

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

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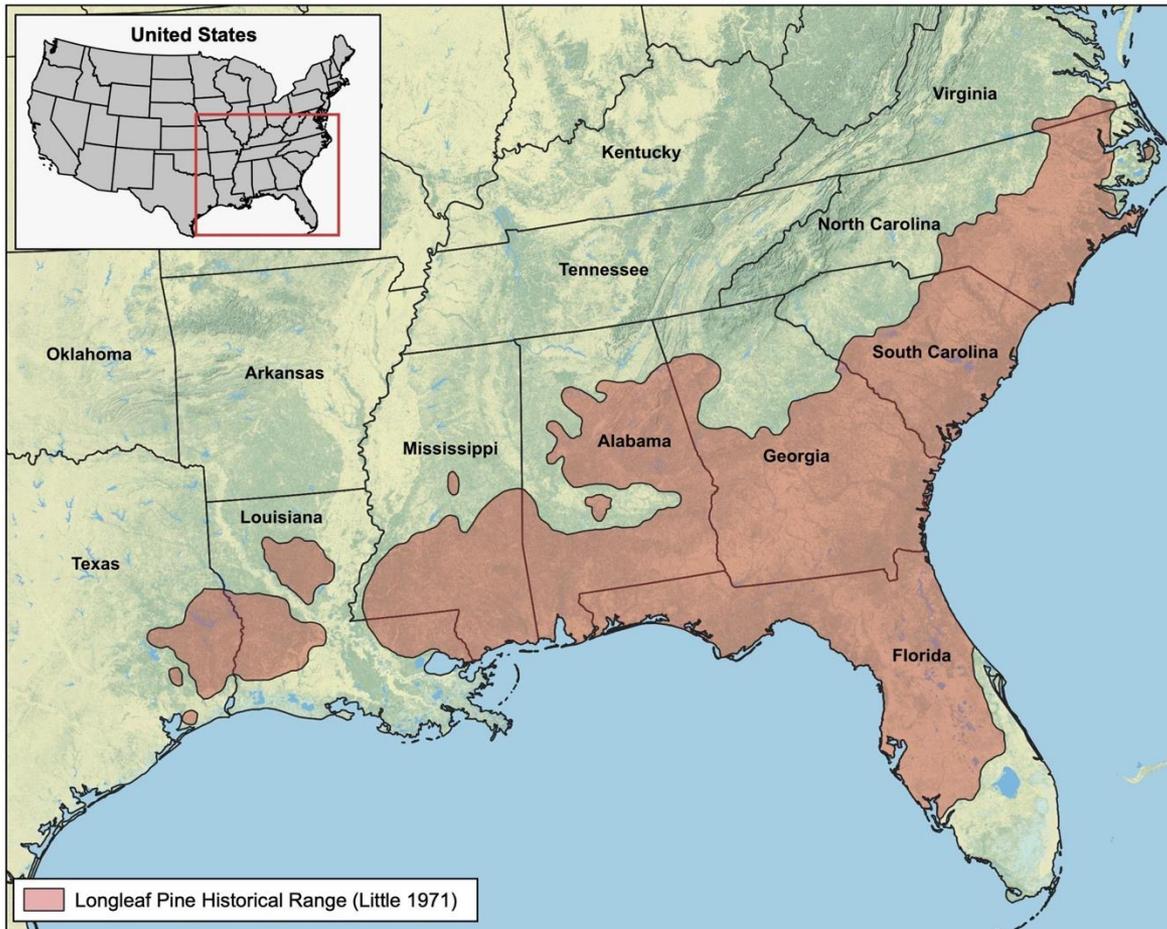
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New Mexico Consortium





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.



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**

The Forest Built by Fire



Historically, low intensity fires frequently moved through the landscape.

Today these fires are mimicked using prescribed fire.



Immediately after prescribed fire.

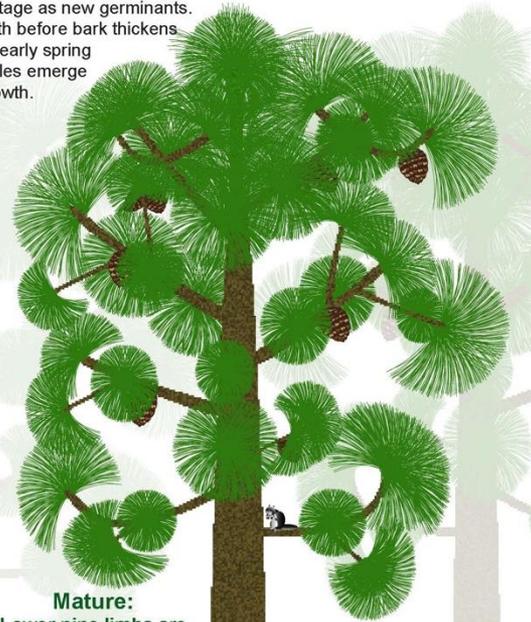
Fire reduces competition from hardwoods and other pines, maintaining open conditions necessary for longleaf pines and native plants, while providing food and habitat for wildlife.



Regrowth two weeks after fire.

Fire resistant, not fire-proof
Longleaf is resilient to frequent fires but is vulnerable to fire at certain stages:

- Prior to the grass-stage as new germinants.
- During height growth before bark thickens
- While "candling" in early spring before needles emerge on new growth.



Sapling:
Lateral branches emerge at 6-10 ft in height.

Mature:
Lower pine limbs are pruned by fire, keeping the canopy above most flame heights.

Thick plates of bark protect the inner trunk from fire.

Native understory plants and longleaf needle litter provide fine fuels to carry fire across the forest floor.



Seeds:
Fire consumes litter on the forest floor, creating optimal conditions for germination.



Grass Stage:
Young longleaf resemble a clump of grass. The dense needle cluster protects the bud from fire and will quickly regrow post burn.

Rapid height growth increases longleaf's competitive advantage for sunlight and moves the growth bud above typical flame heights.

Bottlebrush:
Longleaf bolts in height with no branching.



Most grass-stage growth occurs underground as seedlings develop extensive root systems.

Fire recycles nutrients back into the soil.

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



Which landscapes?

When?

Why?

017652. IN THE PINE WOODS, FLORIDA.

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

1. Introduction

Longleaf pine (*Pinus palustris* Mill.) forests once dominated the southeastern Coastal Plain in the United States (US), occupying 36 million hectares (ha) prior to the arrival of European settlers (Frost, 1993). Currently, 3% of the historical area of longleaf pine forests (1.3 million ha) remains in the Florida Panhandle, southern Alabama, Georgia and Mississippi, primarily in private ownership and as natural forest (Oswalt et al., 2012). The primary reasons behind this intensive decline include land use change for agriculture and human occupation, suppression of natural fire regimes, and conversion to economically more attractive southern pines (Frost, 1993; Landers et al., 1995).

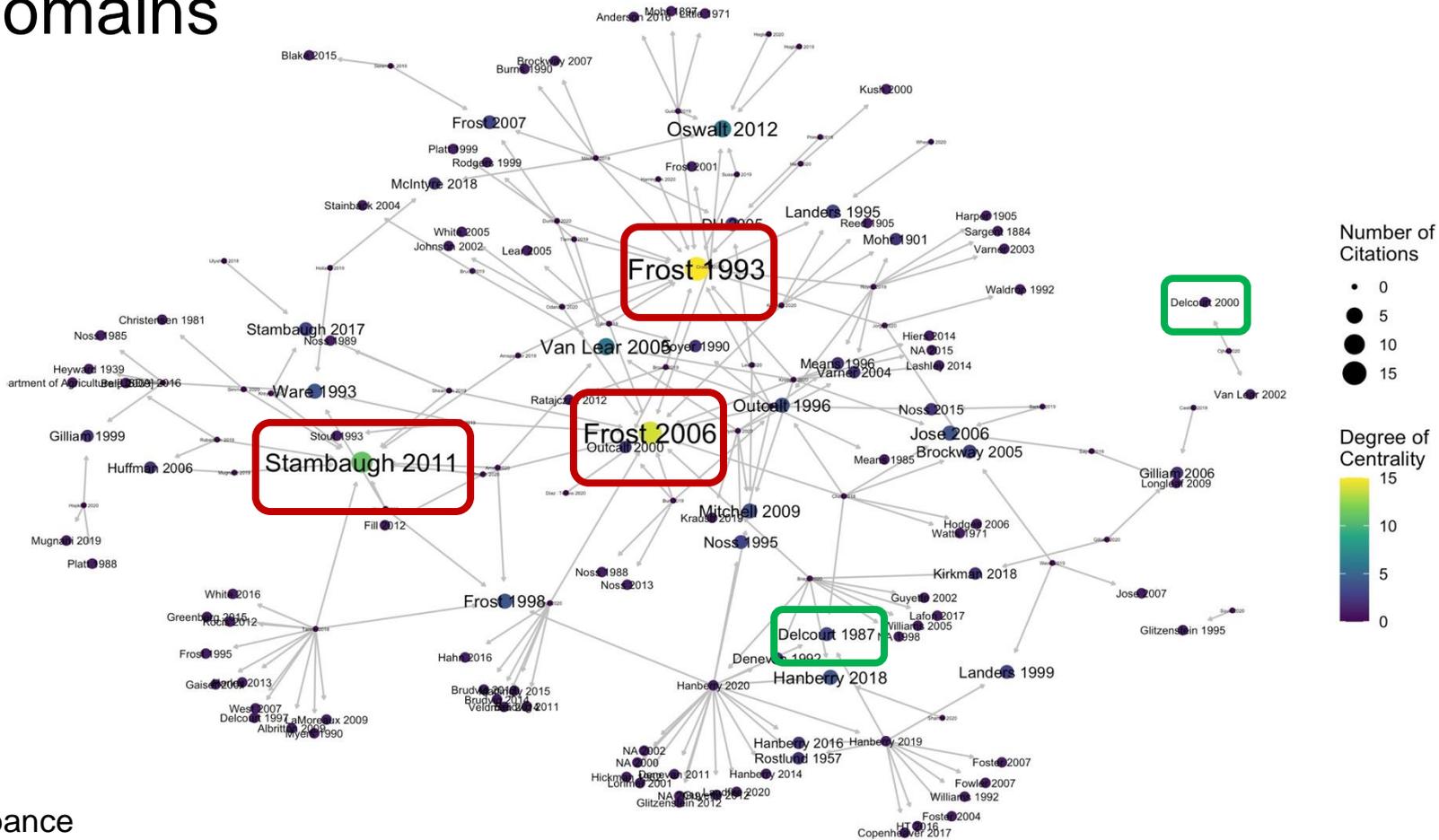
Domain Codes

Historic Distribution

Historic Disturbance

Historic Disturbance

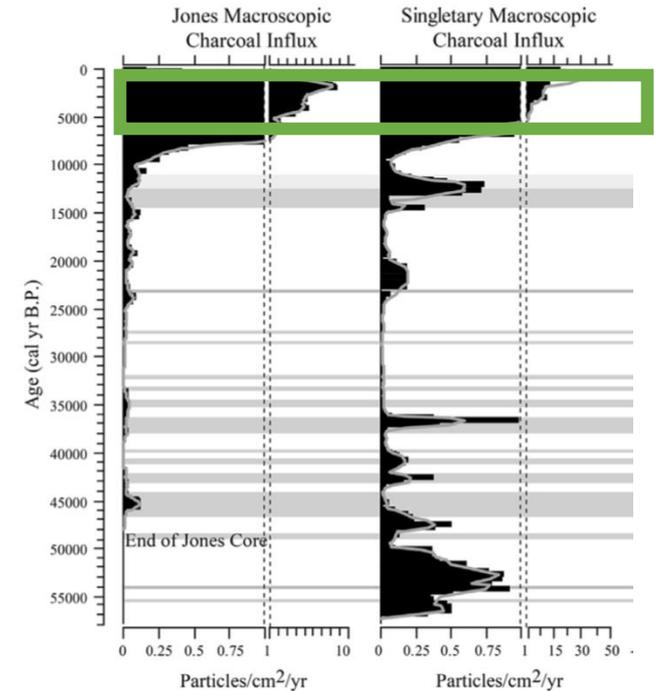
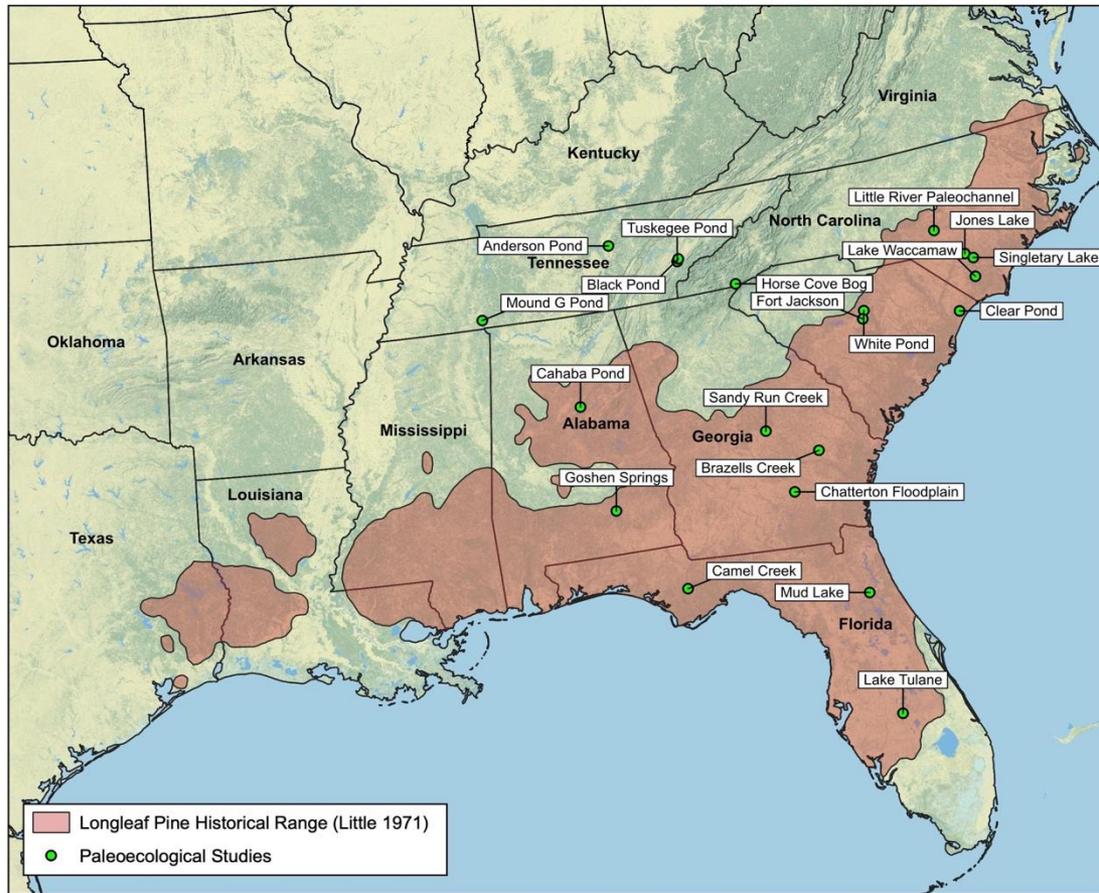
Citation network for all coded domains



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

A photograph of a pine forest with tall, thin trees and a grassy foreground, serving as a background for the text.

Palynology
Charcoal Studies
Climate Proxies

Fundamental Gap in Knowledge

A photograph of a pine forest with tall, thin trees and a grassy foreground, serving as a background for the text.

Historic Timber Inventories
Travelogues
Historical Photos
Fire-Scarred Trees

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

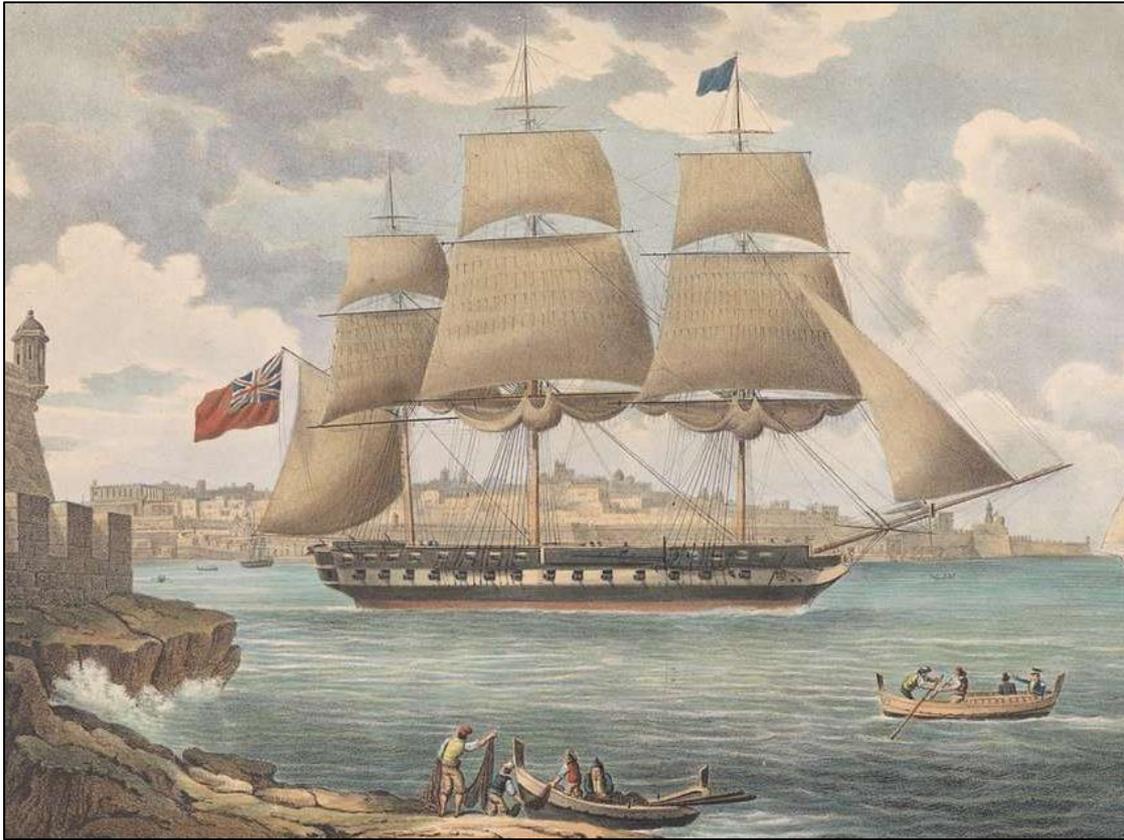


Time

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



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

AD 1600s
Sporadic references to naval stores in North America

AD 1730s
Removal of British bounty reduces naval store production

AD 1780s – 1830s
Continued high production of tar and pitch, but turpentine gradually becoming the dominate industry

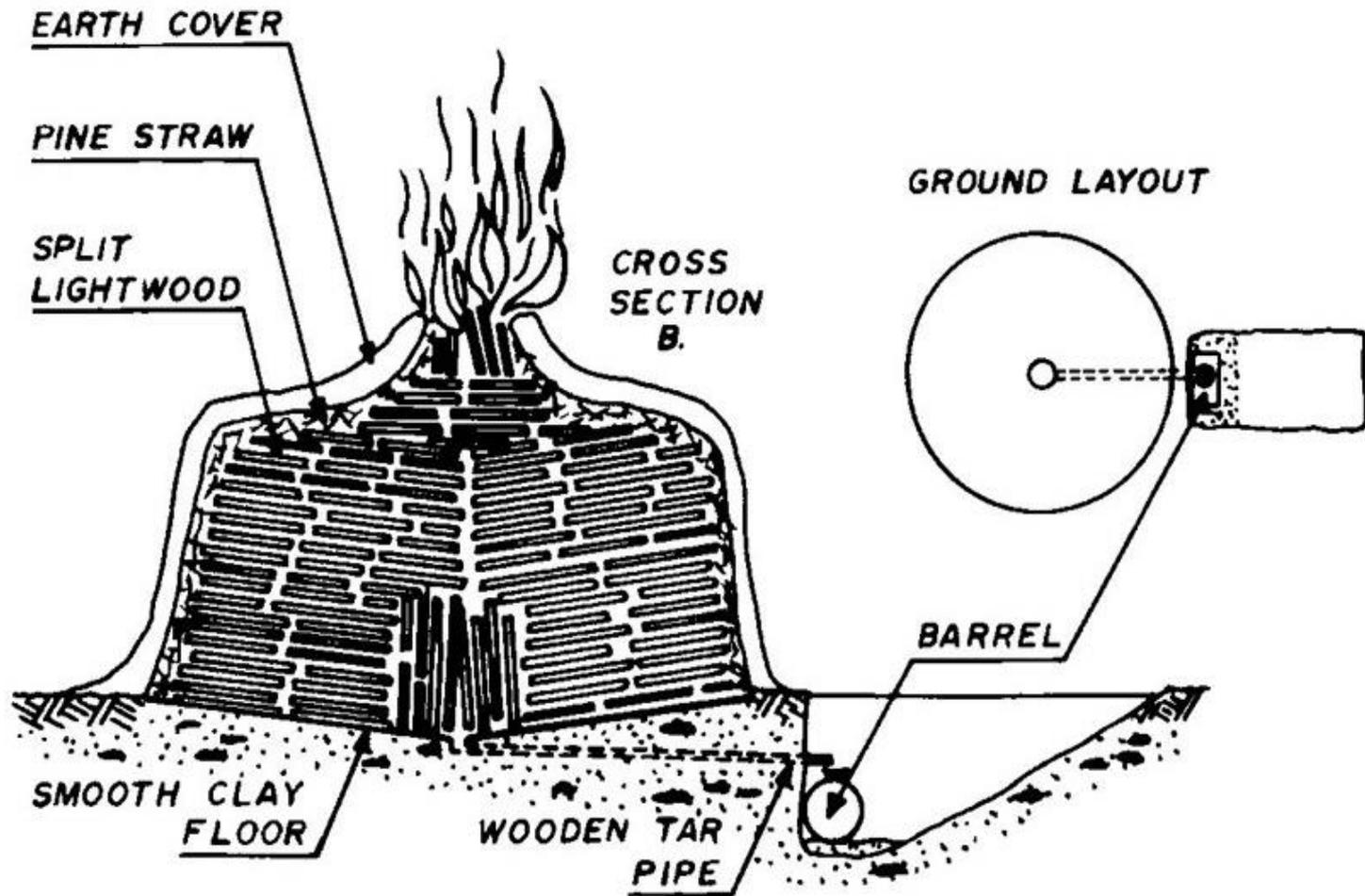
AD 1900s
Tar and pitch production are very minor industries and turpentine production continues to grow until the 1930s and 1940s

AD 1705
British Naval Stores Act creates economic incentives for colonies to export tar, pitch, turpentine

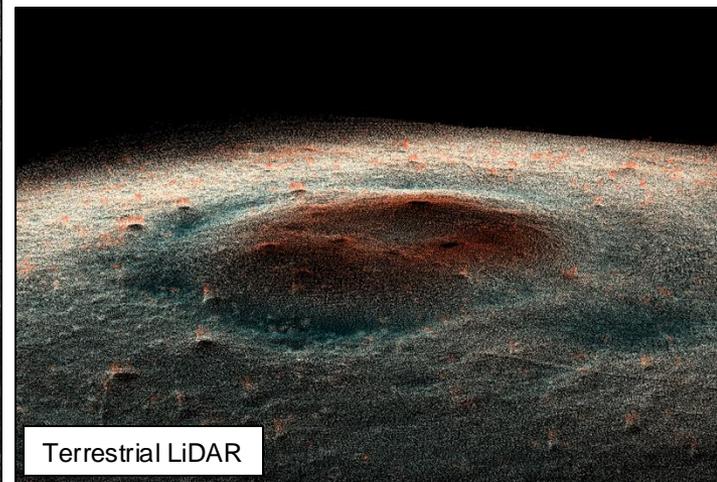
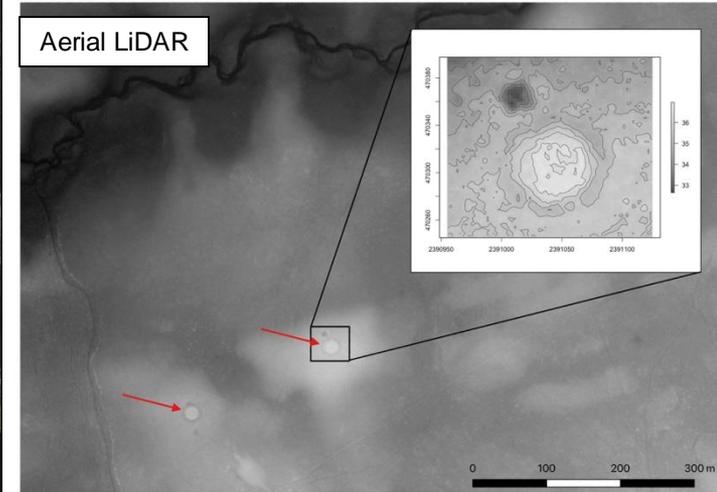
AD 1775 – 1783
Increased demand for domestically produced Naval stores during the American Revolutionary War

AD 1830s – 1900
Continued decline in tar and pitch production, but increased turpentine production, particularly after the American Civil War

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



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



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, coarse 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

Project Objectives

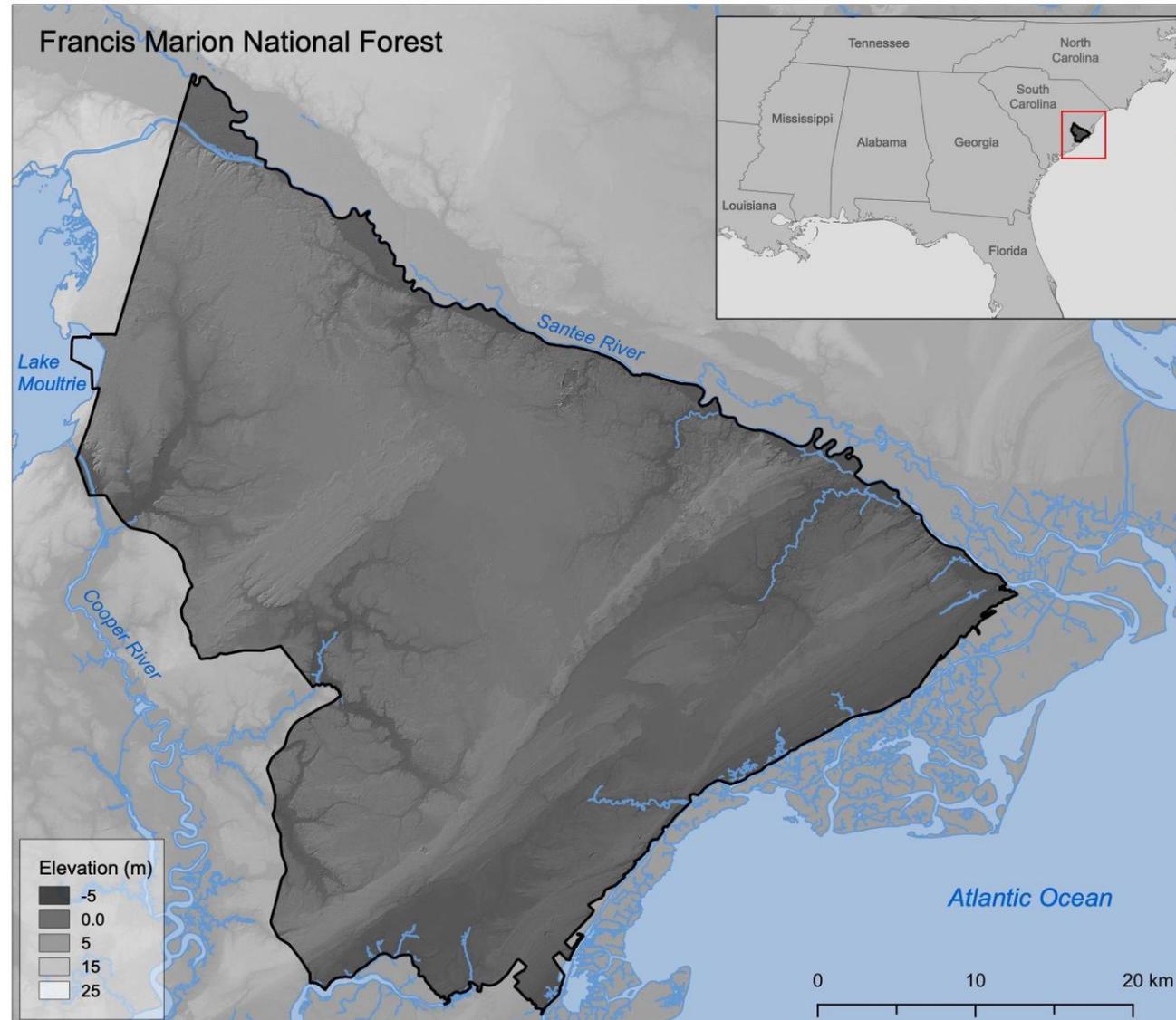
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Specific metrics important for restoration ecology

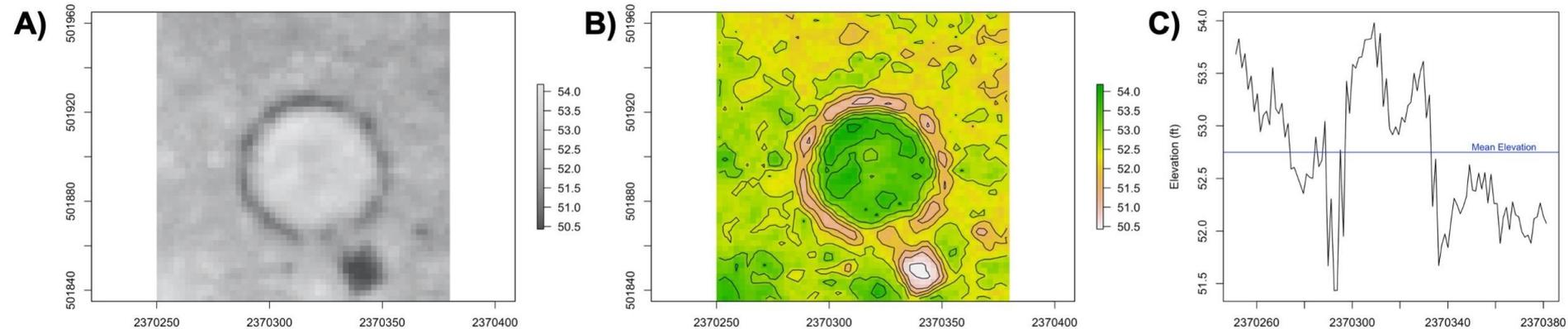
- Local spatial variability in historical Longleaf pine stands
- Quantity of fuels removed from these systems
- Extent of human impacts on fuels in these systems from ~ AD 1670 - 1900.

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.



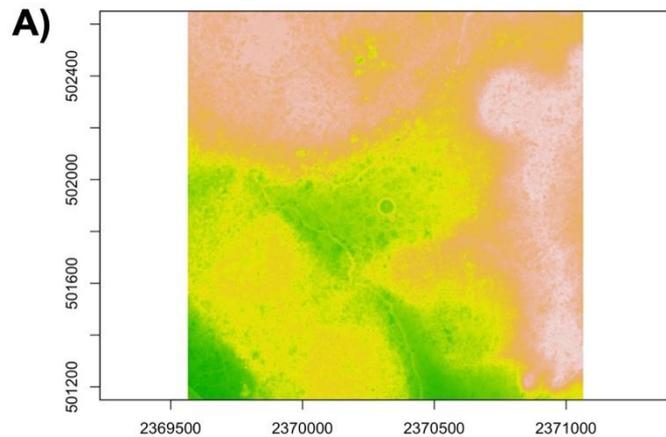
The Tar Kiln Feature Detection (**TKFD**) workflow



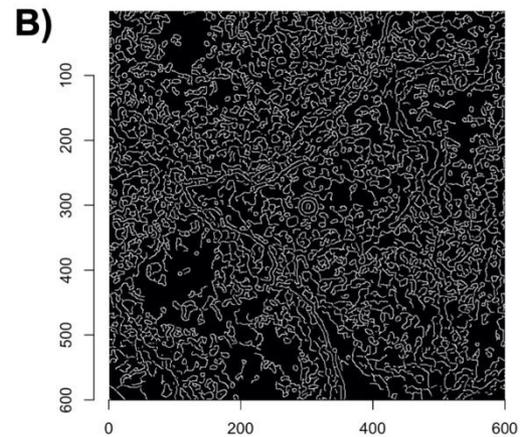
- Scripted, open-source workflow linking R and FIJI
- Computer vision technique to extract archaeological features that might not be highly visible in the field
- Relies on tar kiln morphology for detection: **[A]** circular, **[B]** slightly mounded, and **[C]** surrounding trench

The Tar Kiln Feature Detection (TKFD) workflow

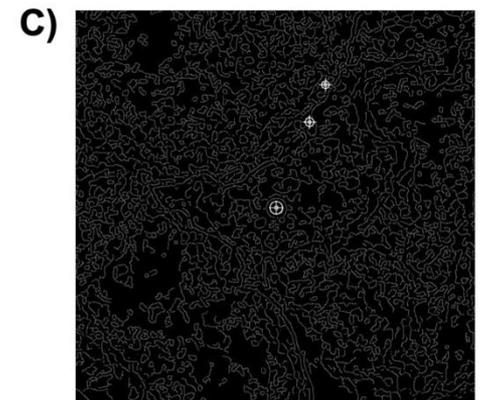
Brief overview



1-meter DEM from
aerial Lidar

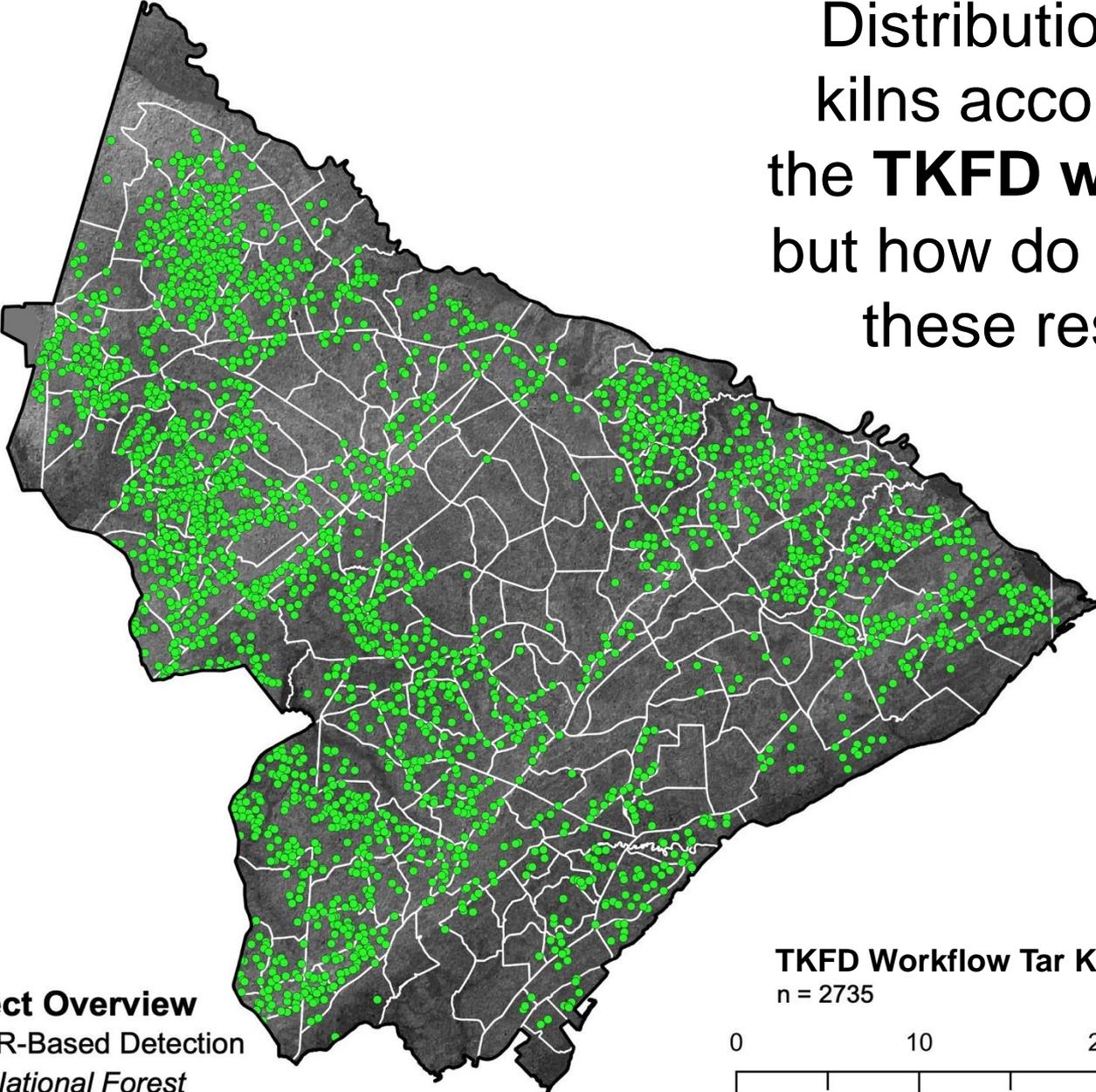


Canny edge detector to
extract image structure



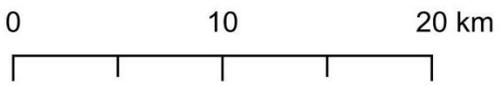
Circle Hough Transform
to detect circular objects

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

TKFD Workflow Tar Kilns
n = 2735



Validation of **Tar Kilns** detection

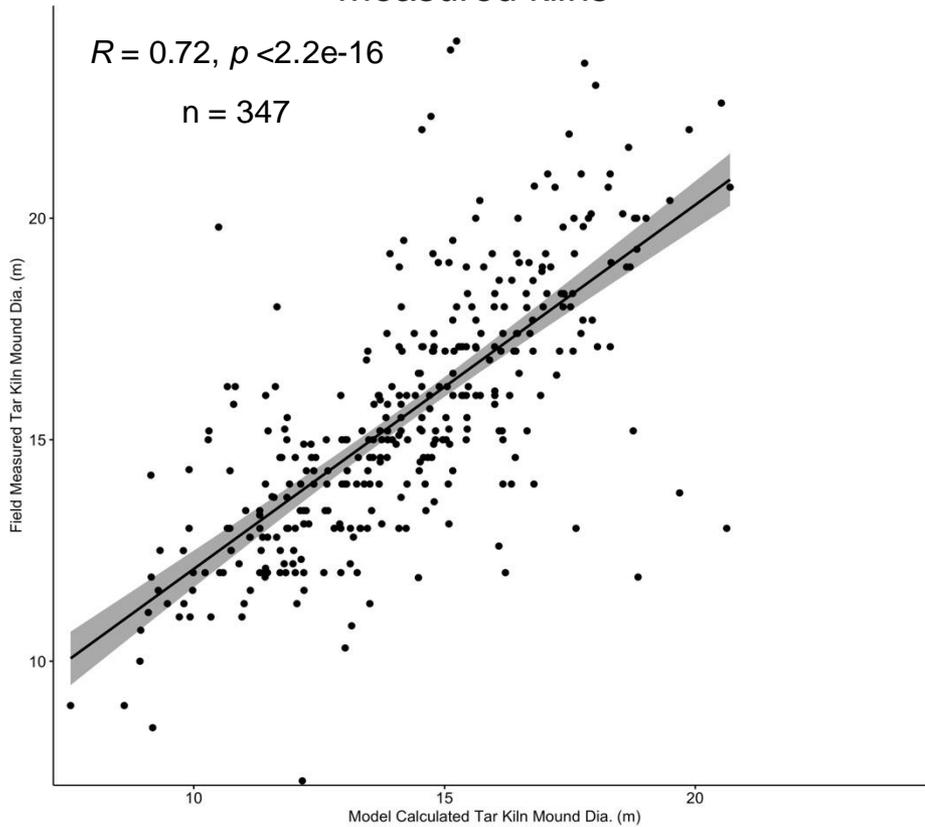
Previously known tar kilns, fieldwork, and random points



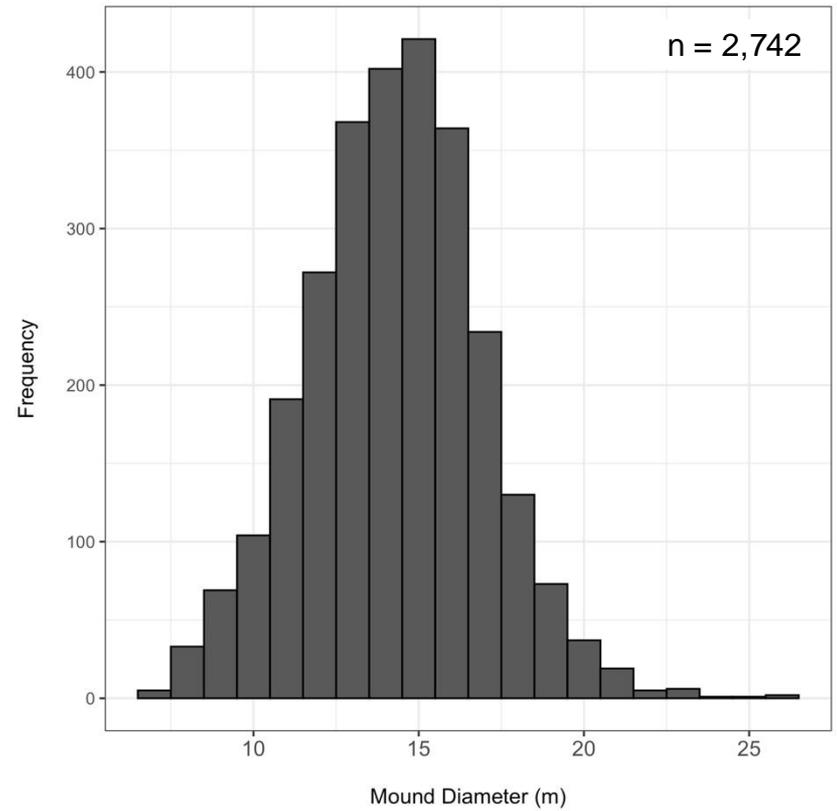
**Balanced
Accuracy:
90.6%**

Measuring and validating of tar kiln diameter

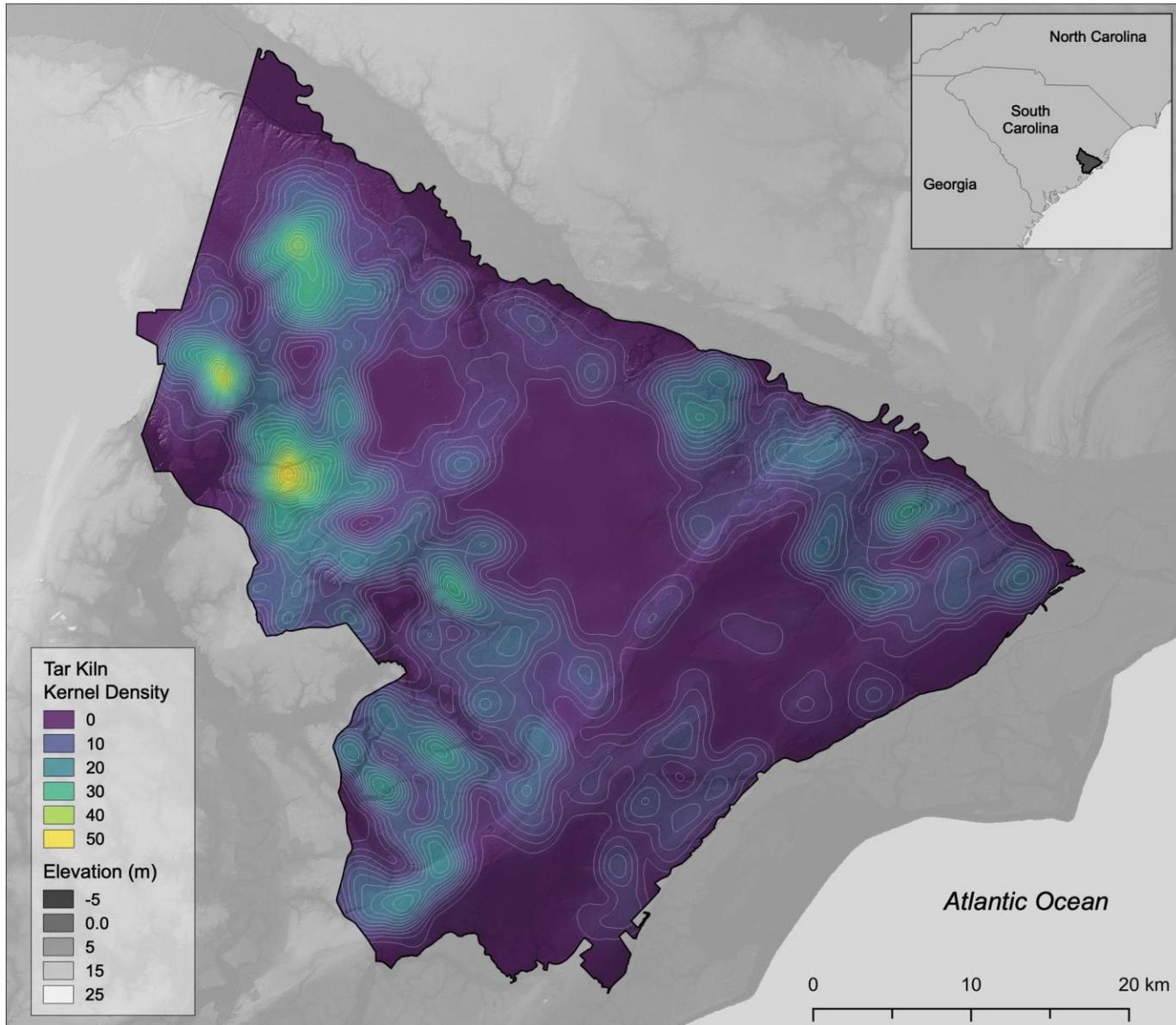
Comparison to field measured kilns



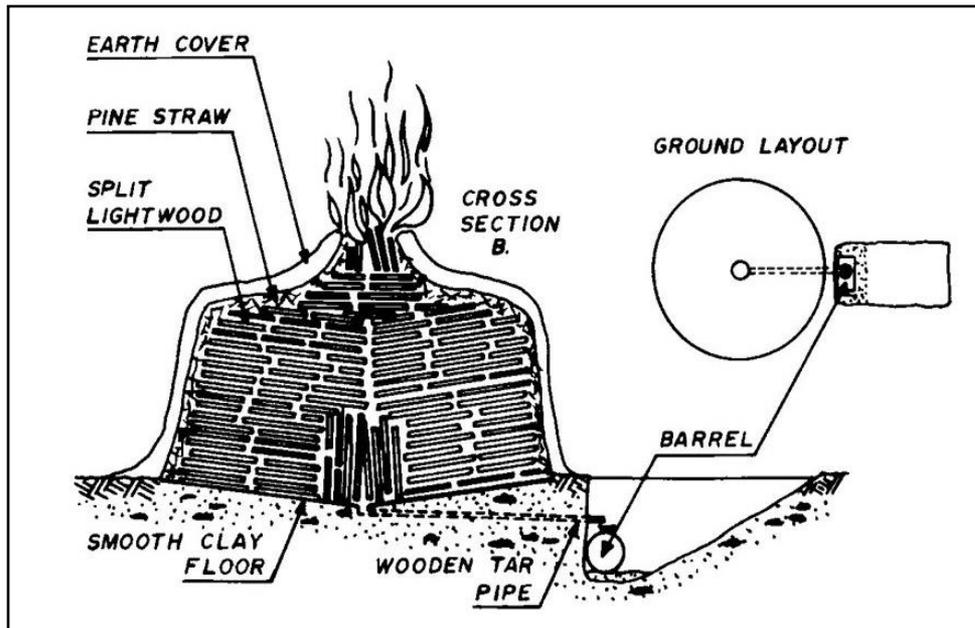
Tar Kiln Diameter (m) Distribution



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



- Kiln volume calculated from diameter

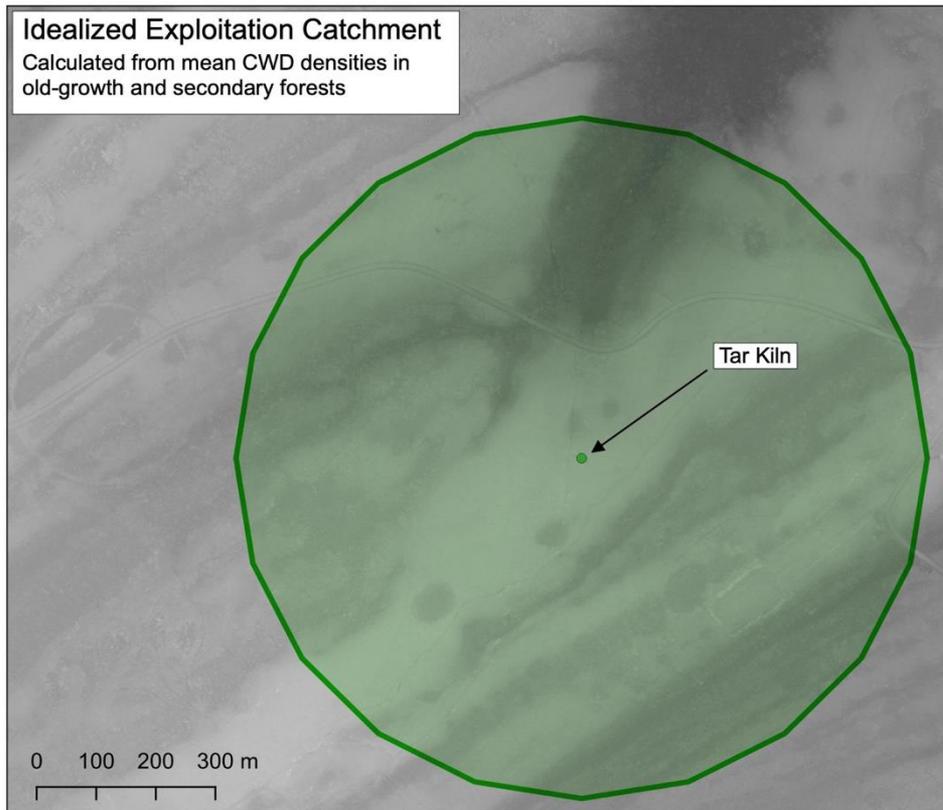
$$V = \pi r^2 \frac{h}{3}$$

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

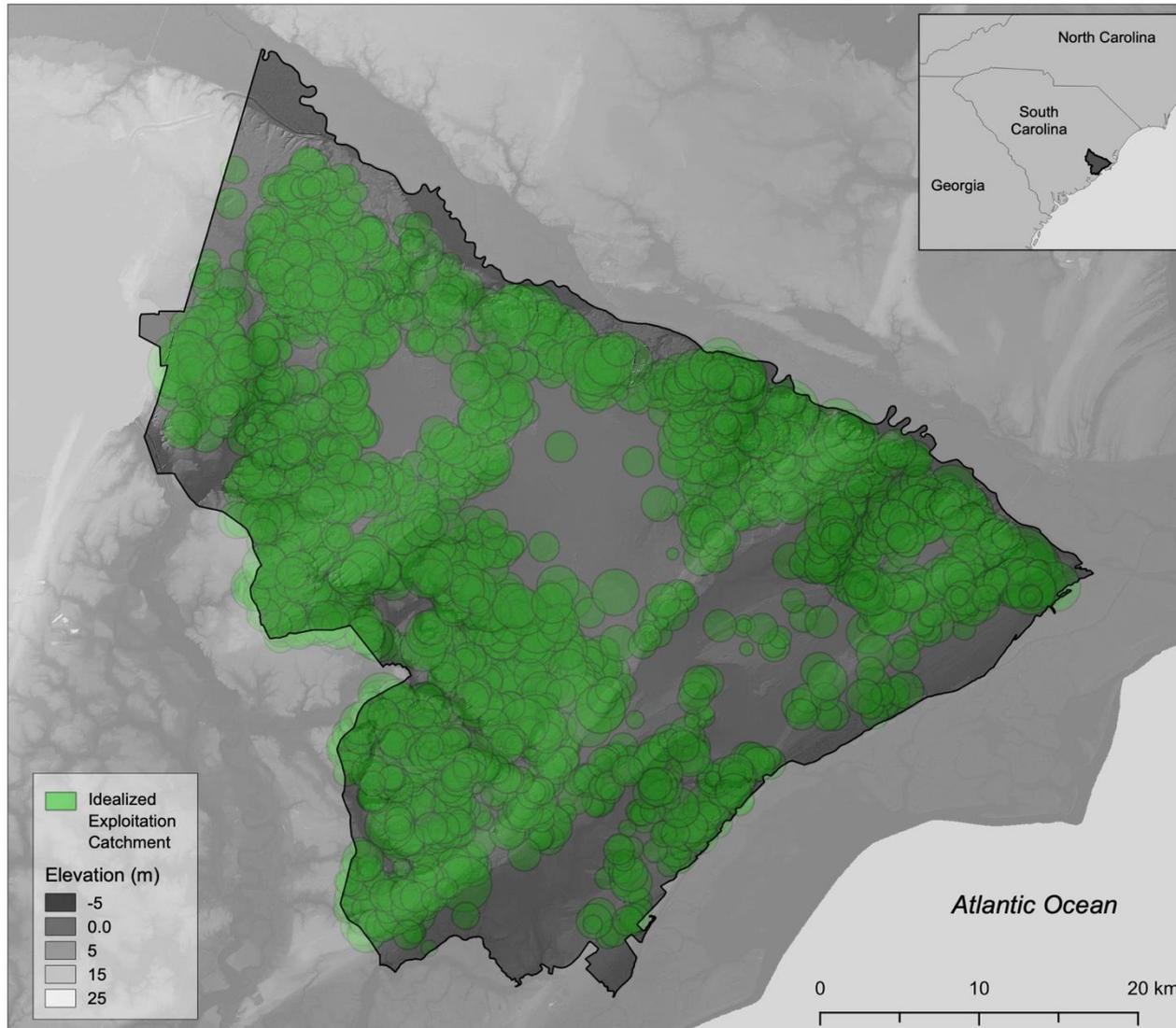
Lightwood calculations based on: Gonzalez-Benecke, C.A., Gezan, S.A., Martin, T.A., Cropper, W.P., Samuelson, L.J., Leduc, D.J., 2014. Individual Tree Diameter, Height, and Volume Functions for Longleaf Pine. Forest Science 60, 43–56. <https://doi.org/10.5849/forsci.12-074>

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,
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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/>