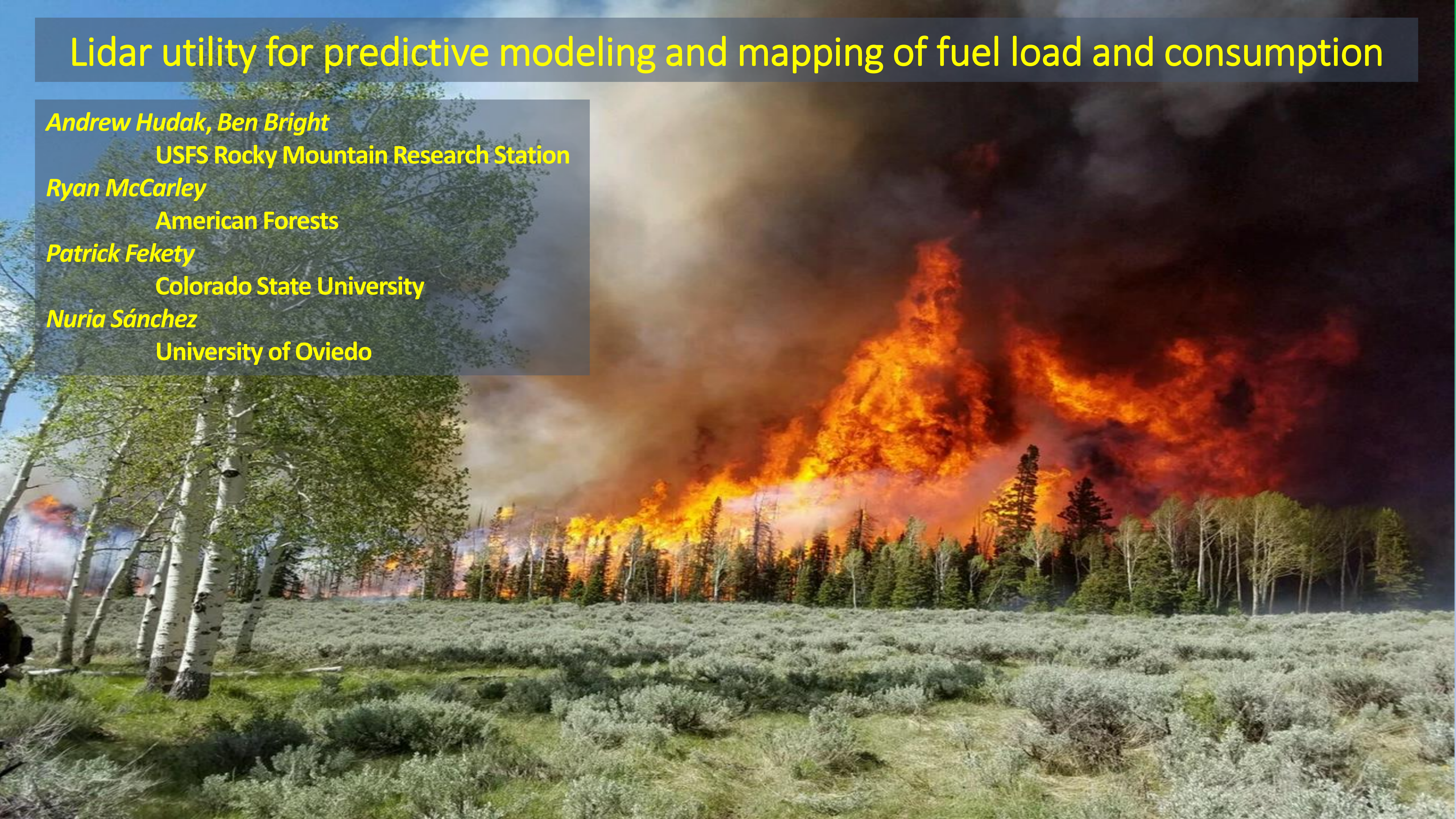
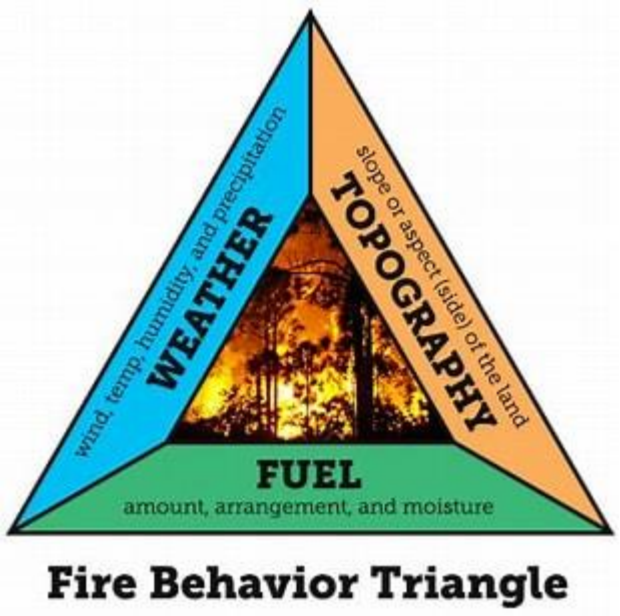
Lidar utility for predictive modeling and mapping of fuel load and consumption

Andrew Hudak, Ben Bright
USFS Rocky Mountain Research Station
Ryan McCarley
American Forests
Patrick Fekety
Colorado State University
Nuria Sánchez
University of Oviedo



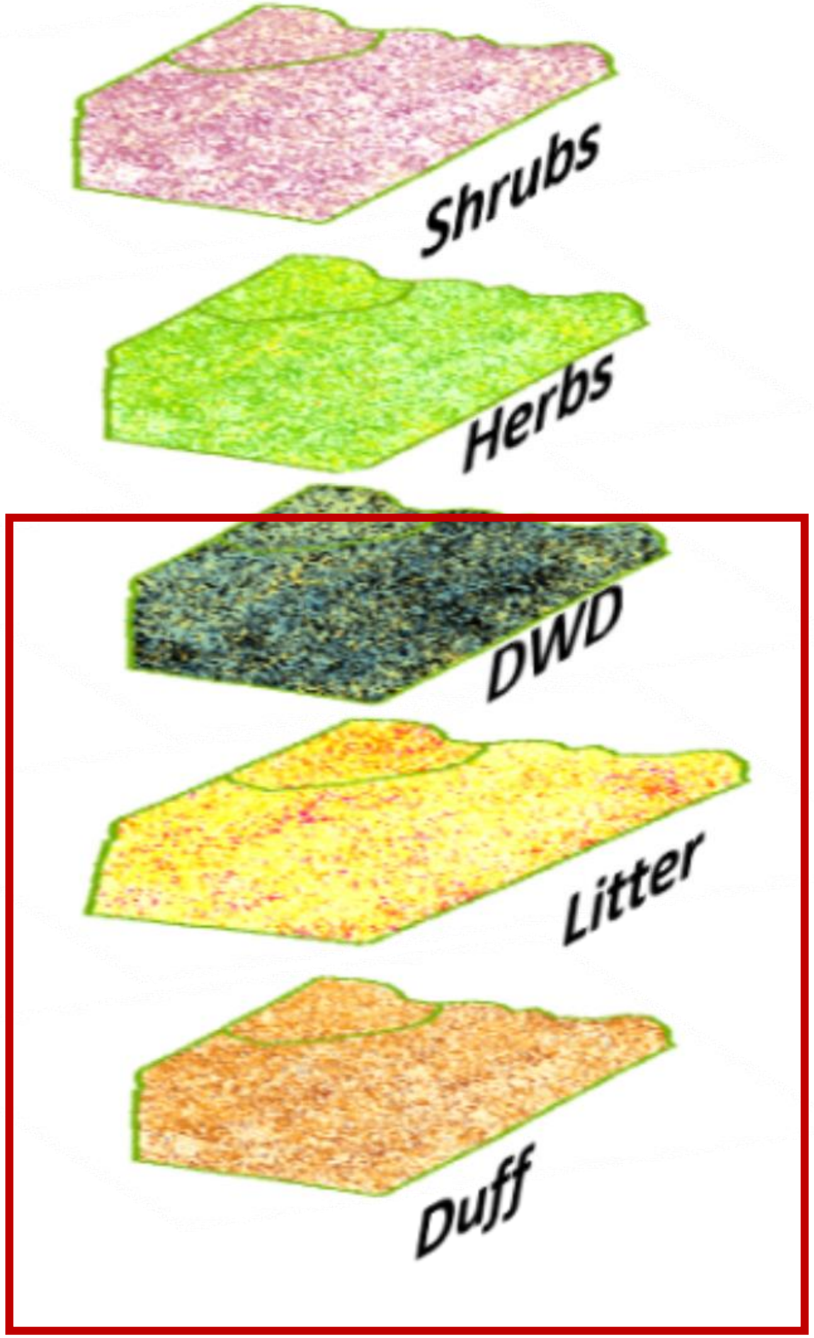
Why?

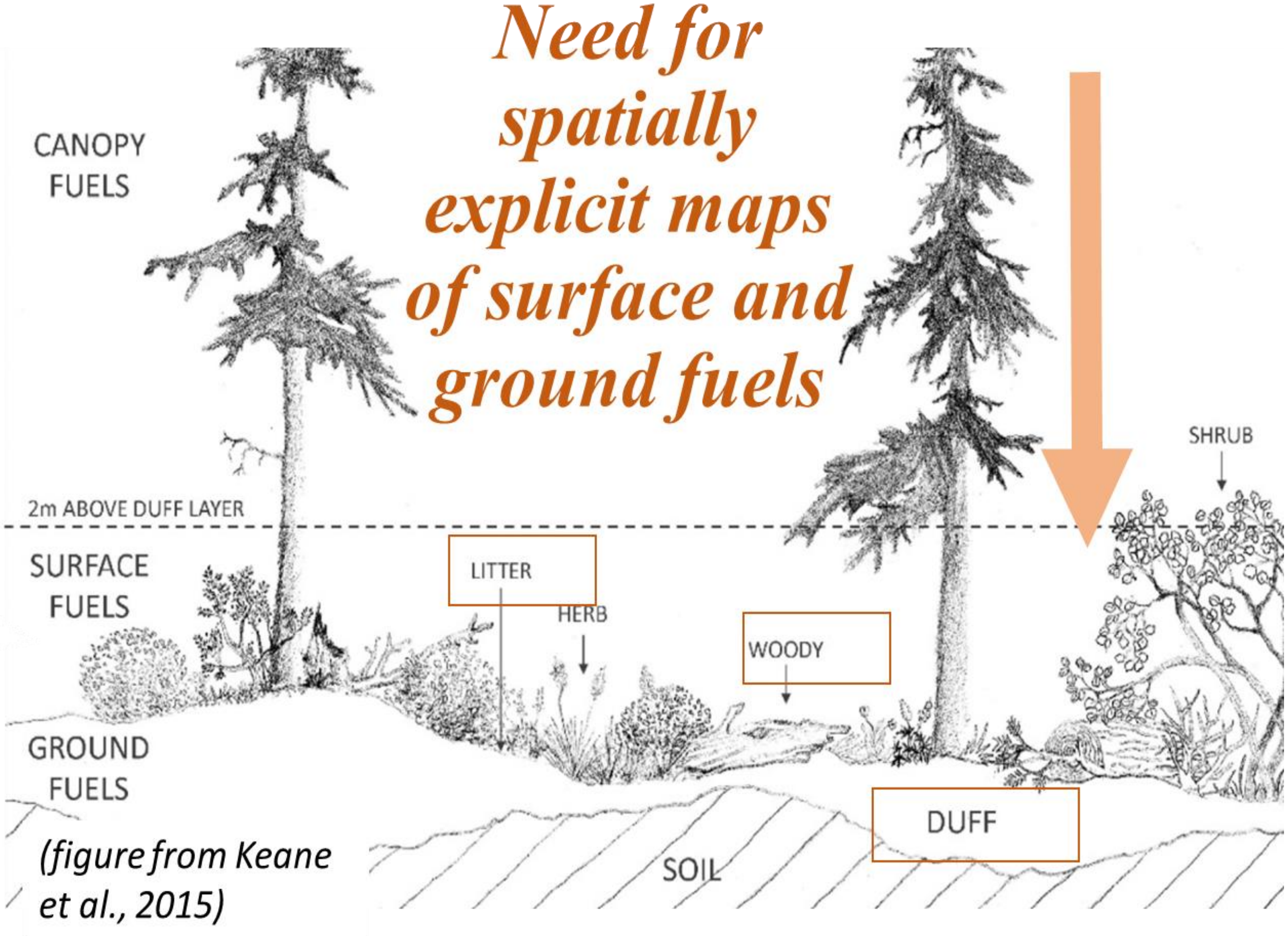


Only fuels can be managed to affect wildland fire outcomes

Introduction and Outline

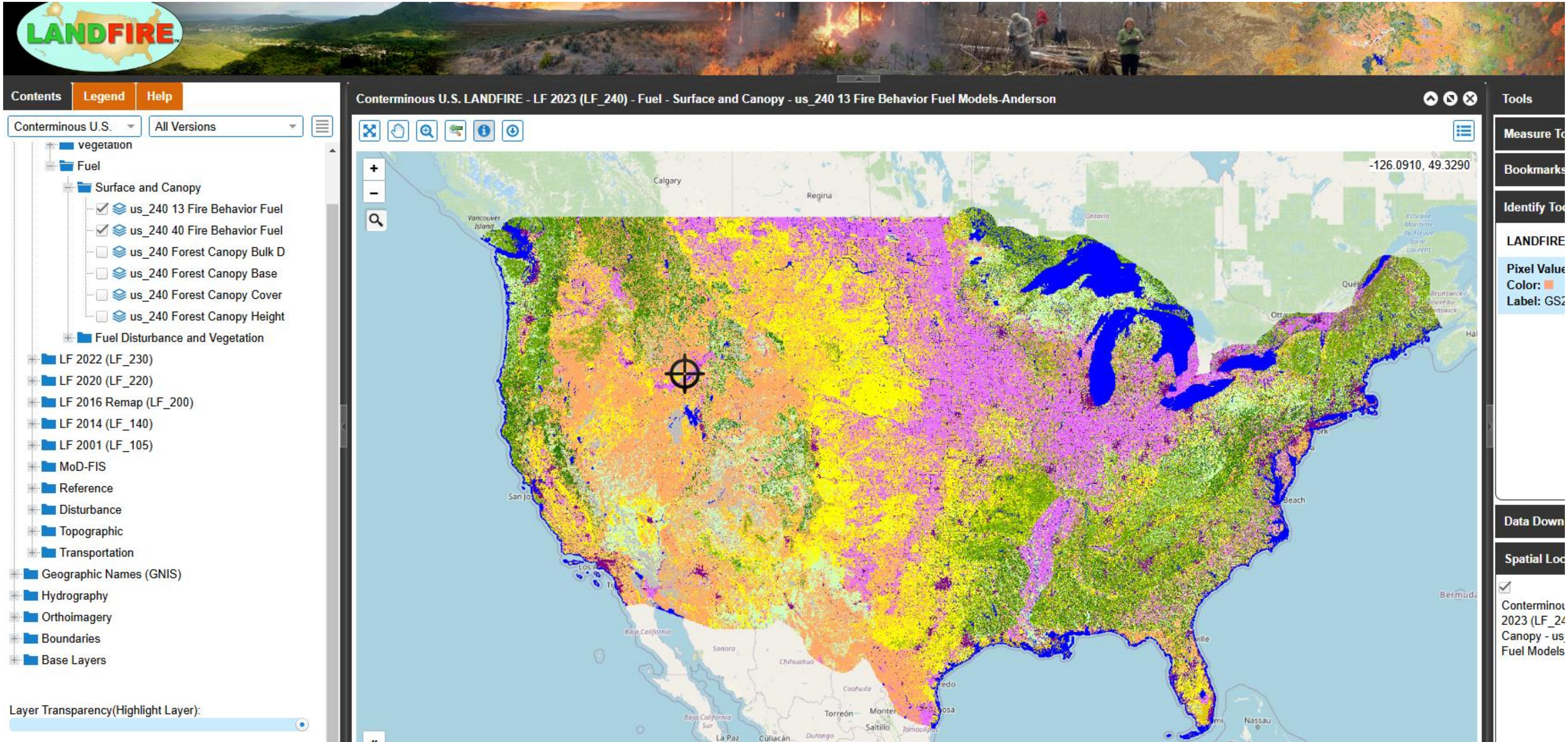
- Airborne lidar: next generation landscape-regional fuel maps
  - Physical fuel attributes as continuous variables; e.g., fuel load (density, Mg/ha)
  - Opportunities for consumption mapping
- Opportunities for estimating fuel consumption
  - Prescribed fires
  - Wildfires
- Coupling surface fuel estimation to canopy biomass
  - Model canopy fuels from lidar directly
  - Model surface fuels from lidar indirectly


Shrubs
Herbs
DWD
Litter
Duff


Need for spatially explicit maps of surface and ground fuels
CANOPY FUELS
2m ABOVE DUFF LAYER
SURFACE FUELS
GROUND FUELS
LITTER
HERB
WOODY
SHRUB
DUFF
SOIL
(figure from Keane et al., 2015)

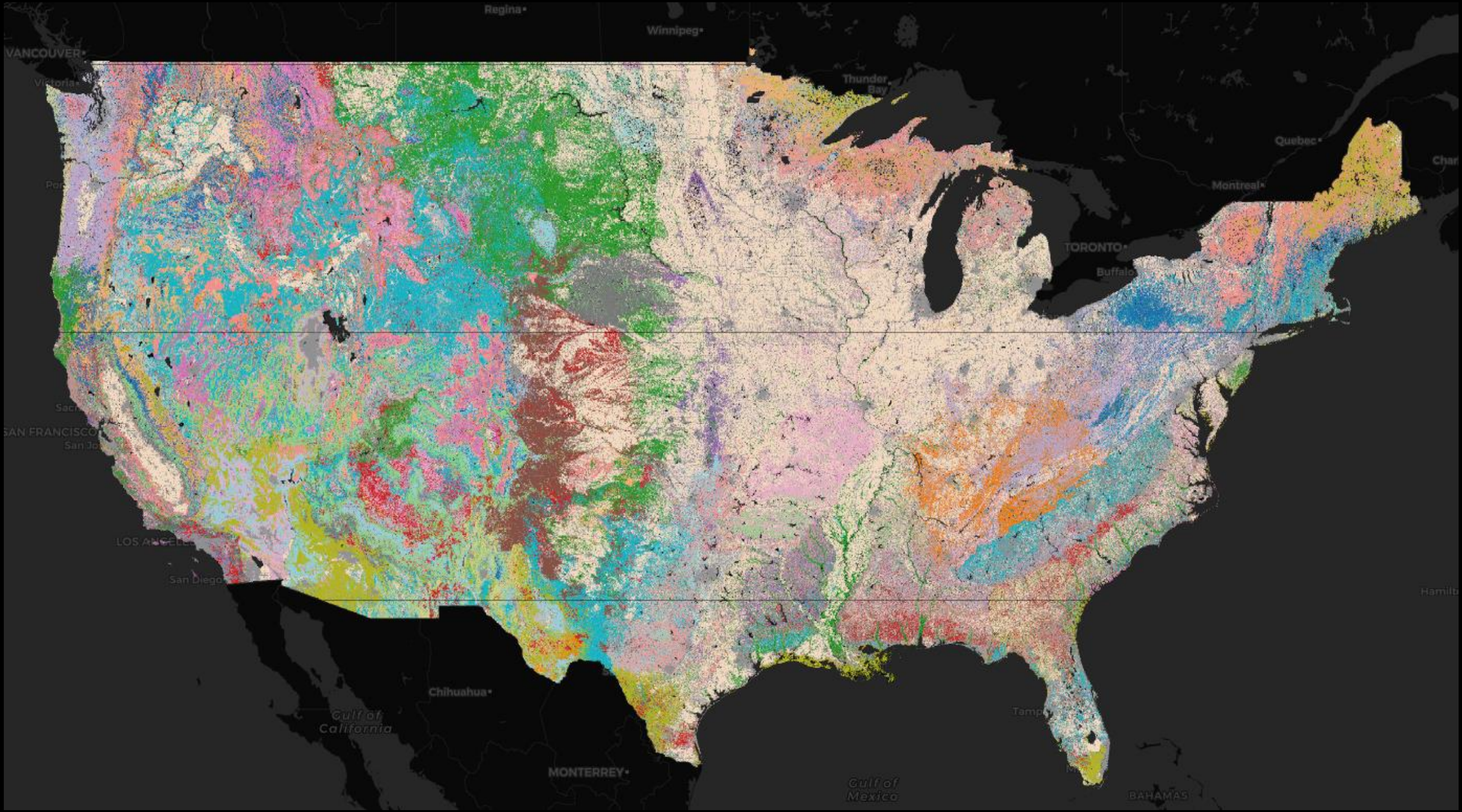
Limitations of current techniques

Characterization of fuel properties by classification -- FUEL TYPES



NAWFD: The North American Wildland Fuels Database

Michigan Tech
Research Institute



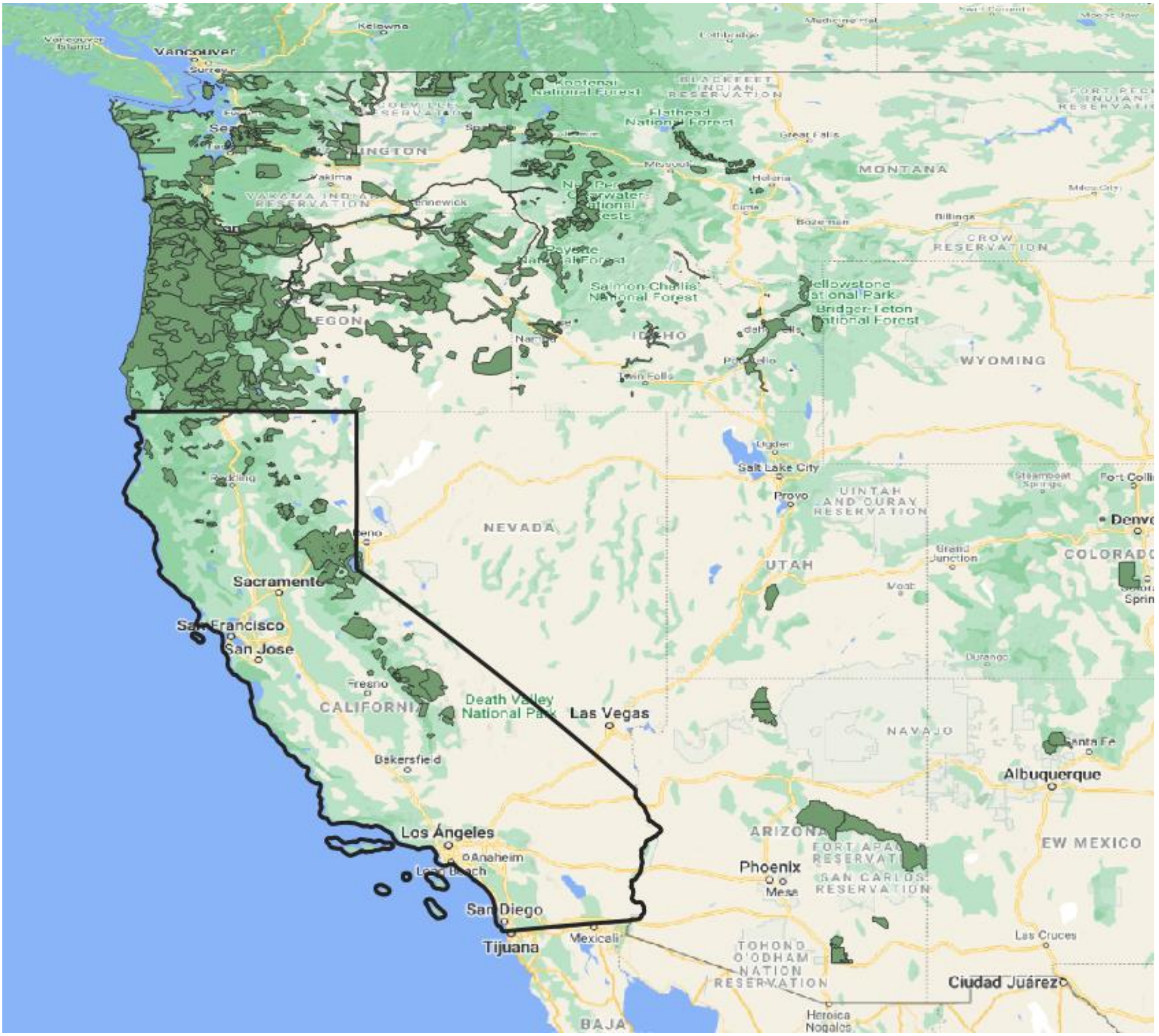
Existing Vegetation

- 211 groups aggregated from LANDFIRE EVT's
- Landsat-based; CONUS+Alaska mapped at 30m spatial resolution

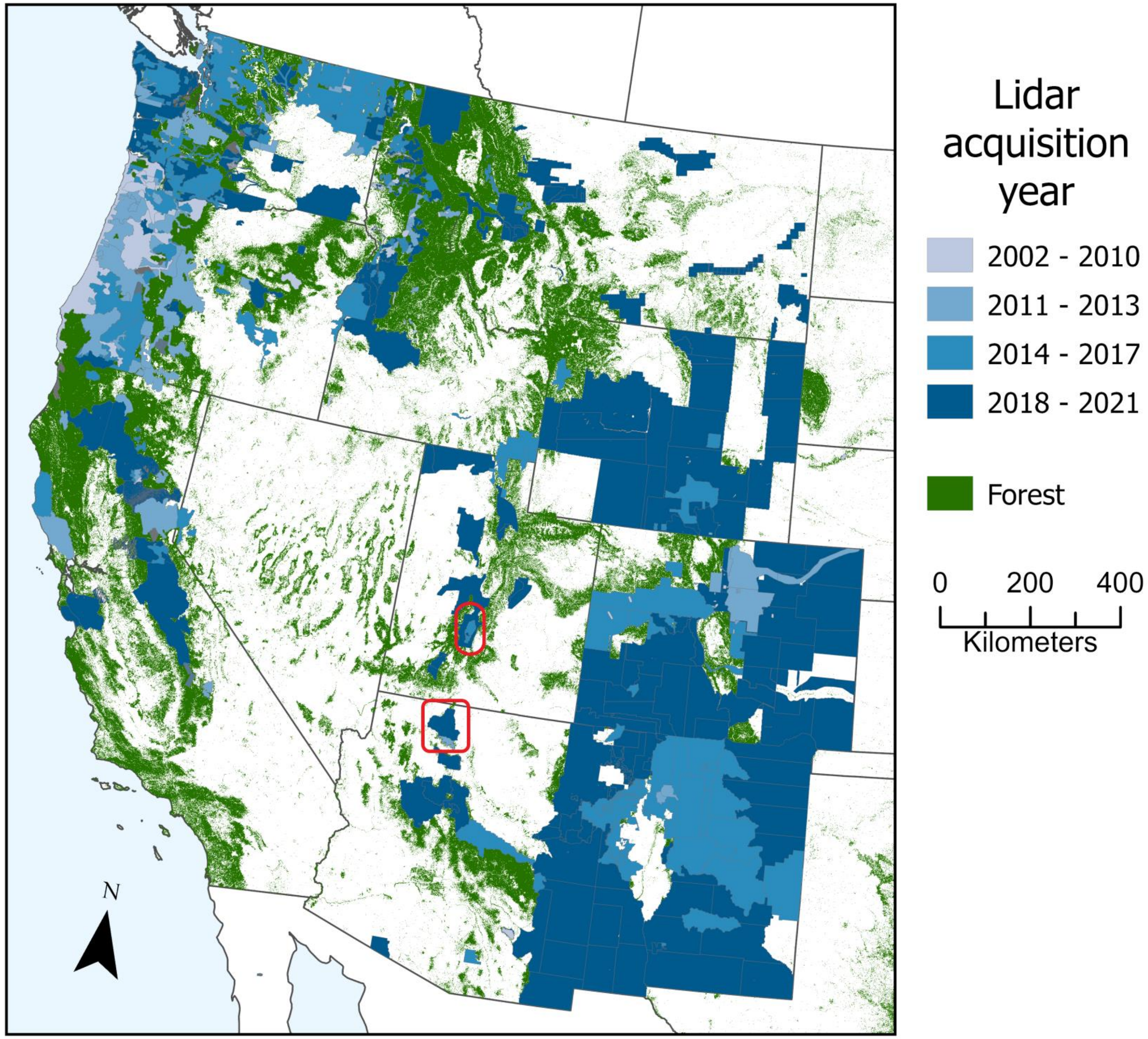
https://fuels.mtri.org

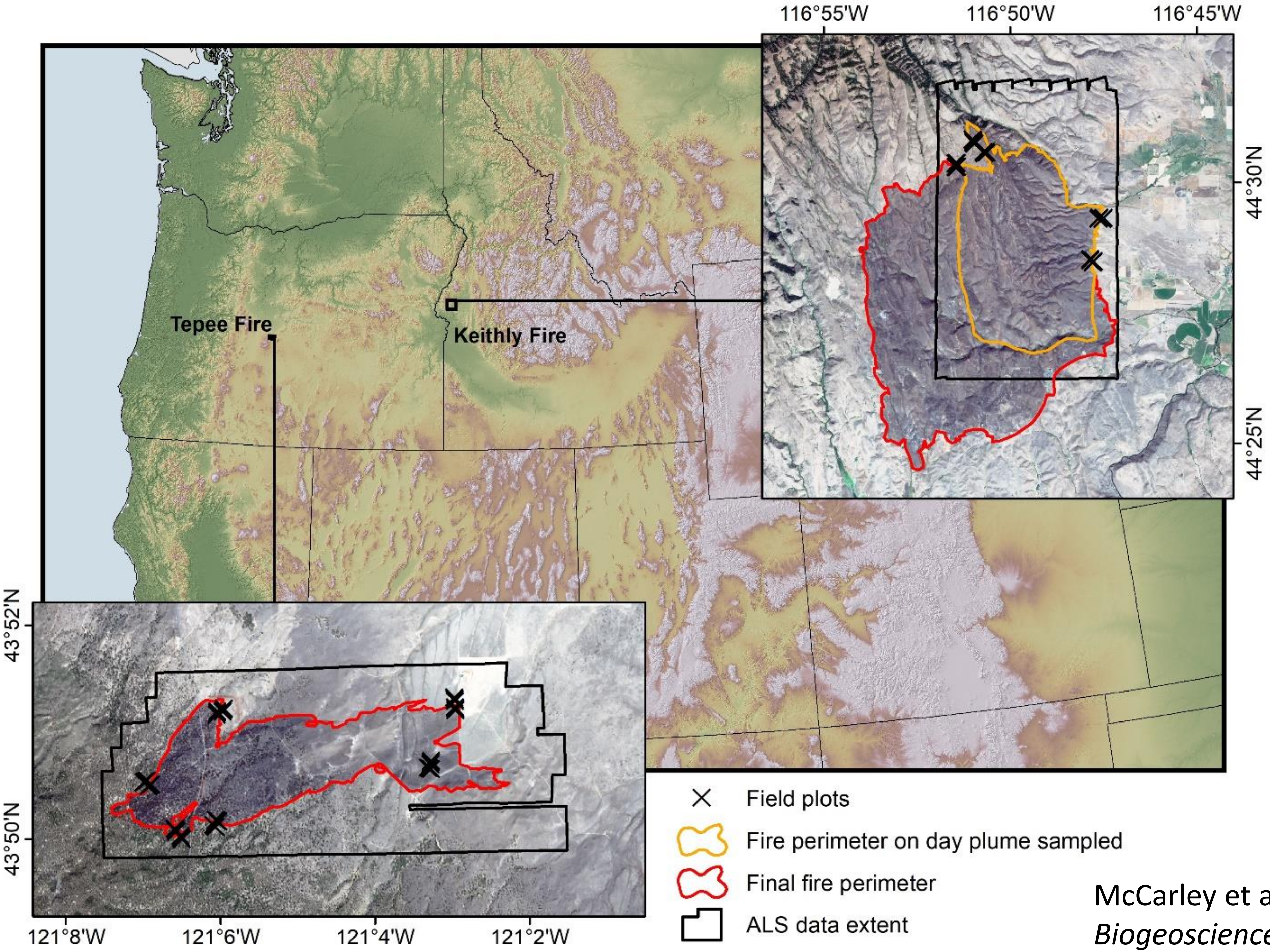
Lidar Coverage in Western US

circa 2019



circa 2023





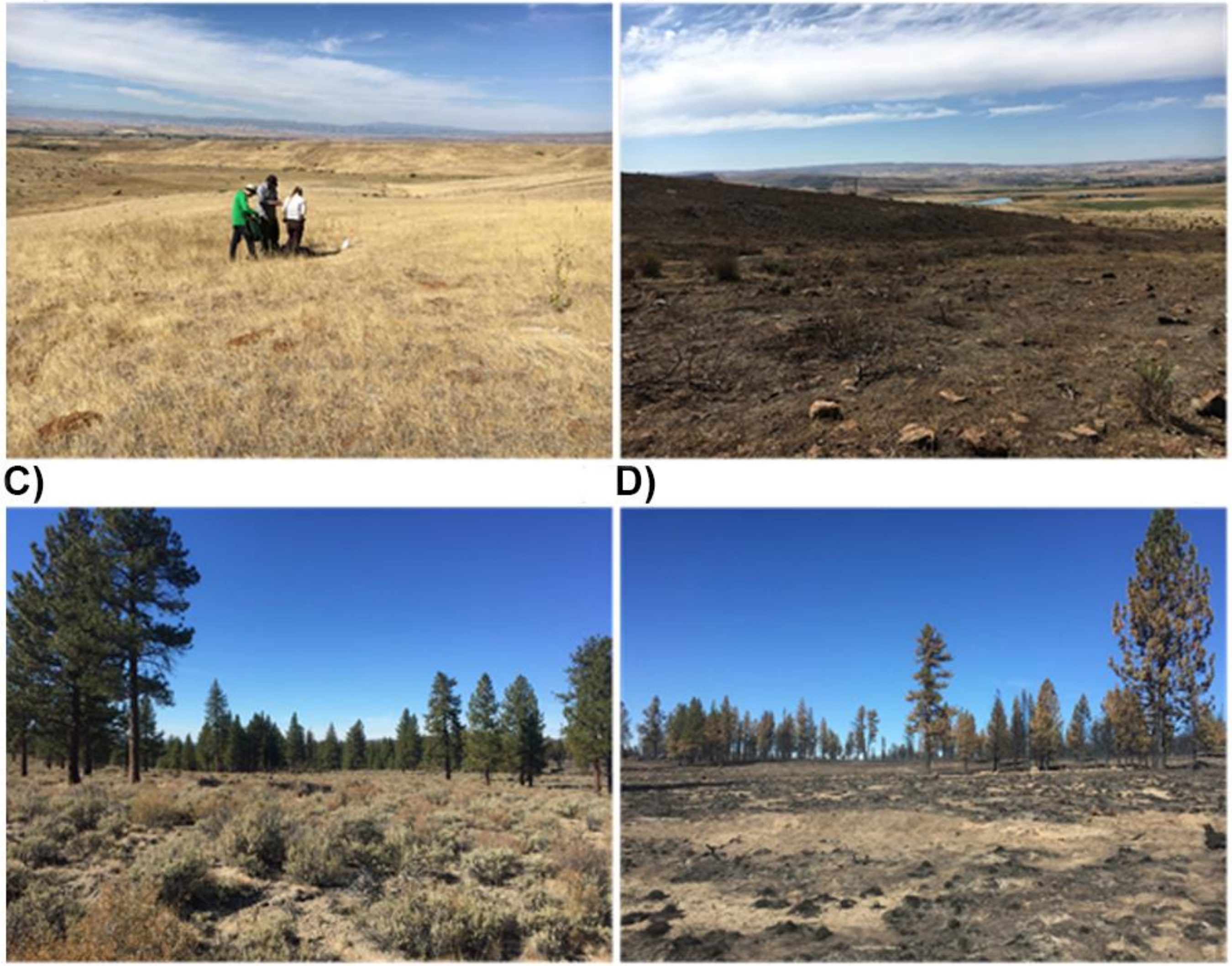
McCarley et al. (2022) *Geophysical Research: Biogeosciences* 127: e2021JG006733.

A) Keithly unburned

B) Keithly burned

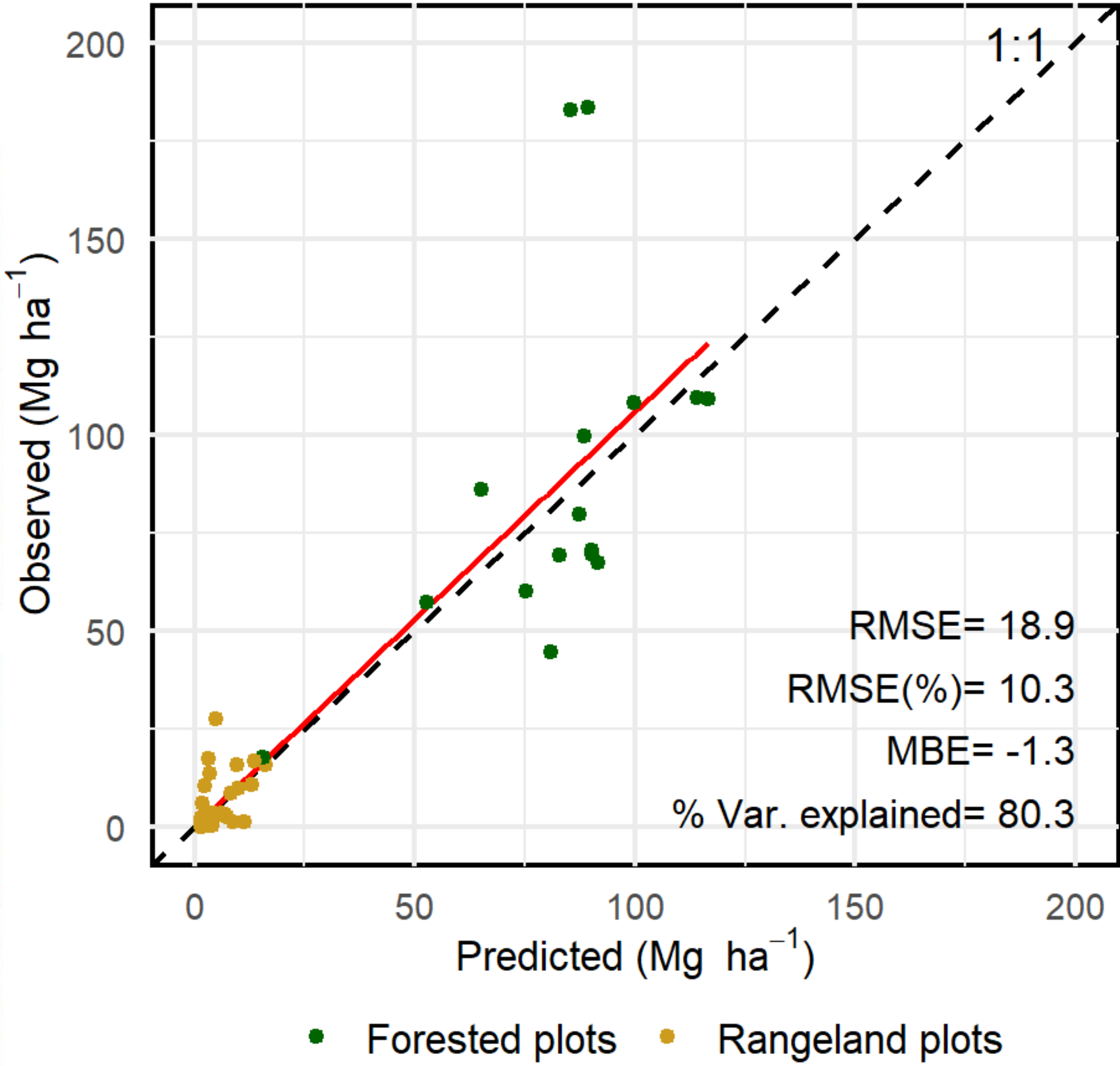
C)

D)

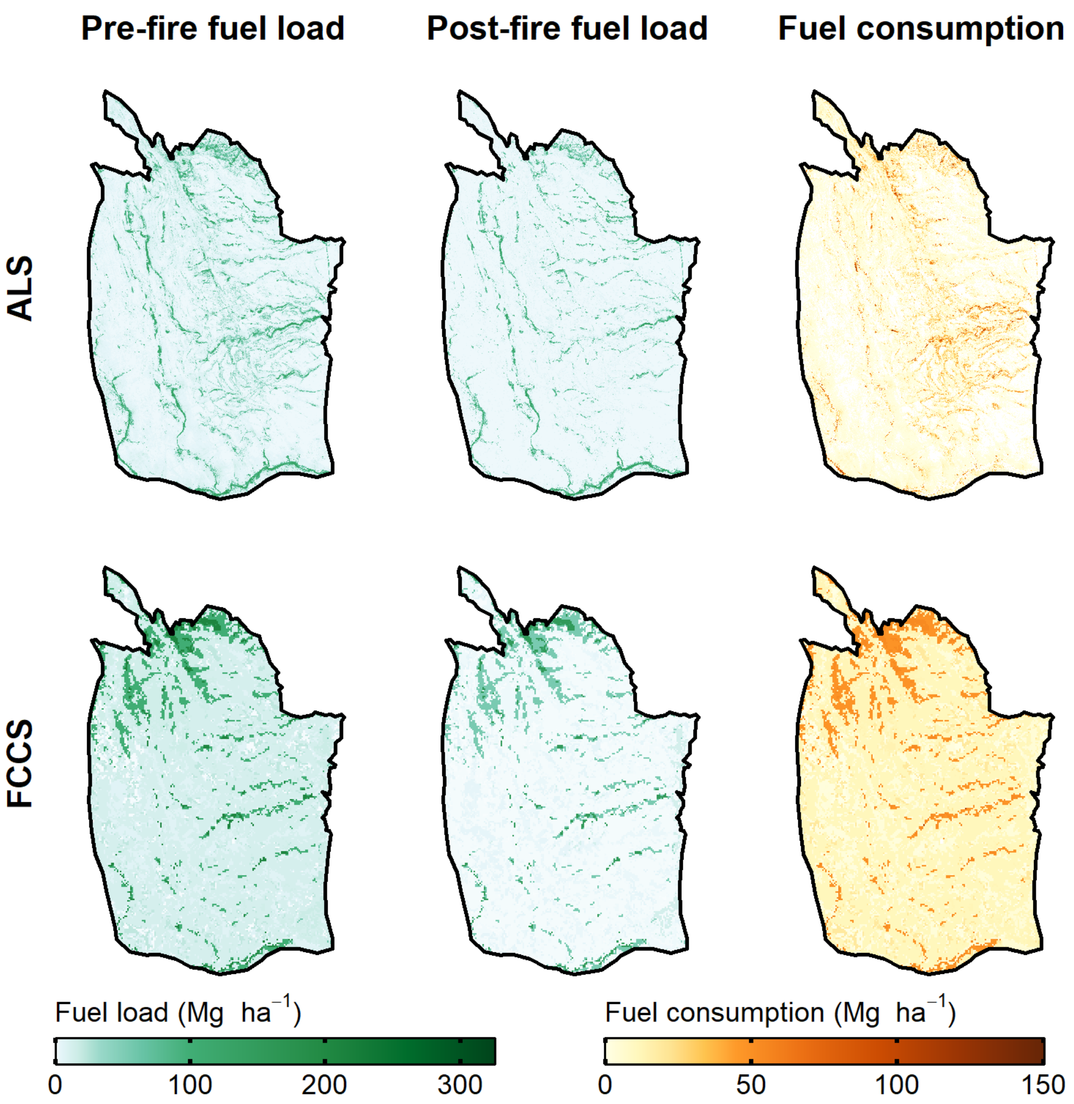


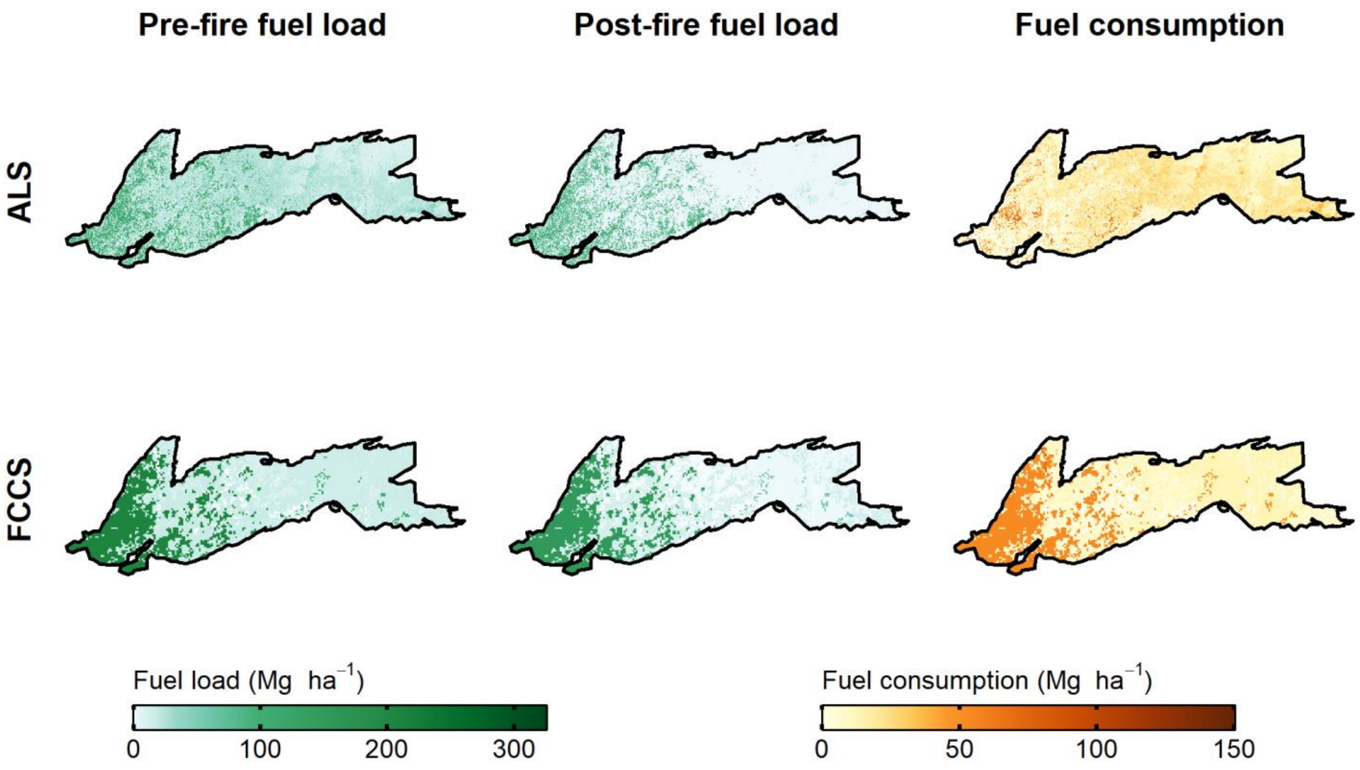
Tepee unburned

Tepee burned

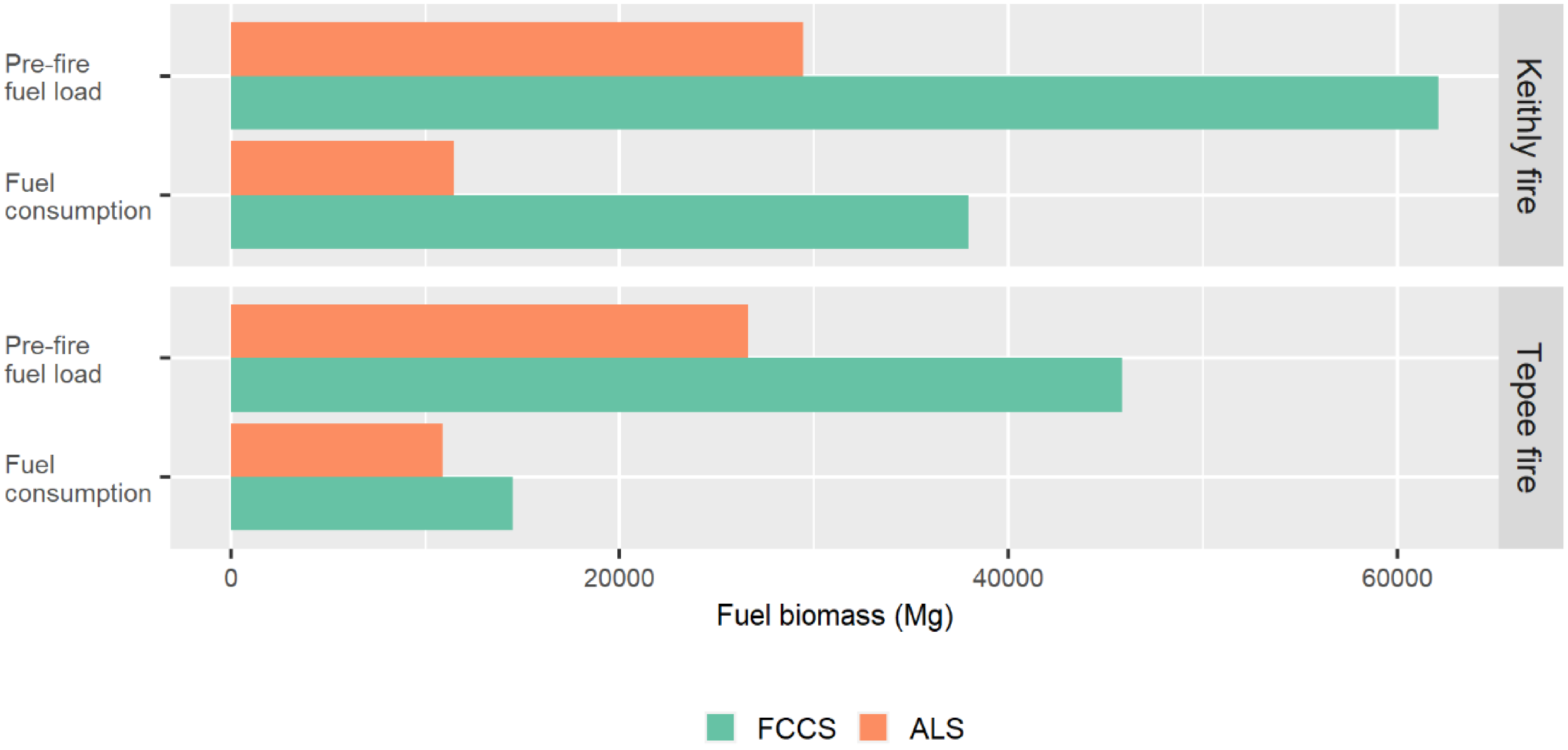


McCarley et al. (2022) *Geophysical Research: Biogeosciences* 127: e2021JG006733.





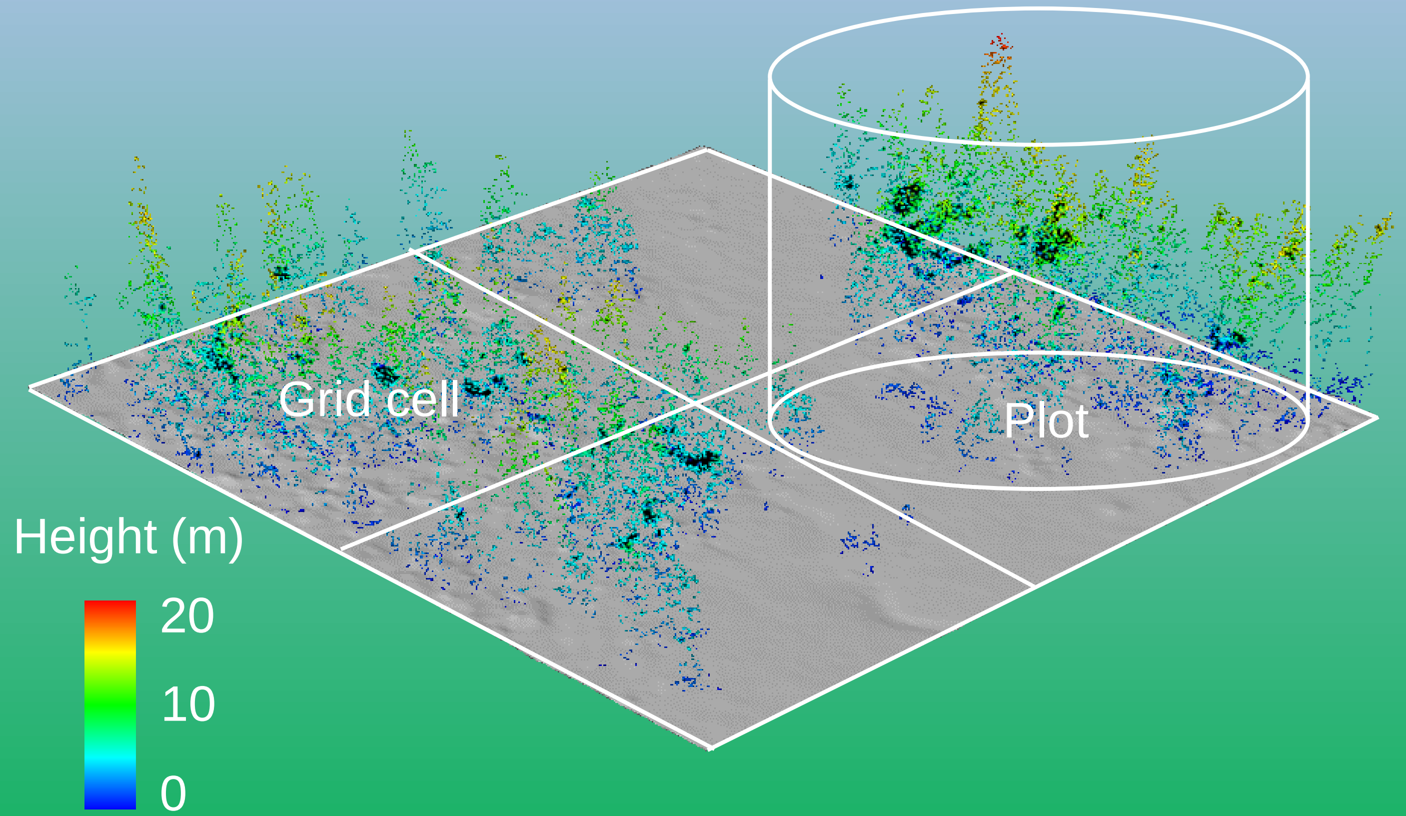
McCarley et al. (2022) *Geophysical Research: Biogeosciences* 127: e2021JG006733.



McCarley et al. (2022) *Geophysical Research: Biogeosciences* 127: e2021JG006733.

Airborne lidar data processing to predict forest structure and fuel attributes

- Forest structure attributes measured in forest inventory plots
- Absolute return heights converted to heights above ground level
- Returns coincident with plots summarized to produce metrics
- Models fitted to predict plot attributes from plot-level lidar metrics
- Same lidar metrics calculated in raster grid cells across lidar extents
- Fitted models applied to gridded lidar metrics



“Living” Database of Project-Level Reference Plots

(This “living” database is comprised of field AND lidar reference data.)

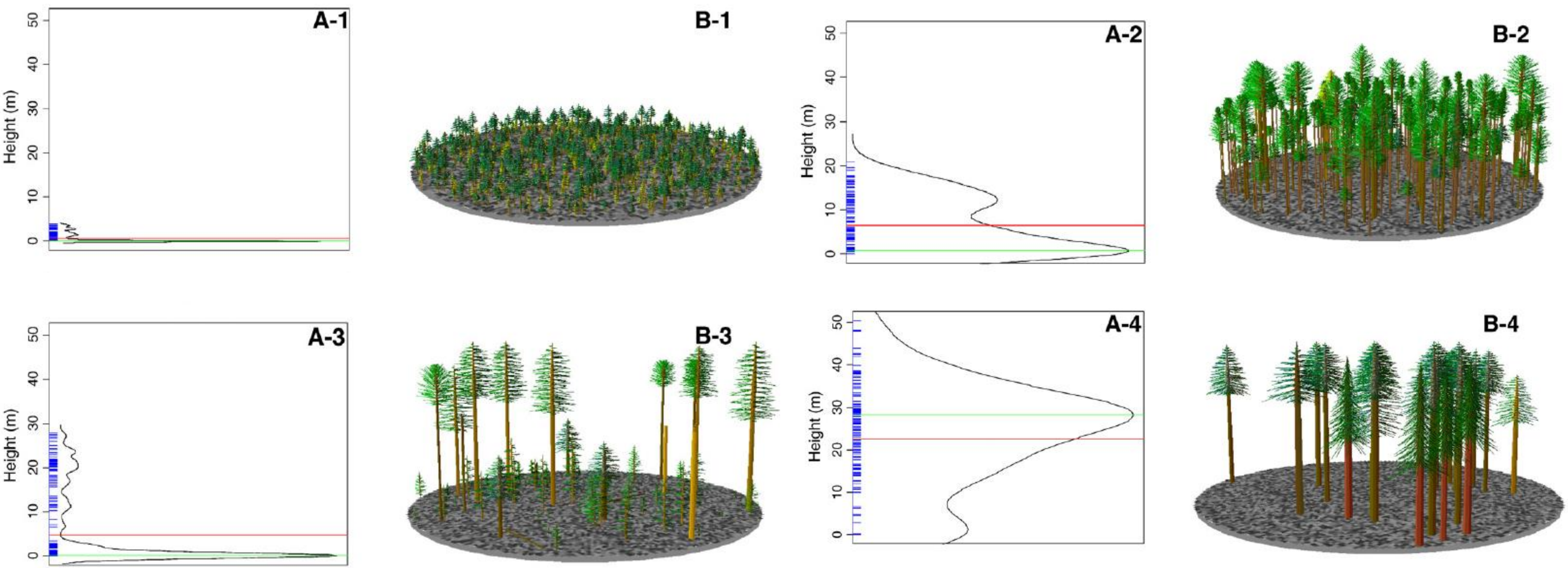


Figure credit: Patrick Fekety

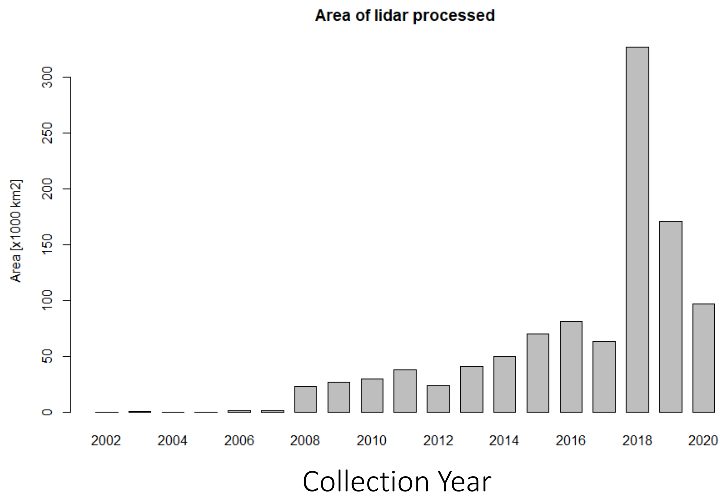
Expanding database of stakeholder-contributed plots and lidar

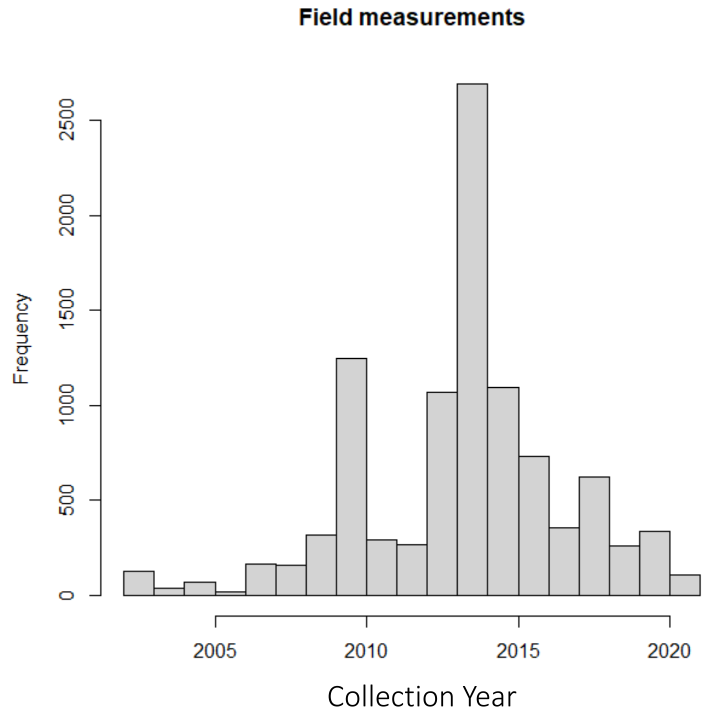
Through Phase 2:

- Processed >1.2M km^2 lidar collections for 604 project areas (colors indicate which cooperator processed the lidar using a divide-and-conquer strategy)
- Assembled 9,988 project-level inventory plots contributed by USFS, other federal, state, tribal, academic stakeholders (n=45…*and counting*)

Phase 3:

- Continue to add lidar collections and inventory plots contributed by stakeholders





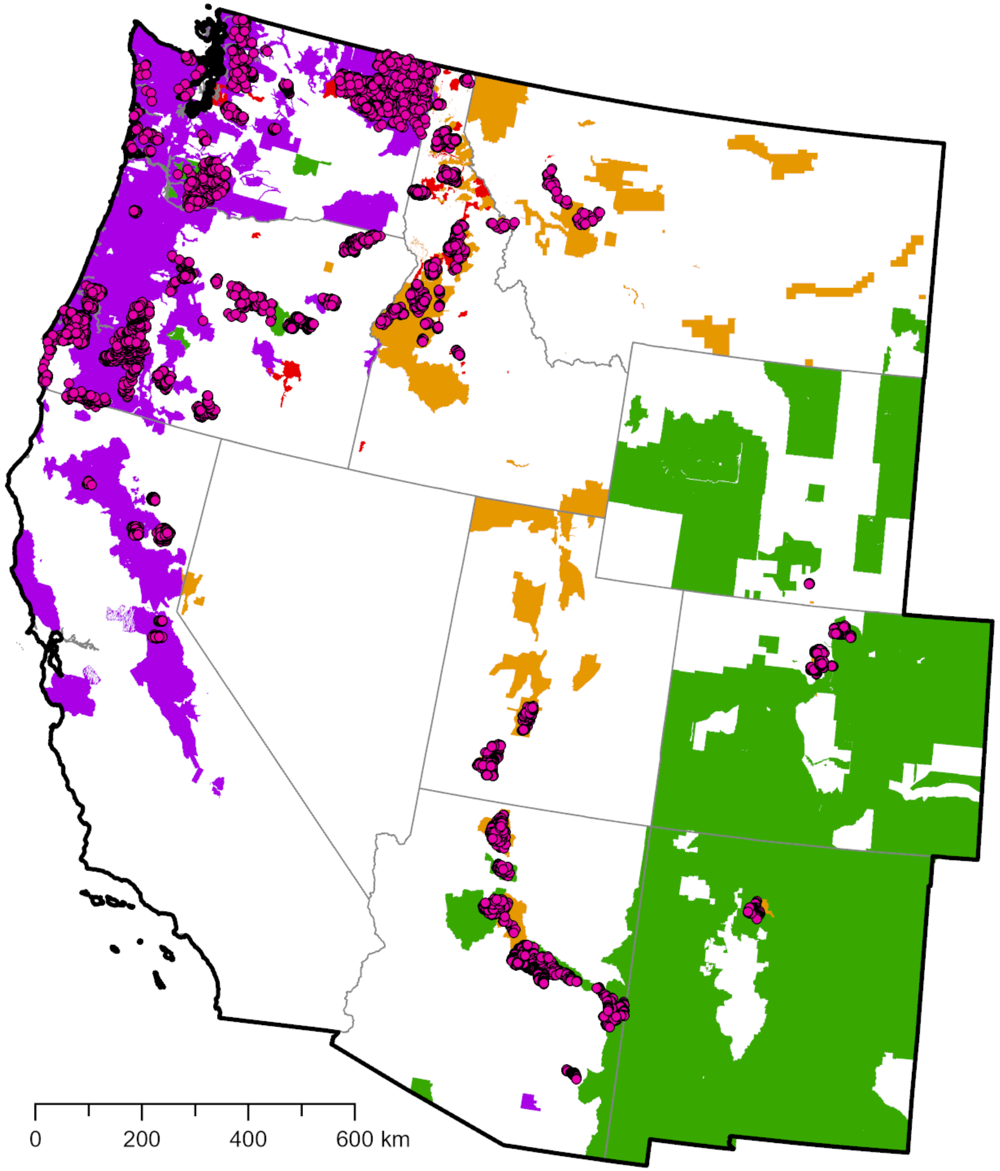


Figure credit: Patrick Fekety

Forest structure and fuel attributes needed by stakeholders:

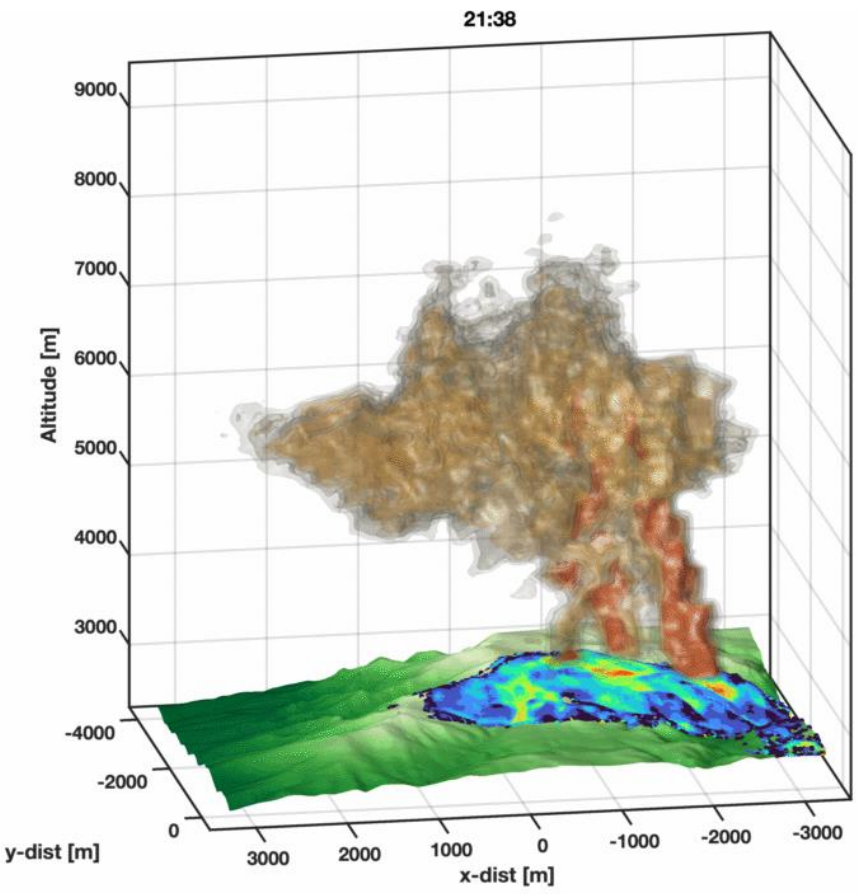
- Aboveground Biomass (carbon)
- Basal Area (timber)
- Total Volume (timber)
- Board Feet (timber)
- Quadratic Mean Diameter (timber)
- Stand Density Index (timber)
- Trees Per Hectare (timber)
- Snags Per Hectare (wildlife)
- Canopy Bulk Density (fuels)
- Canopy Fuel Load (fuels)
- Foliage Biomass (fuels)
- Downed Woody Biomass (fuels)

These variables are being mapped wall-to-wall and annually (1985-present); Next step is to provide plot ID maps at 30m resolution that join to tree lists.

NASA Carbon Monitoring Systems (CMS) project survey

- https://forms.office.com/r/TSx9CYnGnw

Western Prescribed Fire and Wildfire Opportunities



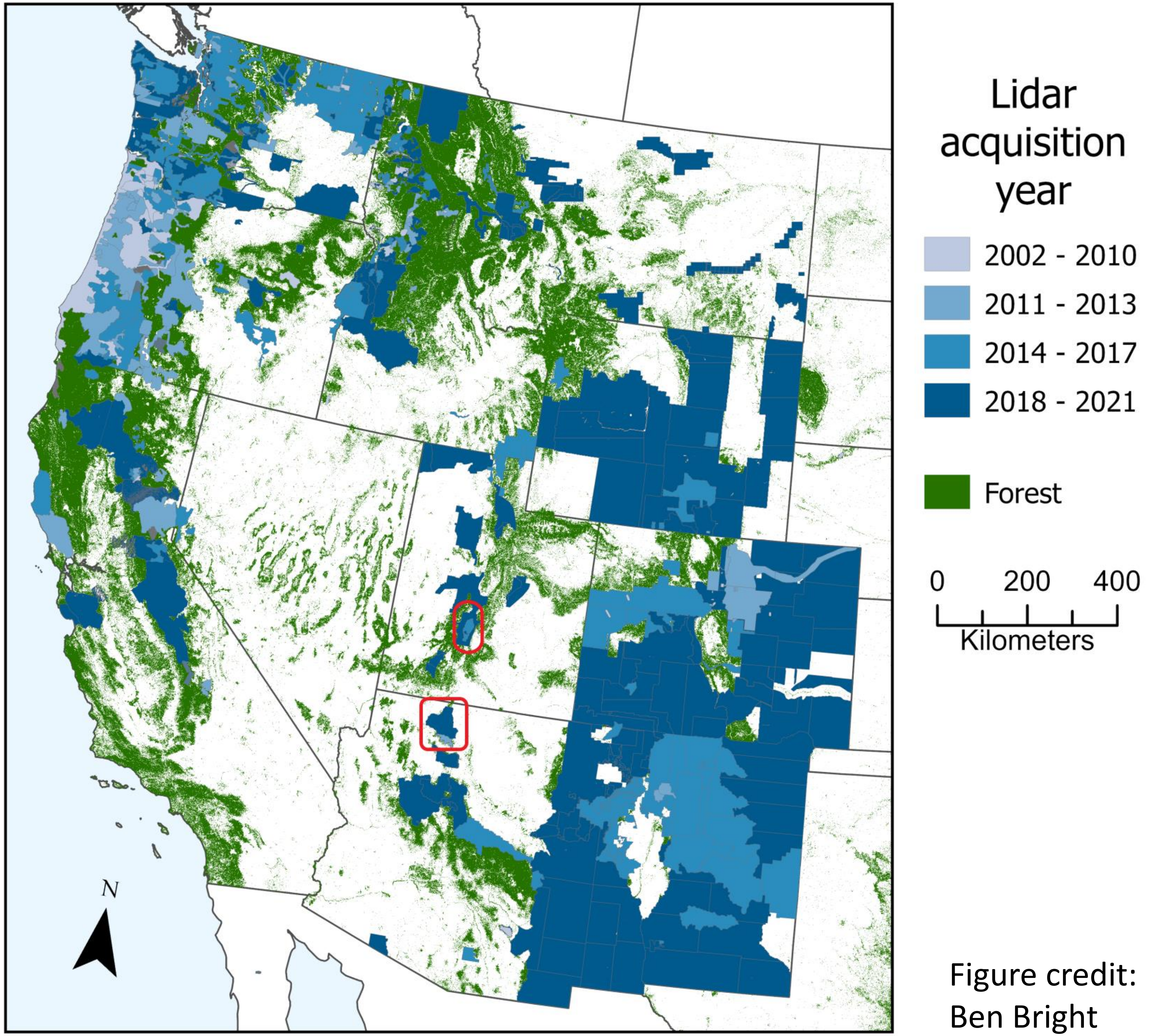


Figure credit: Ben Bright

Western Prescribed Fire and Wildfire Opportunities

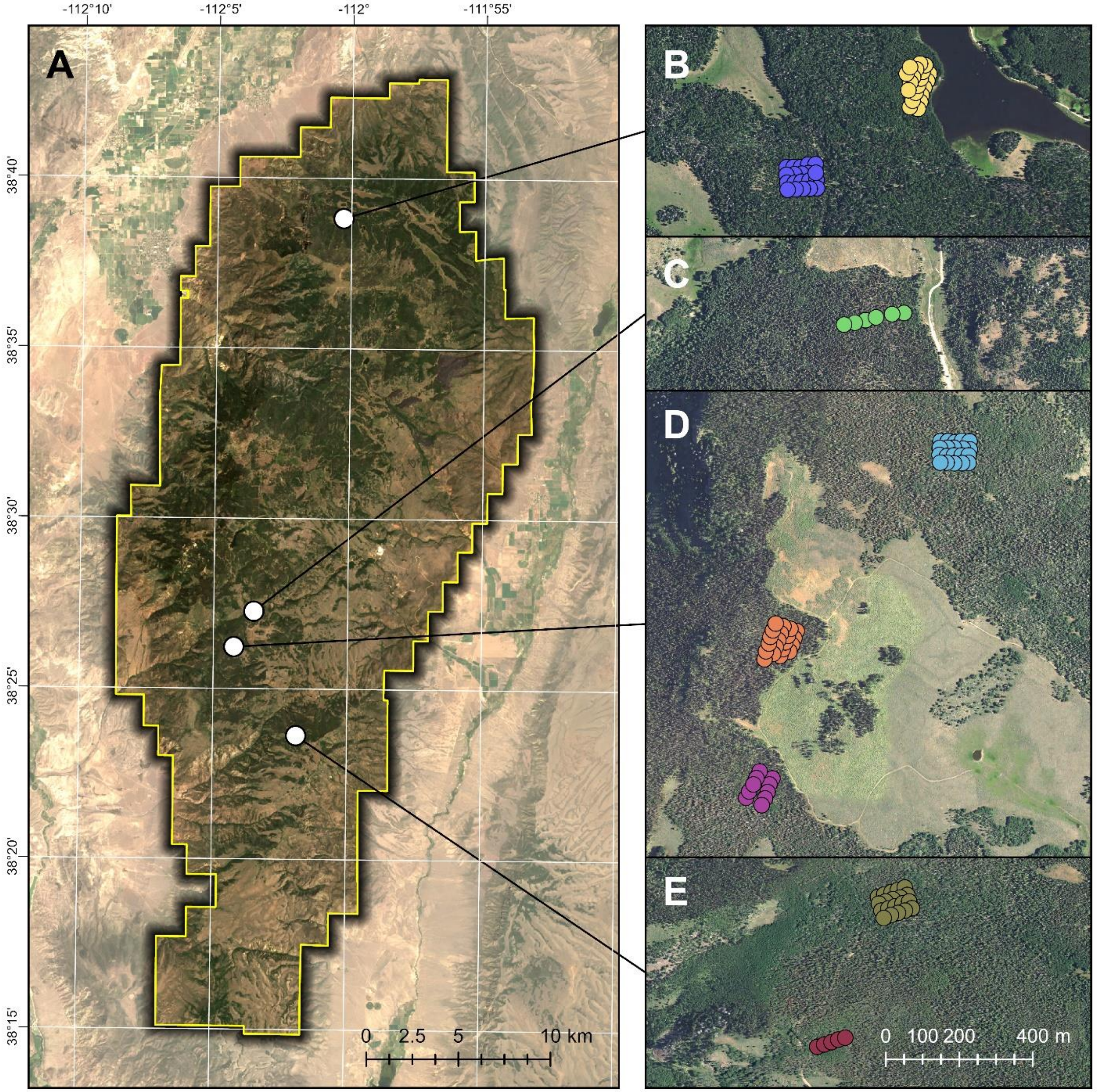
Monroe Mountain, Fishlake National Forest, Utah

Pre-fire

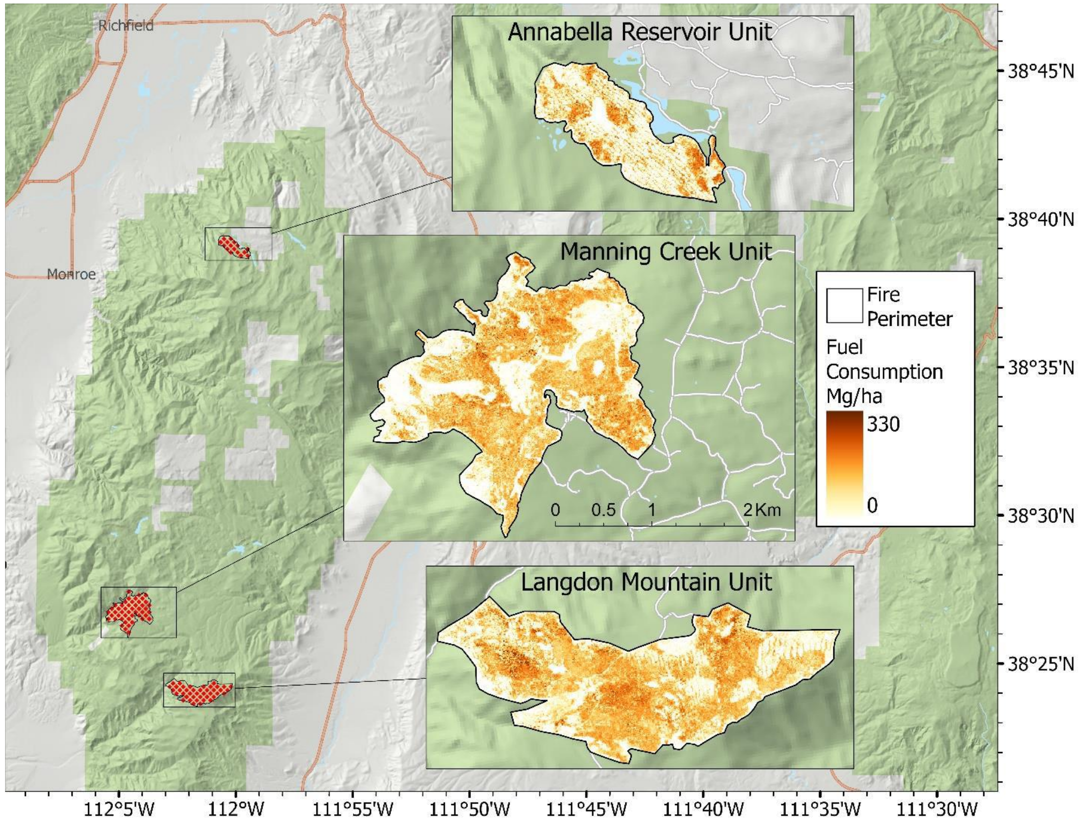
Post-fire

Prescribed crown fires behaving like wildfires create safer opportunities for co-located pre- and post-fire field plots

Monroe Mountain, Utah



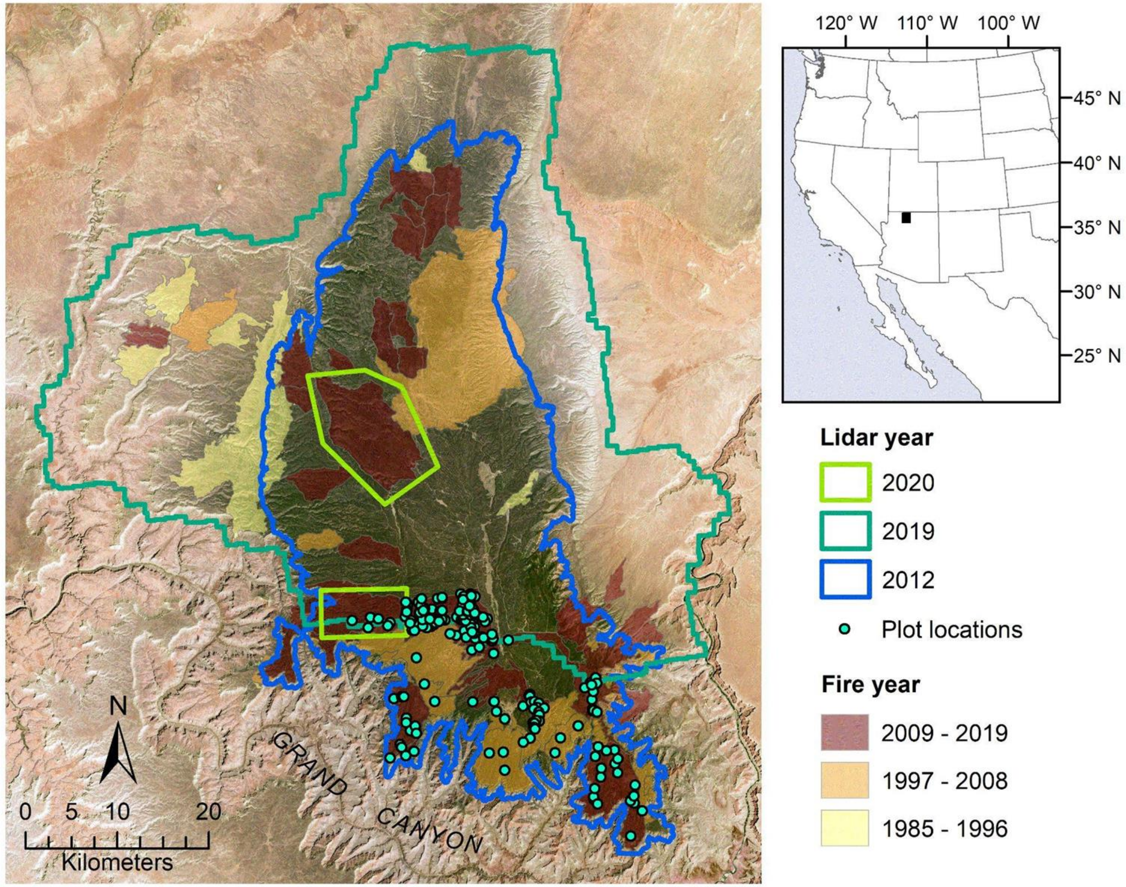
Campbell et al. (In Review), *Science of Remote Sensing*

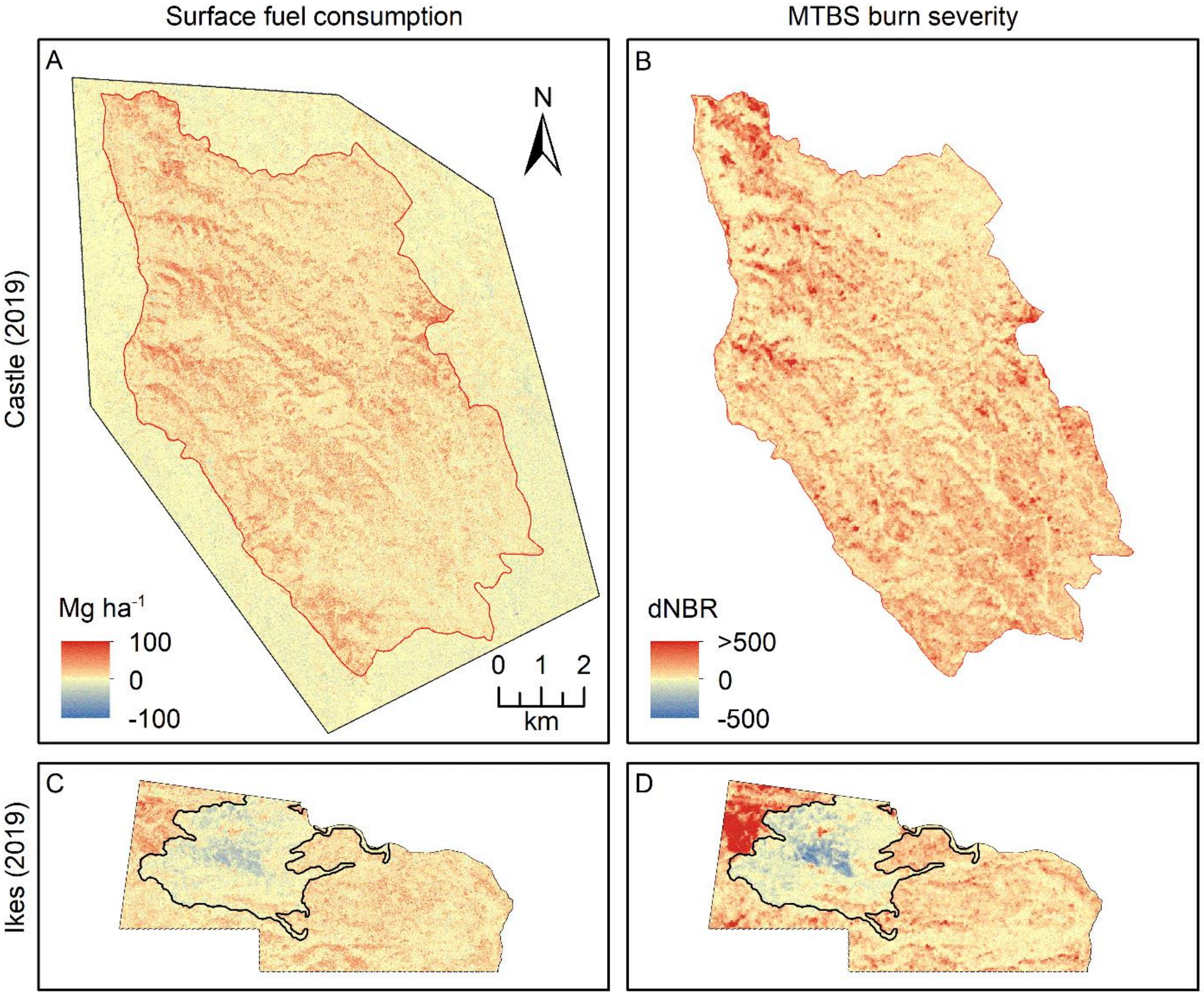


	%Var. Exp.
Fuel Type	*RF Model*
Canopy	76.0
DWD	33.9
Litter	42.9
Duff	25.6
Total fuel	64.9
Subcanopy fuel	31.4
ACF	73.7

McCarley et al. (2024) *IJWF* 33: WF23160

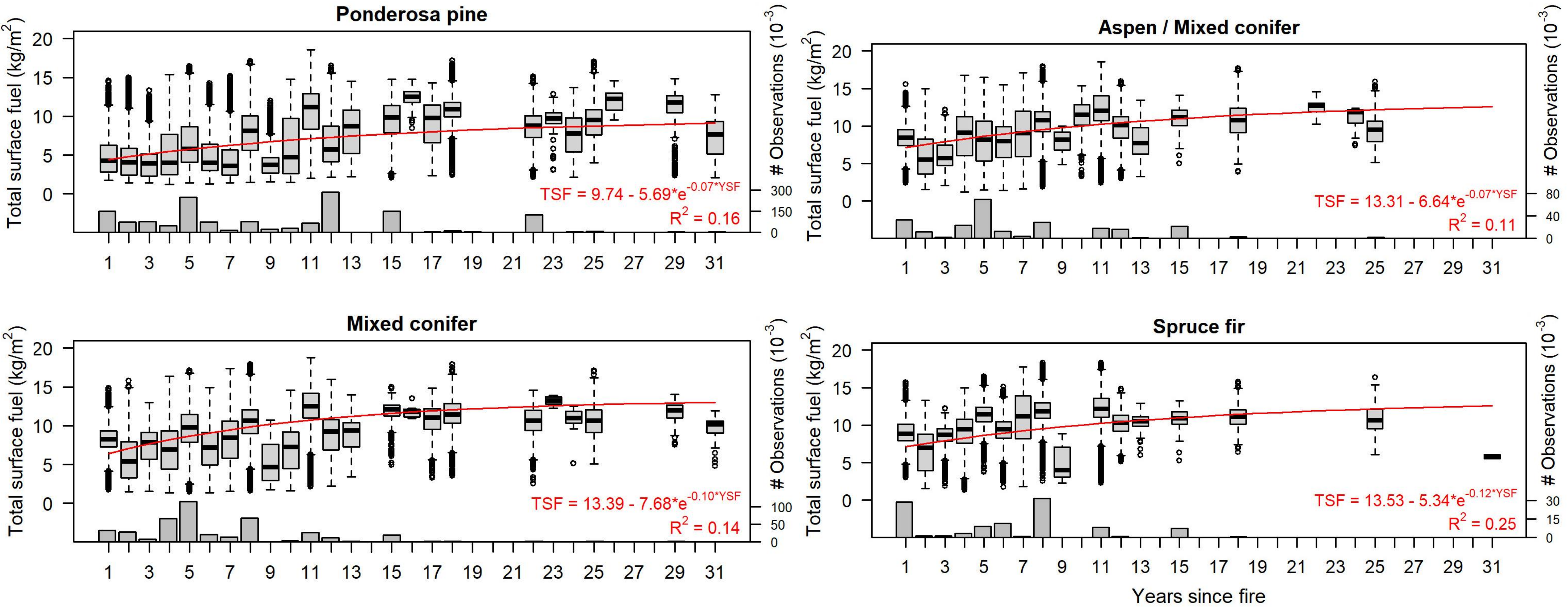
Kaibab Plateau, Arizona





Maps of predicted surface fuel consumption versus burn severity at the 2019 Castle Fire and Ikes Fire in Arizona. The black perimeter represents the 2018 Stina Fire within the 2019 Ikes Fire (Bright et al. 2022).

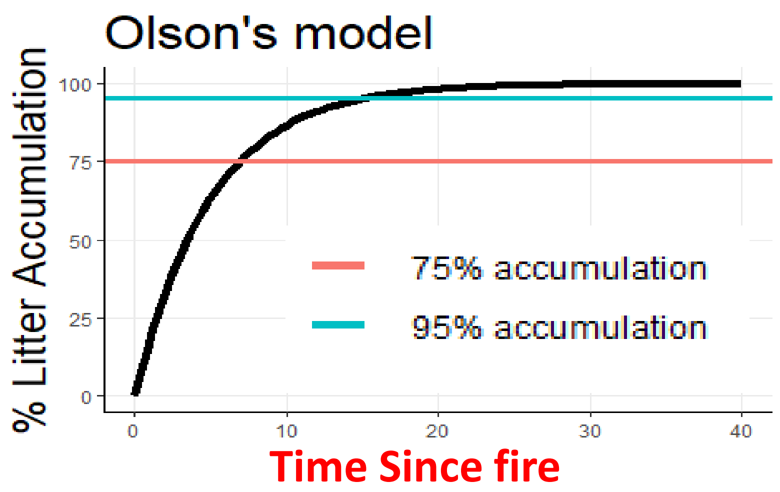
Surface fuel accumulation with time since fire



Bright et al. (2022) *Fire Ecology* 18: 18

Coupling surface fuelbeds to canopy fuels

Fuel Type	Avg. % fuel
Biomass >10cm	17.08
Shrubs	4.37
Grass	8.17
Litter	42.97
DWD	8.95
Duff	18.66
Other	0.11



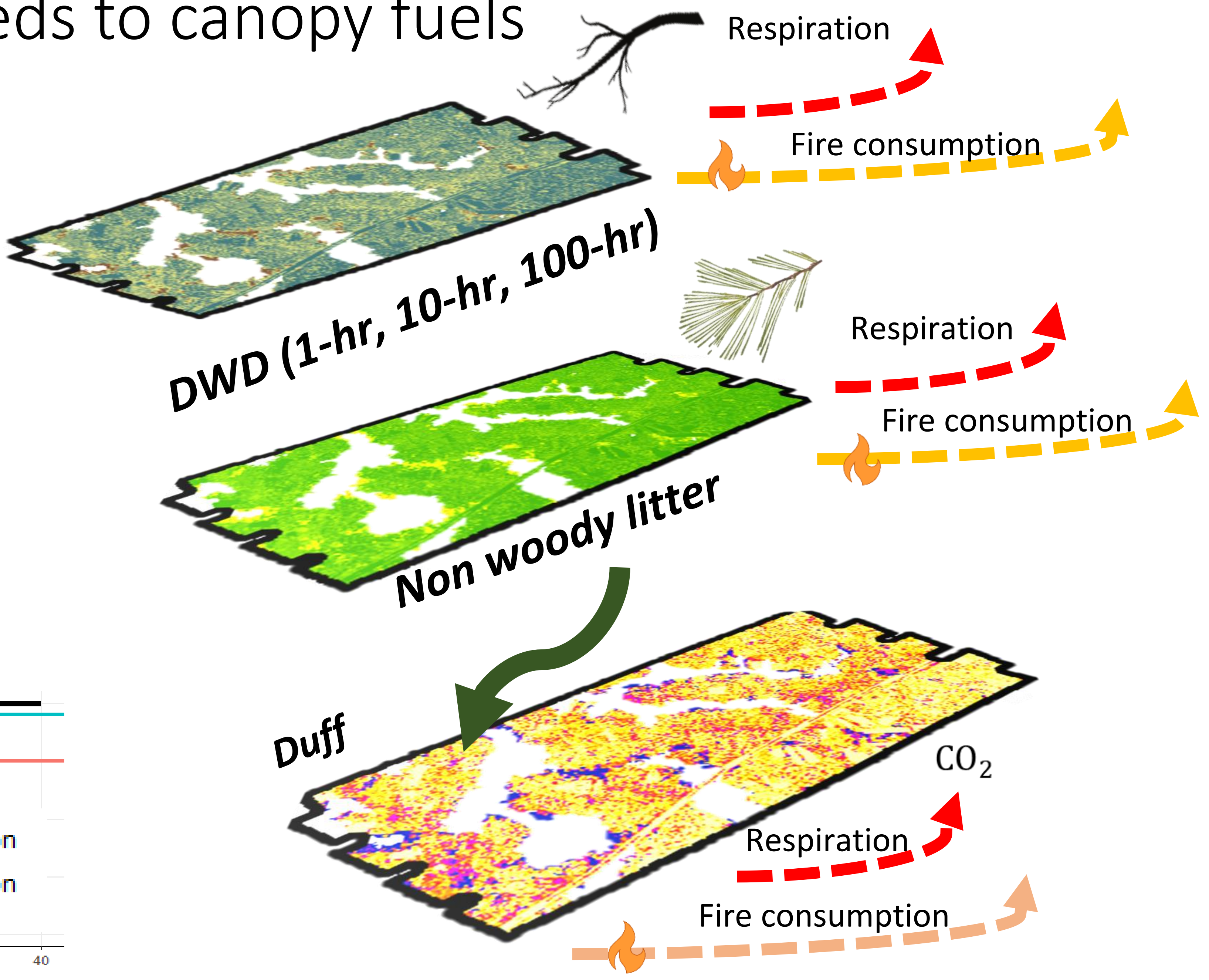


Figure credit: Nuria Sánchez

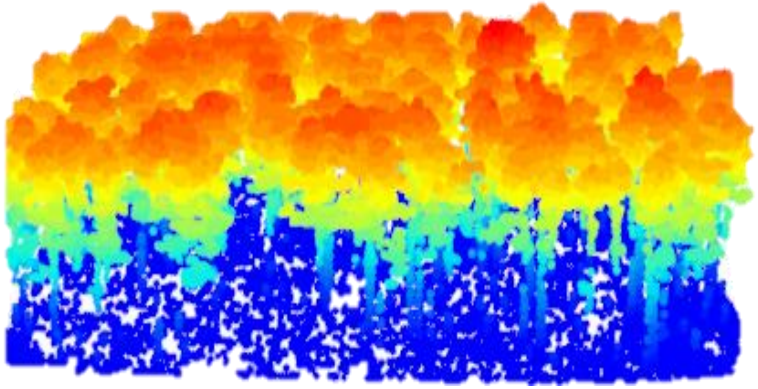
Spatially explicit maps of surface fuel components are limited

High heterogeneity and complexity of surface fuel beds

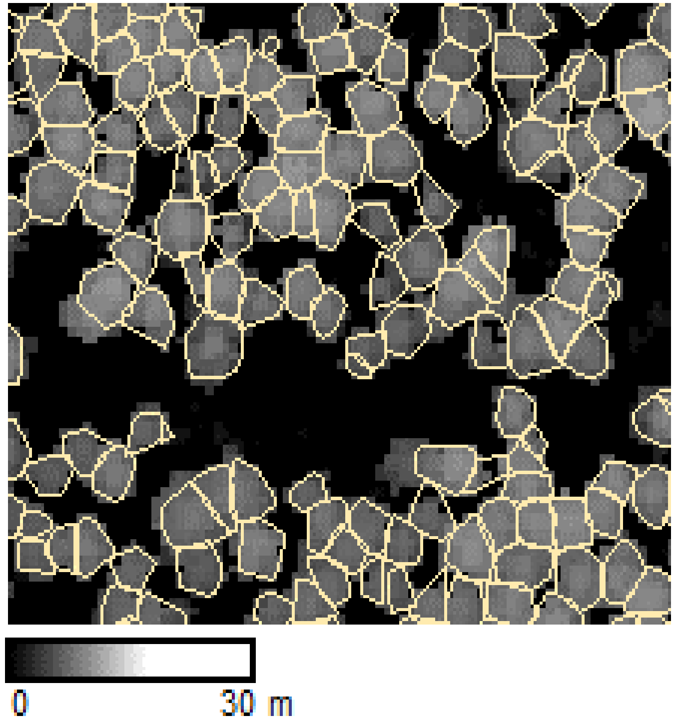
Low sensitivity of remote sensing systems

Figure credit: Nuria Sánchez

AIRBORNE LASER SCANNING (ALS)



Individual tree crown segmentation



ALS crown attributes

Crown height
Crown base height
Crown length
Crown density
[....]

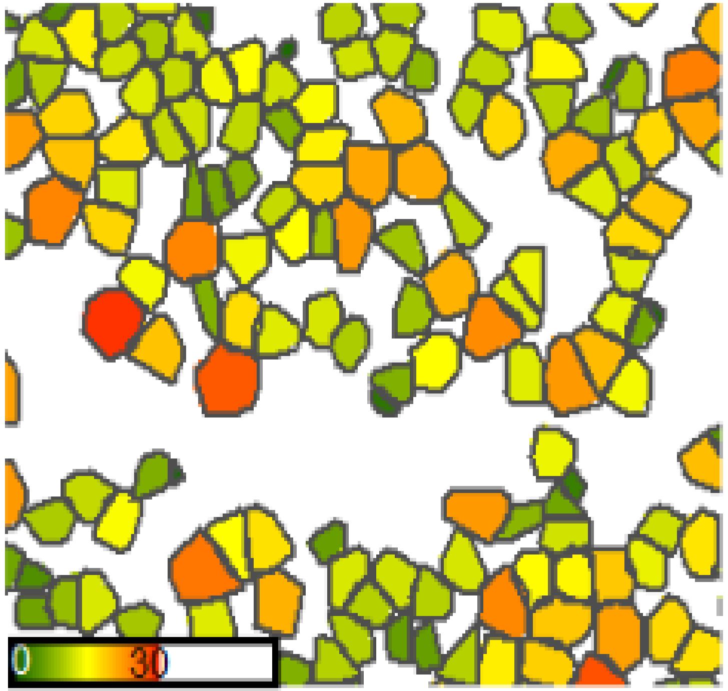
Tree canopy fuels

Foliage biomass
Stem branches
Fine wood components

Statistical Modeling Random Forest

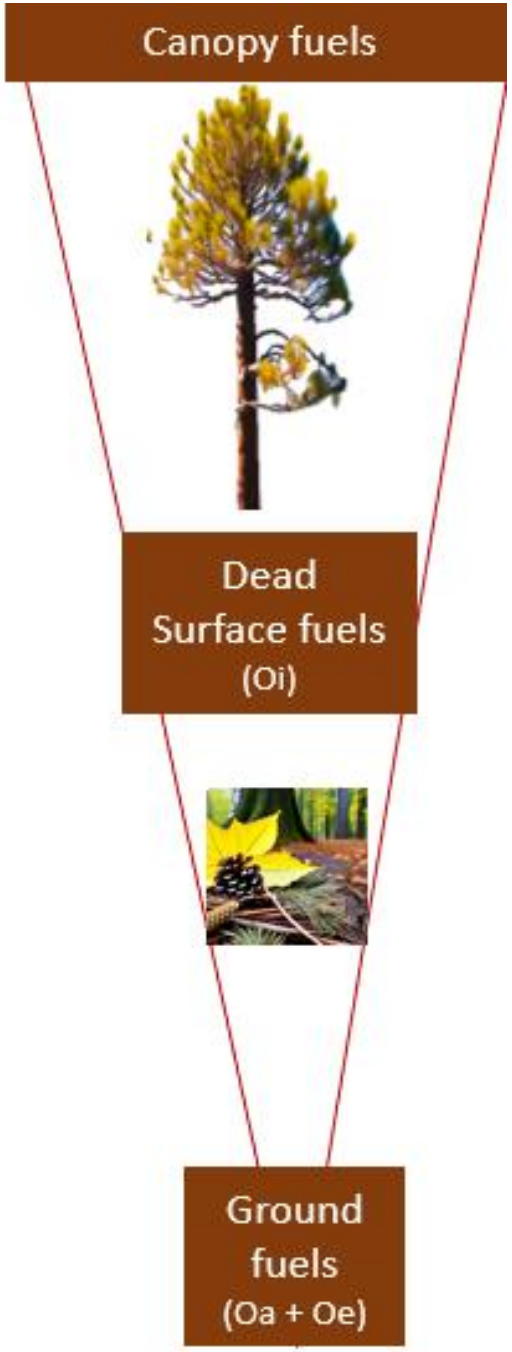
Tree crown fuels

e.g., foliage biomass, branch biomass, fine wood components



TREE INVENTORY DATA

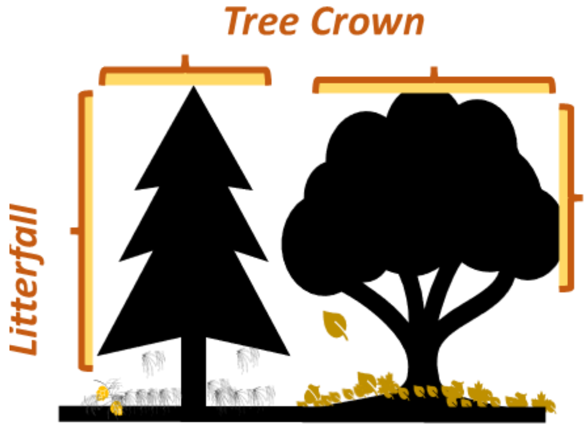
Figure credit: Nuria Sánchez



1. Estimation of biomass of different **standing tree components**

2. Estimation of **annual production** of surface fuels

2. Estimation of **surface fuel accumulation** from ancillary data, and ecological based models.



Litter:
Leaves, needles, bark, fruits, etc.

FWD:
1-hr (<0.635 cm)
10-hr (0.635-2.54 cm)
100-hr (2.54-7.62 cm)

CWD:
1000-hr (>7.62cm)

Figure credit: Nuria Sánchez

Maps of surface fuels are KEY

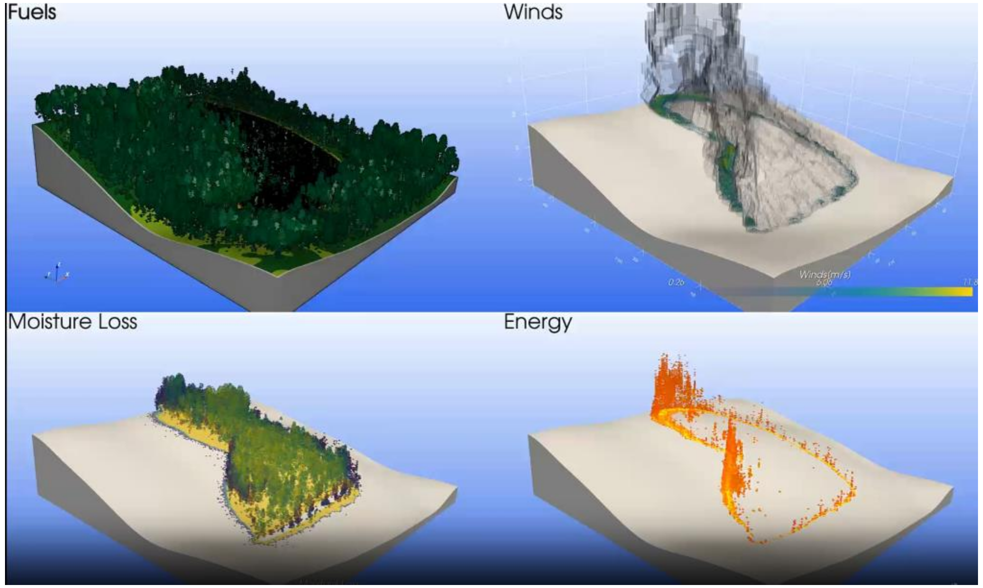


Figure credit: Nuria Sánchez

Forest management

Fire risk

Fire effects

Forest productivity

Consumption and emissions

Synthetic forest simulations

Fire behavior modelling

Terrestrial carbon fluxes

Conclusions

- Towards mapping fuels as continuous, physical variables
- Lidar data capture spatial heterogeneity in fuel structure
- Lidar data fail to reliably capture surface fuel bed depth
    - However, surface fuel are coupled to the canopy, other driving variables
- Need for traditional field measurements of physical loads will continue
- Prescribed fires present the best research opportunities
    - Ability to choose optimal or workable weather and fuel moisture conditions
    - Ability to collocate pre-fire and post-fire fuel measurements
- Improved consumption estimates relate to other fire science attributes
    - Fire behavior
    - Emissions
    - Fire Effects

Questions?

Funding:

DOD SERDP Awards:
2019-2024 RC19-1064 (3D Fuels)
2019-2024 RC19-1119 (Fire Behavior & Effects)
2020-2026 RC20-1346 (Objects)

NASA CMS Awards:
2014-2018 #NNH15AZ06I (Phase 1)
2019-2023 #80HQTR20T0002 (Phase 2)
2024-2027 #NNH24OB24A (Phase 3)

JFSP and USFS Funding:
Fire And Smoke Modeling of Emissions Evaluation (FASMEE)

NASA Carbon Monitoring Systems (CMS) project survey

- https://forms.office.com/r/TSx9CYnGnw