Detecting Post-fire Pine Regeneration in a Madrean Sky Island: Topography, Landsat, ECOSTRESS?

Andrew M. Barton[1], Helen M. Poulos[2], George. W. Koch[3], Thomas E. Kolb[3], and Andrea E. Thode[3]

[1]Univ Maine at Farmington, Farmington, ME, USA (Barton@maine.edu); [2]Wesleyan Univ, Middletown, CT, USA; [3]Northern Arizona Univ, Flagstaff, AZ, USA

Session B23F-2144, Poster 1304358

INTRODUCTION

The American Southwest is experiencing increased aridity and wildfire incidence, triggering conversion of some frequent-fire forests to non-forest. These dynamics are well-established in ponderosa pine forests, but we know far less about **Madrean pine-oak forests** in the **Sky Islands** of Mexico and USA. We have documented scarce pine regeneration and vigorous post-fire oak resprouting in these forests over 27 yrs.

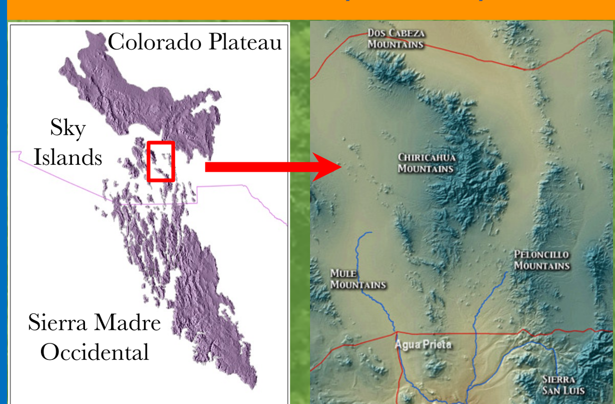
We investigated pine regeneration patterns in long-term plots during severe drought, 10 yrs after the Horseshoe 2 Megafire in the Chiricahua Mountains, AZ—a follow-up to a 5-yr assessment. Our goals were to (1) document changes in **pine regeneration** and (2) develop **remote-sensing** tools to identify pine refugia across landscapes.

For (2), we tested whether two remotely-sensed predictors—**Landsat NDVI** & **ECOSTRESS evapotranspiration**—provided predictive power beyond indices of fire severity and topographic moisture.

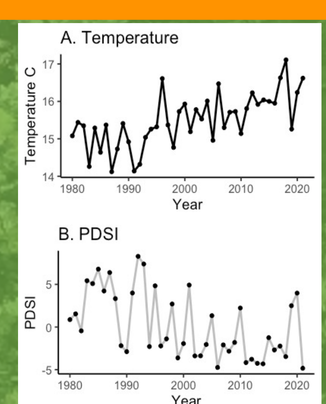
WHY IS THIS QUESTION IMPORTANT?

The reliability of projections and restoration under intensifying drought and wildfire depends on a fine-grained understanding of refugia for at-risk tree populations.

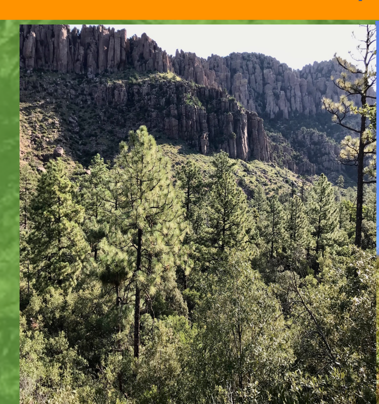
THE DRY, HOT, FIERY CHIRICAHUA MOUNTAINS, AZ, USA



LOCATION



HOTTER,DRIER



BEFORE FIRE

AFTER FIRE

METHODS

- Resampled 51 plots in Madrean pine-oak forest: 17 low, moderate, and high fire severity
- Recorded number of seedlings of *Pinus engelmannii* & *P. leiophylla* & resprouts of the latter
- Recorded plot elevation, aspect, slope, position, and surface shape (field & 30-m DEM)
- For each plot, fire severity, Landsat NDVI, and ECOSTRESS ET (see below)
- Assessed predictor variables using multivariate adaptive regression splines (MARS)

4 PREDICTORS OF PINE REGENERATION – WHICH WORK BEST?

Fire Severity: Landsat differenced Normalized Burn Ratio (**dNBR**; *30-m resolution*):
- NBR = (NIR - SWIR) / (NIR + SWIR), dNBR = Pre-fire NBR – Post-fire NBR

NIR - near infrared, SWIR - short-wave infrared, R - red

Topography:
- **elevation**
- topo relative moisture index (**TRMI**) = aspect + position + % slope + surface shape

Landsat Normalized Difference Vegetation Index (**NDVI**; *30-m resolution*):
- vegetation greenness: NDVI = (NIR– R) / (NIR+ R)

ECOSTRESS evapotranspiration (*70-m resolution*):
- land surface temperature + other inputs → Priestly-Taylor algorithm → **ET**

RESULTS: CONTINUED POOR PINE REGENERATION

- Conversion of pine-oak forest to oak shrublands continued 6-10 yrs post-fire. Few pine recruits were found in a matrix of dense, oak sprouts, especially after severe fire (***FIG 1***)
- Fewer large pine seedlings in 2021 (a dry season of record aridity) than 2016
- *P. leiophylla* post-fire resprouts continue to survive and, unlike seedlings, are beginning to overtop the oak resprout canopy (***FIG 2***)

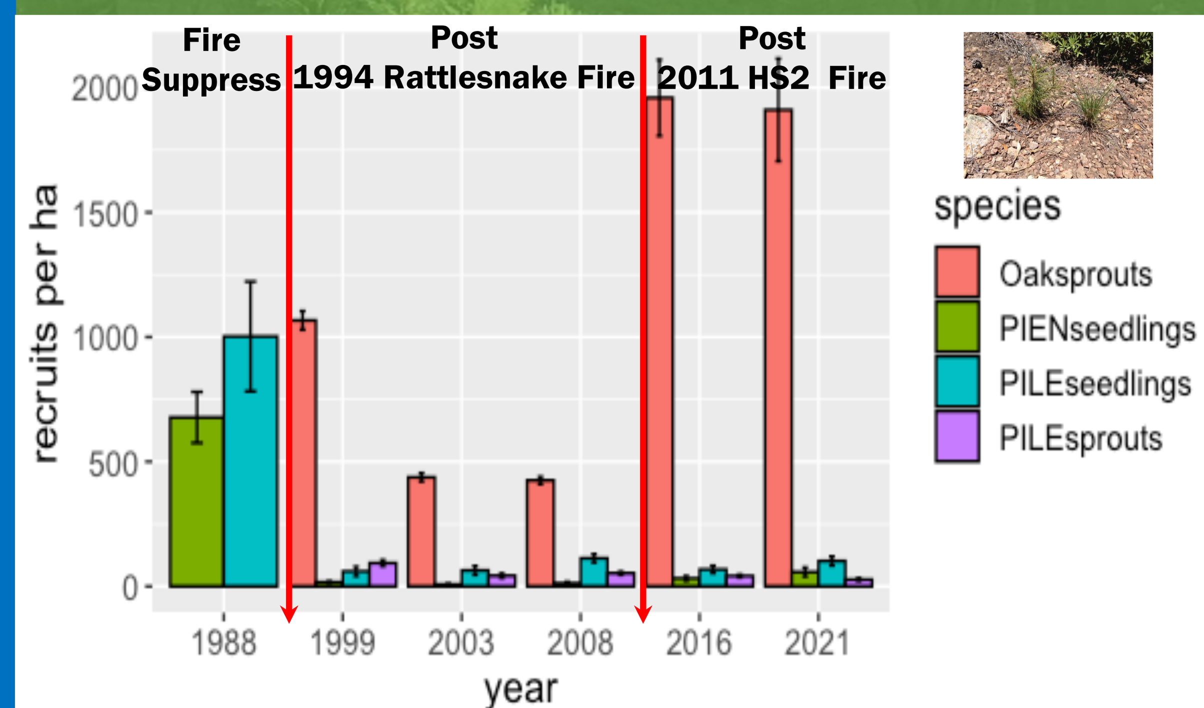


FIG 1. Recruits per ha for pines vs oaks from 1988 to 2021.

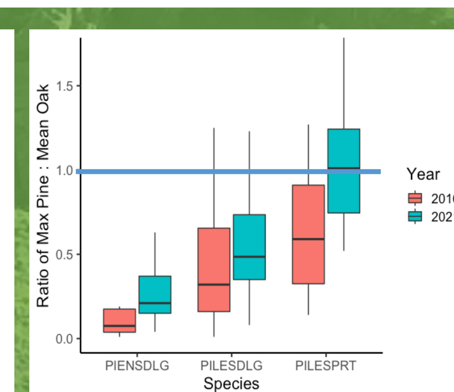
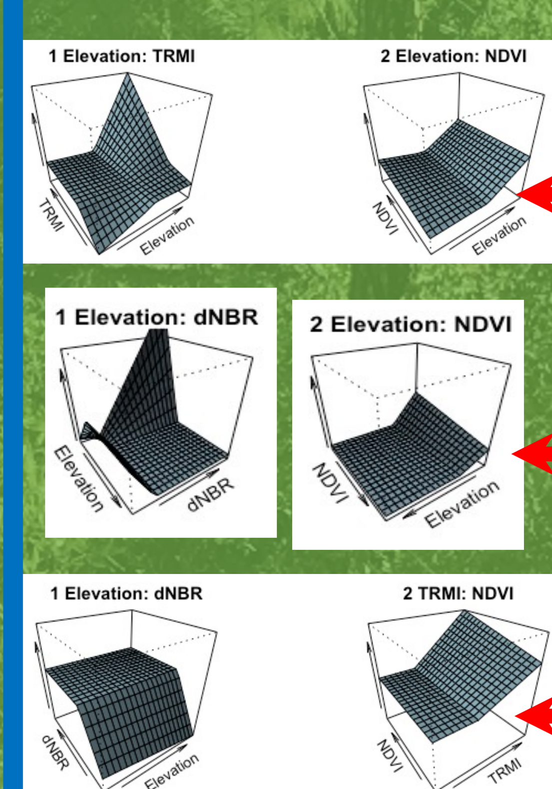


FIG 2. Height of pine recruits vs. mean oak sprout canopy

RESULTS: FIRE SEVERITY, TOPO, NDVI ARE GOOD PREDICTORS

- **Best MARS models**: some combination of **elevation**, **topography**, **fire severity,** and **NDVI** – but **NOT ECOSTRESS ET** (***TABLE 1***)
- *P. engelmanni* establishes best at higher elev, mesic topo, higher greenness (***TABLE 1***)
- *P. leiophylla* establishes best at lower elev, lower fire severity, higher greenness (***TABLE 1***)
- *P. leiophylla* resprouts best at low elev, high fire severity, more mesic topo, high greenness.

TABLE 1. MARS models for recruits/ha vs **Elev**, Fire Severity (**dNBR**), Topographic Moisture (**TRMI**), Landsat Greenness (**NDVI**), and ECOSTRESS Evapotranspiration (**ET**). Model fit assessed using generalized cross validation (right); graphical depiction on left.

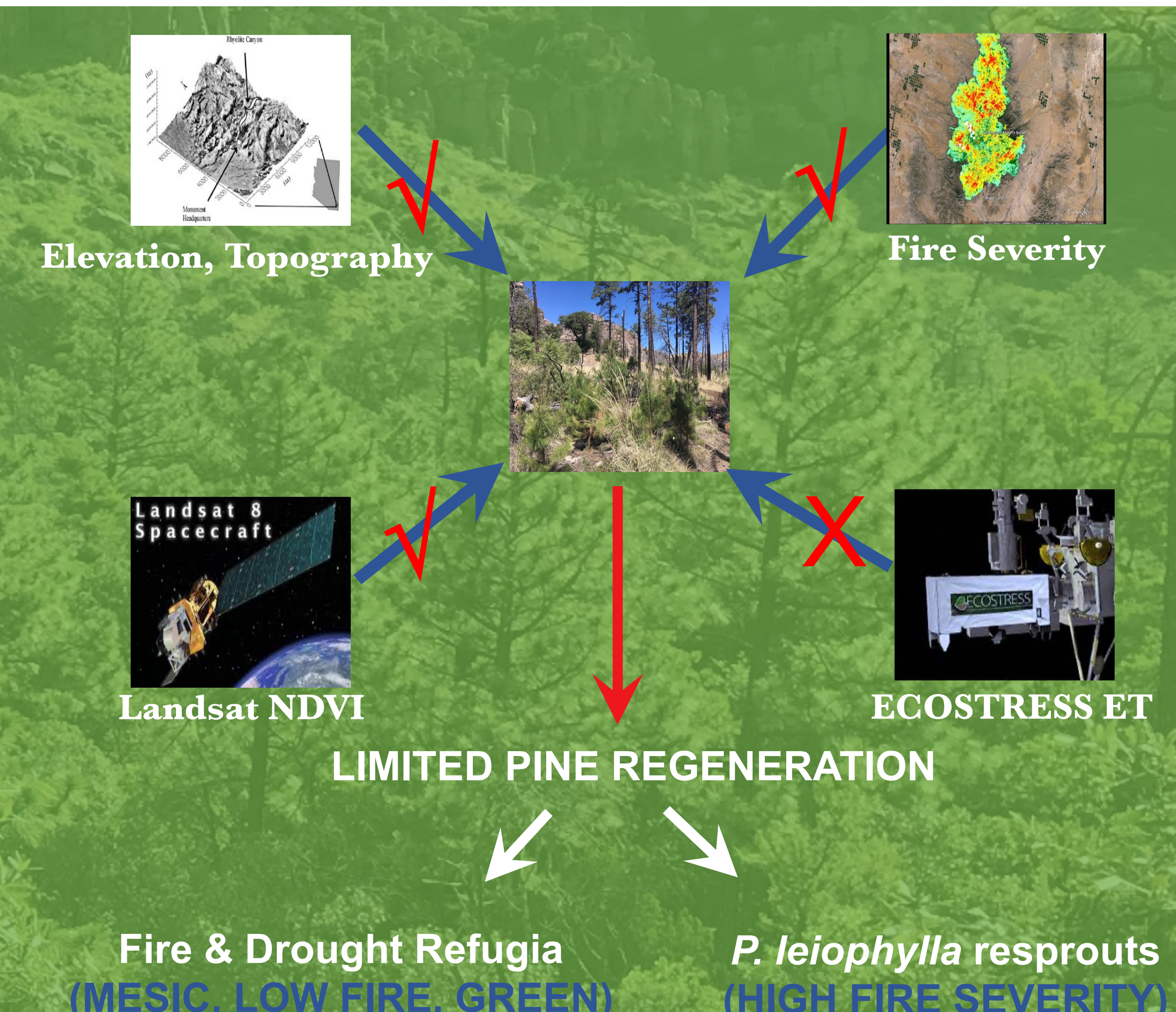


red – eliminated by model; **green** – best model

MODELS				GCV	R^2
P. engelmannii seedlings					
Elevation	dNBR	TRMI		16.5	0.81
Elevation	**dNBR**	TRMI	NDVI	11.3	0.87
Elevation	dNBR	TRMI	**ET**	16.5	0.81
P. leiophylla seedlings					
Elevation	dNBR	TRMI		38.9	0.47
Elevation	dNBR	**TRMI**	NDVI	32.7	0.44
Elevation	**dNBR**	**TRMI**	**ET**	38.1	0.16
P. leiophylla resprouts					
Elevation	dNBR	TRMI		3.2	0.27
Elevation	dNBR	TRMI	NDVI	3.1	0.29
Elevation	dNBR	TRMI	**ET**	3.2	0.26

CONCLUSIONS

- Nearly three decades of **conversion of pine-oak forest to oak shrublands** after high-severity wildfire.
- **Post-fire resprouting**, unusual in pines, may be a lifeline for *P. leiophylla*.
- Remotely-sensed **Landsat NDVI**, combined with **topography** and **fire severity**, do a good job of predicting the locations of pine refugia.
- **ECOSTRESS ET** does not help, likely due to larger, less stationary pixels than **NDVI**
- Field data and models suggest *P. engelmannii* is more drought sensitive and at risk to climate change and wildfires than *P. leiophylla*.



REFERENCES

Azpeleta, T.A., P. Fulé, A.G. Arévalo. In press. Mexican mixed-species forest shows resilience to high-intensity fire. *Canadian Journal of Forest Research*

Barton, A. M. (2002). Intense wildfire in southeastern Arizona: Transformation of a Madrean oak–pine forest to oak woodland. *Forest Ecology and Management*, *165*, 205–212.

Barton, A. M., & Poulos, H. M. (2018). Pine vs. Oaks revisited: Conversion of Madrean pine-oak forest to oak shrubland after high-severity wildfire in the Sky Islands of Arizona. *Forest Ecology and Management*, *414*, 28–40.

Barton, A.M., H.M. Poulos, G.W. Koch, T.E. Kolb, and A.E. Thode. 2023. Detecting patterns of post-fire pine regeneration in a Madrean Sky Island with field surveys and remote sensing. *Sci of the Tot Env*, doi.10.1016/jscitotenv.2023.161517

Coop, J. D. et al. (2020). Wildfire-driven forest conversion in western North American landscapes. *BioScience*, *70*(8), 659–673. doi.org/10.1093/biosci/biaa061

Poulos, H.M., M.R. Freiburger, A.M. Barton, and A.H. Taylor. 2021. Mixed-severity wildfire as a driver of vegetation change in an Arizona Madrean Sky Island System, USA. *Fire* 2021, *4*(4),78; doi/10.3390/fire4040078

Rodríguez-Trejo, D. A., & Fulé, P. Z. (2003). Fire ecology of Mexican pines and a fire management proposal. *International Journal of Wildland Fire*, *12*, 23–37.

ACKNOWLEDGEMENTS

We are grateful for financial support from NASA (#80NSSC20K0077), Western National Parks Assoc (2017), National Park Service (#P17AC00940), Joint Fire Sciences Program (#L15AC00152), Univ Maine Farmington, and Wesleyan Univ. The research would not have been possible without enthusiastic field assistance from Mark Briggs, Annika Shiffer Delegard, Jordan Green, Margaret Judge, Richard Sternberg, Darren Wallis.