

Carbon Market and Southern Forestry: Implications for Management and Workforce

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**I. Carbon
Forestry in
the South**

**II. Carbon
Offsets IFM
Protocols
Comparison**

**III. Climate-
Smart
Forestry
Workforce**

I. Carbon Forestry in the South



- Biophysical carbon potential

The southern United States is a major, dynamic carbon reservoir with substantial current stocks and a substantial potential for further sequestration.

U.S. timberlands (much of which is in the South) could increase annual sequestration capacity by approximately 20 per year (Cook-Patton et al., 2020)

Harvested Wood Products (HWP) in the South represent a significant "pool" that offsetting roughly 12.4% of total gross greenhouse gas emissions in the U.S. (USDA Forest Service, 2023).

I. Carbon Forestry in the South

- Dominant Timber-producing region

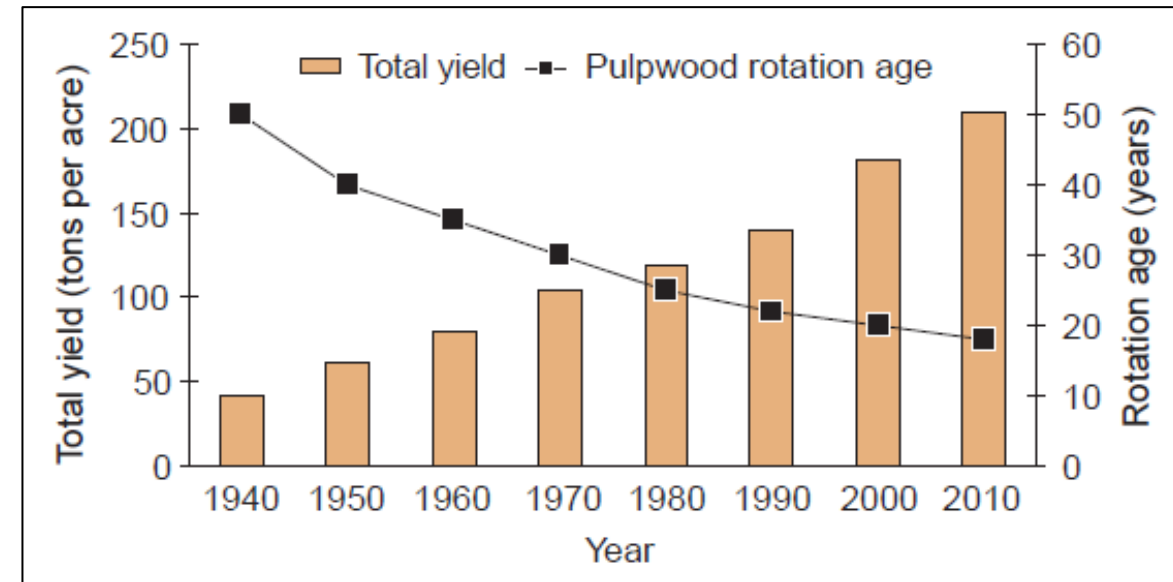
It produces a large share of U.S. timber due to extensive plantation forestry. Only 11% of U.S. timberland is planted, but 67% of that planted area is in the South.

- Economic Impact

Southern forests are a massive engine for both state and national economies. Over \$251 billion annual economic impact from forestry and forest products industries with 1.1 million jobs.

- Private Landowner Influence

Management decisions by diverse private landowners affect carbon market strategies and timber production balance.



Fox, T. R., Jokela, E. J., & Allen, H. L. (2007). The development of pine plantation silviculture in the southern United States. *Journal of Forestry*, 105(7), 337-347.

I. Carbon Forestry in the South

- Economic Trade-Offs

Carbon projects often require reduced timber harvests, delaying income and creating opportunity costs for landowners.

- Market Uncertainty

Uncertain carbon market rules and potential protocol changes cause hesitation among landowners for long-term commitments.

- High Transaction Costs

Project development, monitoring, and verification costs are burdensome for small and medium landowners.

- Climate Change Risks

Risks like hurricanes, wildfire, and pests can cause credit reversals, increasing uncertainties for carbon projects.

I. Carbon Forestry in the South

- IFM and Carbon Offsets

IFM projects generate carbon credits by increasing forest carbon stocks beyond baselines. Practices include extending rotation, reducing harvest, boosting stocking, and favoring high-carbon species.

- Several registries exist for generating carbon offsets

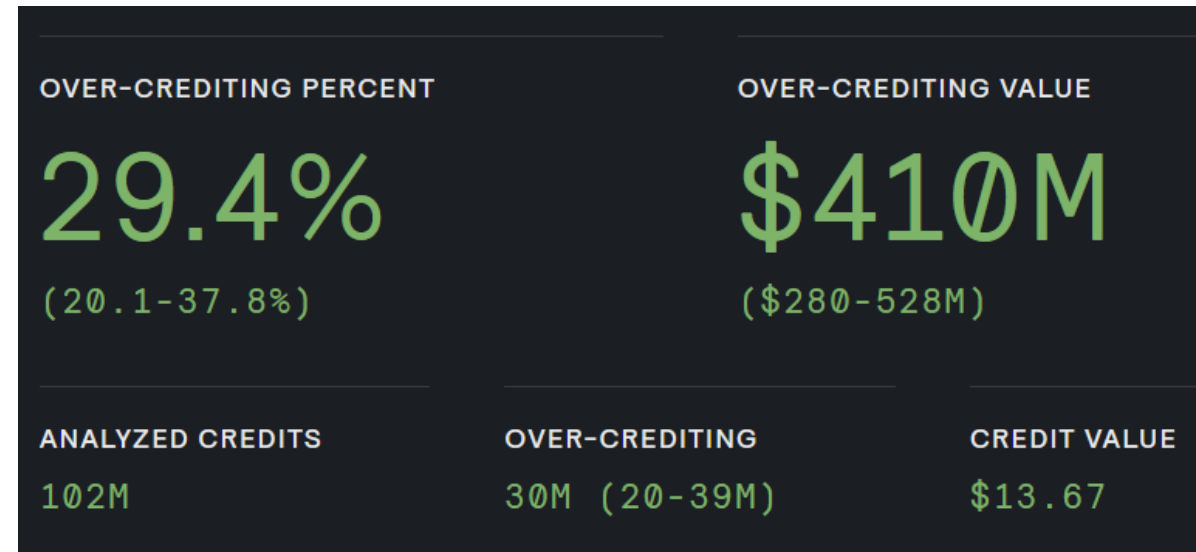
American Carbon Registry (ACR) and the Climate Action Reserve (CAR)

- IFM Benefits and Relevance

IFM is scalable, flexible, integrated into working forests, and important for southern US carbon projects.

- Challenges and Controversies

IFM involves complex assumptions about baselines, raising concerns over additionality and over-crediting.



Source: <https://carbonplan.org/research/forest-offsets-explainer> (2021)

II. IFM Offsets Protocols Comparison

- Existing challenges and possible solutions for forest carbon offset (Pan et al. 2022)
 - Methodology issue (Additionality, permanence, leakage)
 - Socio-economic implications (Transaction, social, and opportunity costs)
 - Implementation (Monitoring, reporting, and verification)

Key challenges and approaches to addressing barriers in forest carbon offset projects

J. For. Res. (2022) 33:1109–1122
<https://doi.org/10.1007/s11676-022-01488-z>

REVIEW ARTICLE

Rehabilitation forestry and carbon market access on high-graded northern hardwood forests

Canadian Journal of Forest Research • 13 March 2014 • <https://doi.org/10.1139/cjfr-2013-0437>

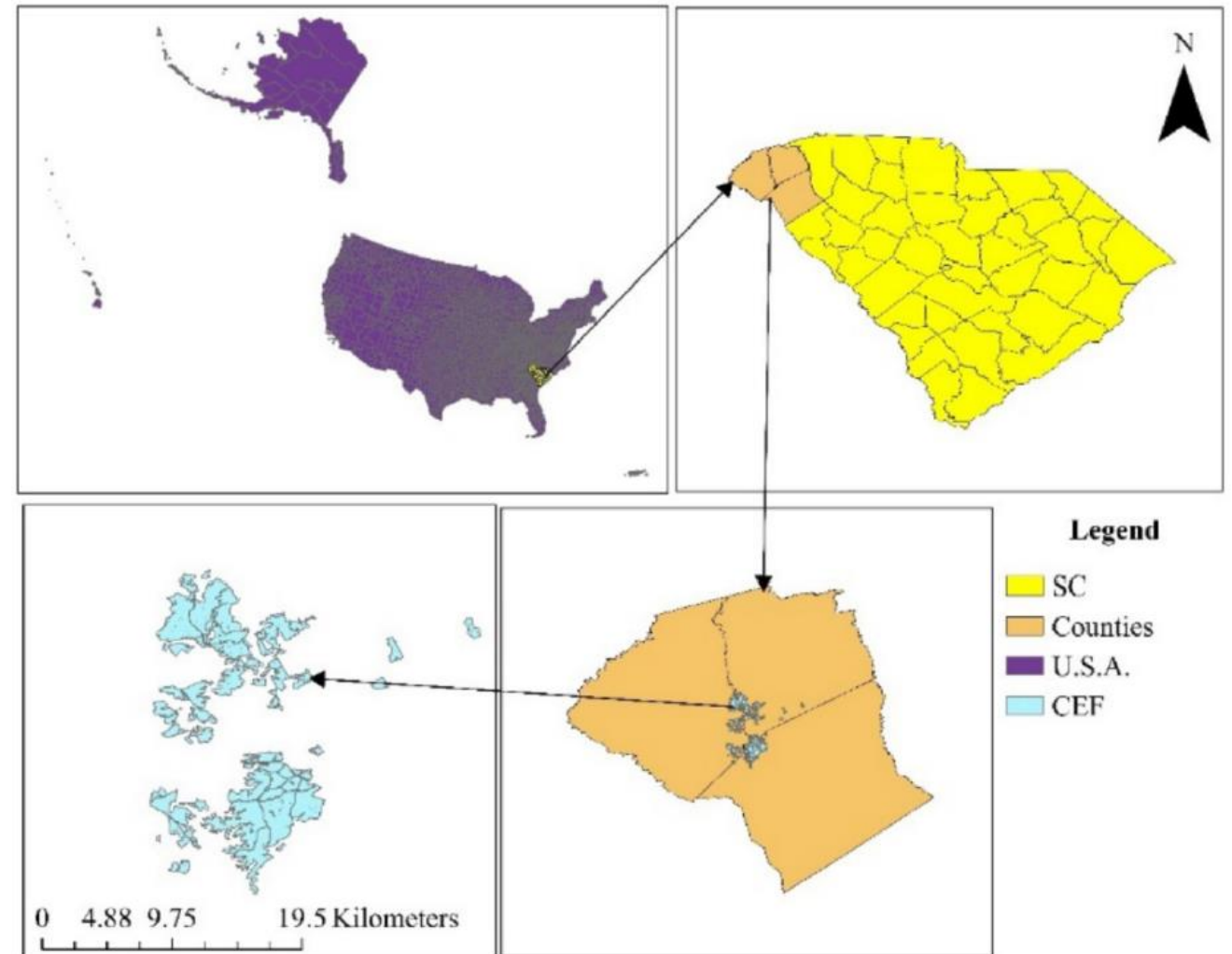
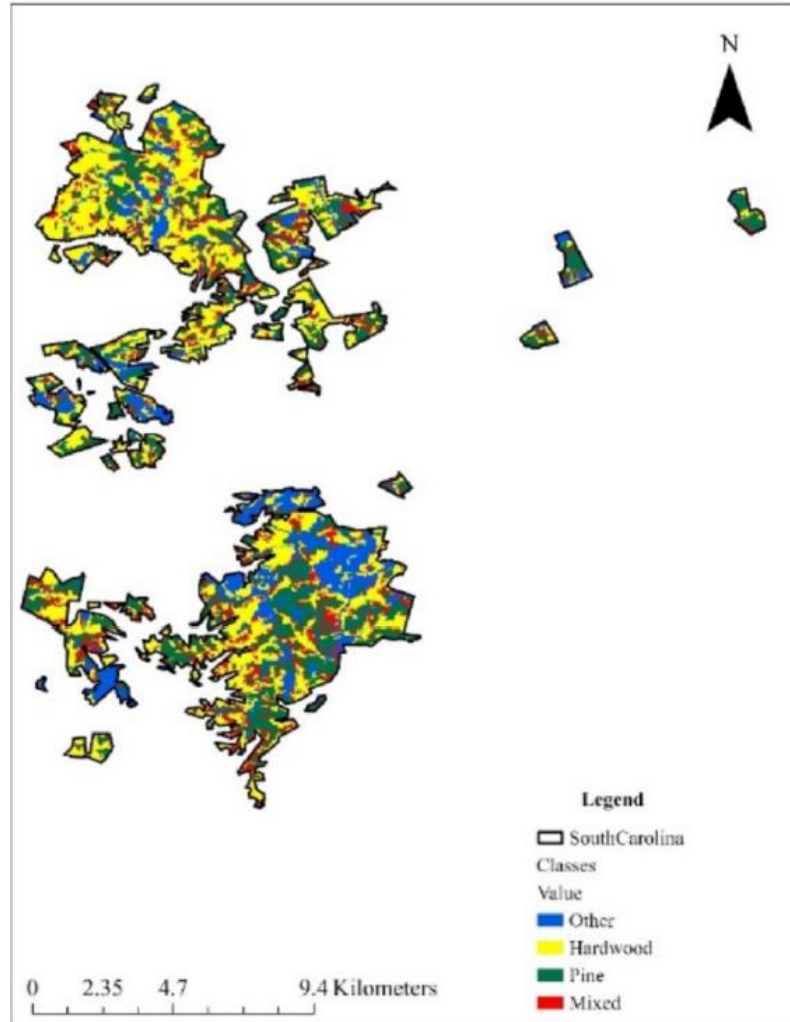
II. IFM Offsets Protocols Comparison

- Study Goals: The study goal was to compare carbon credit generation and economic viability under various management strategies in working forests.
 - How forest management scenarios affect joint timber and carbon management to maximize revenue
 - Compare revenues under current market conditions from CAR and ACR protocols in Clemson University Forest

Citation: Sharma, S., Clay, L., & Khanal, P. (2026). Forest management and carbon market integration at Clemson University forest. *Ecological Indicators*, 185, 114736.

II. IFM Offsets Protocols Comparison

Clemson University Forest, South Carolina



II. IFM Offsets Protocols Comparison

Clemson University Forest, SC

- Representative Southern Working Forest
 - Clemson Experimental Forest features diverse pine, hardwood, and mixed-species stands managed for timber, non-timber benefits, research, and education.
- Empirical Data Collection
 - Stand-level inventory data from 185 permanent plots provide a strong empirical basis for modeling growth and carbon dynamics.
- Real-World Management Conditions
 - The site reflects practical forest management rather than idealized scenarios, suitable for evaluating IFM protocols.

II. IFM Offsets Protocols Comparison

- Integrated Modeling Framework

The study uses a 100-year simulation integrating forest growth, harvest, carbon stocks, and crediting rules for comprehensive assessment.

- Protocol Comparison

Forest inventory data evaluated under CAR and ACR IFM protocols evaluate effects of protocol design on outcomes.

- Economic Assessment

NPV calculations include credit issuance, buffer deductions, and cash flow timing for financial analysis.

Comparison of the ACR and CAR IFM Protocols applied for comparison analysis.

Category	ACR	CAR
Methodology	Version 2.1, released in 2024	Version 5.1, released in 2023
Eligibility Criteria	No minimum acreage; applicable to U.S.A. lands; must be certified by FSC, SFI, or ATFS within one year of project start	No minimum acreage; applicable to U.S.A. lands; must be certified by FSC, SFI, ATFS, or meet other sustainability criteria
Carbon Pools Consideration	Above-ground	Above-ground
Quantification Tool	FVS	FVS
Baseline Scenario Applied	Scenario with maximum NPV	Based on a “business as usual” scenario
Minimum Project Duration	40 years (two 20-year crediting periods) i.e. one crediting and one maintenance, but in this study projected to 100 years for comparison with CAR	+100 years crediting period, but in this study projected to 100 years for comparison with CAR
Deductions Applied	Adjustments made for leakage, uncertainty, and risk of carbon loss	Adjustments made for leakage, uncertainty, and risk of carbon loss
Monitoring and verification Cost Applied	Annual or biennial reporting with 5-year verification minimum applied	Annual monitoring with third-party verification every 6 years

II. IFM Offsets Protocols Comparison

Management Scenarios in Clemson University Forest

Scenario	Management class	Key treatments & timing	Structural targets/rules (metric)	Regeneration	Fire
M0	No management	No silvicultural interventions	Natural growth and mortality only	None	None
M1	Even-aged thinning	Thin from below in 2036, 2051, 2081	185 trees ha ⁻¹ (2036); 124 trees ha ⁻¹ (2051, 2081); no BA or proportional constraints	None	None
M2	Even-aged thinning (periodic)	Thin from below starting 2036, every 15 yrs	185 trees ha ⁻¹ each entry; condition-based	None	None
M3	Fire-based (moderate frequency)	Prescribed burn starting in 2028, every 7 yrs	50% area burned; early spring; dry fuels; 7.2 km h ⁻¹ wind, 7.2 °C; FFE mortality	None	✓
M4	Fire-based (high frequency)	Prescribed burn starting in 2024, every 3 yrs	50% area burned; early spring; dry fuels; 7.2 km h ⁻¹ wind, 7.2 °C; FFE mortality	None	✓
M5	Uneven-aged (selection)	Thin-to-Q starts 2036, every 20 yrs	27.6 m ² ha ⁻¹ BA; Q = 1.4; DBH 5–61 cm; no legacy trees	None	None
M6	Uneven-aged (low frequency)	Thin-to-Q starting 2036, every 30 yrs	27.6 m ² ha ⁻¹ BA; Q = 1.4; DBH 5–61 cm; no legacy trees	None	None
M7	Even-aged regeneration	Clearcut w/ retention in 2041, 2056, 2091	All trees ≥13 cm DBH removed: 12 legacy trees ha ⁻¹ (≥ 38 cm DBH)	Loblolly pine planting (75%) + natural regen (100%)	None
M8	Thinning + regeneration	Thin (2036); clearcut (2041); repeat cycles	Thin to 185 → 124 trees ha ⁻¹ ; clearcut rules as M7	Same as M7	None
M9	Shelterwood	Prep cut 2021; shelterwood cut 2031	BA reduced to 11.5 → 2.3 m ² ha ⁻¹ ; no removal cut	Natural	None
M10	Uneven-aged w/ retention	Thin-to-Q starting cycle 3, every 30 yrs	19.1 m ² ha ⁻¹ BA; Q = 1.3; DBH 5–61 cm; 12 legacy trees ha ⁻¹	None	None
M11	Threshold-based thinning	Thin from above when BA >20.7 m ² ha ⁻¹	Residual BA = 9.0 m ² ha ⁻¹ ; ≥ 20-yr re-entry	None	None
M12	Integrated (fire + thinning + regeneration)	Burn from 2025 every 4 yrs.; thin 2036, 2046; clearcut 2061 (pine)	Fire: 50% area, early spring; Thinning: 185 → 124 trees ha ⁻¹ ; Clearcut: 12 legacy trees ha ⁻¹ (≥ 38 cm DBH)	Pine: regen 2063 (plant 75% + natural 100%); Hardwood: delayed regen 2101–2103	✓

II. IFM Offsets Protocols Comparison

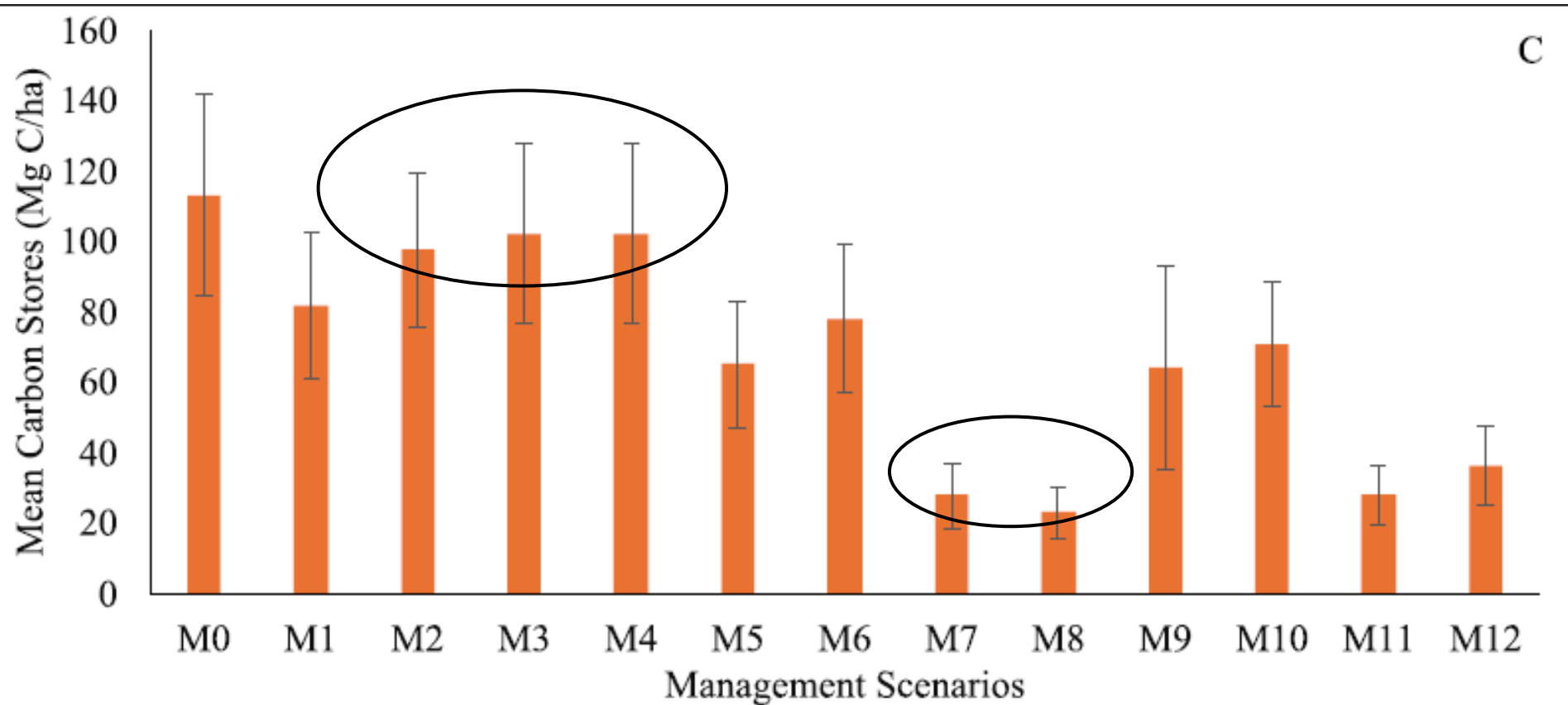
- Project associated costs (treatment implementation, carbon project development, monitoring, and verification)
- Project associated revenues (Anticipated revenue from timber sales and carbon credit earnings)
- Risk deduction rules of respective ACR & CAR
- Carbon baseline price (\$ 15/tCO₂e) and sensitivity range (\$ 15–45/tCO₂e) considered
- NPVs were calculated over a 100-year horizon with a 5% annual discount rate, detail method in Davis et al. (2000).

Cost and Revenue Assumptions for Net Present Value Calculations.

Cost Category	ACR (\$)	CAR (\$)	Frequency
Project Development (\$ per project)			
Initial project setup	94,283		One-time
Membership and account creation	943		One-time
Submission and screening	1886	943	One-time
Annual account maintenance	943		Annually
Greenhouse gases plan validation	7543	–	Each crediting period
Account closure	283	–	One-time
Desk-based verification	–	7543	Annually
Ongoing project oversight	9428		Annually
Field verification	30,170		Every 5 years (ACR) / 6 years (CAR)
Offset Administration (\$ per ton CO ₂ e)			
Credit issuance and activation	0.28	0.37	Upon credit verification
Credit retirement	0.03	–	Upon credit sale
Field Inventory Costs (\$ per hectare)			
Forest inventory	70		Every 10 years (ACR) / 12 years (CAR)
Forest Management Costs (\$ per hectare)			
Marked forestry	163		During thinning, individual tree selection, or shelterwood methods
Unmarked forestry	151		During clear-cutting or shelterwood removal

II. IFM Offsets Protocols Comparison

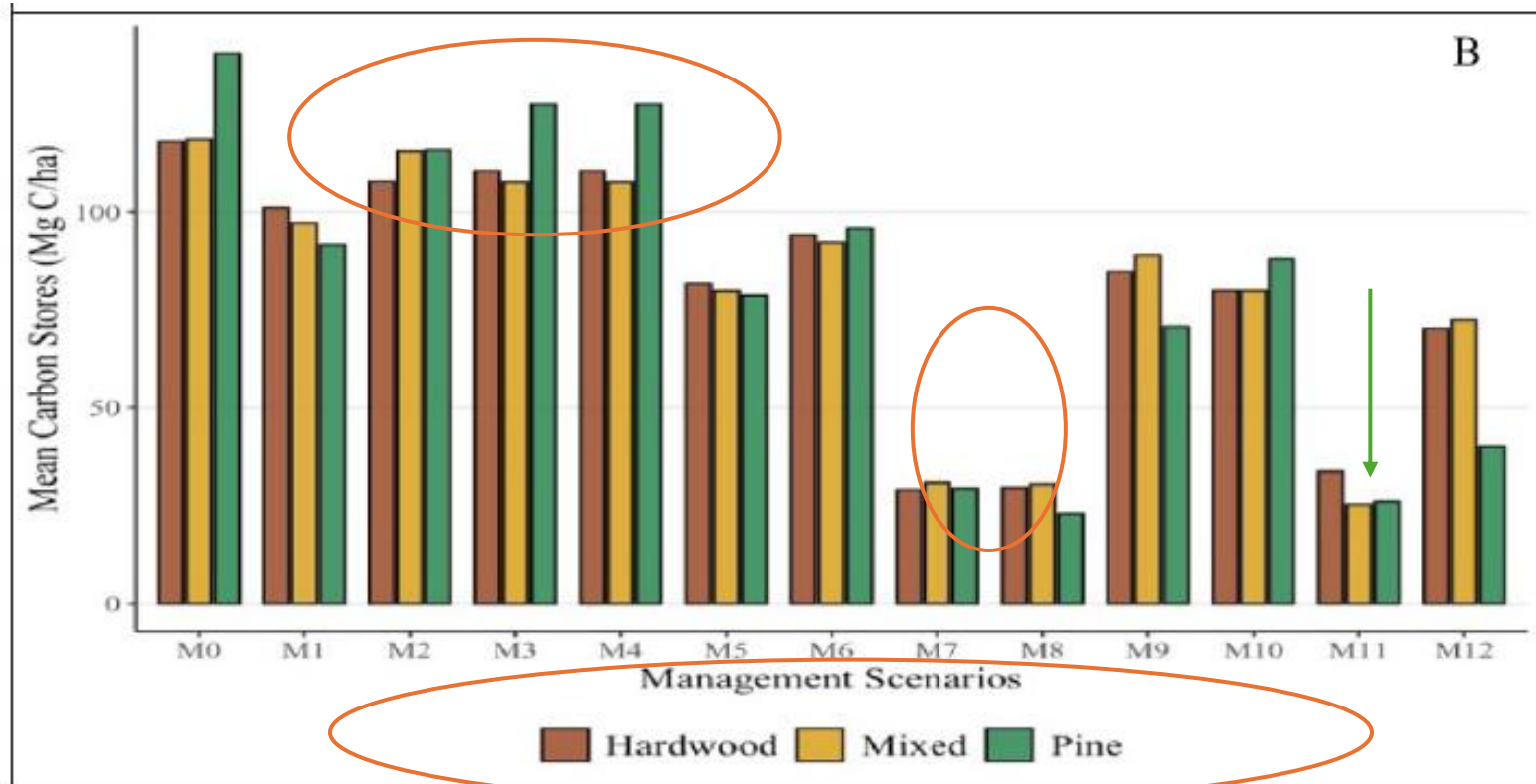
- Across all forest types, no management (M0) consistently delivered the highest mean offsets



Scenario	Management class
M0	No management
M1	Even-aged thinning
M2	Even-aged thinning (periodic)
M3	Fire-based (moderate frequency)
M4	Fire-based (high frequency)
M5	Uneven-aged (selection)
M6	Uneven-aged (low frequency)
M7	Even-aged regeneration
M8	Thinning + regeneration
M9	Shelterwood
M10	Uneven-aged w/ retention
M11	Threshold-based thinning
M12	Integrated (fire + thinning + regeneration)

II. IFM Offsets Protocols Comparison

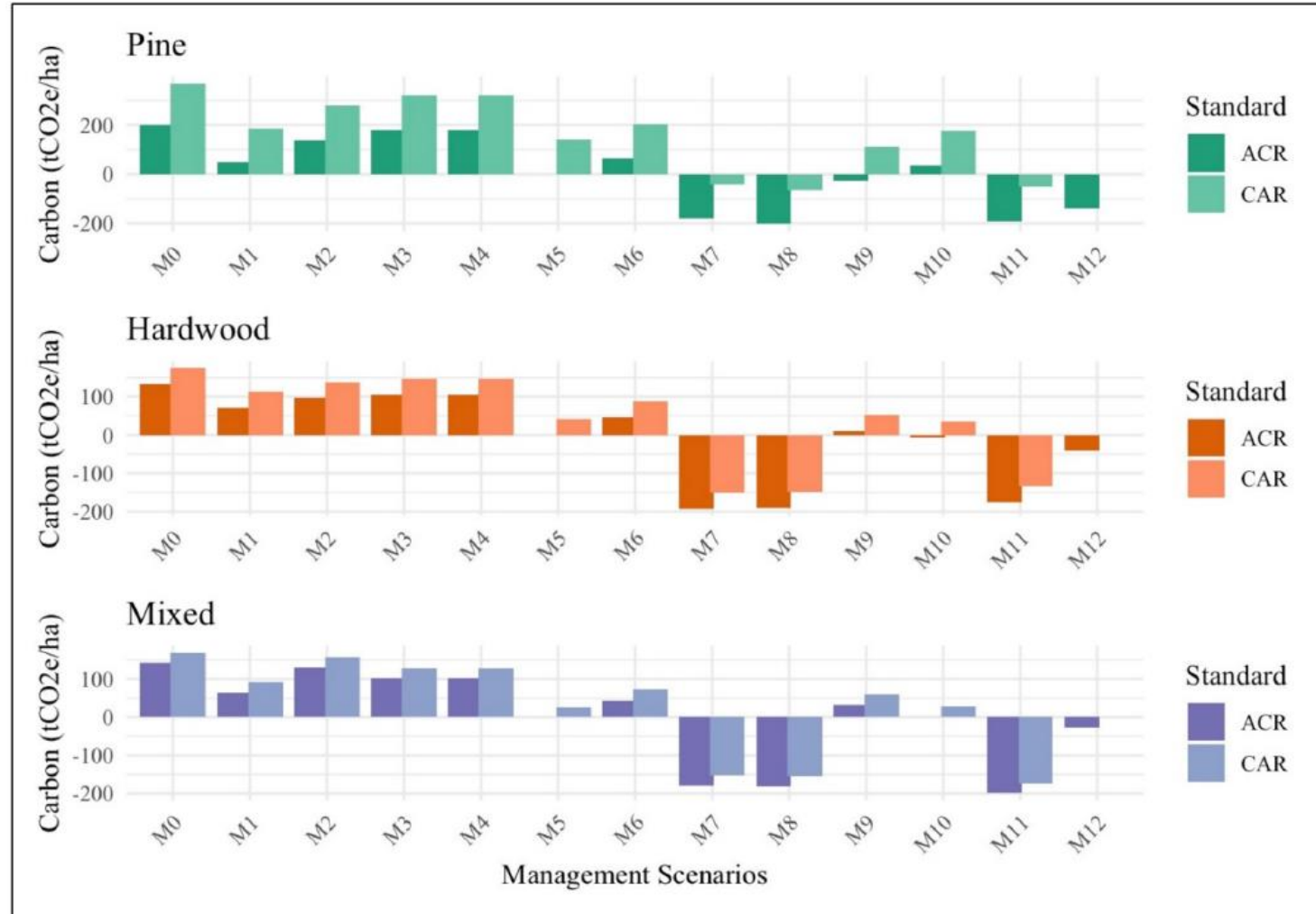
- For both pine & hardwood forests, increase in carbon stock depended on management scenarios



Scenario	Management class
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II. IFM Offsets Protocols Comparison

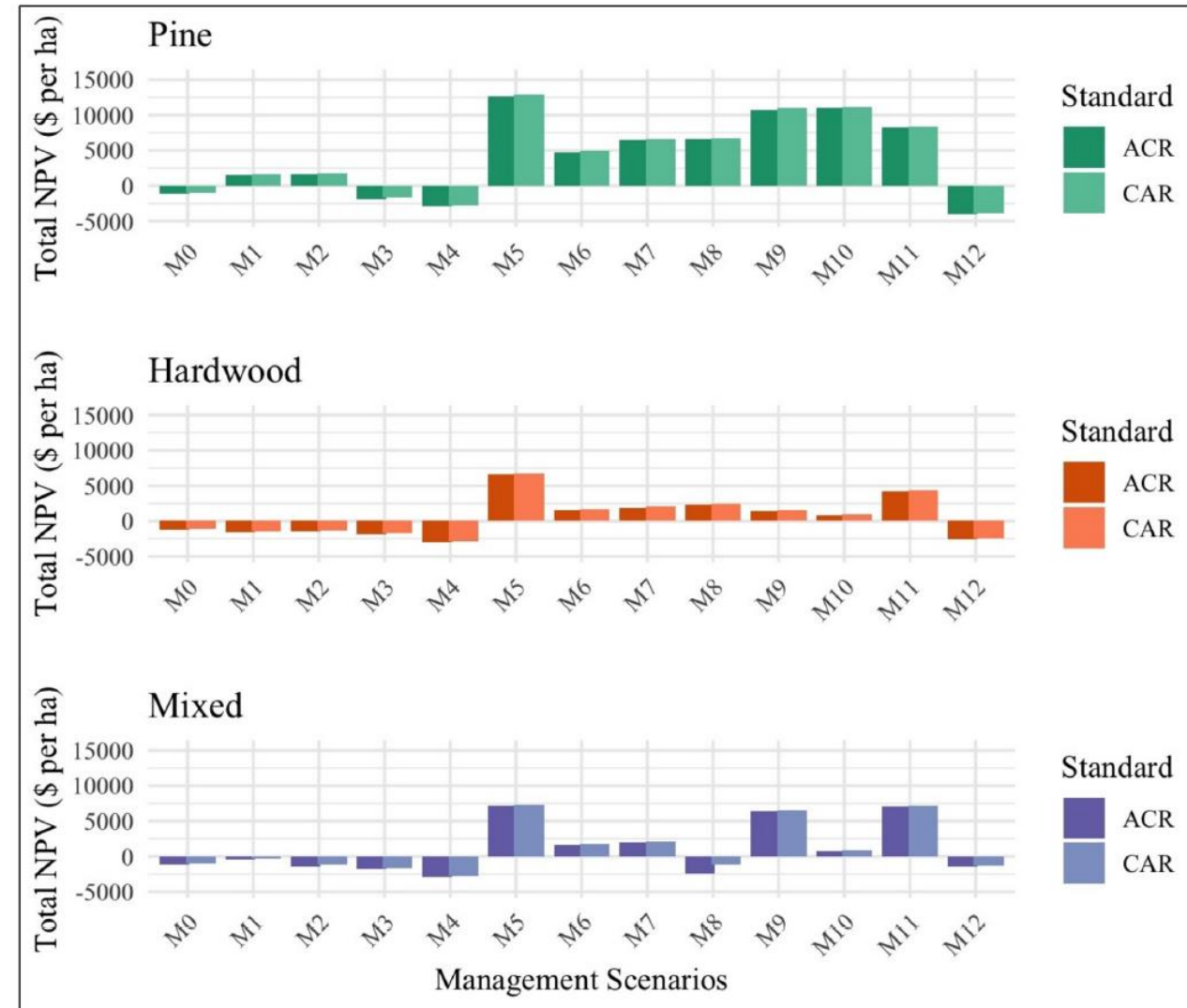
- Across all forest types, no management (M0) consistently delivered the highest mean offsets
- CAR generally yielded higher credited carbon than ACR, reflecting protocol-specific methodological differences



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II. IFM Offsets Protocols Comparison

- The total NPV of different forest management scenarios varied widely across forest types and carbon offset protocols
- Pine stands generally contributed the highest positive NPVs under both ACR and CAR
- Notably, M5-M11 produced the highest NPVs, with CAR often outperforming ACR in these cases.



Scenario	Management class
M0	No management
M1	Even-aged thinning
M2	Even-aged thinning (periodic)
M3	Fire-based (moderate frequency)
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M6	Uneven-aged (low frequency)
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II. IFM Offsets Protocols Comparison

Dynamic baseline implications:

- Traditional baseline approaches often relied on static assumptions that failed to adequately reflect the dynamic nature of forest ecosystems and the evolving socio-economic context of land management.
- In contrast, dynamic baselines recalibrate carbon accounting to better align with actual forest conditions and harvest trends, enhancing the environmental integrity and credibility of credits issued.
- Specifically, ACR's dynamic baseline approach requires projects to reassess baselines at each reporting period using ex-post data, ensuring that crediting is based on observed, plausible business-as-usual scenarios rather than speculative projections. This might help in resolving the issue of over or under crediting for overall benefits.
- The strength of the project specific dynamic baseline lies in its dual emphasis on specificity and adaptability. By incorporating landowner intent, ownership type, site accessibility, forest type, and harvest feasibility, the methodology ensures that crediting reflects realistic alternative management scenarios.

III. Climate Smart Forestry Workforce

- Survey Scope and Regions

The study surveyed natural resource professionals in Alabama, Georgia, and South Carolina across key (timber) southern regions to assess carbon forestry capacity.

- Focus on Climate-Smart Forestry

Survey assessed understanding and preferences for resilient and climate-smart forestry including carbon management practices.

- Role in Carbon Market Adoption

Natural resource professionals are key to translating complex carbon market rules into practical guidance for landowners.

State	% Respondents
Alabama	34
Georgia	98
South Carolina	28
Other	8

Eco-region	% Respondents
Appalachian Mountain	9
Piedmont and Upstate	31
Mississippi Delta region	1
Coastal Plains and the Lowcountry	52
Urban regions and forests	5
Other	2

III. Climate Smart Forestry Workforce

Building workforce capacity ensures credible and practical implementation of climate-smart forestry and carbon markets.

- Climate Disturbance Experience

Forestry professionals face frequent climate-related disturbances including hurricanes, wildfires, and rainfall/droughts.

- Risk Perception Variation

Coastal professionals worry about storm risks, while inland experts focus on fires and pests, influencing carbon market views.

Impact of extreme events on forests by eco-regions	Mean Response
Exterme rainfall	A moderate - A little impact
Extreme temperature	A moderate - A little impact
Hurricane and strong wind events	A lot - A moderate impact
Flooding	A little impact
Droughts	A lot - A moderate impact
Wildfires	A moderate - A little impact
Ice-storms	A little impact
Changing seasonality	A moderate - A little impact
Saltwater intrusion	Not much impact

III. Climate Smart Forestry Workforce

- Knowledge about Forest carbon programs and offsets

Question: Please answer each of the following statements about forest carbon programs.

- Strong NO response on how to estimate baseline for carbon offset estimation

- Region has a varied level of previous engagement with forest carbon programs and technical support proficiency.

Statements	Mean Response
I have heard about one or more forest carbon programs	Yes(1) - May be (2)
I have talked to landowners about forest carbon programs	May be – NO (3)
I know how to get information about forest carbon programs	Yes - May be
I am interested in learning more about forest carbon programs	Yes - May be
I have attended a few trainings on forest carbon trading	May be - NO
I know how to estimate baseline for carbon offset estimation	NO - May be



Summary:

- Carbon markets can complement timber management, but benefits vary depending on site and protocol specifics
- Design choices in carbon offset protocols, such as baselines and crediting, significantly affect outcomes
- Dynamic baselines improve integrity but introduce uncertainty that requires careful management
- A skilled workforce and refined policies are essential for expanding carbon forestry effectively

Citation: Sharma, S., Clay, L., & Khanal, P. (2026). Forest management and carbon market integration at Clemson University forest. *Ecological Indicators*, 185, 114736.