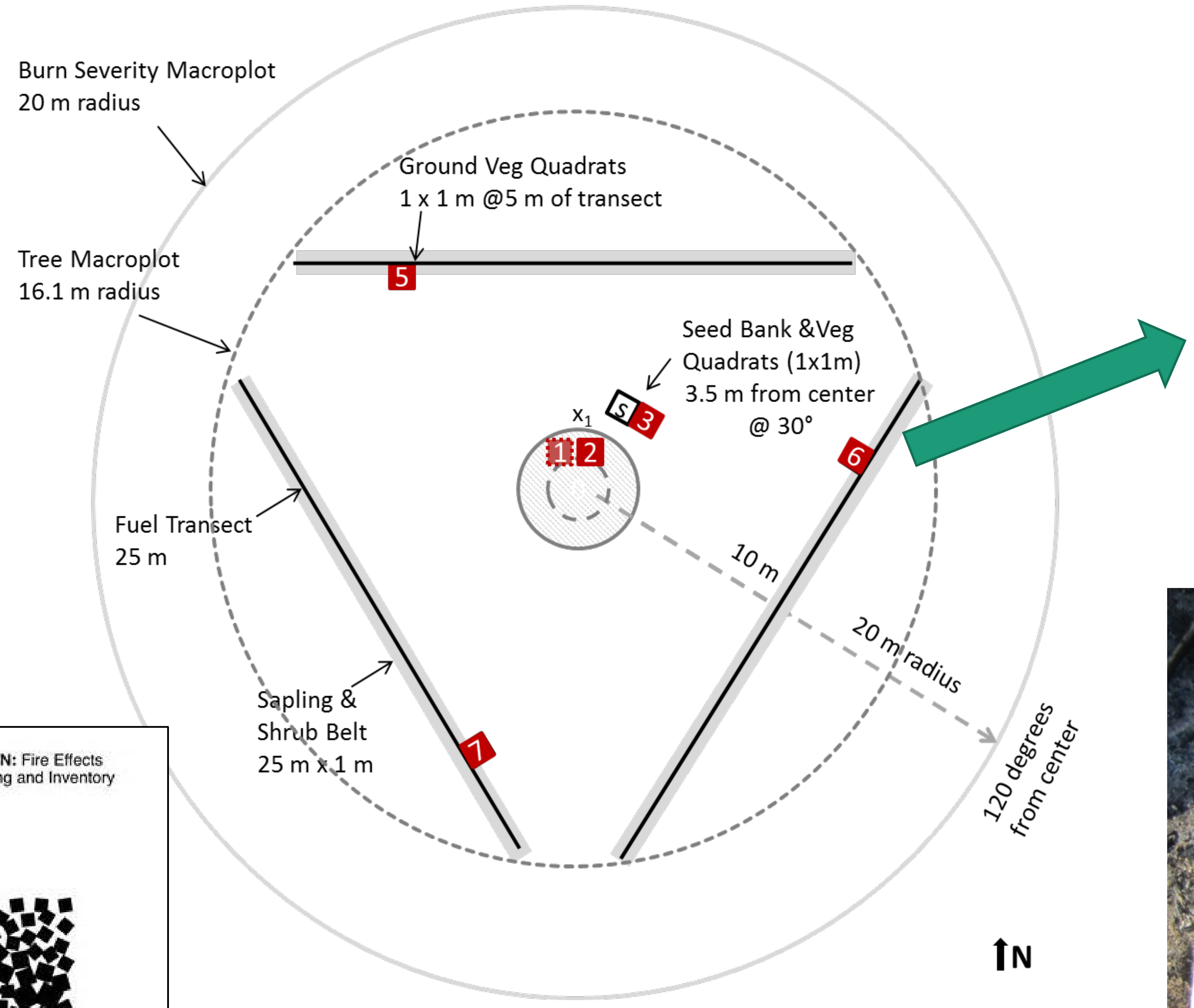
- Six vegetation types:
  1. Closed canopy hardwood forest
  2. Closed canopy, naturally regenerated pine forest
  3. Closed canopy pine plantations (furrowed)
  4. Recently thinned pine plantation (furrowed)
  5. Brush transitional stage
  6. Open grassland

112 Burn plots + 23 unburned “reference” plots

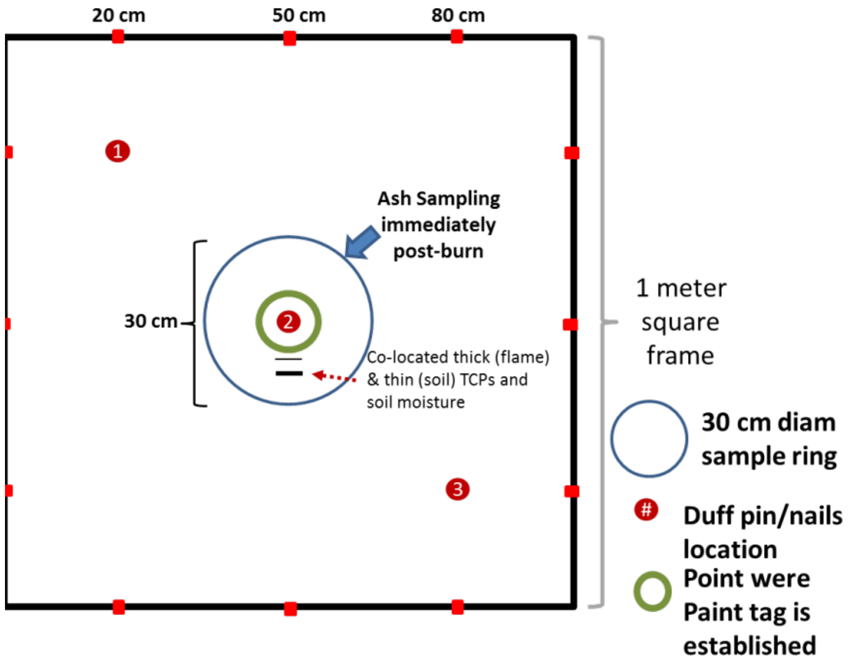


Burn unit D, 2 days after fire (May 2018)

Plot Layout

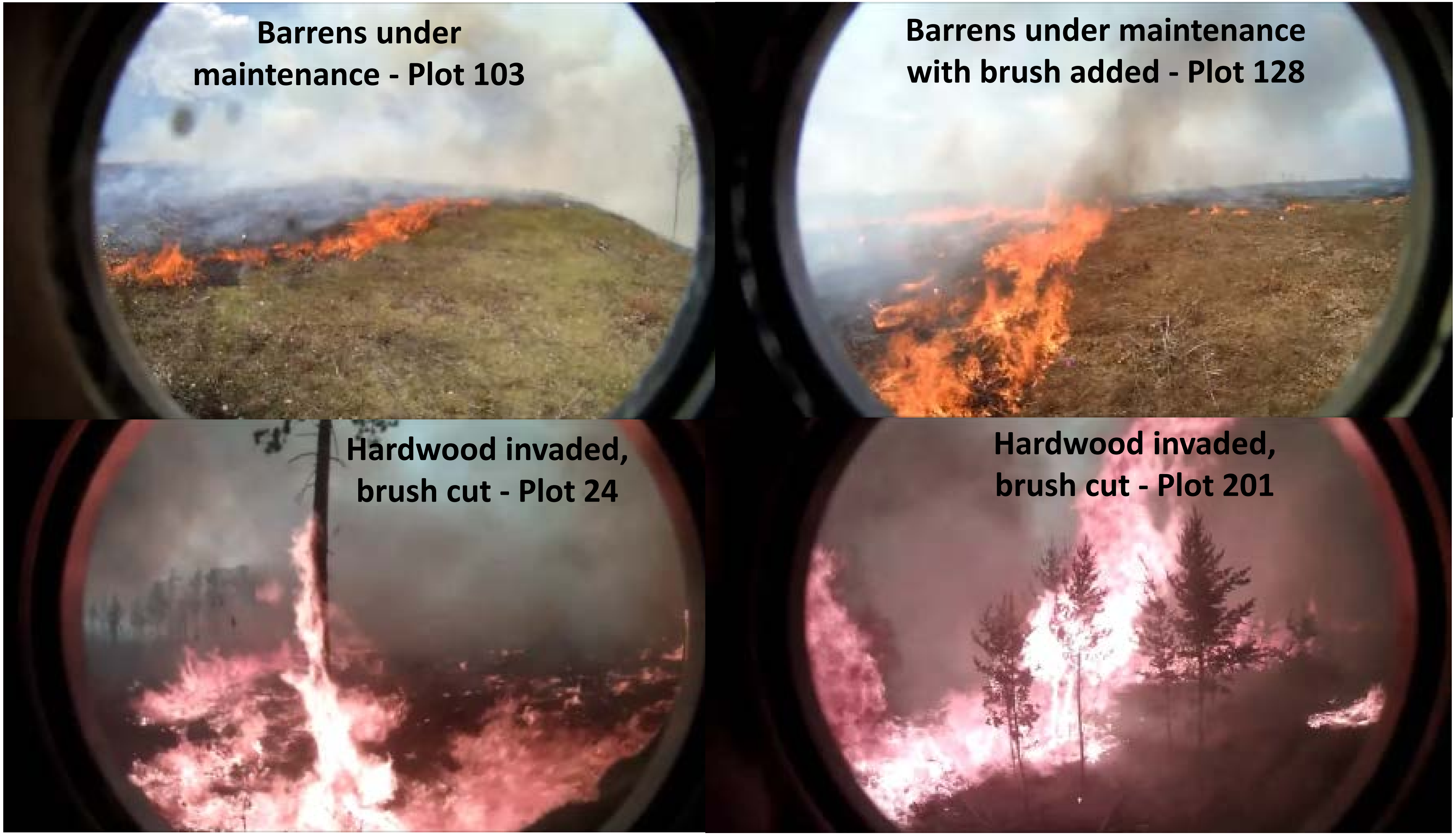


Quadrat subplots



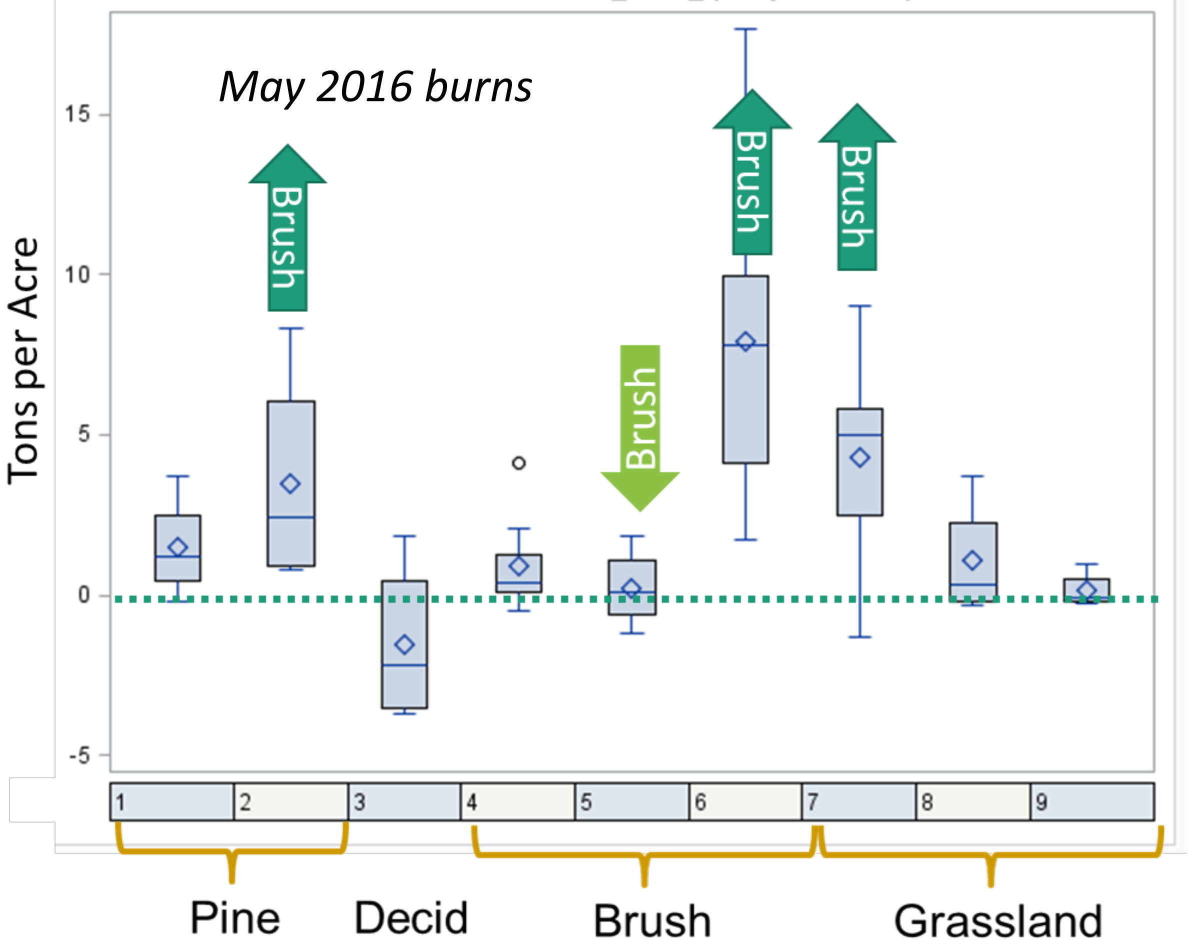
2016 Burns:
Block F - May 18
Block I – May 19

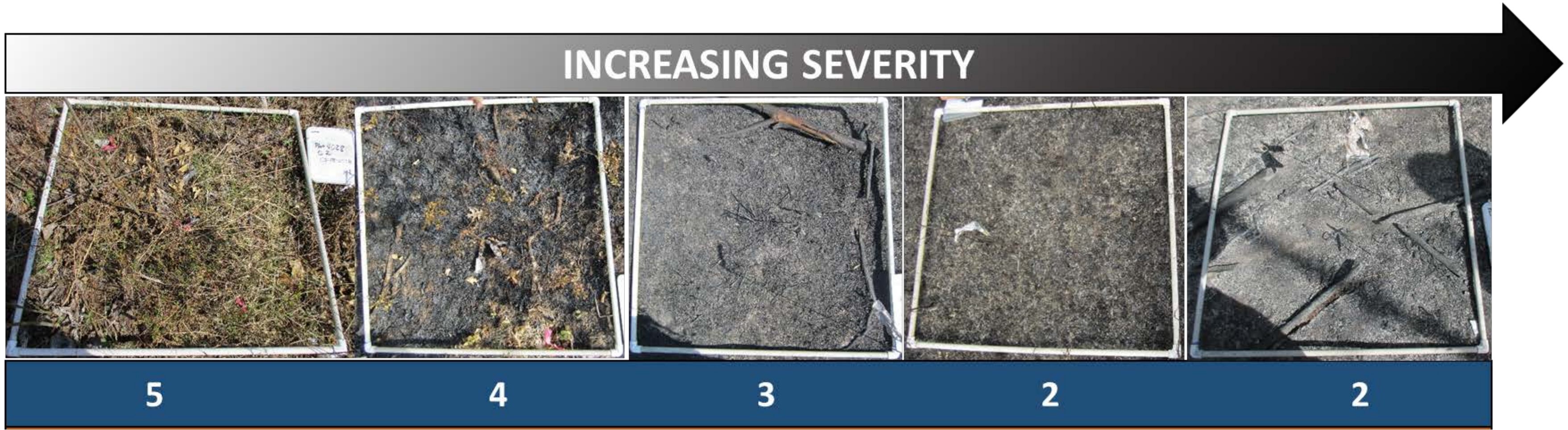
How did fuel additions affect aboveground fire intensity?



Consequences of Enhanced Fuel

- High woody fuel consumption
  - Greater burn severity
  - Enhanced ash loading
- Restoration Goals (?)
  - *Duff consumption*
  - *Hardwood stem mortality*
  - *Seedbank response*
  - *Soil fertility and moisture retention*





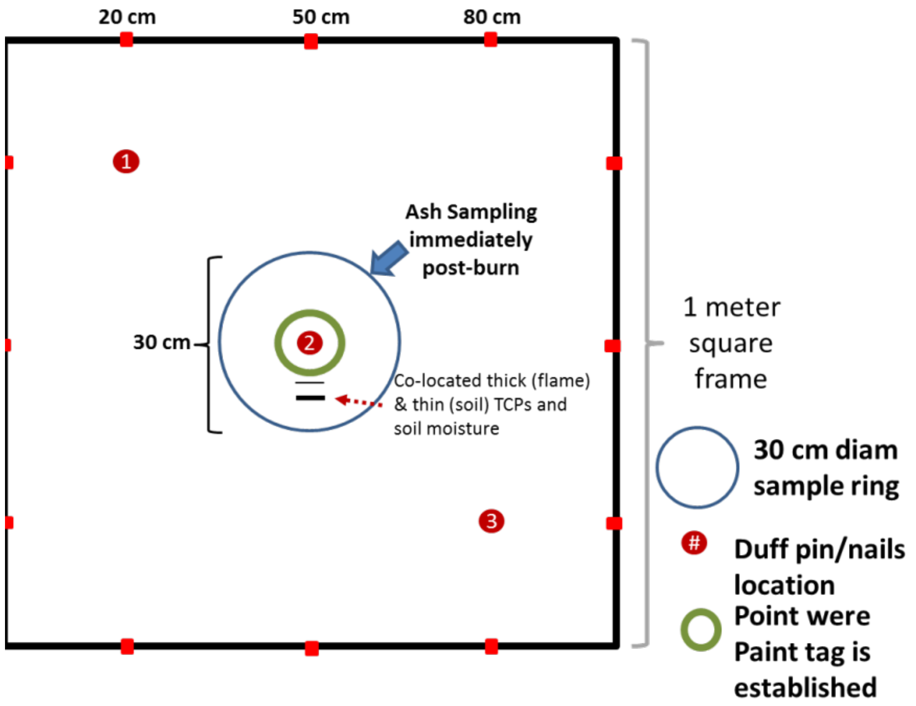
NPS

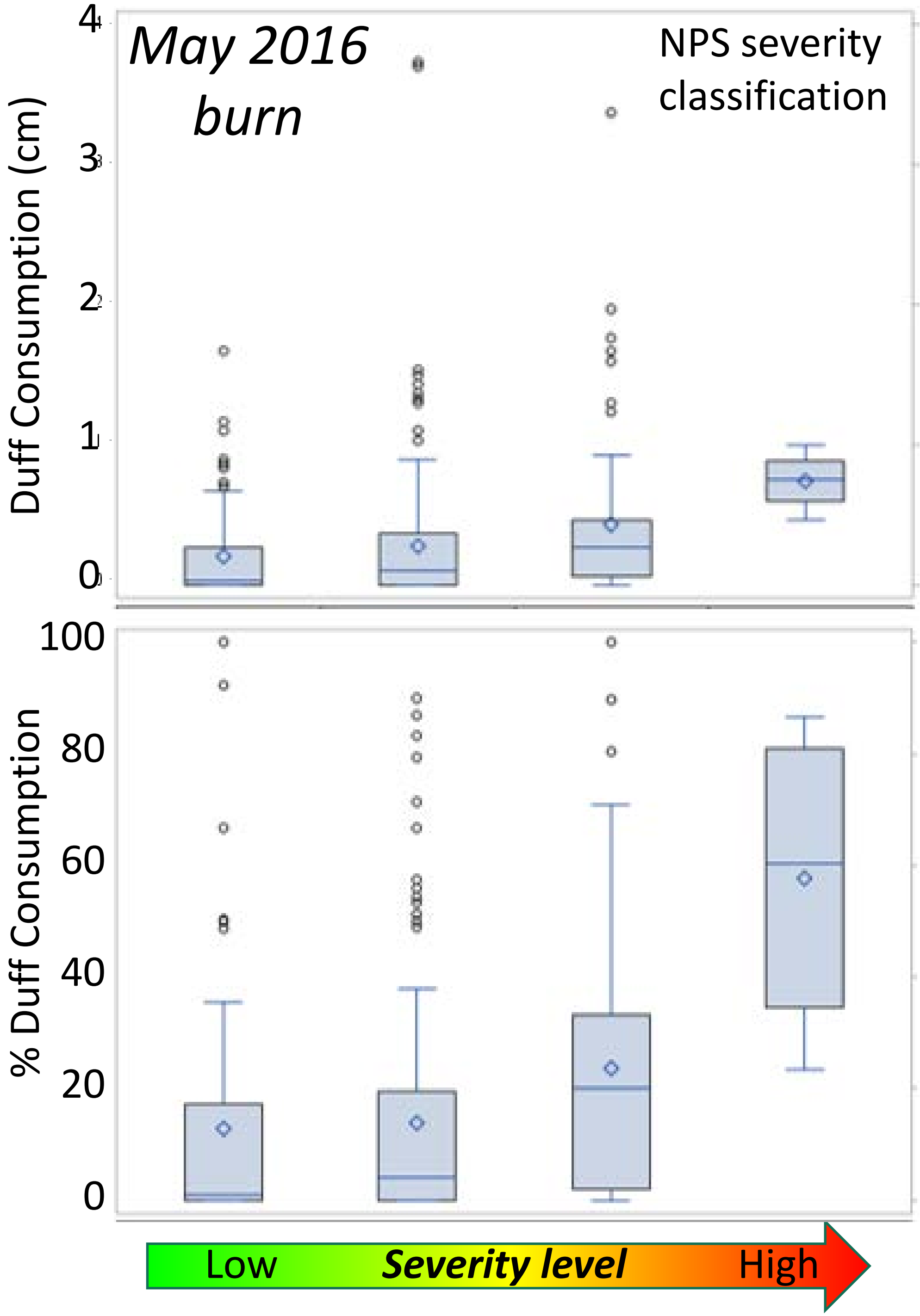
USDI National Park Service. 2003. Fire Monitoring Handbook. Boise (ID): Fire Management Program Center, National Interagency Fire Center. 274p.

How much duff is consumed by a spring burn? *And, does burn severity matter?*

Not much!

- Duff consumption was generally low (< 1 cm)
- The NPS severity system tracked this variable well





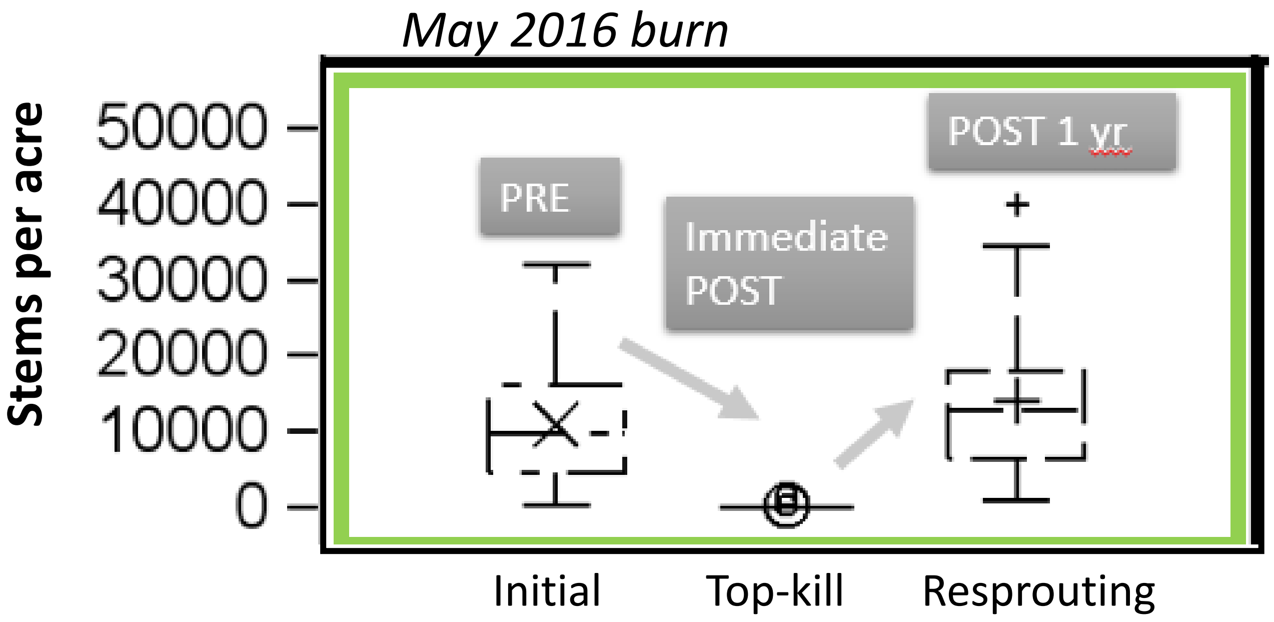
How effective are spring burns for decreasing shrub stem density?

Top-kill – very effective!

- Fire caused near elimination of hardwood stems (top-kill)

Below-ground – Not very effective!

- Re-sprouting returns to prefire stem densities within a year
- Similar trend where brush was cut



Top-kill after burn

Resprouting 1 season later

How do spring burns affect seed bank density?

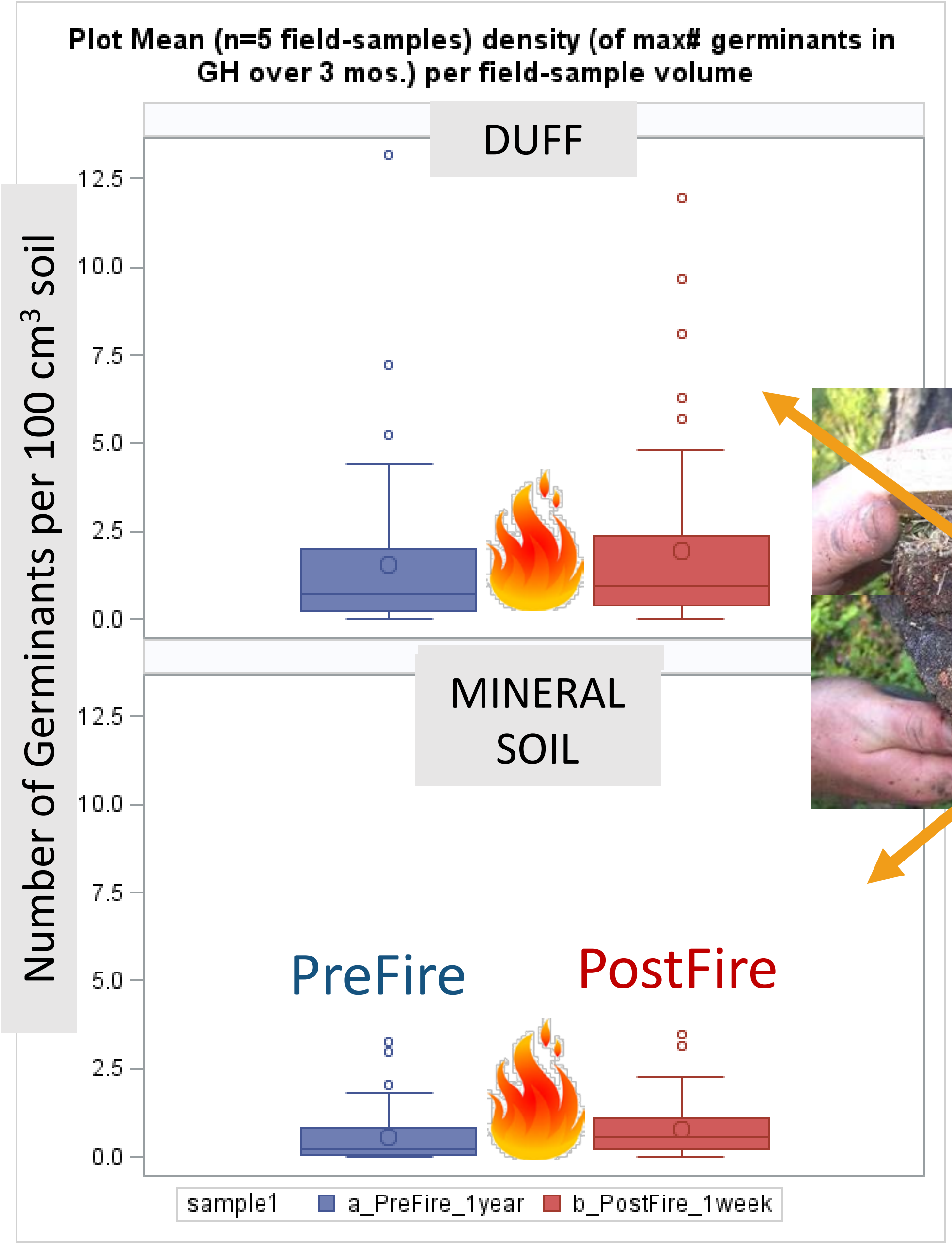
Minimal change

- Minimal density change pre to post fire
- More seeds in duff than mineral soil layers
- Species composition common to Barrens
- Rare or Sensitive sp. not detected

Sweet fern (*C. peregrina*)

Sand violet *(V. adunca)*

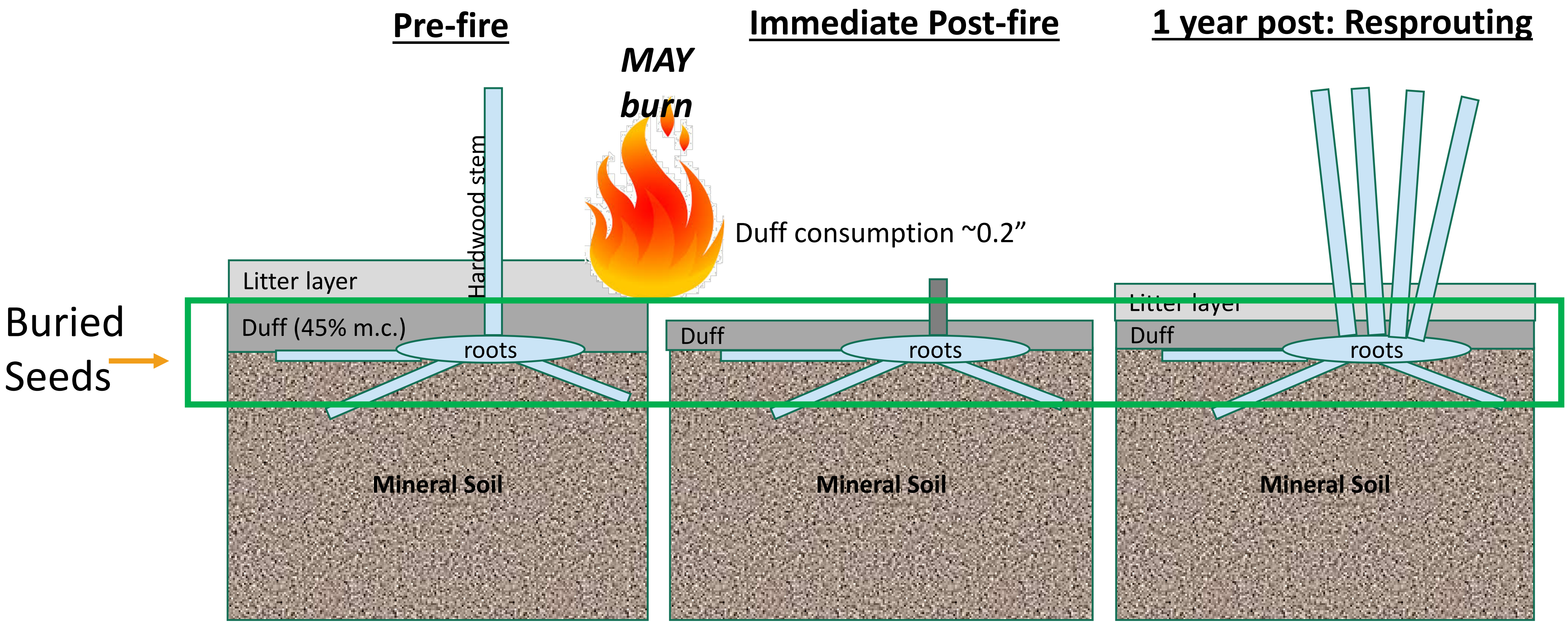
May 2018 burn



Take home messages & implications for vegetation

- Sprouting trees and shrubs are resilient to top-kill only disturbances
    - Late dormant season Rx fire had minimal effects on total woody stem composition and density
    - Consider growing season fire and/or other methods (mechanical, chemical) to address woody encroachment reduction objectives
- Duff and upper mineral soil layers are seed sources for common plants of the pine barrens.
    - Likewise – this type of burning had minimal effects on total seedbank composition and density
    - For rare or sensitive plant species, continue to use other restoration methods (e.g., seeding, planting, translocation)

Why did we not see a stronger belowground ecological response to burn intensity?



- Heat rises!
- **Insulation by duff layer?**

The role of duff in soil heating during late dormant-season fires

Duff has accumulated in forested stands

Duff is either a heat sink (insulator) or a heat source for soil heating:
- No combustion – duff impedes soil heating
- Independent duff smoldering – enhances soil heating

So, what is duff doing?

Guidance from the literature:

When It's Hot, It's Hot ... or Maybe It's Not!
(Surface Flaming May Not Portend Extensive Soil Heating)

Roberta A. Hartford and William H. Frandsen

U.S. Department of Agriculture, Forest Service, Intermountain Research Station
Intermountain Fire Sciences Laboratory P.O. Box 8089, Missoula, MT 59807
Tel. 406 329 4820; Fax 406 329 4863

Int. J. Wildland Fire 2(3): 139-144, 1992

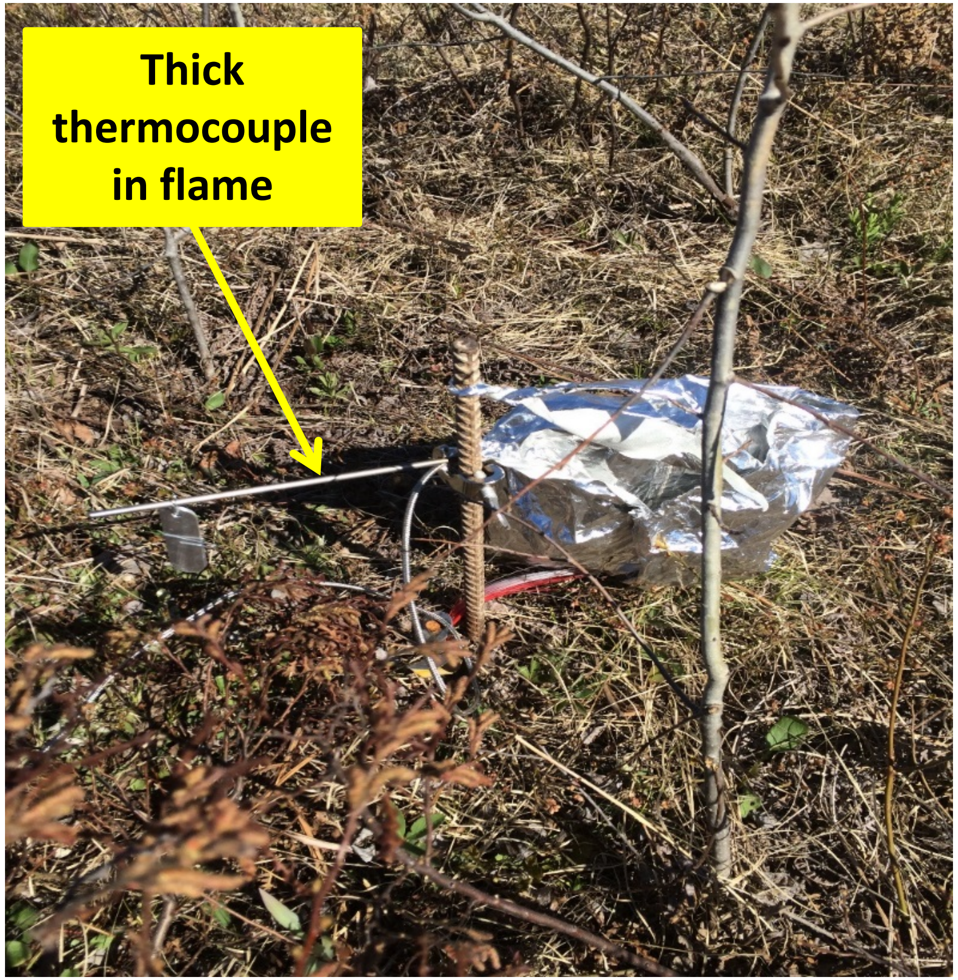
Fuels	Behavior	Soil heating
Slash over moist duff	• Large flames/high intensity • Duff consumption dependent on external heat subsidy?	Minimal
Litter over dry duff	• Small flames/low intensity • Independent duff smoldering	A lot

Where on the spectrum are the Moquah Barrens fires?

Data sources for this talk

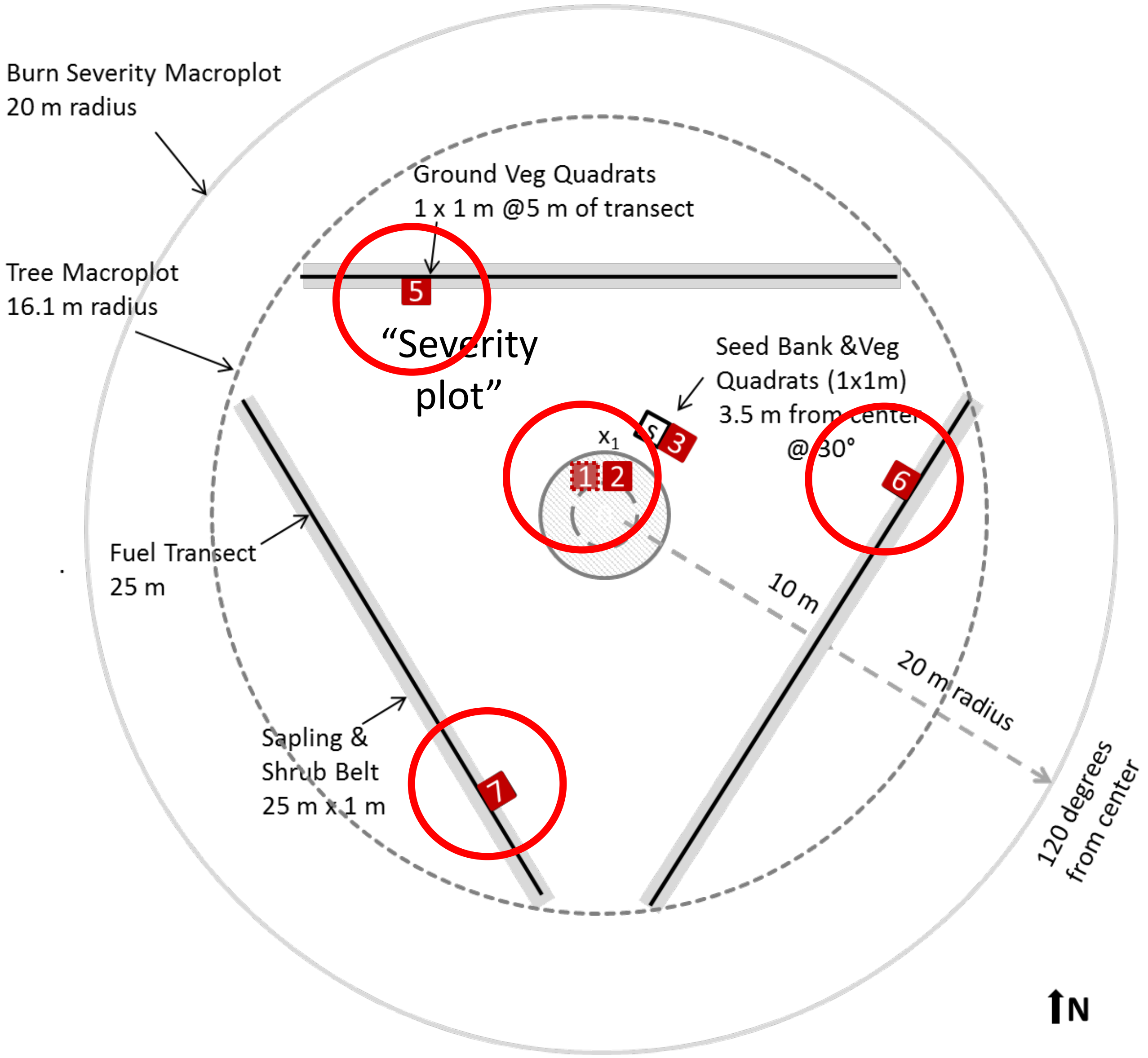
Fire behavior from calibration (Bova & Dickinson 2008):

- Fuel consumption
- Fireline intensity
- Flame residence time



Duff & soil heating

Plot layout



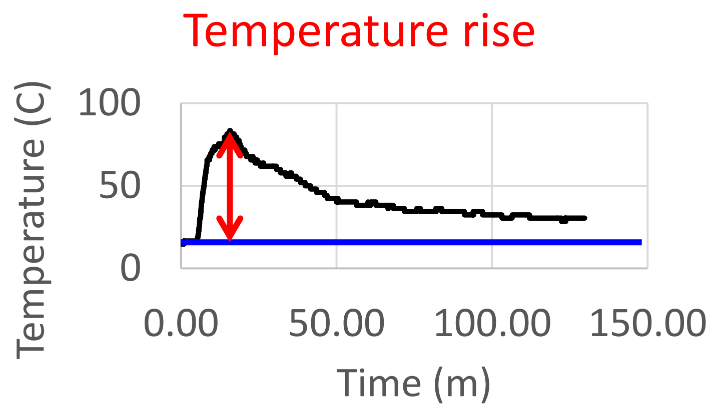
Data from severity plots

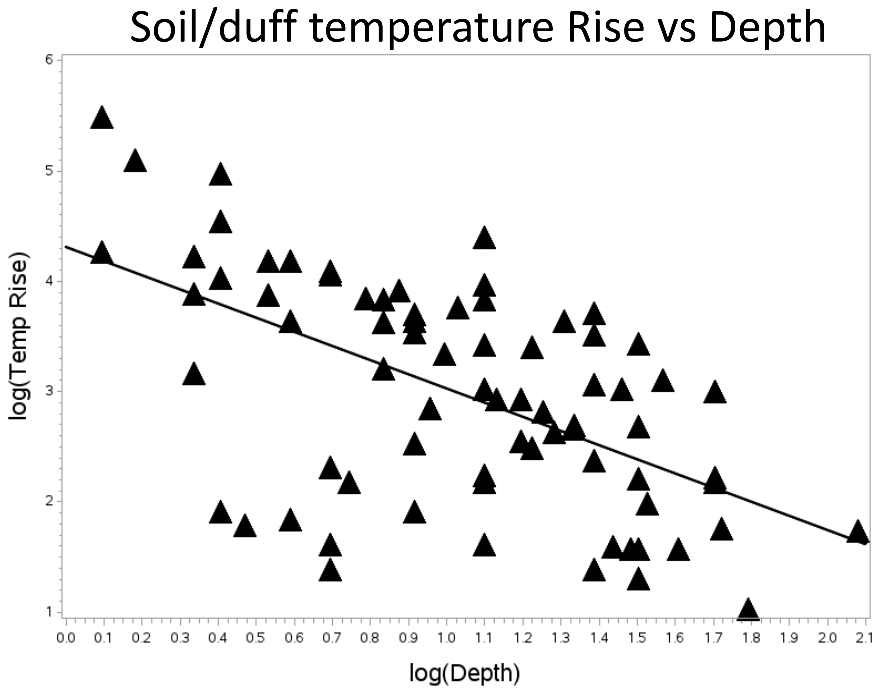
Localized fire behavior – not plot averaged

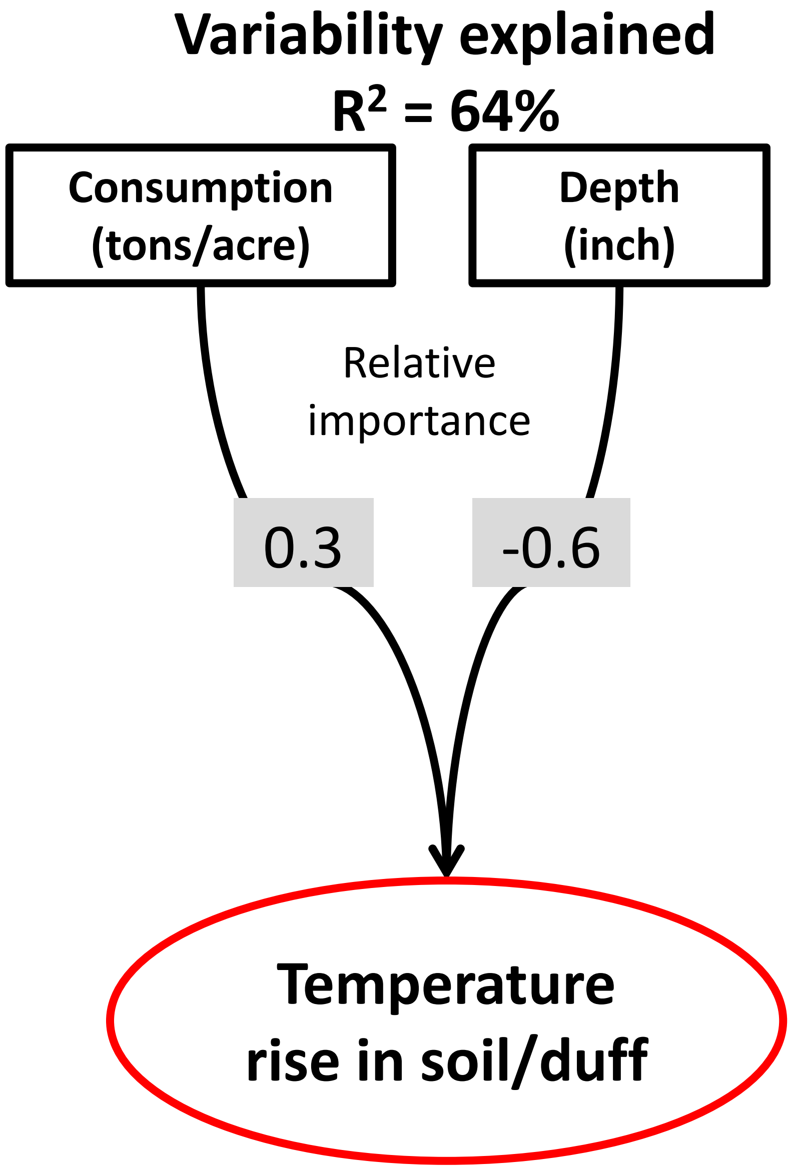
Range in fire behavior and soil heating - 2016 and 2018

Variables	Units	N	MEAN	MIN	MAX	STD
Consumption	tons/acre	106	7	0	39	6
Intensity	kW/m	113	564	115	1472	314
Intensiy	BTU/ft*s	113	163	33	425	91
Moisture	%	281	51	21	110	17
Duff depth (pre-fire)	inches	128	0.9	0	2.4	0.6
Duff consumption	inches	107	0.2	0	1.6	0.3
Soil/duff temp. rise	Farenheit	117	167	35	889	214

What are the controls on soil heating?



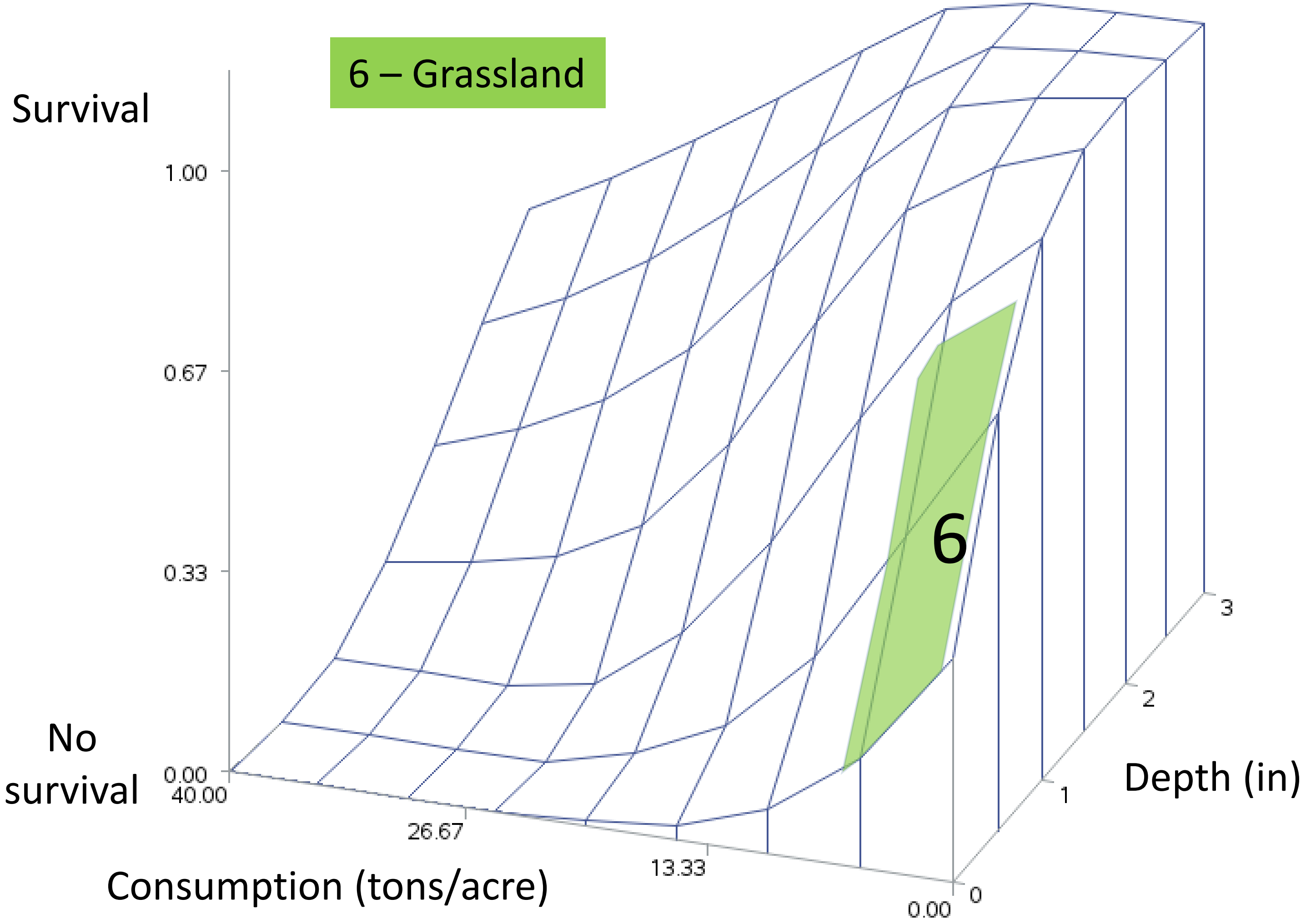




Modeled heat impacts at soil/duff interface

Microbial community cell population survival

More work needed on dormant seed & woody stem impacts



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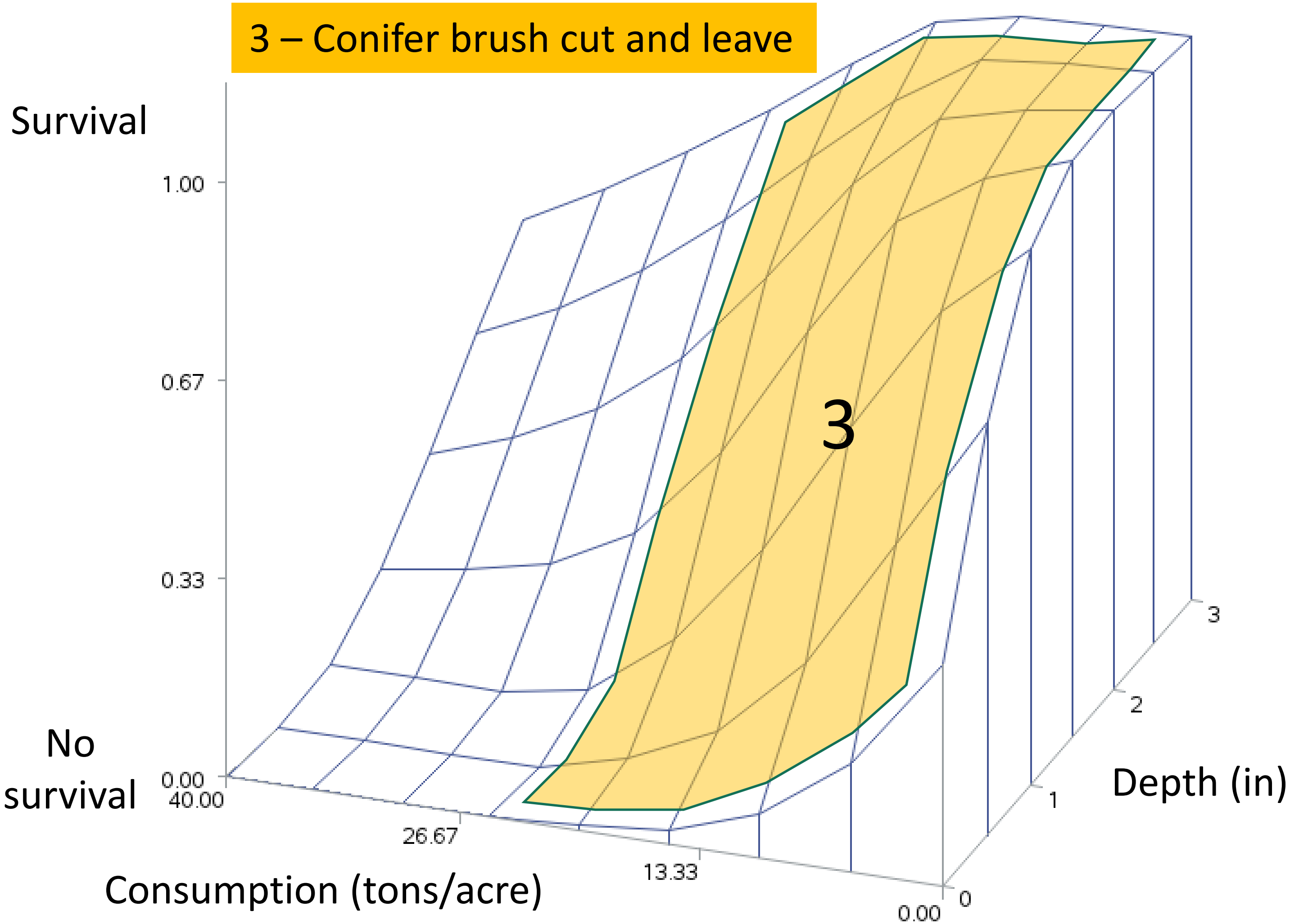

Modeled heat impacts at soil/duff interface

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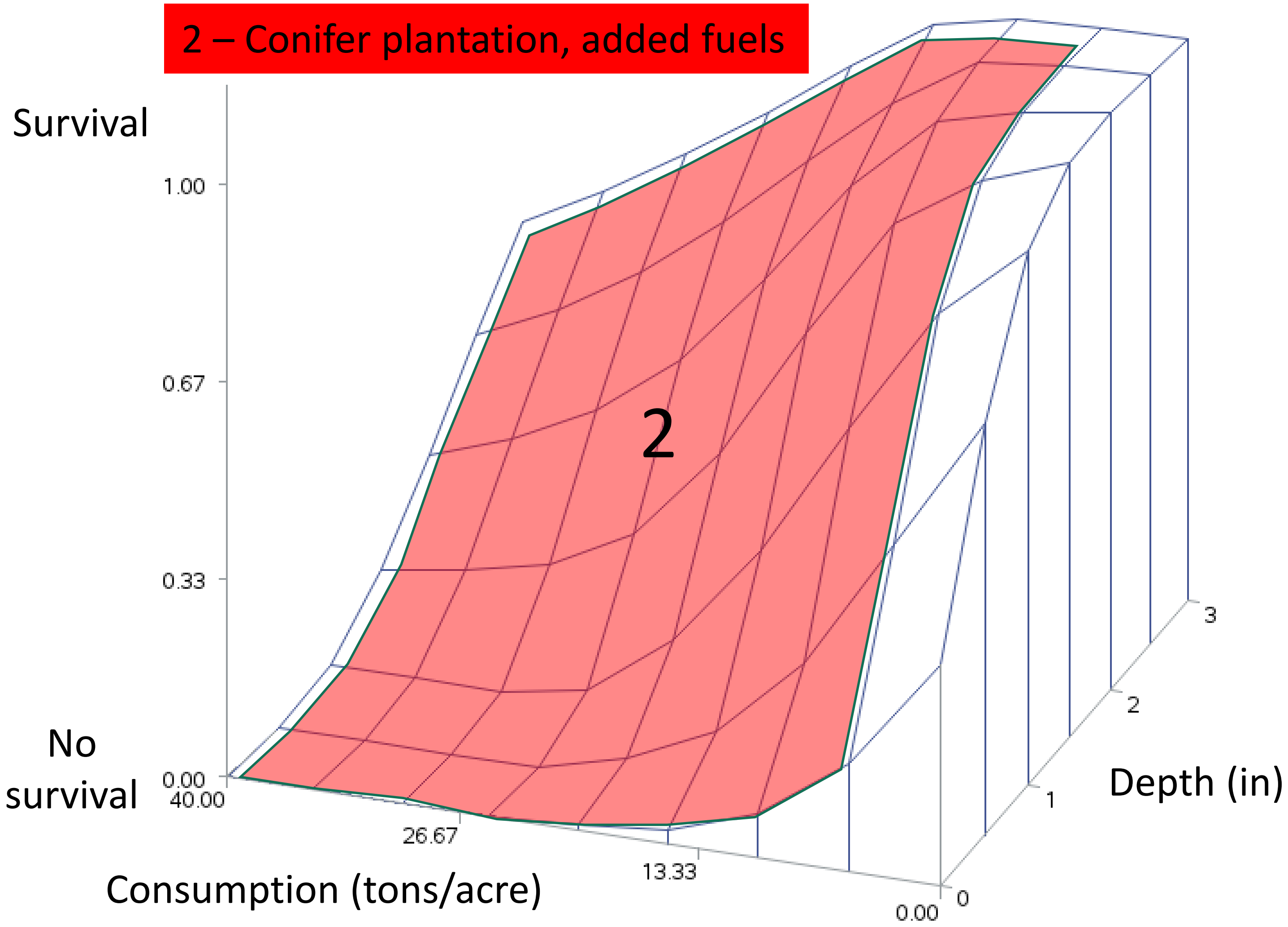

Conclusion on duff and soil heating

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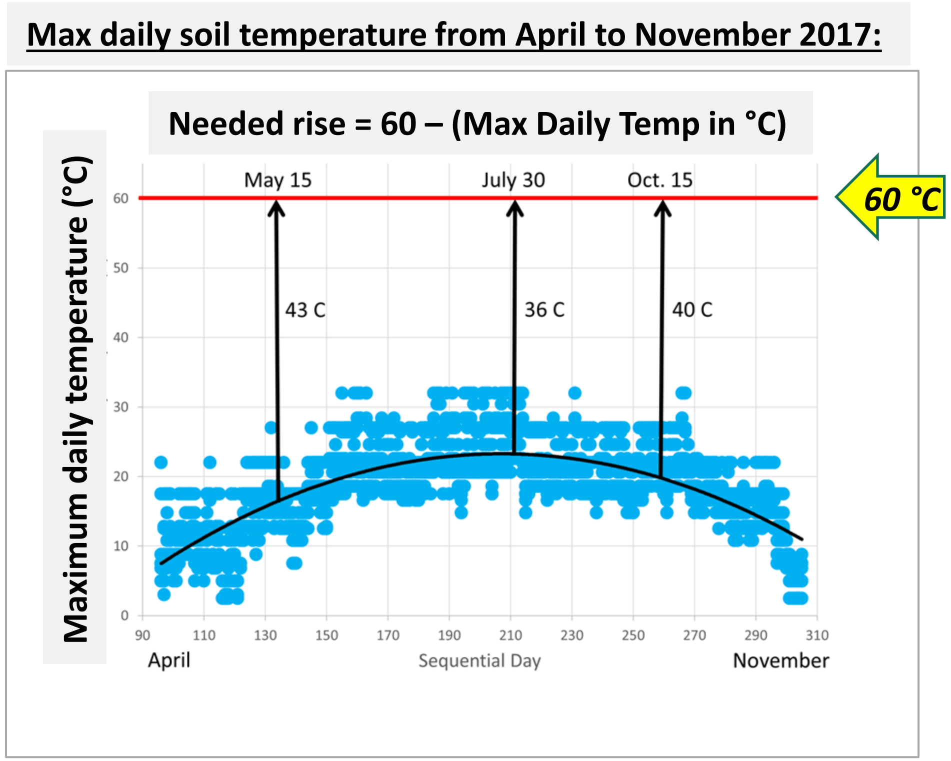
Fuels	Behavior	Soil heating
Slash over moist duff	• Large flames/high intensity • Duff consumption dependent on external heat subsidy?	Minimal
Litter over dry duff	• Small flames/low intensity • Independent duff smoldering	A lot

- Duff is a great insulator, but only if its thick enough!
- Conjunction of thin duff and high woody fuel loads can result in high duff/soil interface temps.

Food for thought: could growing-season fire season help improve restoration success?

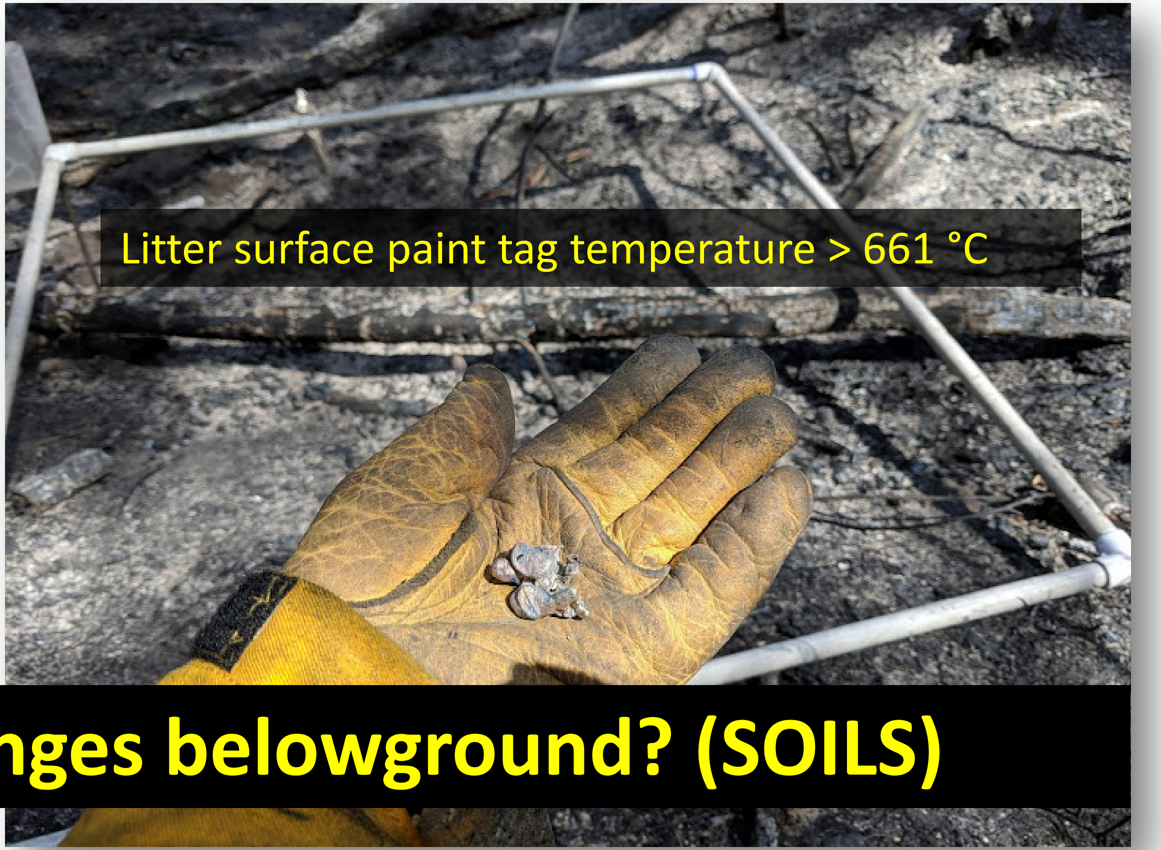


- 60 °C is a rough threshold for thermal impacts
- Does warmer duff and soil mean greater heat impacts?
- Will dryer duff mean independent smoldering and more soil heating?

Late dormant season fire results in:

1) Woody fuel consumption & topkill

2) Limited duff consumption & soil heating



What about less apparent changes belowground? (SOILS)

Fire maintains **soil conditions** that allow native barrens plant communities to persist

Fire and the Northern Wisconsin Pine Barrens

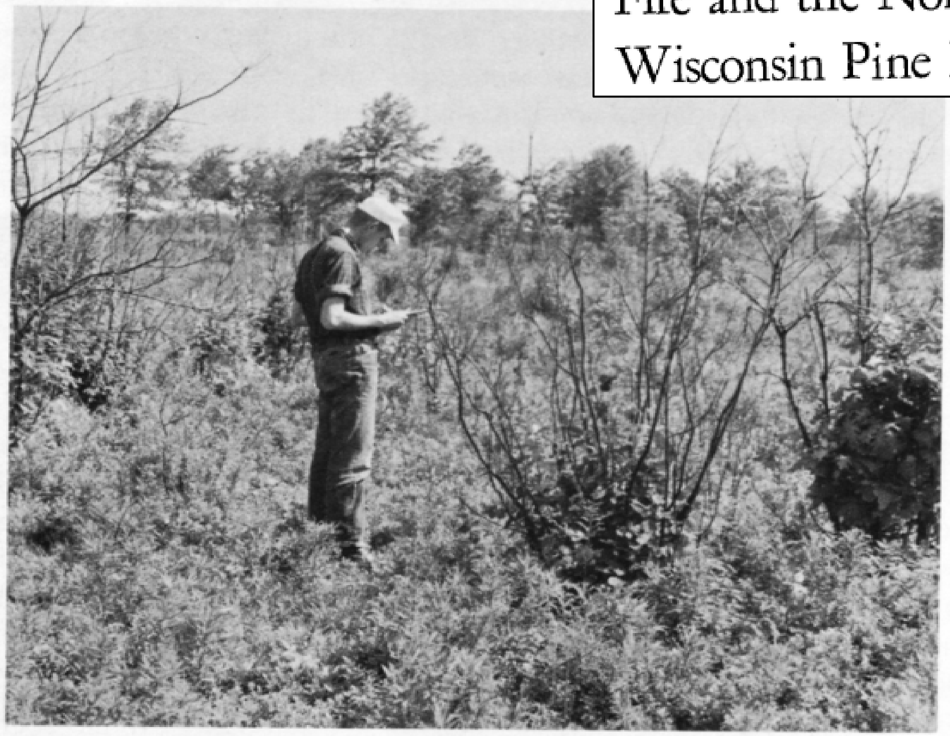
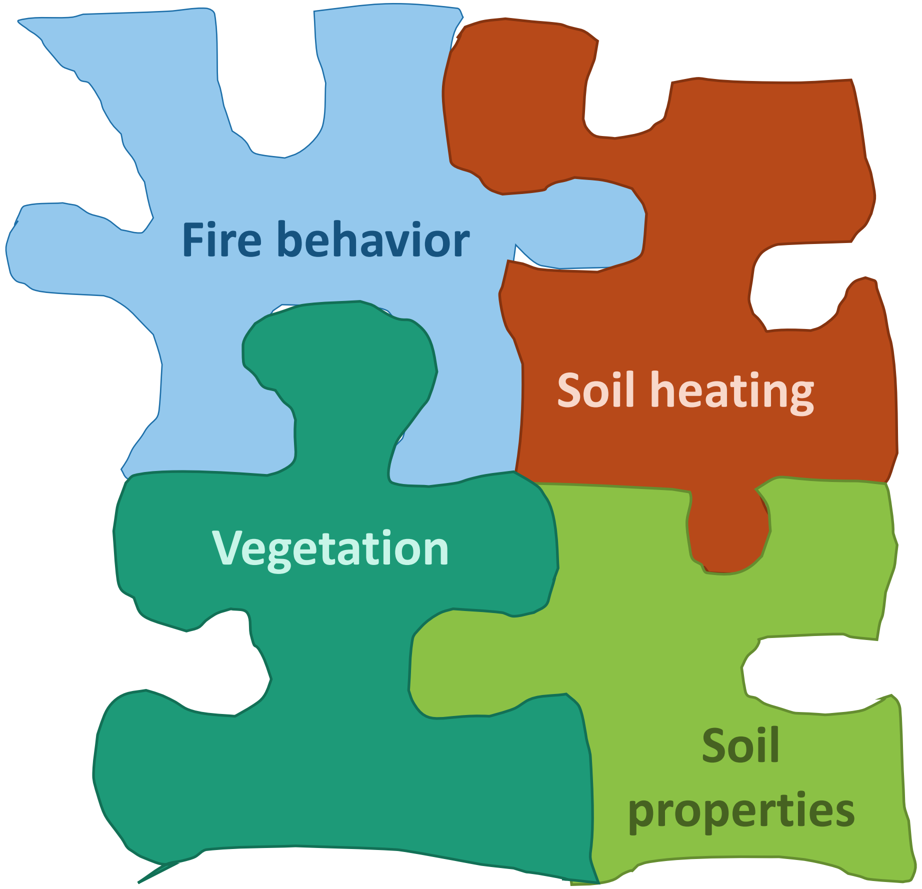
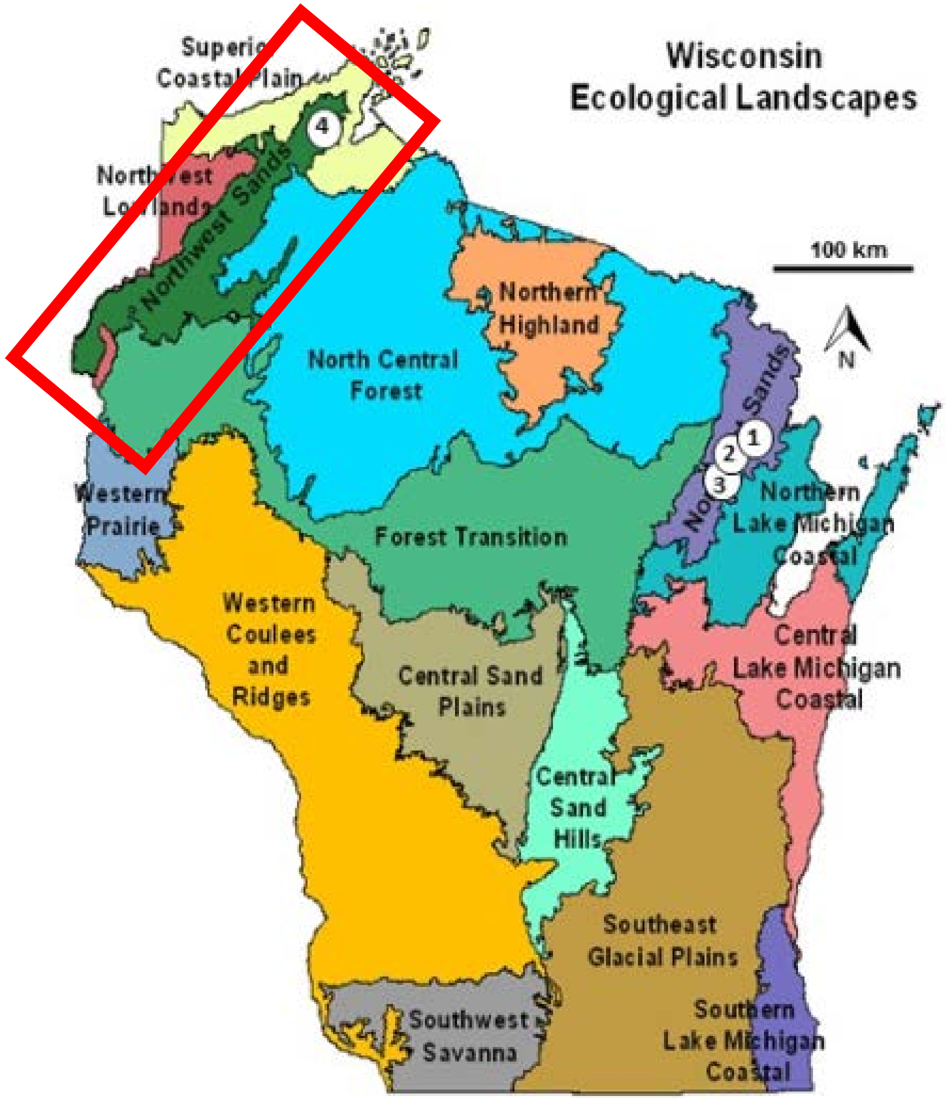


FIG. 5. Oaks are reduced in size and cover with each burning but recover by producing root-crown sprouts. Woody plant encroachment on these barrens appears to be controlled edaphically with fires contributing to the open nature of the barrens.



Soils are an important piece of the *restoration puzzle.*

Soils of the **Northwest Sands** are nutrient-poor sands



- Glacial outwash
- Excessively drained
- *Barren* of nutrients

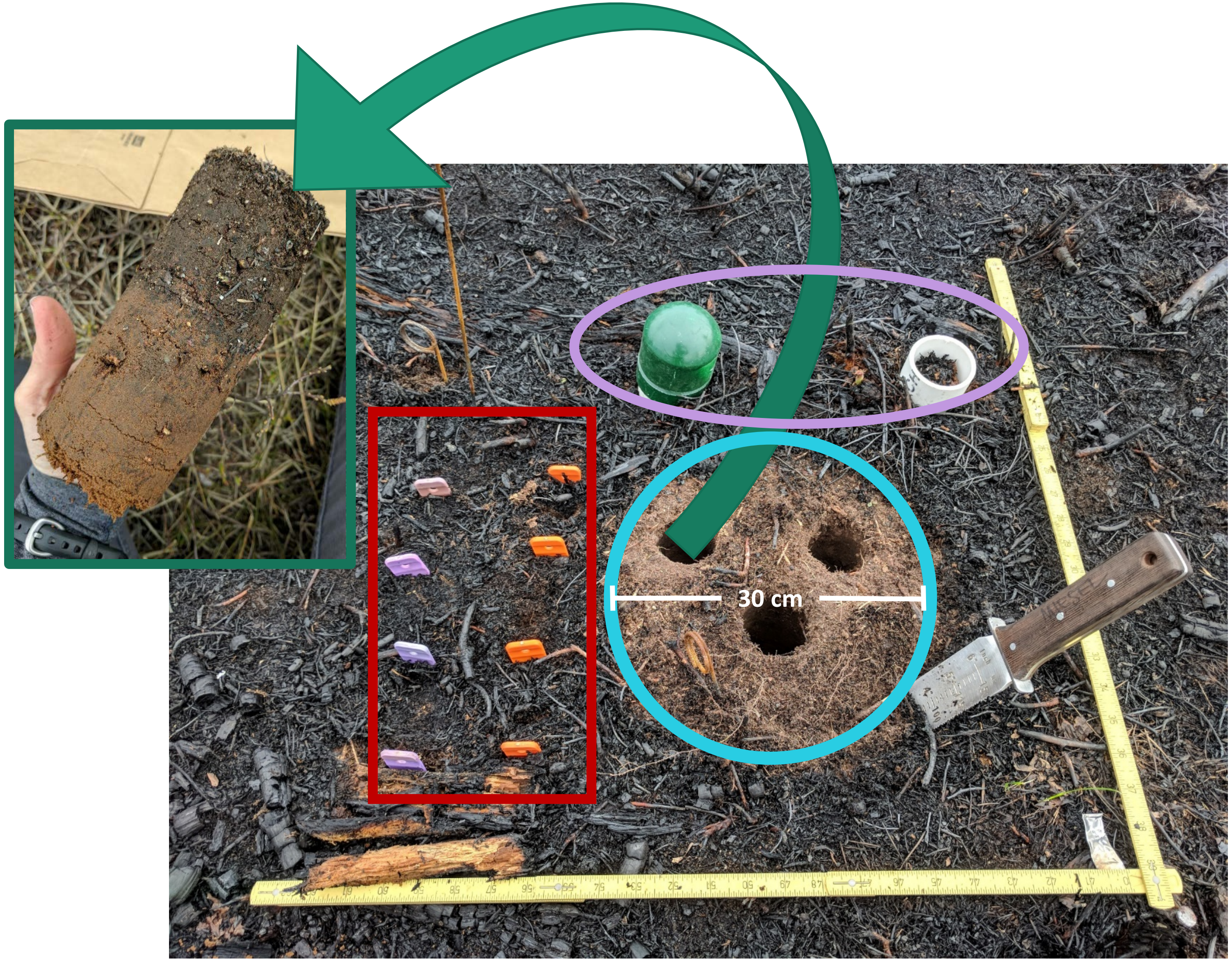
- **Native pine barrens plant communities are well-adapted to droughty, nutrient-poor soils.**

Our goal is to understand how prescribed fire alters soil properties:

1) Before, immediately after, and 1-year after burns

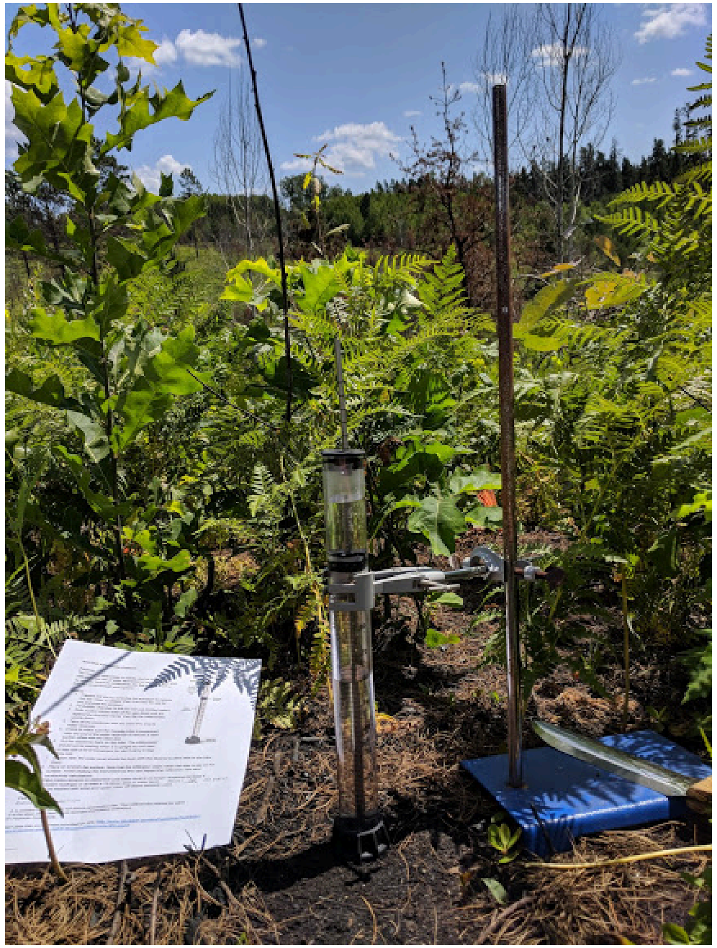
2) Relative to long-unburned (50+ years) reference plots

Soil sampling overview



- Forest floor (litter, duff, and O horizon) sampled within 30 cm ring
- Mineral soils cores divided into 0-5 cm and 5-10 cm fractions
- Nutrient exchange rates (ug/area/time) estimated with PRS probes
- Nitrogen mineralization rates estimated with PVC soil incubation cores

Mineral soils and forest floor analyzed for a suite of properties:

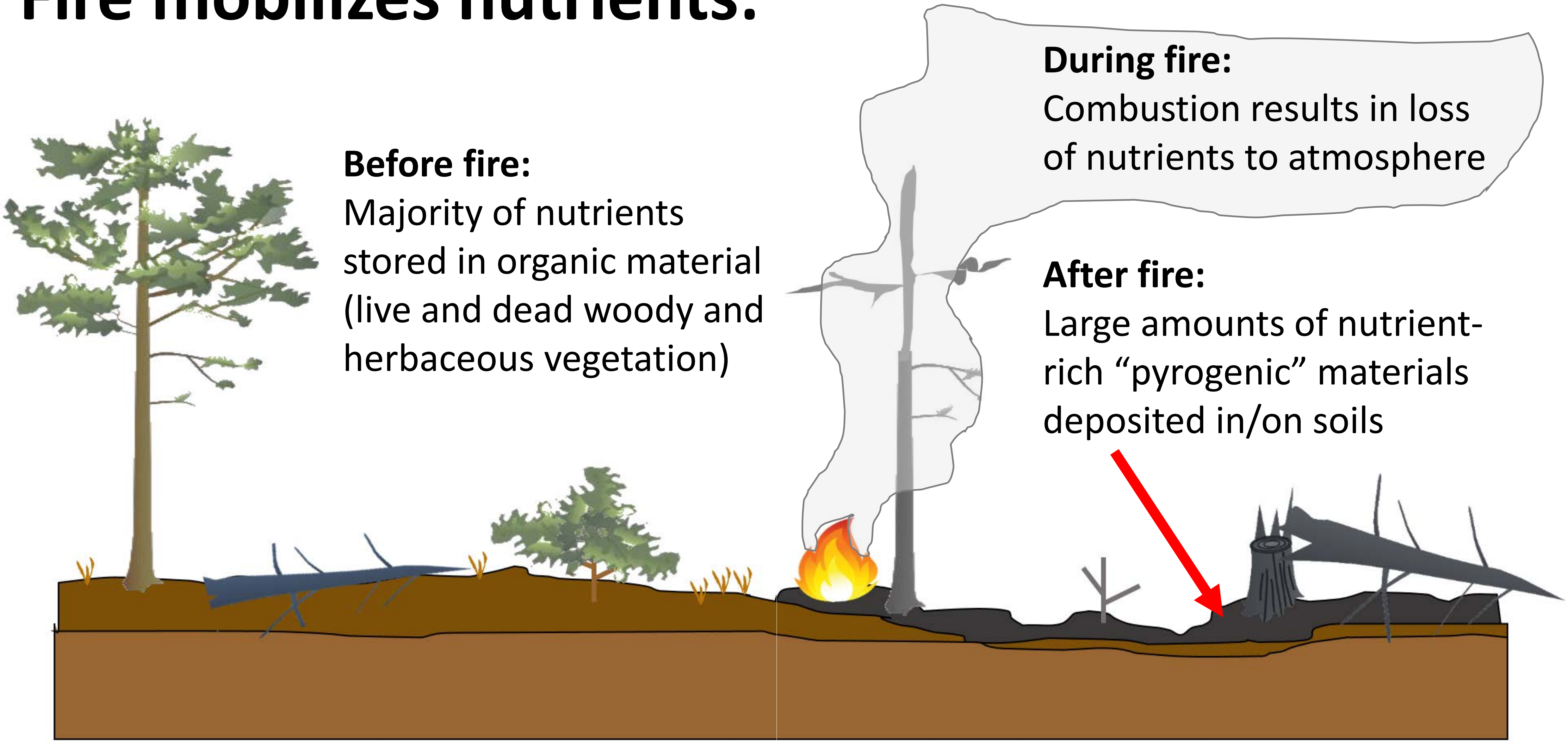


- Essential plant nutrients: N, P, S, K, Ca, Mg
- Total and "pyrogenic" carbon (black C /charcoal)
- pH and bulk density (mass per volume)

- Nutrient exchange rates estimated via PRS probes:
  - NO_3^-, NH_4^+, $H_2PO_4^-$, SO_4^{2-}, cations, and metals

- Additional soil traits measured at *some* plots:
  - Water infiltration rates (hydraulic conductivity)
  - Soil greenhouse gas emissions
  - Soil microbial community composition

Fire mobilizes nutrients:



Before fire:
Majority of nutrients stored in organic material (live and dead woody and herbaceous vegetation)

During fire:
Combustion results in loss of nutrients to atmosphere

After fire:
Large amounts of nutrient-rich “pyrogenic” materials deposited in/on soils

Chemical transformations are temperature-dependent

- Charcoal and ash form at temps from < 200 °C to > 600 ° C
- Ash generally enriched in cations, which require *very high* volatilization temperatures
- Nutrients may be mobilized by wind, leached through sandy soil after rainfall, or taken up by recovering plant communities

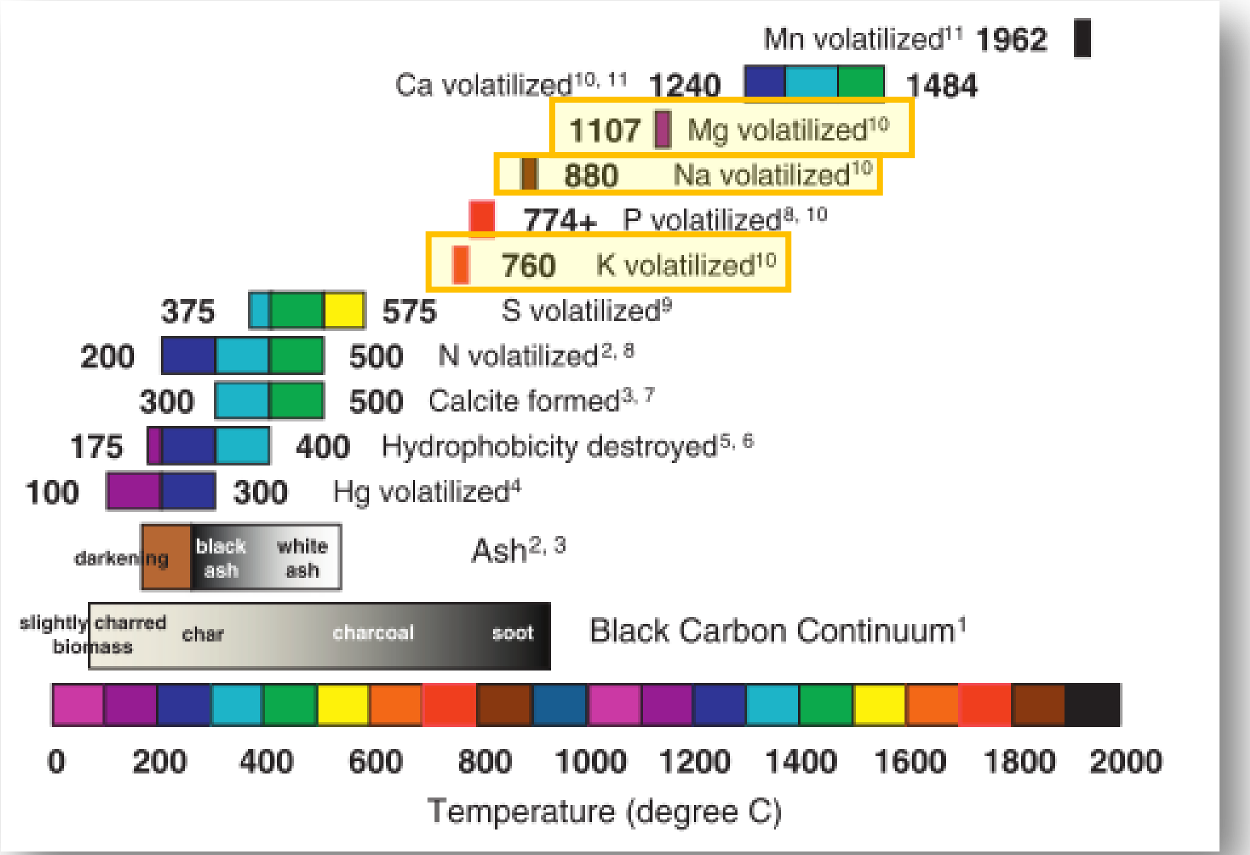
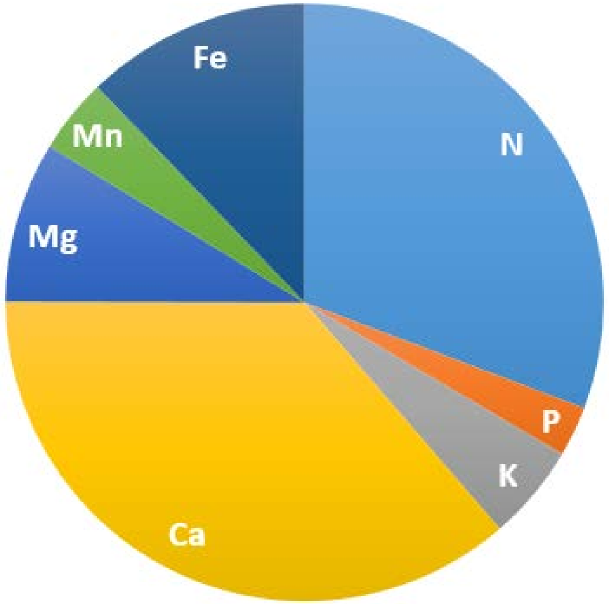


*Figure from Bodi et al. 2014. *Earth-Science Reviews* 130: 103-127.

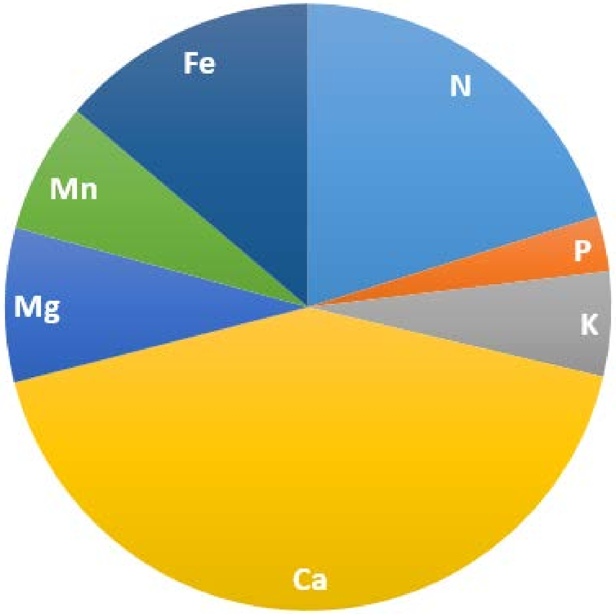
General expectation: postfire pulse (+), followed by a decline (-) in nutrients

Ash is an important post-fire soil nutrient source

- 2016 burns resulted in ash inputs of ~ 2000 kg ha^{-1} – enriched in N and cations
- Fire temperature, **vegetation cover**, and fuel load influence ash quality and quantity



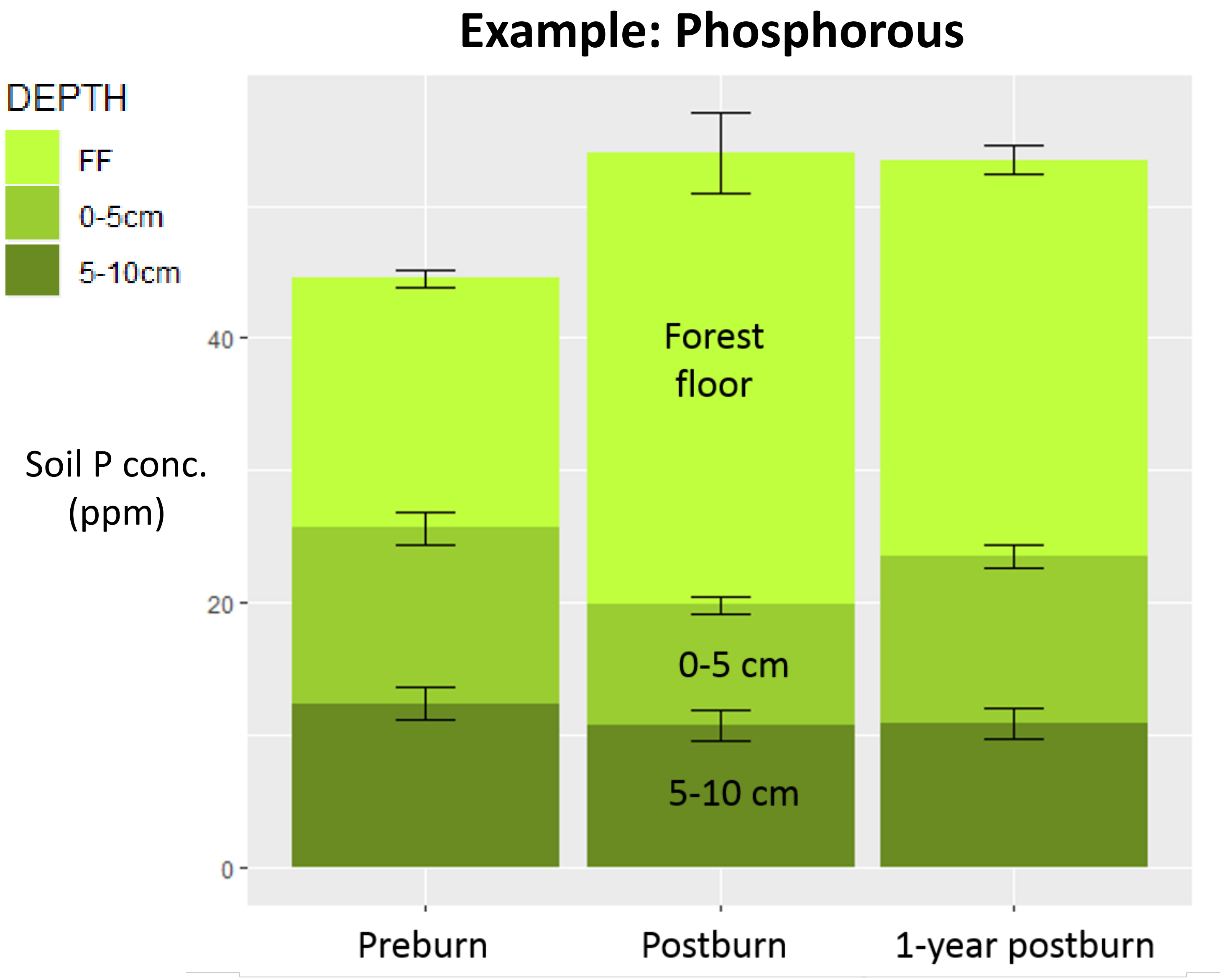
Grassland ash



Deciduous forest ash

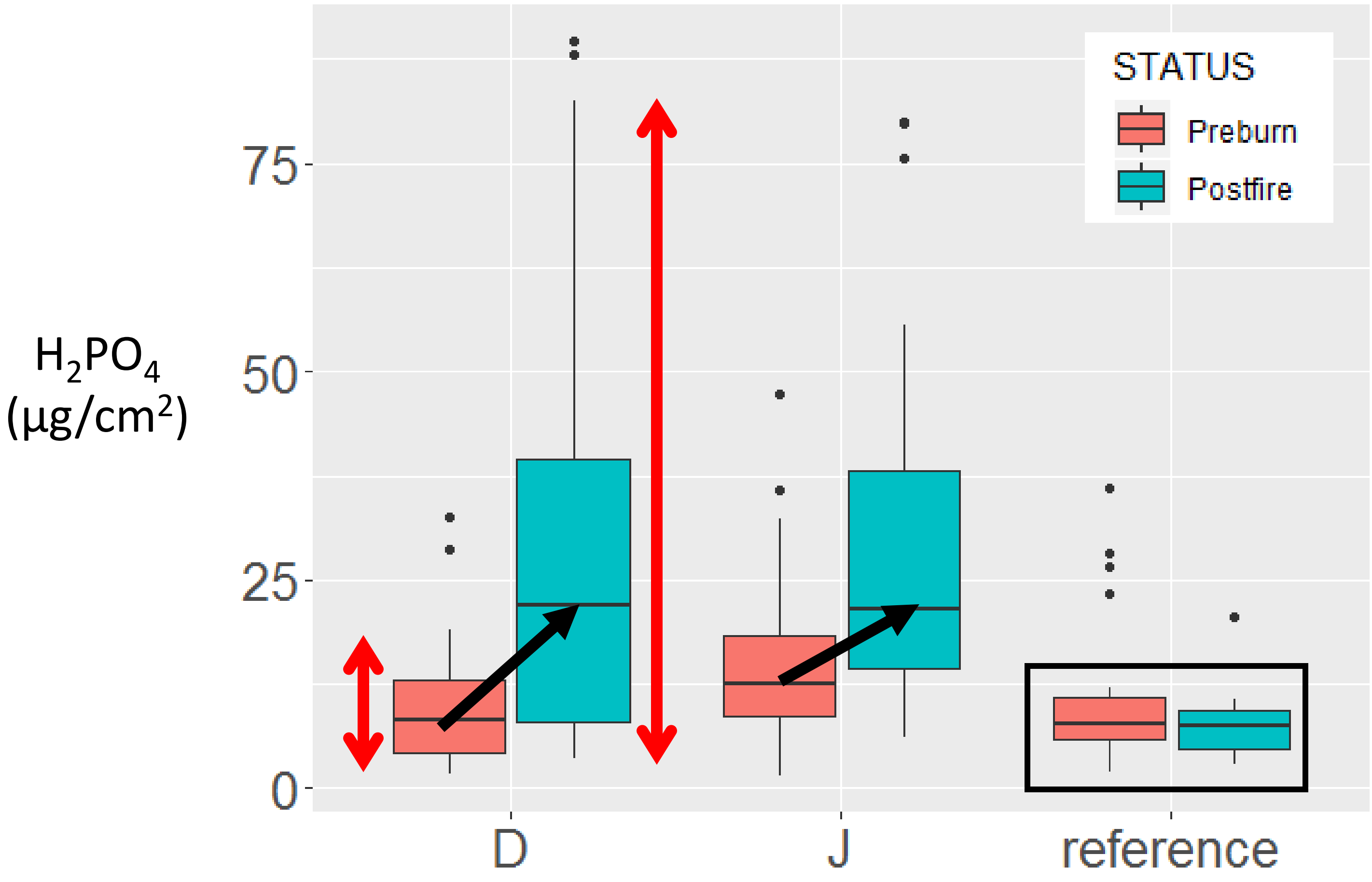
**excluding carbon (~40 % wt)

We observed a pulse (+) in soil nutrients after burns



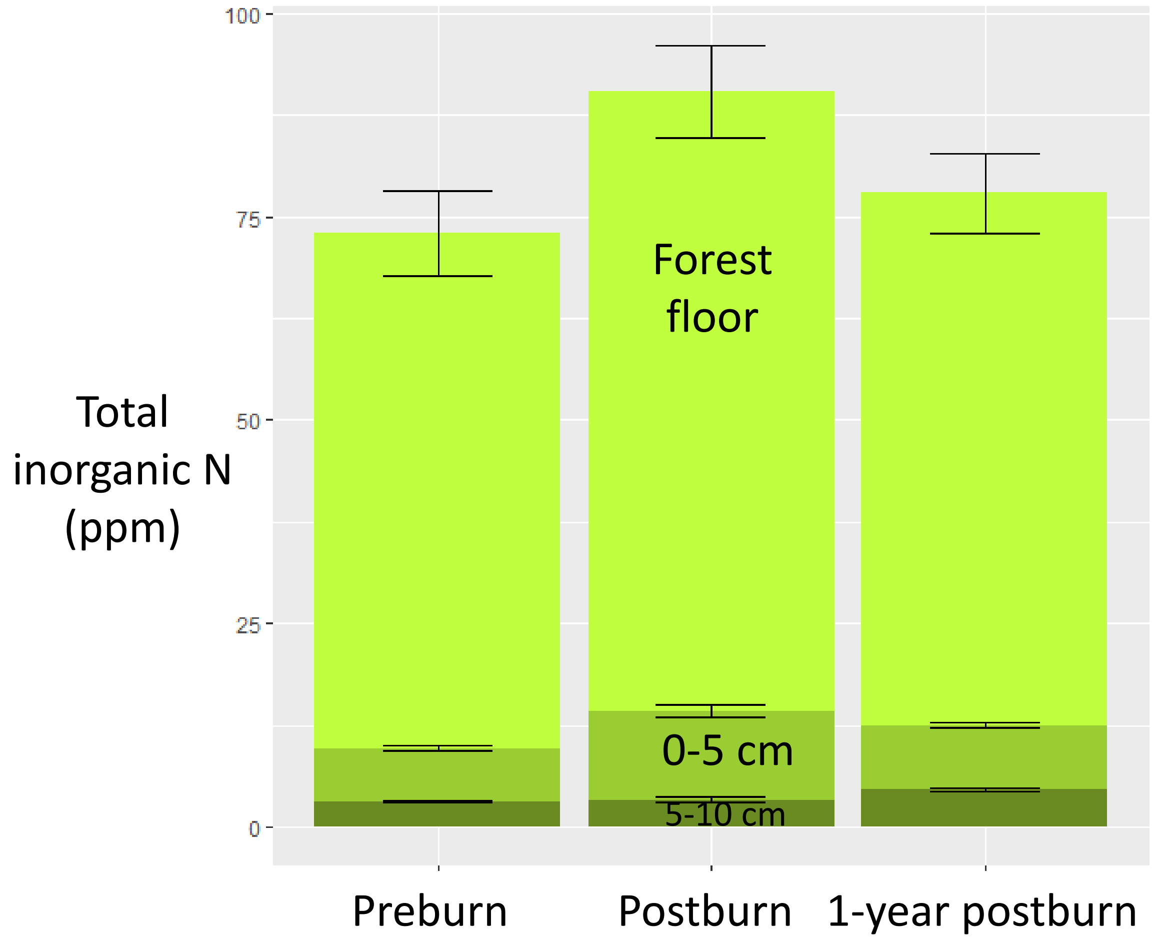
- Soil P concentration increased immediately postfire due to a gain in forest floor
- Total soil P remained higher than prefire values by 1 year postfire, but some forest floor P was translocated to upper mineral soil

PRS probes indicate a similar increase in plant-available phosphorous (H_2PO_4)

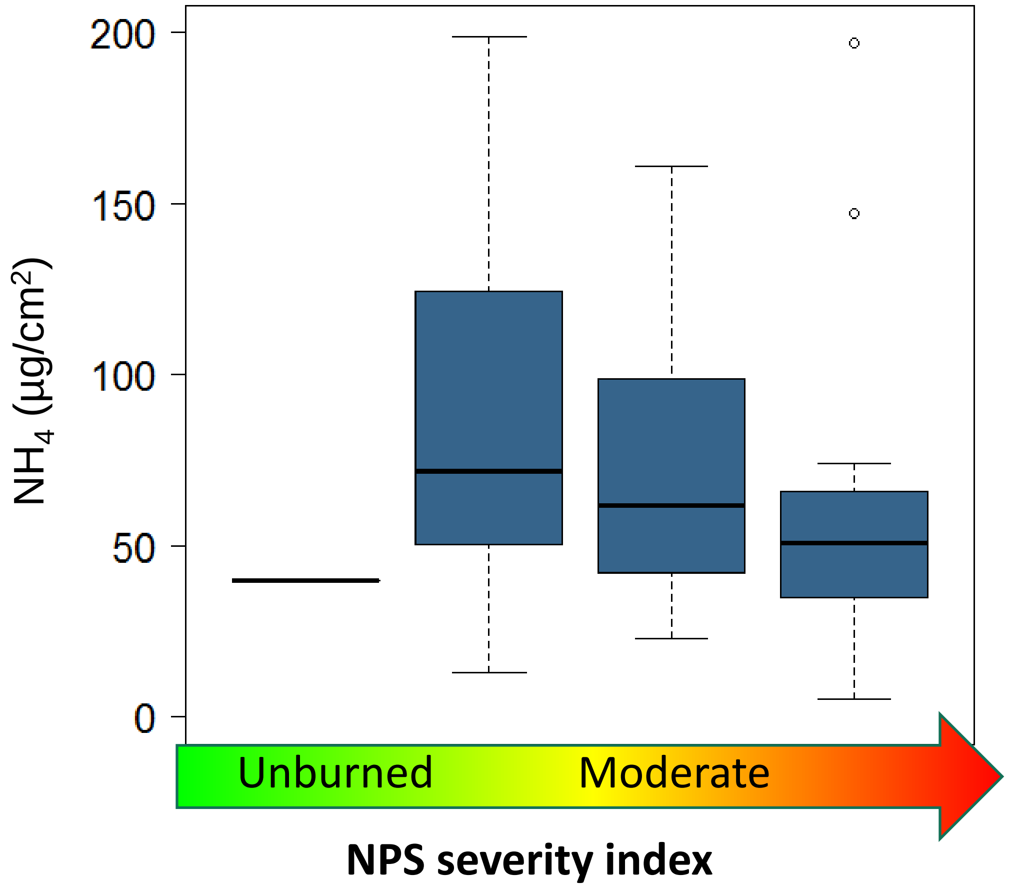


- Available phosphate in the plant rooting zone nearly doubled after fire
- Greater variation in P after burns (vegetation cover)
- No change was observed in reference plot P availability

What are the consequences of greater fire intensity & burn severity on soil nutrient status?

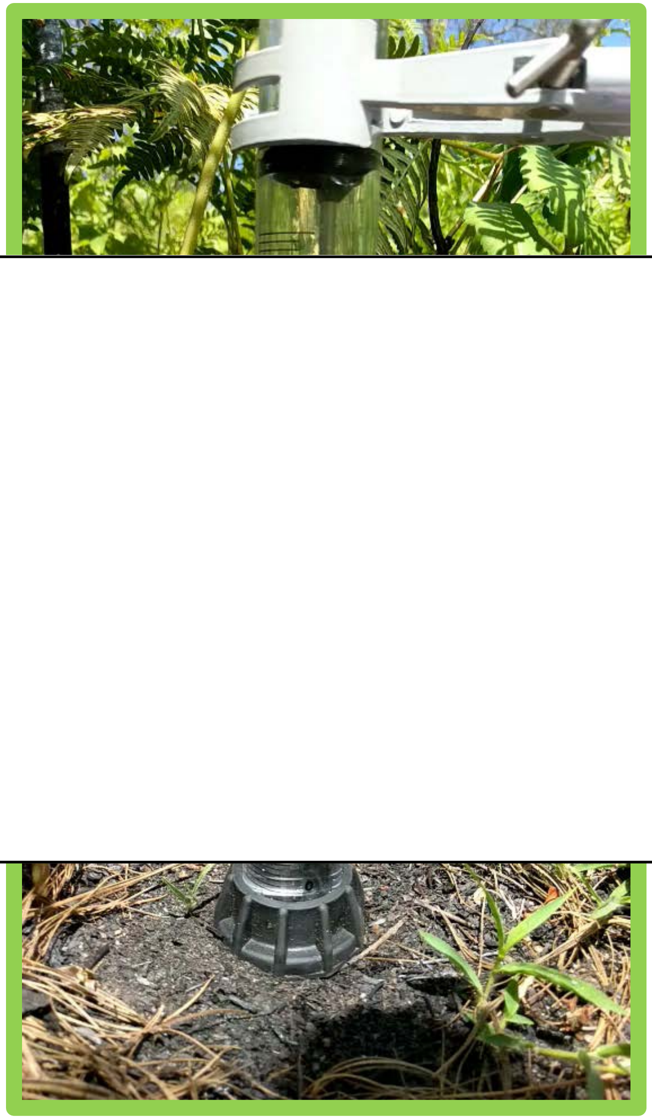


Fire increased plant-available N
($NH_4 + NO_3$)



But effect decreases with increasing burn severity due to greater N volatilization

Fire also affects soil water availability



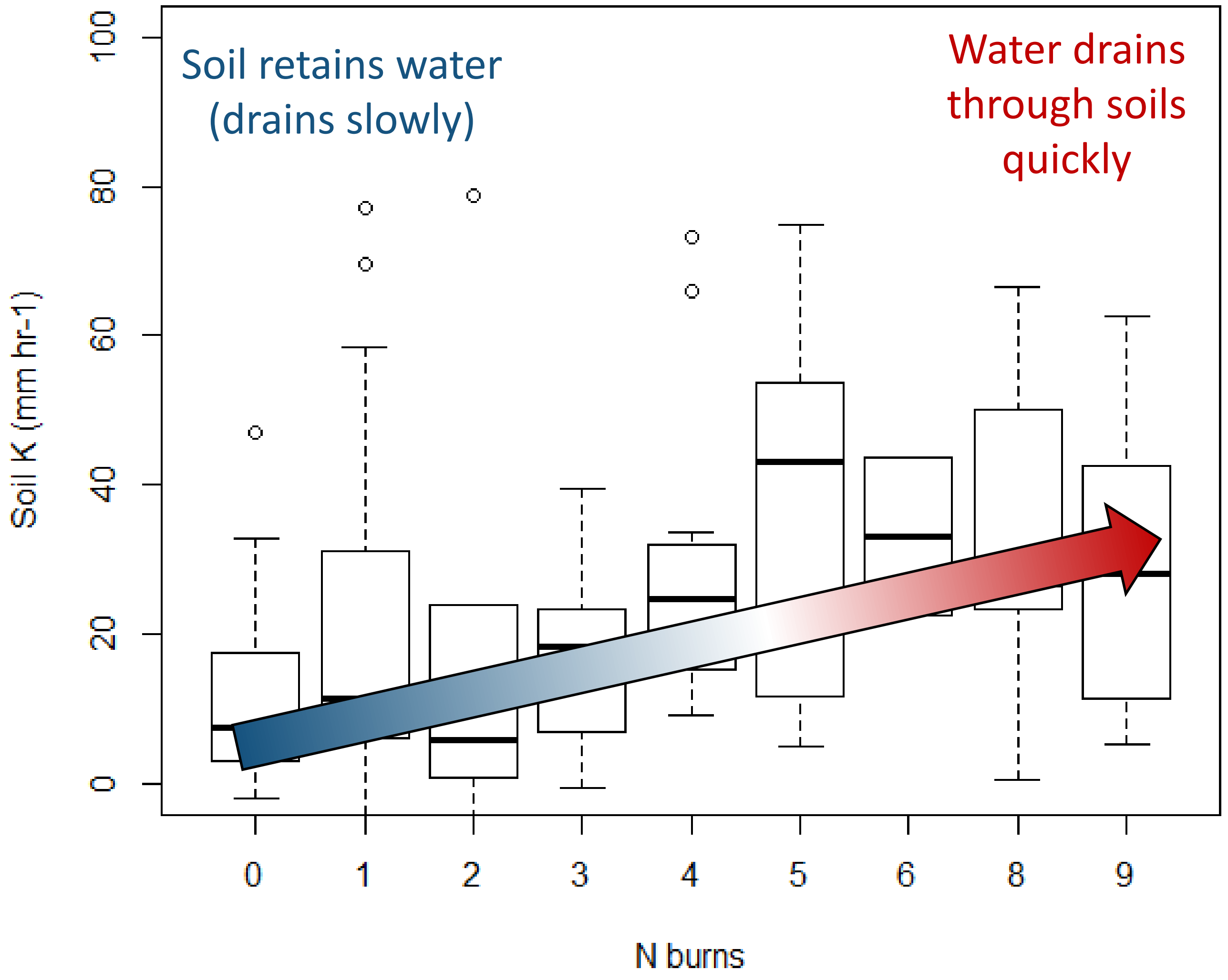
- Fire removes litter, duff, and soil organic matter which all store water
- Fire creates ash (hydrophilic) and char otentially hydrophobic)

Ve used a mini disk infiltrometer to neasure water infiltration rates in 2017 nd 2018

  - Prefire / postfire at blocks D, J
  - 1-year / 2-years postfire at blocks F, I
- Infiltration rates describe how water moves through soil (hydraulic conductivity)

Results: Soil hydraulic conductivity

- SHC shows a positive relationship with number of burns
- High SHC indicates soil conditions which favor native barrens plant communities and limit woody encroachment

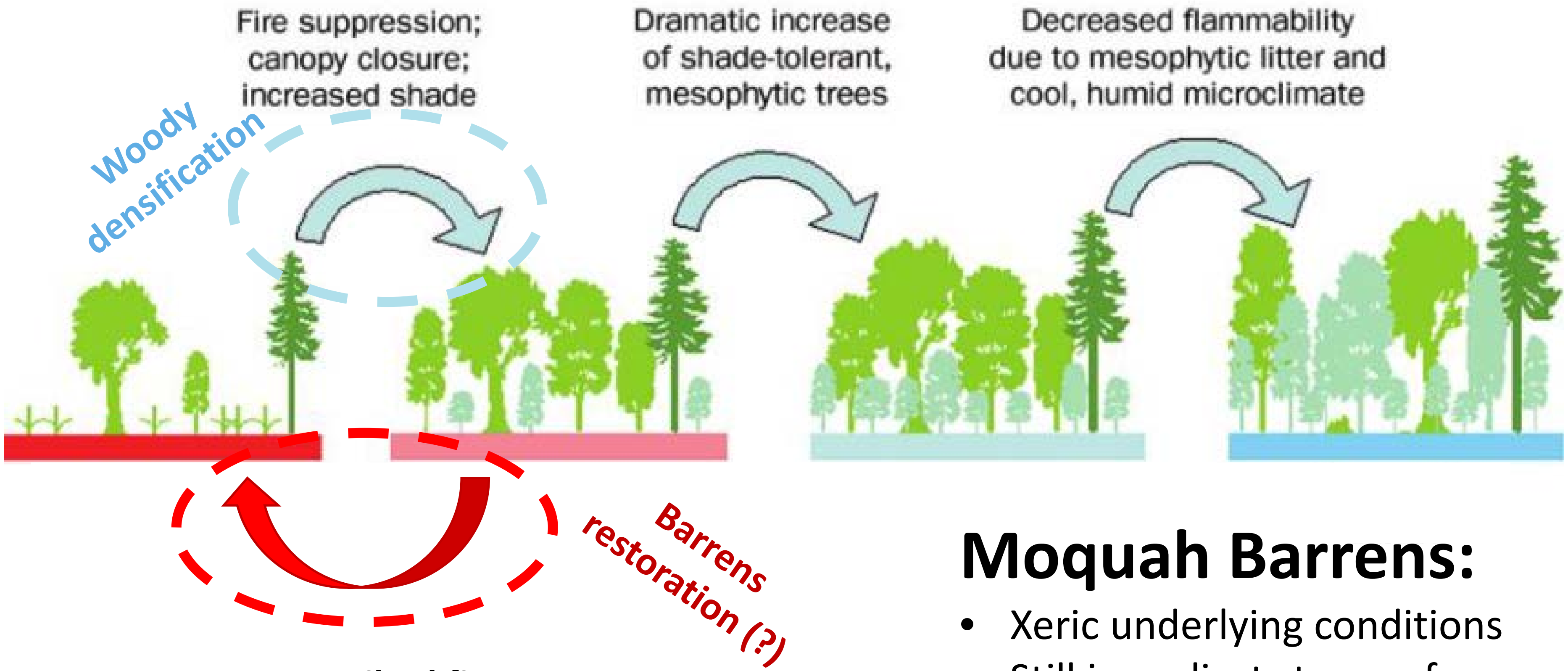


Take home messages & management implications

SOILS:

- Duff consumption and soil heating were minimal
  - Consider burning when duff is drier
- Soil nutrients respond to fire, but the effects of a single burn are minimal and ephemeral
- Plots which have been burned several times recently have higher hydraulic conductivity than unburned reference plots
  - Frequent/repeated burns may be necessary for Rx fire effects to persist (*i.e.* maintain thin duff layer & low organic matter)

Returning to Nowacki and Abrams (2008):

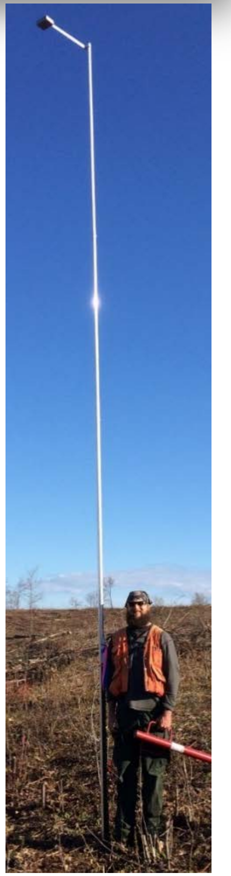


Prescribed fire:
Decreased soil nutrient stocks, increased soil hydraulic conductivity

Moquah Barrens:

- Xeric underlying conditions
- Still in earliest stages of mesophication
- Best chance for reversal of woody densification
- Restore soil conditions to a 'barren' state that supports native species tolerant of drought and low nutrients (sweet fern, blueberry)

It takes a village!



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