Leveraging archaeological perspectives in reconstructing historical fire and fuel conditions: a case study from coastal South Carolina, USA

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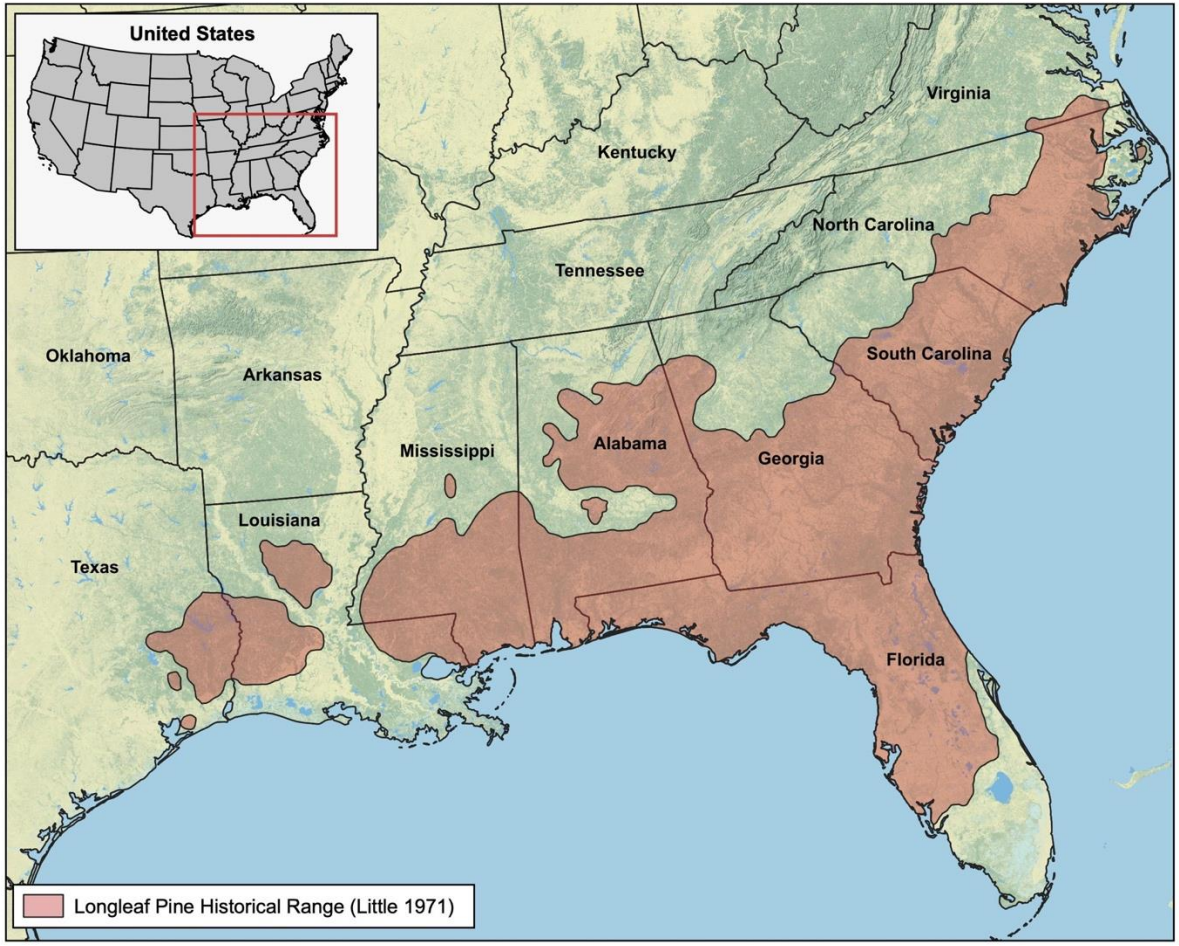
Introduction:
Restoring Longleaf pine Ecosystems

Longleaf pine (*Pinus palustris)* ecosystems cover about 2 million acres of the US Southeast — which some suggest is **4%** of their original range.



The Nature Conservancy

NRCS

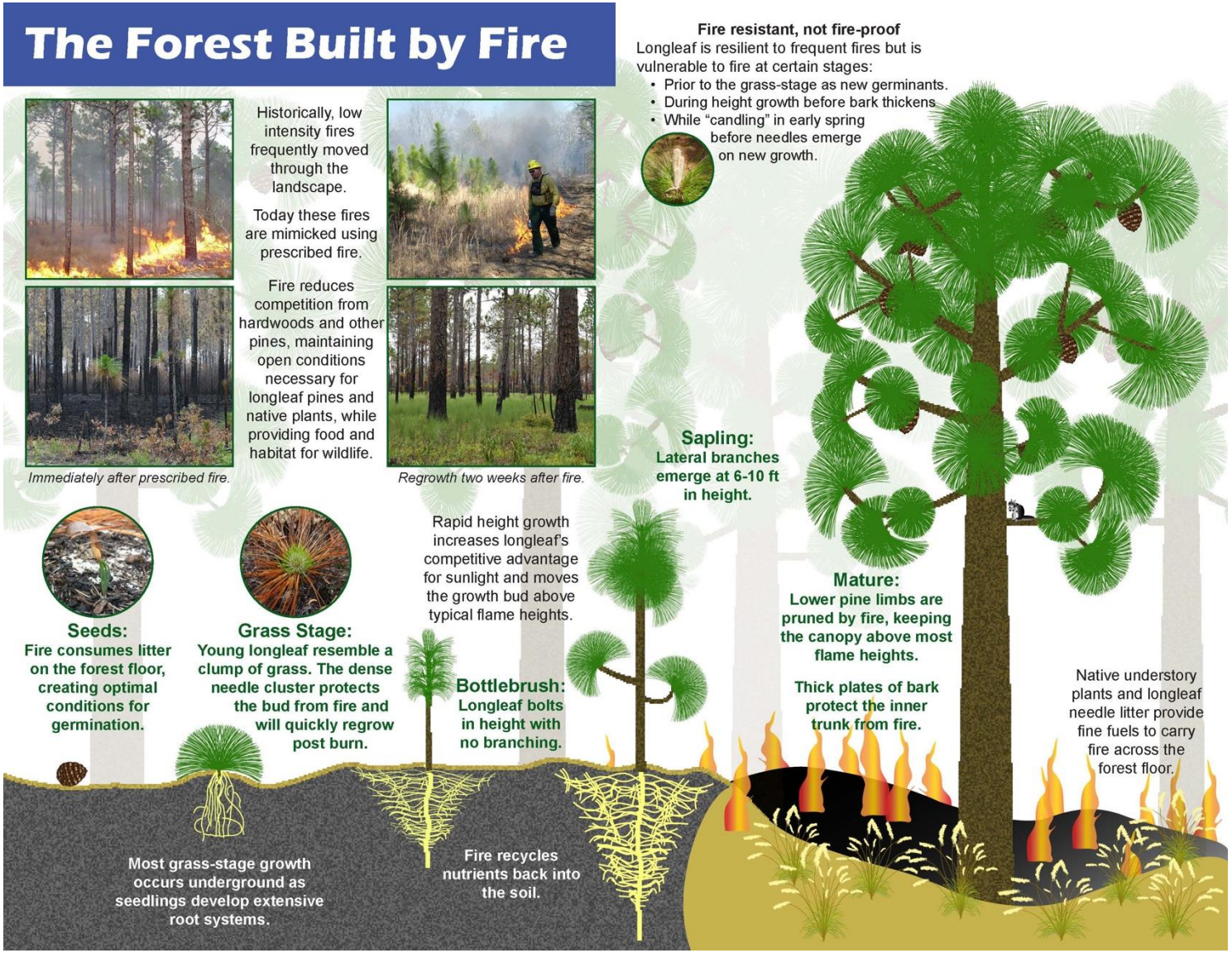
THE LONGLEAF ALLIANCE

U.S. FISH & WILDLIFE SERVICE

FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

Federal, state, private, and academic institutions involved in initiatives to restore and manage these ecosystems.

Fire is a **fundamental** component of Longleaf pine life history – Restoration through **Rx fire**

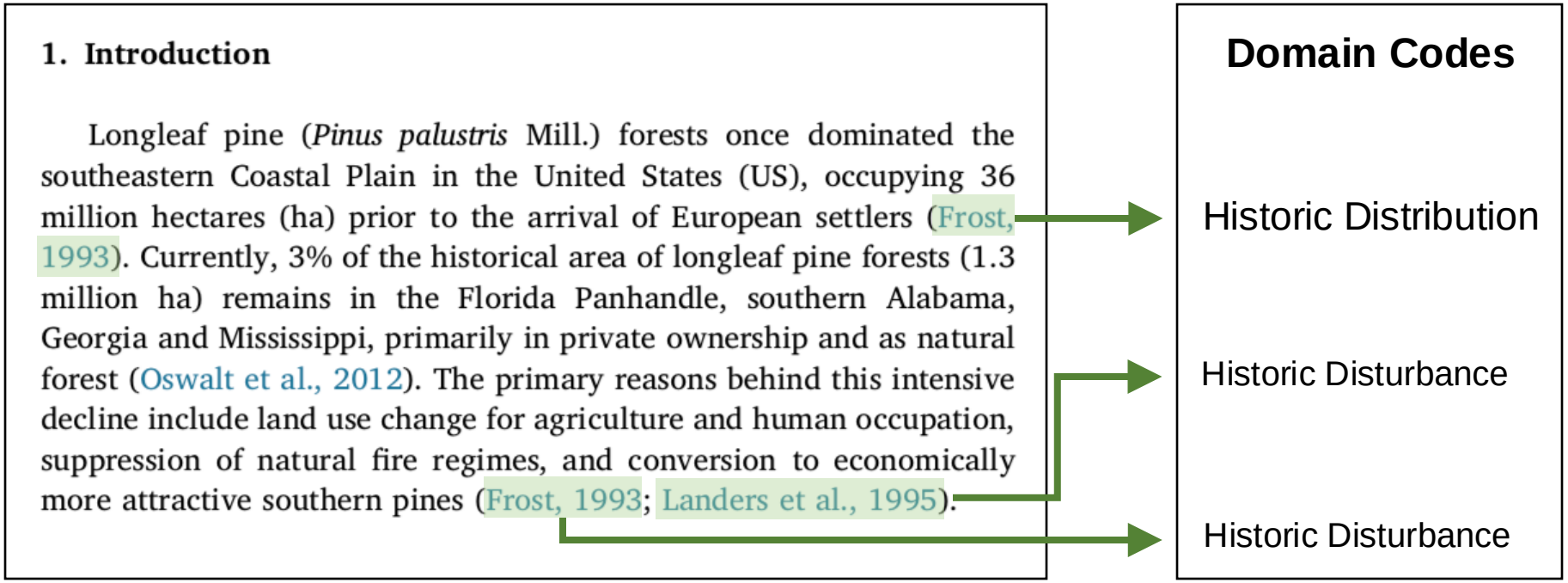


NC Longleaf Coalition: https://www.nclongleaf.org/burningLongleaf.html

Restoration ecology points to **historical baselines** to justify fire frequency, fire intensity, and stand structure...

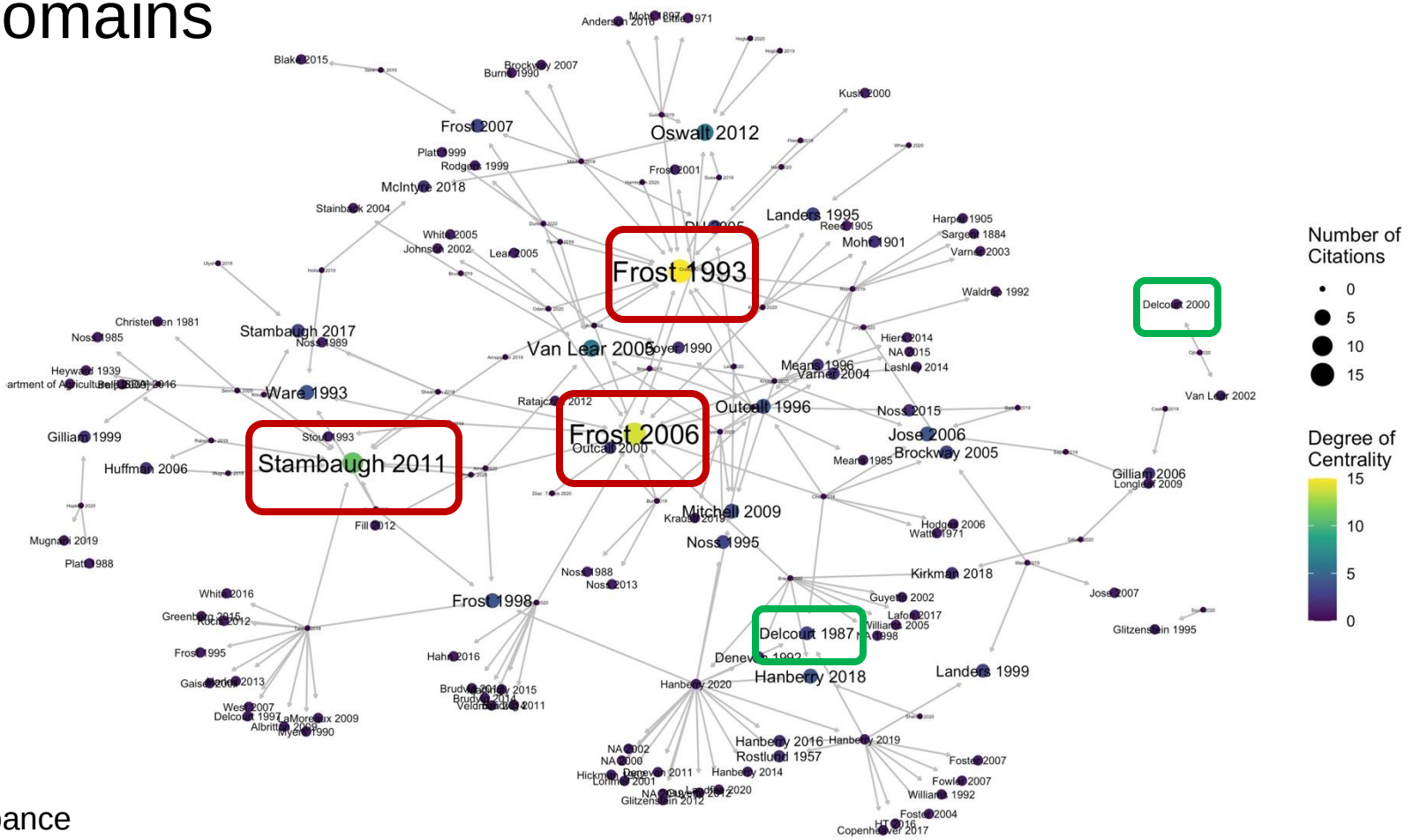
In the pine woods, Florida, 1906. Library of Congress: https://lccn.loc.gov/2016803946

Bibliometric analysis to determine how the current Longleaf pine restoration literature use historical baselines



Susaeta, A., Gong, P., 2019. Economic viability of longleaf pine management in the Southeastern United States. Forest Policy and Economics 100, 14–23. https://doi.org/10.1016/j.forpol.2018.11.004

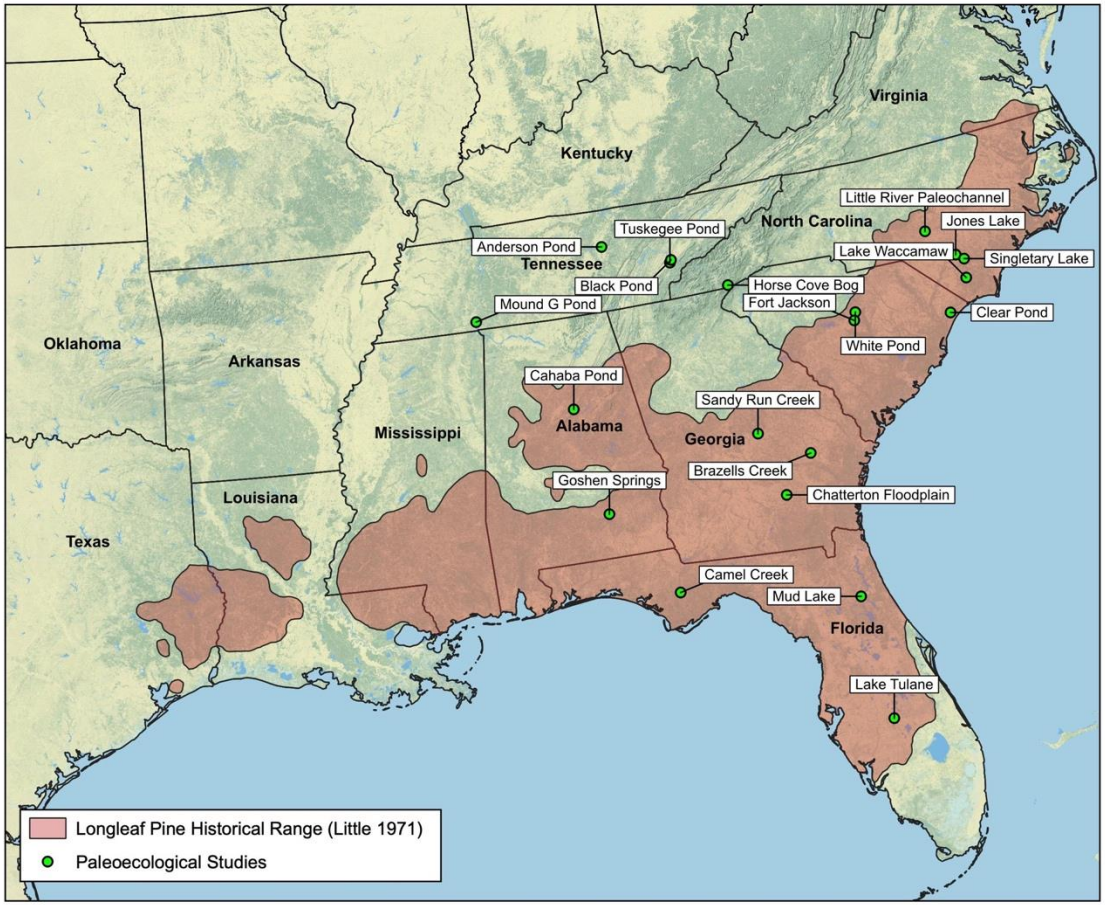
Citation network for all coded domains

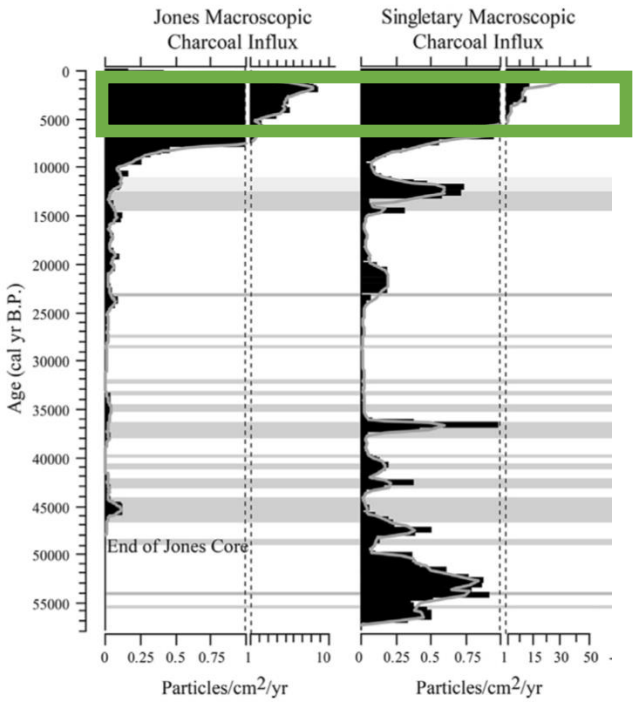


Domains

- Historic Disturbance
- Historic FRI
- Historic Anthropogenic Fire
- Historic Distribution
- Historic Longleaf Ecosystem Condition

What about **palynology** and **charcoal** studies?



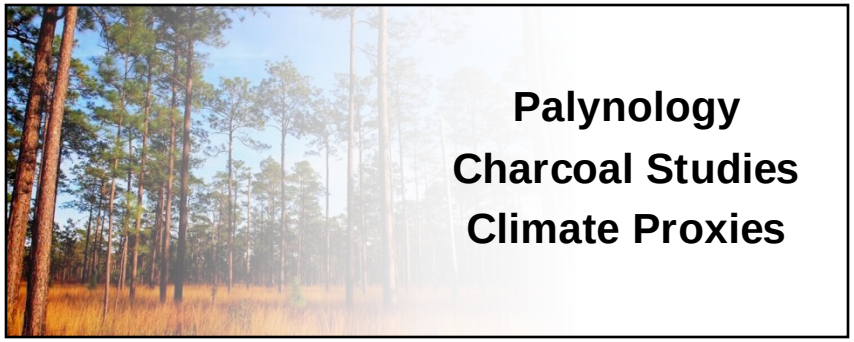


Spencer, J., Jones, K.B., Gamble, D.W., Benedetti, M.M., Taylor, A.K., Lane, C.S., 2017. Late-Quaternary records of vegetation and fire in southeastern North Carolina from Jones Lake and Singletary Lake. Quaternary Science Reviews 174, 33–53. https://doi.org/10.1016/j.quascirev.2017.09.001

This research presents challenges in **resolution** and **scale.**

How can managers use these types of studies?

Historical baseline extends back to the Pleistocene, but lacks fine temporal resolution in recent centuries



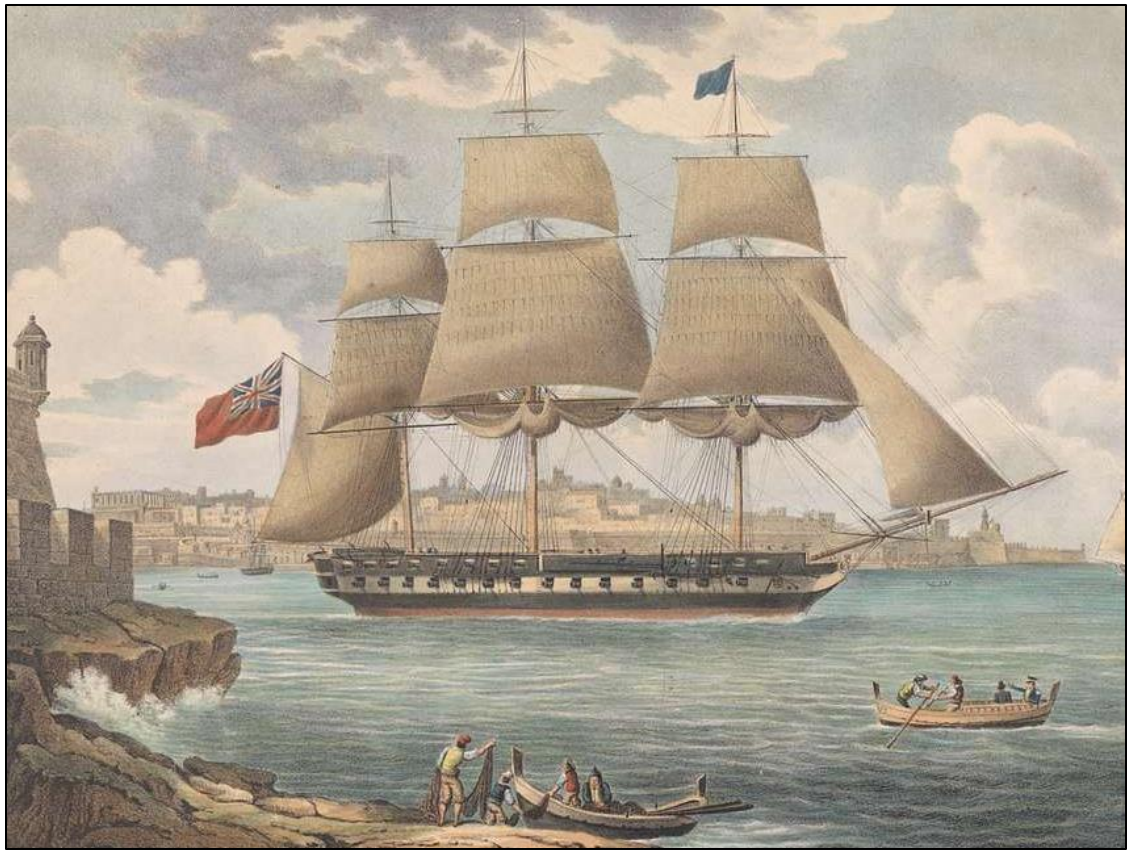
Fundamental Gap in Knowledge

Historical baseline extends back 100-250 years, but well after European colonization

Time

Identifying the **challenge** and **recognizing** opportunities for archaeological approaches

Leveraging Archaeology:
The Naval Stores Industry and Longleaf Pines



Naval stores and the myth of '*pristine forests*'

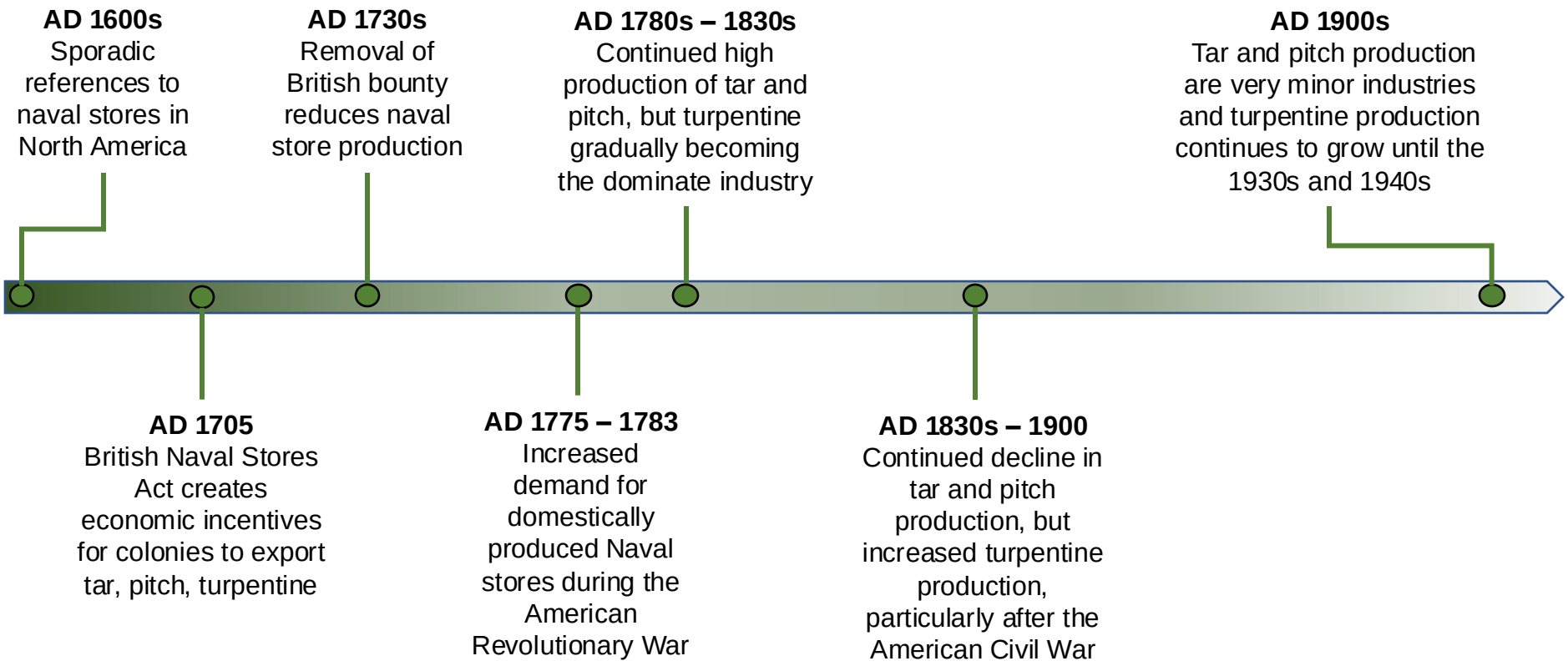
Tar / pitch production in kilns

Turpentine (box cutting / cat faces)

Wood/stump distilling

Photos courtesy of South Carolina Forestry Commission

A Brief History of the Naval Stores Industry in the Southeast US



What is a **tar kiln** in the Southeast US?

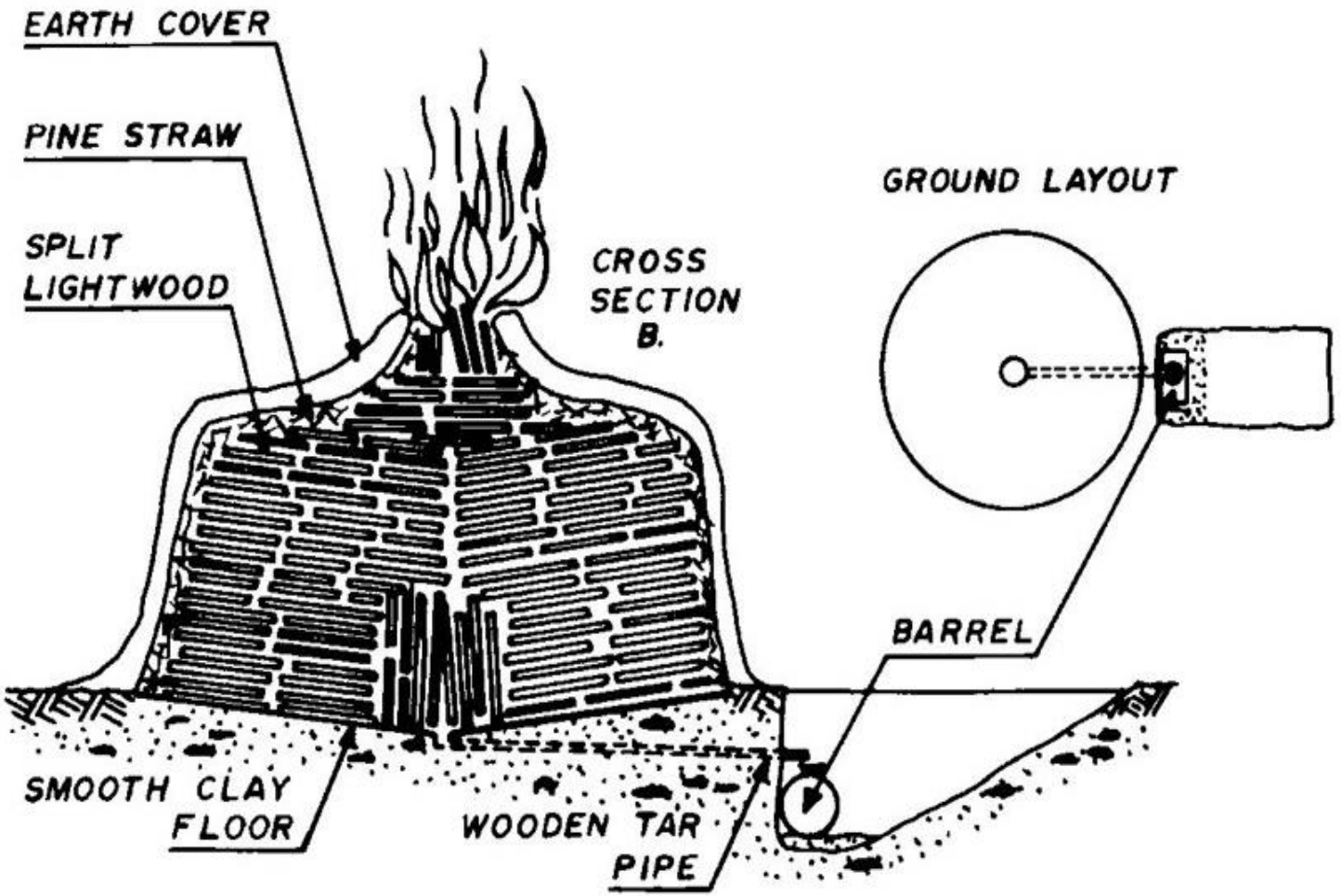
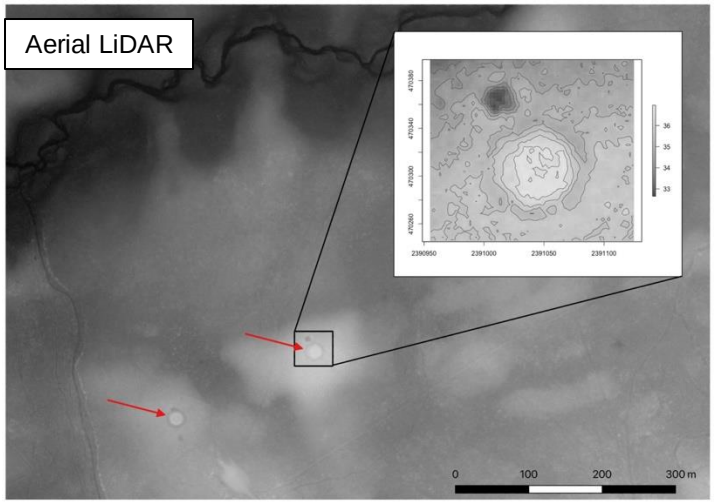
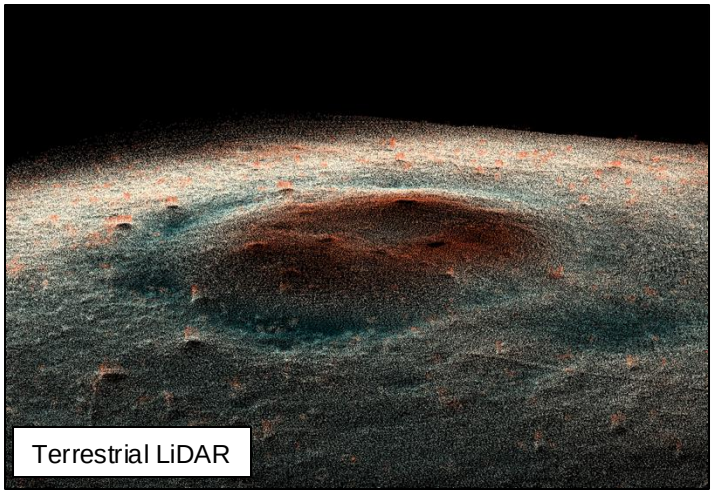


Figure is reproduced from Combes 1974

What does an archaeological **tar kiln** look like in the field?

Photograph of archaeological tar kiln (April 2021)





Connecting tar kilns to **fire and fuels**

- Kiln-produced tar required large quantities of Longleaf pine “light wood”
- Primary accounts suggest ~400 cubic meters of lightwood needed per kiln...**about 10 standard shipping containers**
- Implications for Longleaf pine stand density, course woody debris, and fuel connectivity — all factors that shape our historical baselines.

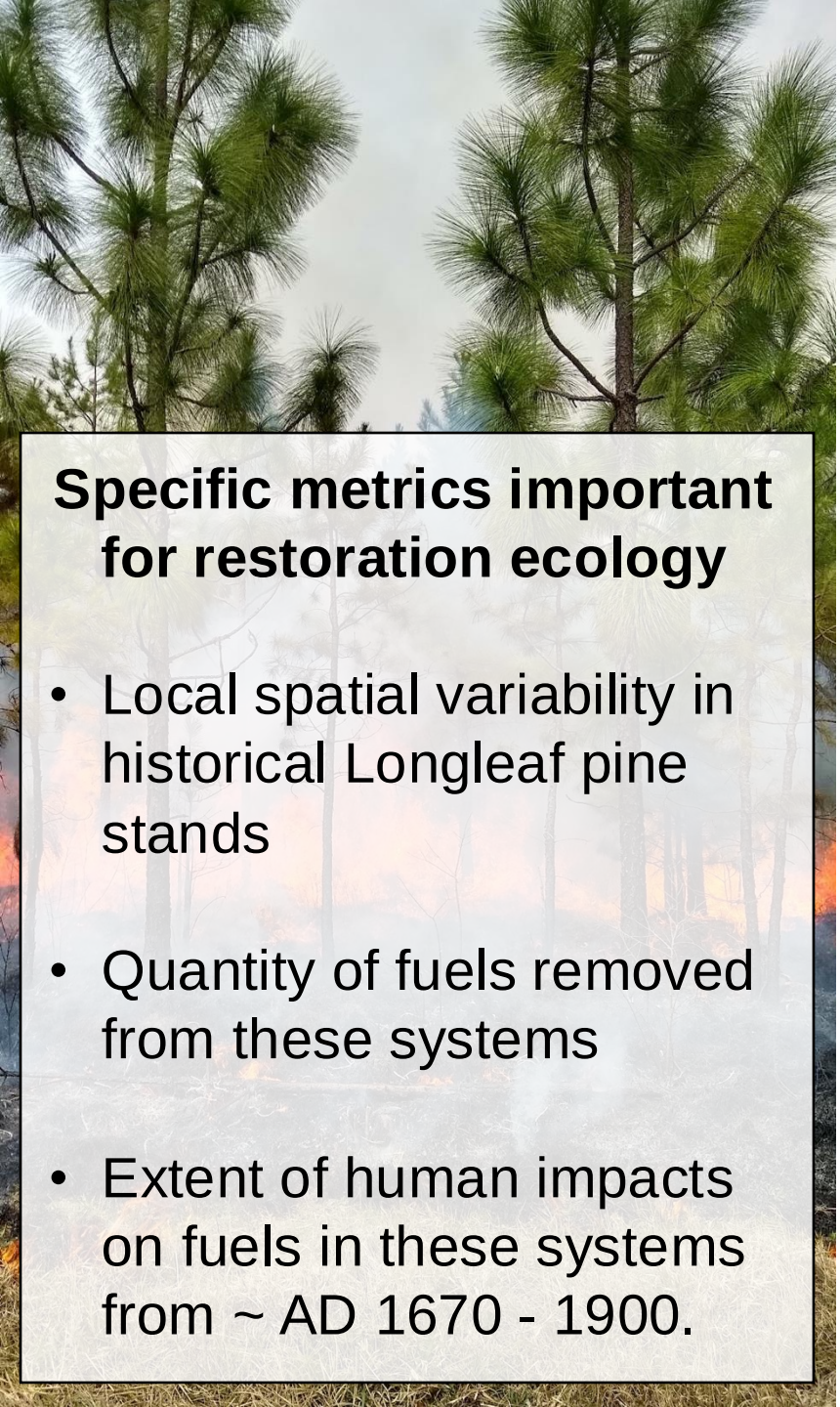
Project Objectives

1. Utilize remote sensing techniques to identify tar kiln production sites

2. Quantify tar kiln sites / attributes within 170,000-hectare study area

3. Validate dataset with archaeological survey and previously known sites

4. Connect tar kilns to the emergence of largescale exploitation of Longleaf pine ecosystems and influence on fire and fuel conditions



Specific metrics important for restoration ecology

- Local spatial variability in historical Longleaf pine stands
- Quantity of fuels removed from these systems
- Extent of human impacts on fuels in these systems from ~ AD 1670 - 1900.

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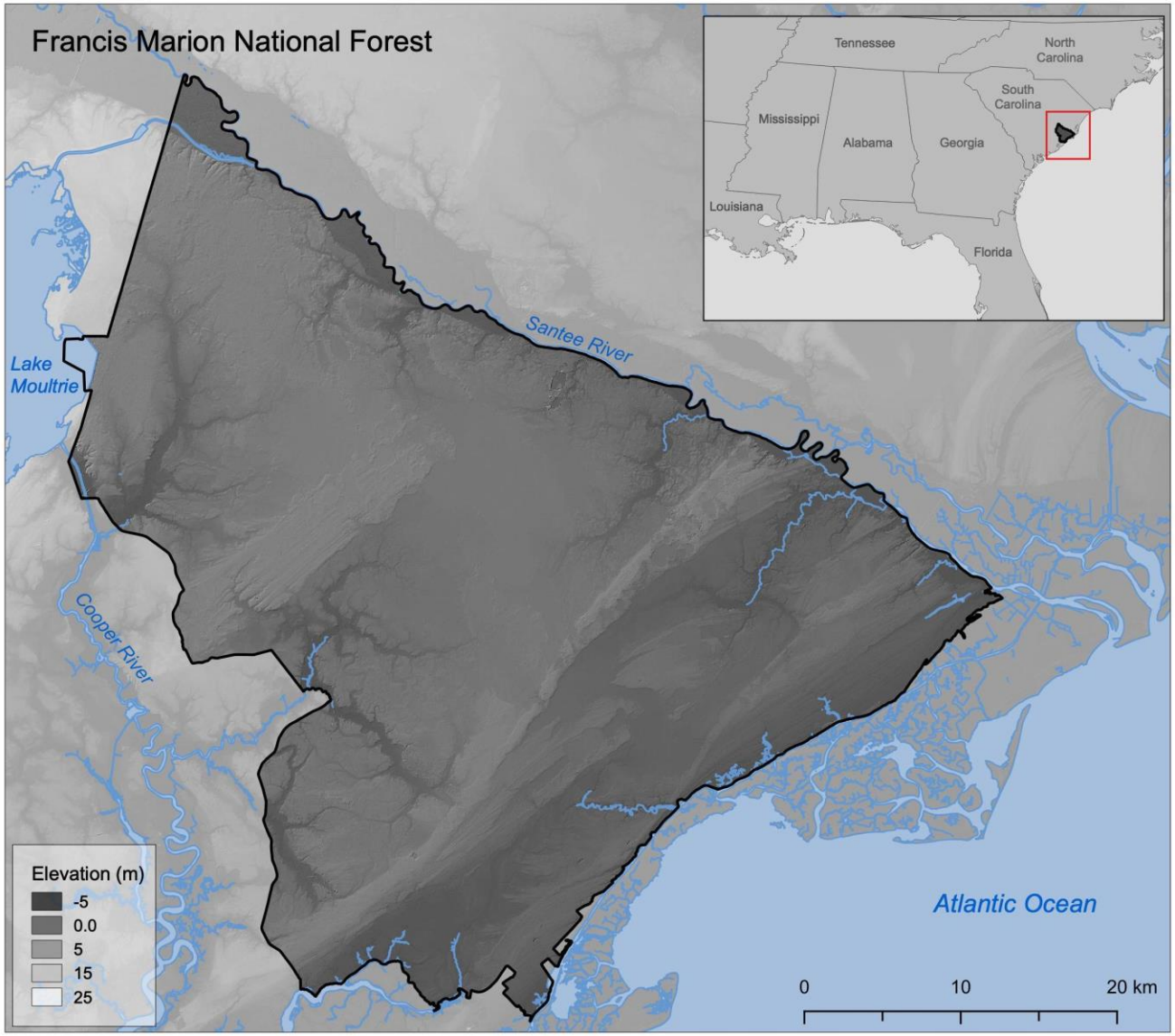
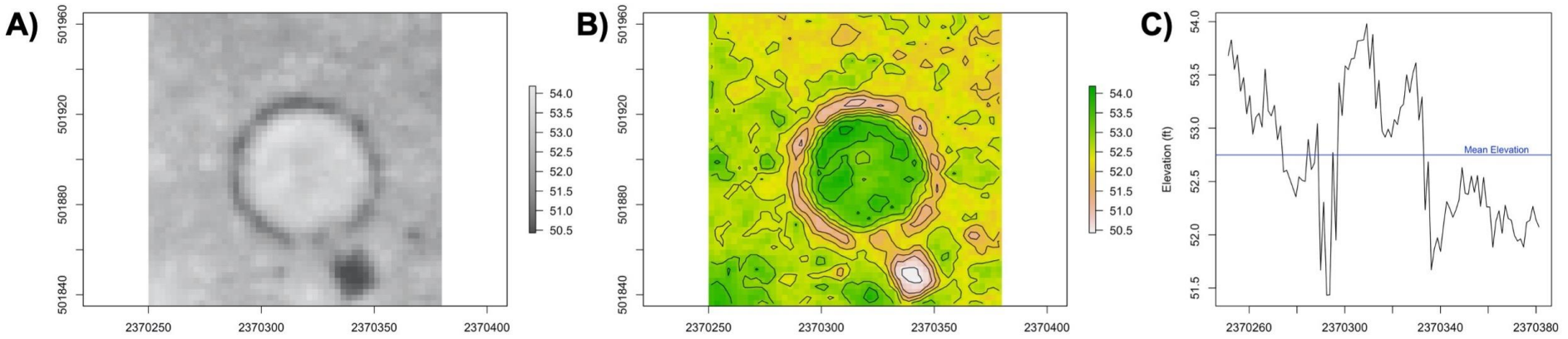
The **Francis Marion National Forest** serves as the study area for this project

- Managed by the US Forest Service (170,000-hectares)
- 50 km northeast of Charleston, SC
- Euro-American land-use since the founding of Charles Town in AD 1670.



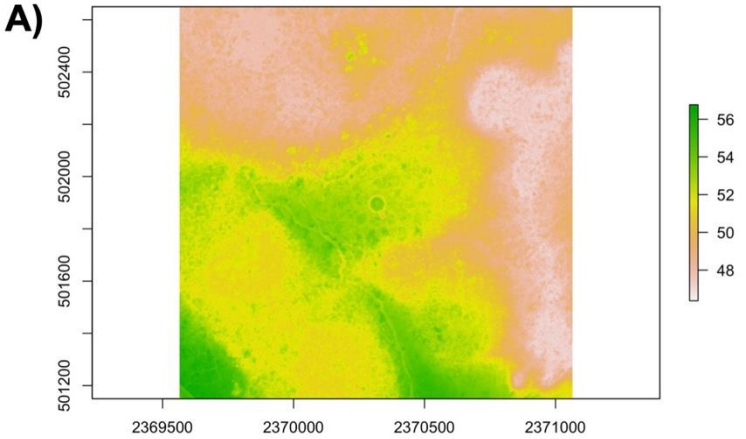
The Tar Kiln Feature Detection (**TKFD**) workflow



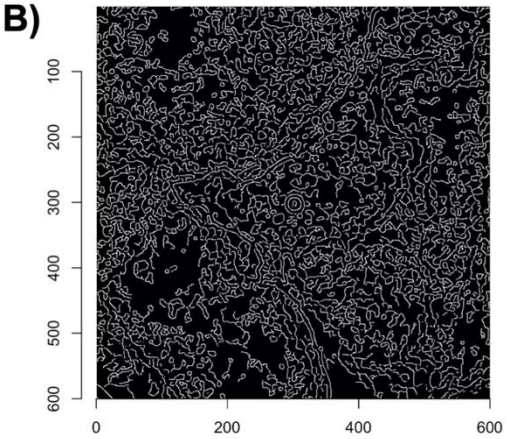
- Scripted, open-source workflow linking R and FIJI
- Computer vision technique to extract archaeological features that might not be highly visible in the field
- Relies on tar kiln morphology for detection: [**A**] circular, [**B**] slightly mounded, and [**C**] surrounding trench

The Tar Kiln Feature Detection (**TKFD**) workflow

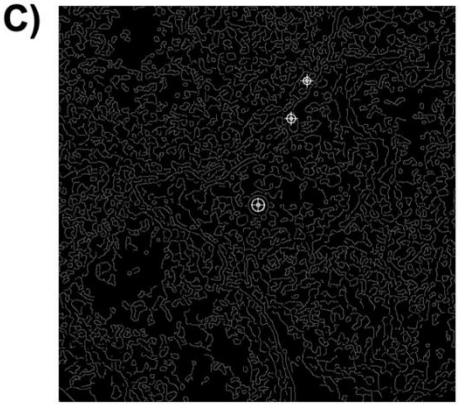
Brief overview



1-meter DEM from aerial Lidar

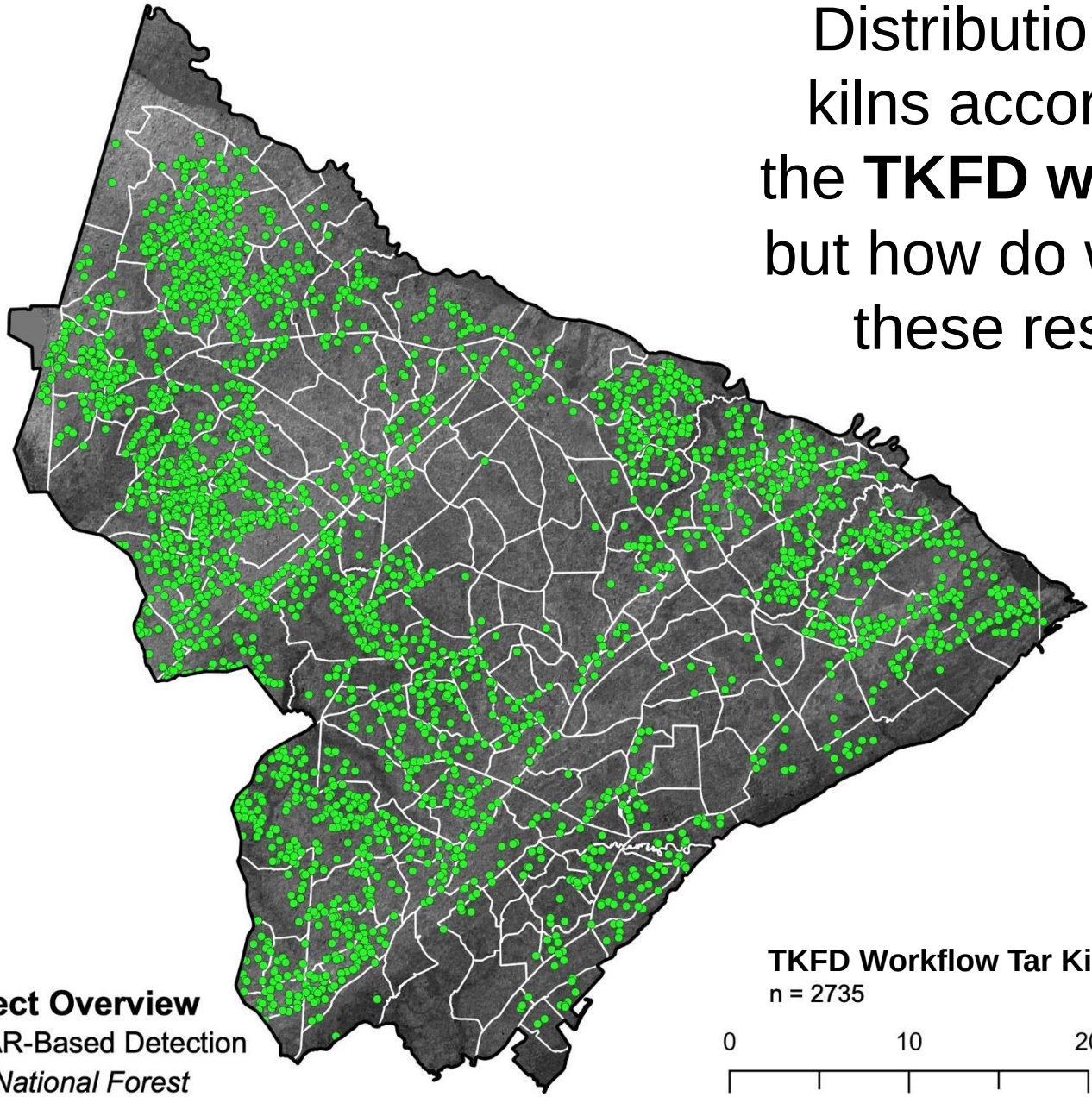


Canny edge detector to extract image structure



Circle Hough Transform to detect circular objects

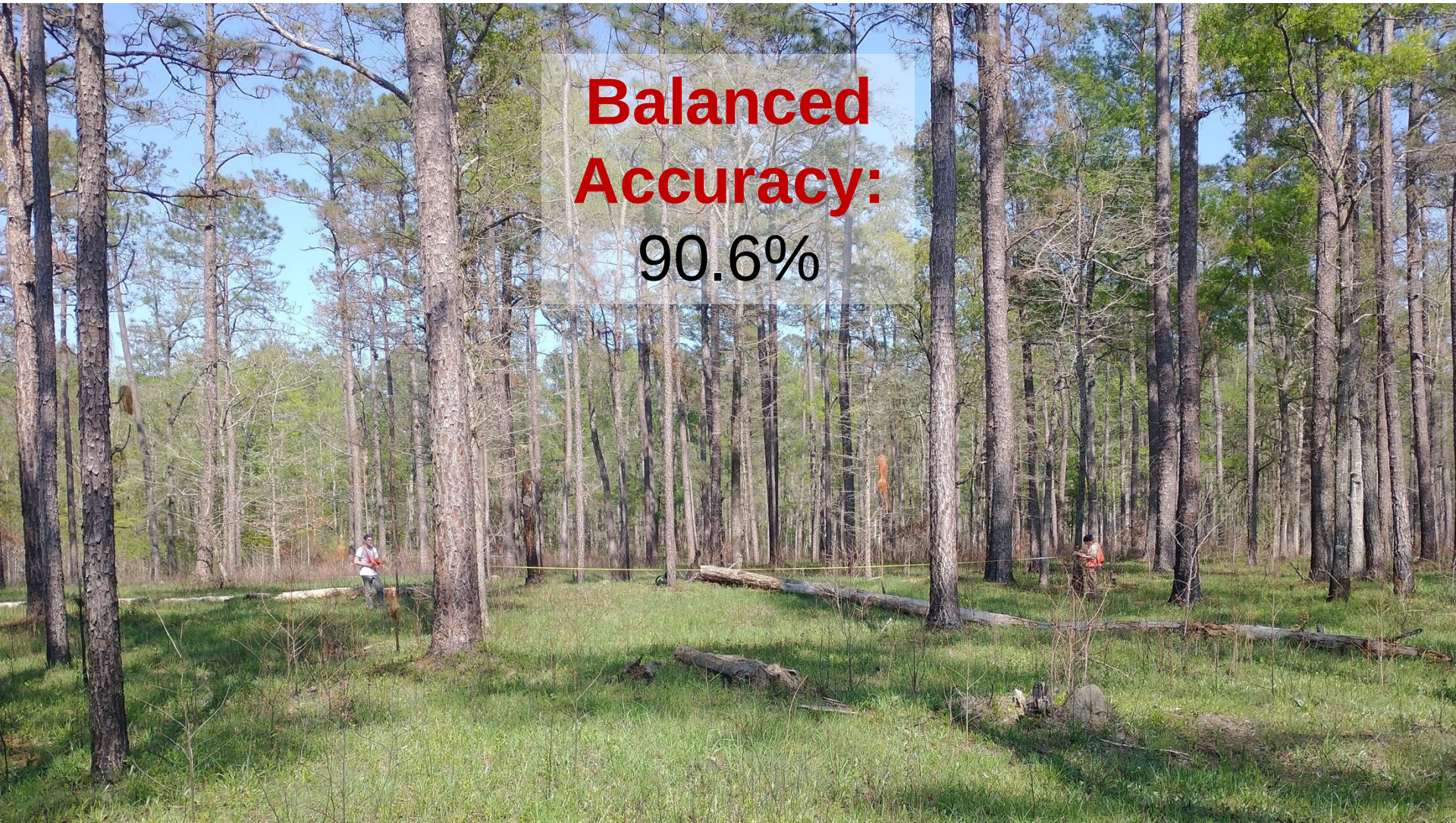
Distribution of tar kilns according to the **TKFD workflow**, but how do we verify these results?



Tar Kiln Project Overview
Automated LiDAR-Based Detection
Francis Marion National Forest

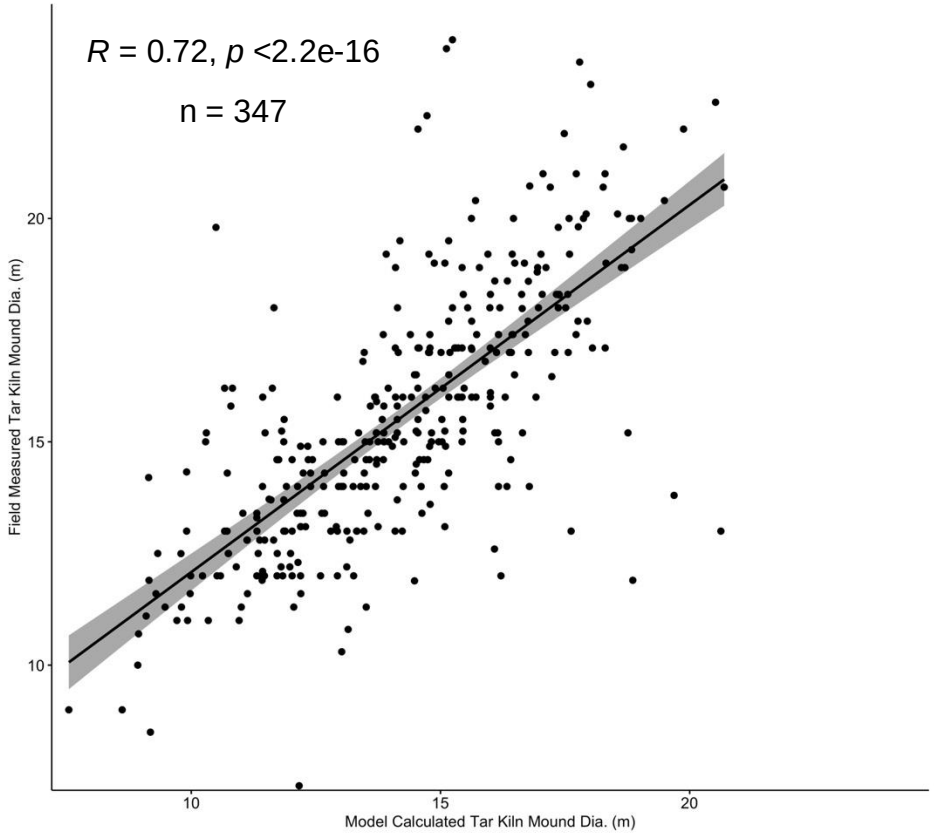
Validation of **Tar Kilns** detection

Previously known tar kilns, fieldwork, and random points

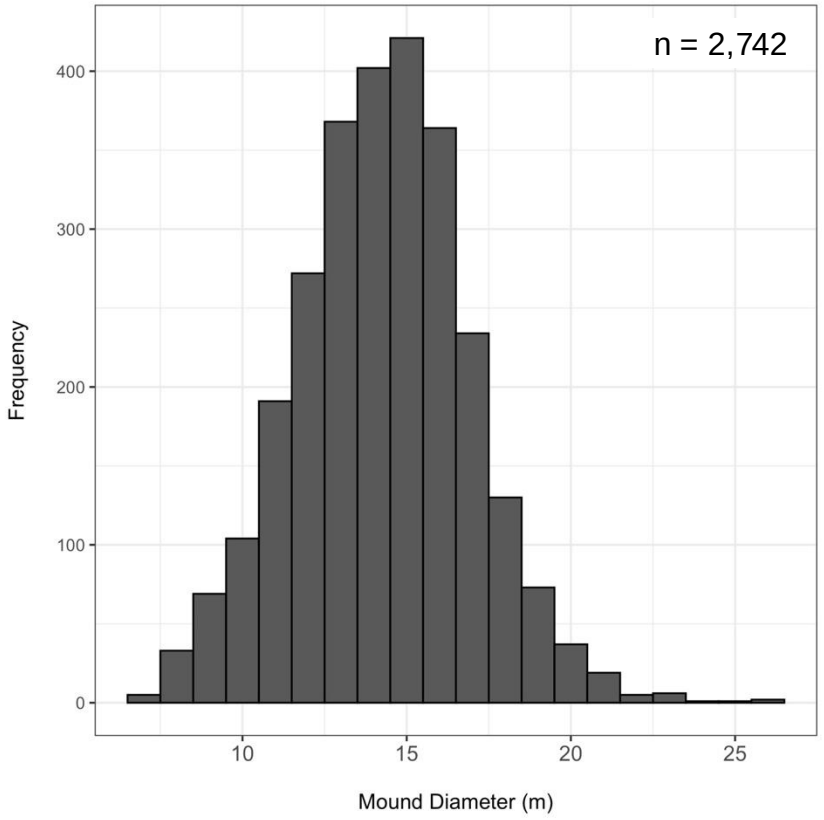


Measuring and validating of tar kiln diameter

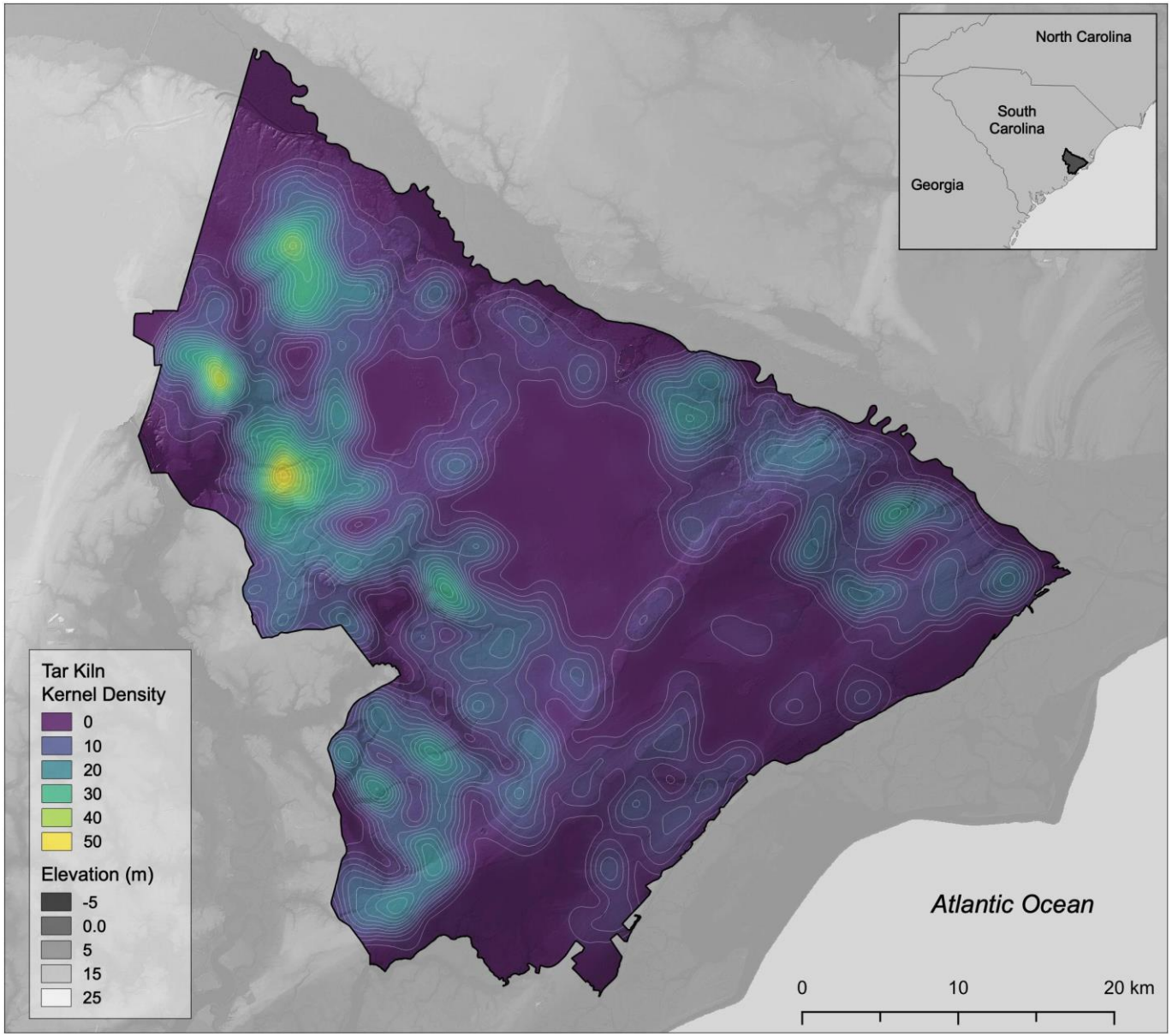
Comparison to field measured kilns



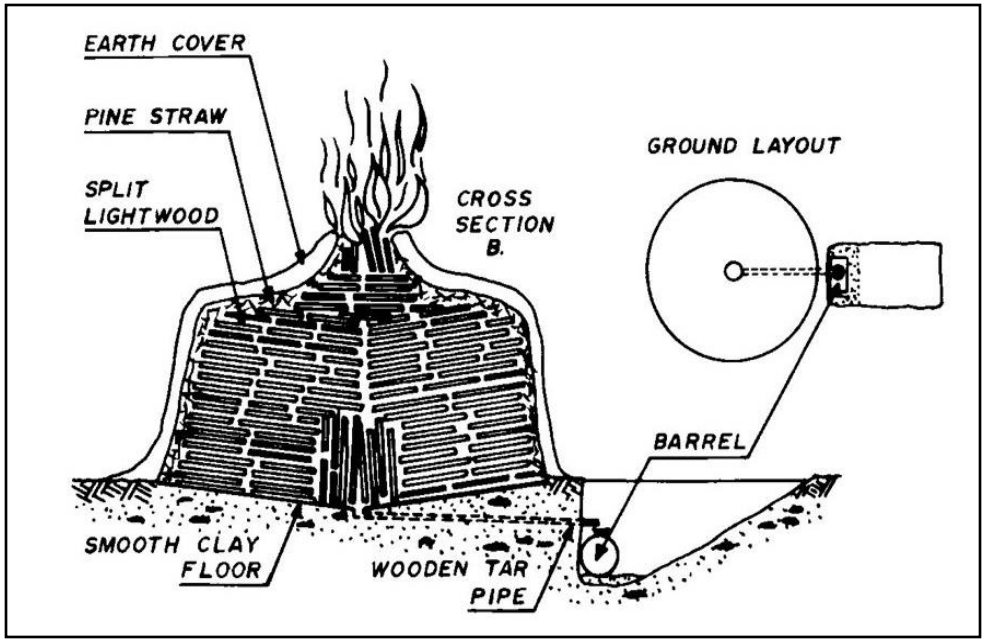
Tar Kiln Diameter (m) Distribution



Tar kilns as a proxy for the local distribution of Longleaf Pine stands



Estimating the **quantity** of Longleaf pine removed from the Francis Marion National Forest



Lightwood calculations based on: Gonzalez-Benecke, C.A., Gezan, S.A., Martin, T.A., Cropper, W.P., Samuelson, L.J., Leduc, D.J., 2014. Individual Tree Diameter, Height, and Volume Functions for Longleaf Pine. Forest Science 60, 43–56. https://doi.org/10.5849/forsci.12-074

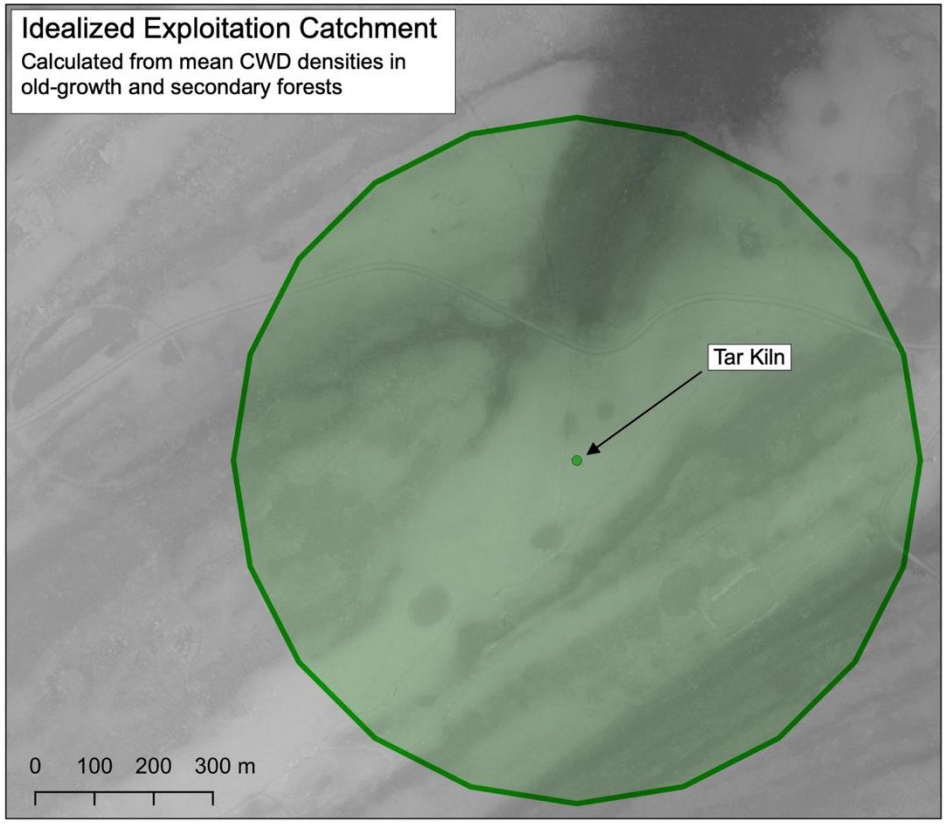
- Kiln volume calculated from diameter

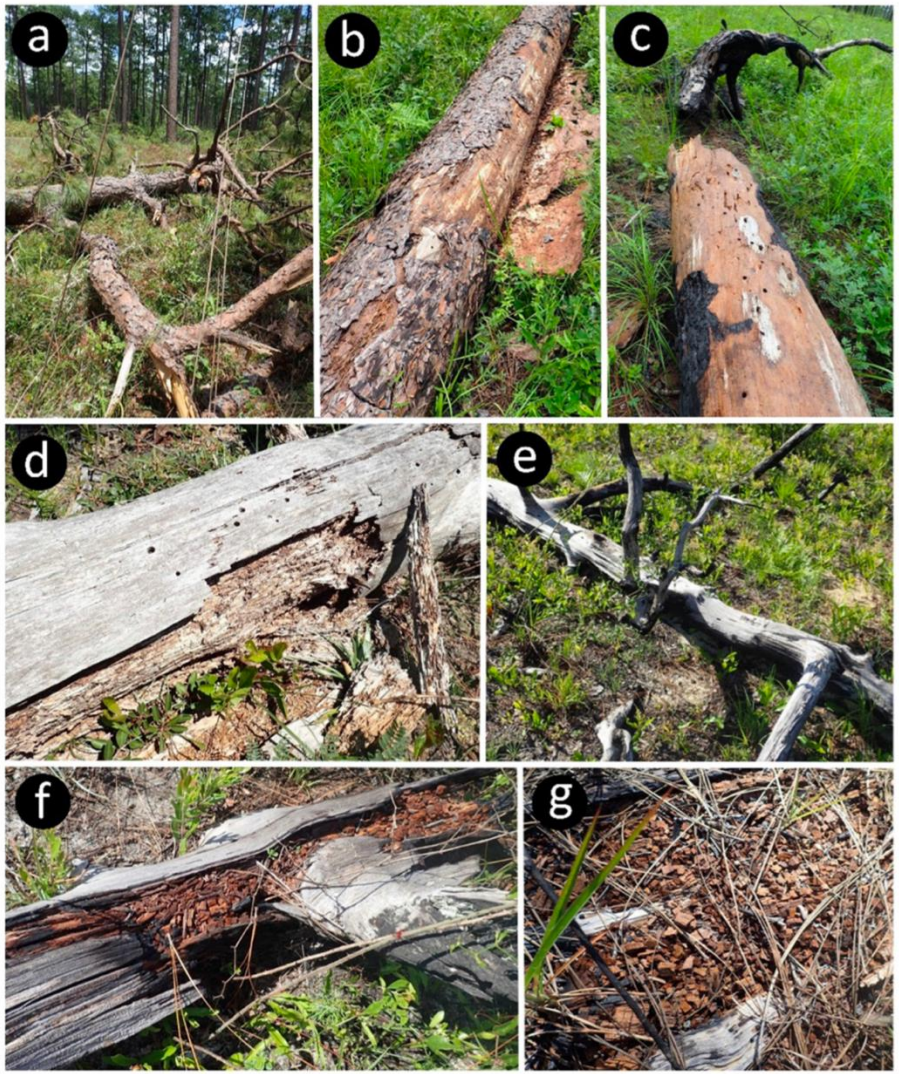
$$V = \pi\, r^2\, \frac{h}{3}$$

If each kiln were used only once...

- Almost **1.2 million cubic meters** of lightwood needed
- Equivalent of over **750,000** mature, old-growth Longleaf pines removed

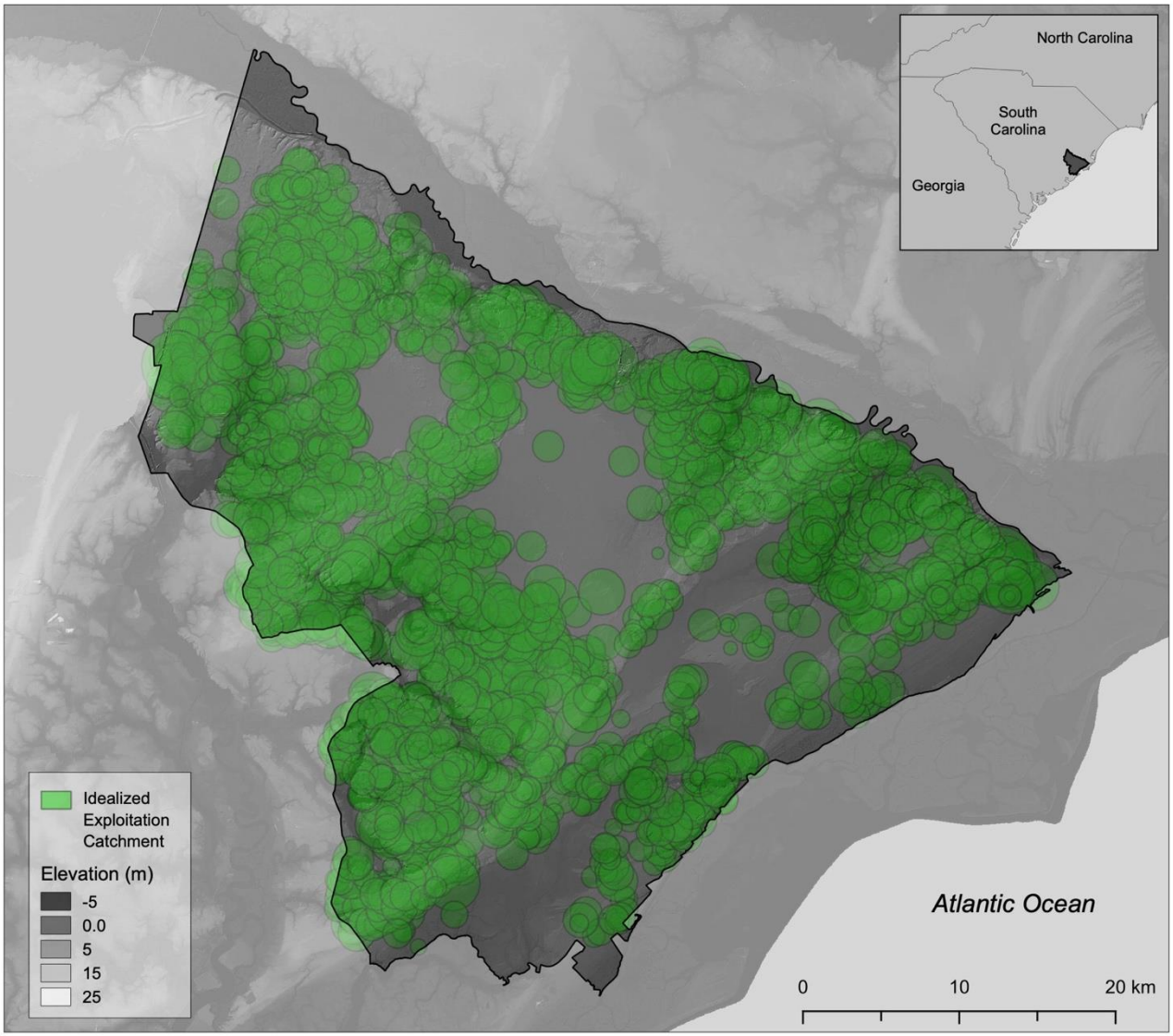
Quantifying the extent of **human impacts** on fuels in these systems from ~ AD 1670 - 1900





Ulyshen, M.D., Horn, S., Pokswinski, S., McHugh, J.V., Hiers, J.K., 2018. A comparison of coarse woody debris volume and variety between old-growth and secondary longleaf pine forests in the southeastern United States. Forest Ecology and Management 429, 124–132. https://doi.org/10.1016/j.foreco.2018.07.017

Estimated that **76%** of the Francis Marion National Forest was impacted by coarse woody debris collection for tar production between ~ **AD 1670 - 1900**



Conclusions and Future Directions: *The Archaeology of Fire and Fuels*

What does this all mean for the restoration of **Longleaf pine ecosystems**?

- Acknowledging that these are, and have been, intensively modified landscapes
- Bias in historical reference conditions
- Situating historical fire regimes into a context of historical fuels

A Social Ecology of Fuels

Where do we go from here?

- Recognize these as social-ecological systems—restoration to a “pristine” condition is not possible or helpful
- How do humans, fire, and fuels interact in these forests in the context of climate change
- Leverage archaeological perspectives and remote sensing techniques (Aerial LiDAR) to understand the social ecology of fire and fuels elsewhere

Many thanks to my collaborators, agency funders, and the Fire in Eastern Oak Forests Conference organizers / attendees.

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Learn more about Longleaf pine restoration

https://www.srs.fs.usda.gov/longleaf/

https://longleafalliance.org/

https://talltimbers.org/