

# Assessing landscape-scale, climate-smart forest management strategies: Is it possible?

Aaron Weiskittel, Erin Simons-Legaard, Adam Daigneault and Ivan Fernandez

*Center for Research on  
Sustainable Forests, University of Maine*



# Natural Climate Solutions



## Climate-Smart Forestry: the missing link

P.J. Verkerk<sup>a,\*</sup>, R. Costanza<sup>b</sup>, L. Hetemäki<sup>a</sup>, I. Kubiszewski<sup>b</sup>, P. Leskinen<sup>a</sup>, G.J. Nabuurs<sup>c</sup>, J. Potocnik<sup>d</sup>, M. Palahí<sup>e</sup>

<sup>a</sup> European Forest Institute, Yliopistokatu 6B, 00100 Joensuu, Finland  
<sup>b</sup> Crawford School of Public Policy, Australian National University, Canberra, Australia  
<sup>c</sup> Wageningen University and Research, Wageningen, the Netherlands  
<sup>d</sup> Systemiq Ltd, Carter Lane 69, London, United Kingdom

### ARTICLE INFO

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### 1. Introduction

The Paris Agreement requires major societal and economic reforms to ensure that the global average temperature remains below 2 °C pre-industrial levels. Achieving this target requires a significant reduction in gross anthropogenic carbon dioxide (CO<sub>2</sub>) emissions and an increase in human and biosphere carbon sinks (Rockström et al., 2017). Forests and forestry can play an important role in this context; reducing deforestation and forest degradation lowers greenhouse emissions, forest management can maintain or enhance forest carbon stocks and sinks and wood products can store carbon over the long-term and can substitute for emissions-intensive materials reducing emissions (IPCC 2019).

"Natural climate solutions" (Griscorn et al., 2017) have been suggested as important means to mitigate climate change that can contribute up to 37% (23.8 Pg CO<sub>2</sub> eq. yr<sup>-1</sup>) of the required global emissions reduction by 2030. Approximately two-thirds of the total mitigation potential from these natural climate solutions could be achieved through storing carbon in forest ecosystems (Griscorn et al., 2017). However, only storing carbon in forest ecosystems ignores three important issues. Firstly, such a strategy mainly provides benefits until the sink saturates and ignores the many other functions that forests fulfil (Nabuurs et al.,

\* Corresponding author.  
E-mail address: hans.verkerk@efi.int (P.J. Verkerk).

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1389-0341/© 2020 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).



## Strategies for Climate-Smart Forest Management in Austria

Robert Jandl<sup>1,\*</sup>, Thomas Ledermann<sup>2</sup>, Georg Kindermann<sup>2</sup>, Alexandra Freudenschuss<sup>3</sup>, Thomas Gschwantner<sup>3</sup> and Peter Weiss<sup>4</sup>

<sup>1</sup> Department of Forest Ecology and Soils, Austrian Research Center for Forests (BFW), 1131 Vienna, Austria  
<sup>2</sup> Department of Forest Growth and Silviculture, Austrian Research Center for Forests (BFW), 1131 Vienna, Austria; thomas.ledermann@bfw.gv.at (T.L.); georg.kindermann@bfw.gv.at (G.K.)  
<sup>3</sup> Department of Forest Inventory, Austrian Research Center for Forests (BFW), 1131 Vienna, Austria; alexandra.freudenschuss@bfw.gv.at (A.F.); thomas.gschwantner@bfw.gv.at (T.G.)  
<sup>4</sup> Umweltbundesamt, 1090 Vienna, Austria; peter.weiss@umweltbundesamt.at  
\* Correspondence: robert.jandl@bfw.gv.at; Tel.: +43-664-826-99-07

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**Abstract:** We simulated Austrian forests under different sustainable management scenarios. A reference scenario was compared to scenarios focusing on the provision of bioenergy, enhancing the delivery of wood products, and reduced harvesting rates. The standing stock of the stem biomass, carbon in stems, and the soil carbon pool were calculated for the period 2010–2100. We used the forest growth model Cáldis and the soil carbon model Yasso07. The wood demand of all scenarios could be satisfied within the simulation period. The reference scenario led to a small decrease of the stem biomass. Scenarios aiming at a supply of more timber decreased the standing stock to a greater extent. Emphasizing the production of bioenergy was successful for several decades but ultimately exhausted the available resources for fuel wood. Lower harvesting rates reduced the standing stock of coniferous and increased the standing stock of deciduous forests. The soil carbon pool was marginally changed by different management strategies. We conclude that the production of long-living wood products is the preferred implementation of climate-smart forestry. The accumulation of carbon in the standing biomass is risky in the case of disturbances. The production of bioenergy is suitable as a byproduct of high value forest products.

**Keywords:** carbon sequestration; forestry management; simulation of aboveground stem biomass and soil; soil carbon; climate smart forestry

### 1. Introduction

Central European forests are currently a sink of greenhouse gases. The growth rate of forests has been increasing for decades because of nitrogen deposition, elevated concentrations of carbon dioxide (CO<sub>2</sub>) and higher temperatures [1,2]. In addition, due to abandonment of marginally productive agricultural land in low elevation areas and the expansion of mountain forests beyond the previous upper timberline, the forest area has increased [3,4]. New young forests have a high growth rate and comprise an effective sink for carbon. Forestry is the only sector of the economy that acts as a net sink for CO<sub>2</sub>. Terrestrial ecosystems in Europe already sequester 7% to 12% of the anthropogenic CO<sub>2</sub> emissions, even though the potential of forests is not fully utilized [5–8].

Historically, Austrian forests have emerged from a low level of forest area in the 19th century. A growing population had required the expansion of agricultural land. High elevation forests were cleared and converted to pastures. This land-use change soon triggered soil erosion and increased the risk of damages from flooding and avalanches [9]. As an immediate mitigation measure a policy

Forests 2018, 9, 592; doi:10.3390/f9100592 www.mdpi.com/journal/forests



**Abstract:** The increasing demand for innovative forest management strategies to adapt to a benefit forest production, the so-called Climate-Smart Forestry, calls for a tool to monitor and see their effects on forest development over time. The pan-European set of criteria and indicators is considered one of the most important tools for assessing many aspects of forest management offers an analytical approach to selecting a subset of indicators to support the implementation on a literature review and the analytical hierarchical approach. 10 indicators were selected to and adaptation. These indicators were used to assess the state of the Climate-Smart Forestry using data from the reports on the State of Europe's Forests. Forest damage, tree species compo most important indicators. Though the trend was overall positive with regard to adaptation a partly hindered by the lack of data. We advocate for increased efforts to harmonize interna: integrating the goals of Climate-Smart Forestry into national- and European-level forest polic

**Résumé:** La demande croissante pour des stratégies innovantes en aménagement forestier, d changement climatique et de s'y adapter tout en ayant un effet positif sur la production des fo intelligente face au climat, exige un outil pour le suivi et l'évaluation de la mise en œuvre de c développement de la foresterie dans le temps. L'ensemble paneuropéen de critères et d'ind forestier durable est considéré comme un des outils parmi les plus importants pour évaluer ph forestier et sa durabilité. Cette étude offre une approche analytique pour choisir un souve supporter la mise en œuvre de la foresterie intelligente face au climat. Sur la base d'une revue analytique hiérarchique, 10 indicateurs ont été sélectionnés pour évaluer plus particulièrement d'adaptation. Ces indicateurs ont été utilisés pour évaluer l'état de la tendance européenne en face au climat de 1990 à 2015 à l'aide de données provenant de rapports sur l'état des forêts eur forêts, la composition en espèces arborescentes et le stock de carbone étaient les indicateurs tendance ait été dans l'ensemble positive en ce qui concerne l'adaptation et l'atténuation, son é par le manque de données. Nous recommandons d'augmenter les efforts visant à harmonis présentation des rapports et d'intégrer davantage les objectifs de la foresterie intelligente face politiques forestières à l'échelle nationale et européenne. (Traduit par la Rédaction)

**Mots-clés:** sylviculture, adaptation, atténuation, inventaire forestier, dommage causé aux for

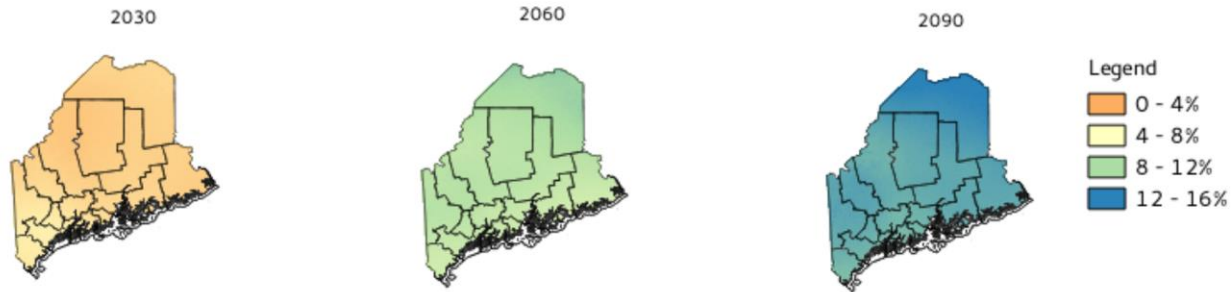
Received 10 April 2020; Accepted 4 June 2020.  
G. Santopoli and R. Tognetti, Dipartimento Agricoltura, Ambiente e Alimenti, Università degli Studi del Molis 86100 Campobasso, Italy; Centro di Ricerca per le Aree Interne e gli Appennini (ArIA), Università degli Studi del 86100 Campobasso, Italy.  
C. Temperli, Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Zürcherstrasse 111 CH-8903 Birm I. Alberdi, Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria, Ctra. A Coruña, 7.5 Km. 28040, M I. Barbeito, Southern Swedish Forest Research Center, Swedish University of Agricultural Sciences Sundsvägen 3, Bo Lorraine, AgroParisTech, INRA, UMR Silva, Nancy, France.  
M. Bosela, Faculty of Forestry, Technical University in Zvolen, Slovakia.  
A. Bottero, Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Zürcherstrasse 111 CH-8903 Birm SwissForestLab, CH-8903 Birmensdorf, Switzerland.  
M. Klopčič, Biotechnical Faculty, Department of Forestry and Renewable Forest Resources, Jamnikarjeva ulica 101, SI J. Lesinski, Department of Forest Biodiversity, University of Agriculture, Al. 29. Listopada 46, 31-425 Kraków, Poland.  
P. Panzacchi, Facoltà di Scienze e Tecnologia, Libera Università di Bolzano, Piazza Università 1, 39100, Bolzano/Boz Aree Interne e gli Appennini (ArIA), Università degli Studi del Molise, via Francesco De Sanctis 86100 Campobasso, It  
Corresponding author: Giovanni Santopoli (email: giovanni.santopoli@unimol.it).  
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Can. J. For. Res. 51: 1741–1750 (2021) dx.doi.org/10.1139/cjfr-2020-0166 Published at www.c

**1 | INTRODUCTION**  
Land management strongly affects the ability of ecosystems to sequester and store carbon (C). Natural climate solutions (NCS), a set of land management, conservation and restoration practices aimed at mitigating climate change, have been introduced as cost-effective tools that increase C sequestration in terrestrial ecosystems (Fargione et al., 2018; Griscorn et al., 2017), while also sustaining biodiversity and other ecosystem services. Of the NCS activities identified, forests pathways for NCS, in particular reforestation, avoided forest conversion and improved forest management (IFM), have the potential to contribute as much as 50% of the total C sequestration possible through NCS globally (Fargione et al., 2018; Griscorn et al., 2017). For example, in 2018, forests in the conterminous United States sequestered 211 Tg C (774 Tg of carbon dioxide), offsetting 11.6% of the total annual greenhouse gas emissions in the United States (EPA, 2020). To date,

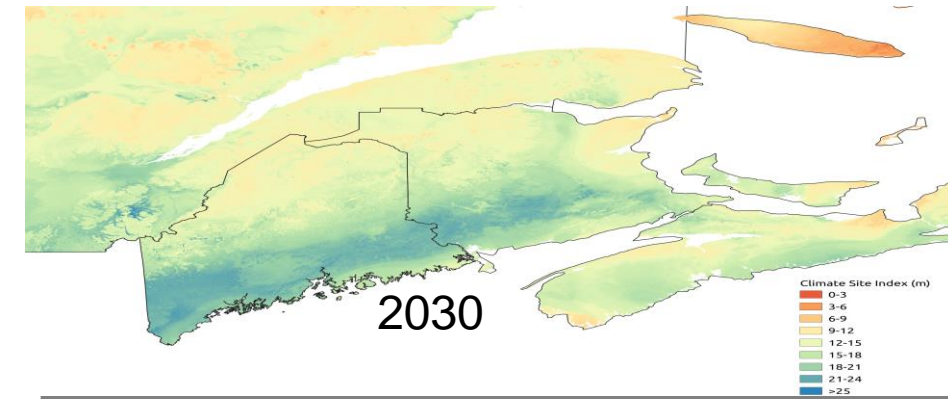
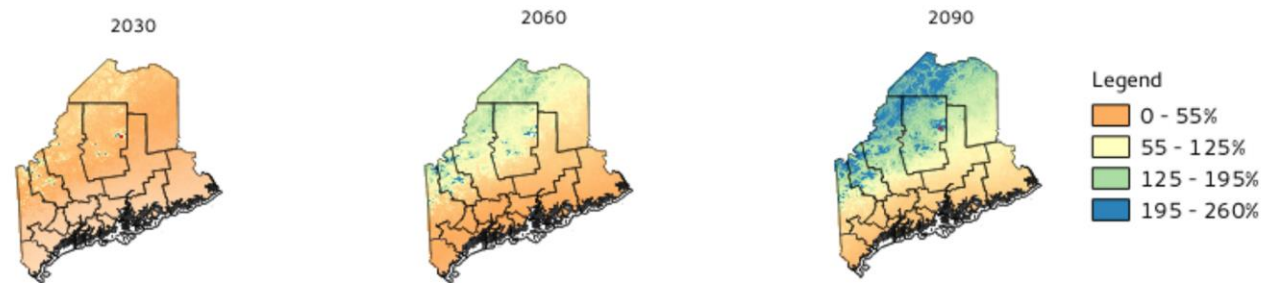


# Overview

Mean % change in annual precipitation from current climate normals



Mean % change in annual temperature from current climate normals



Forest system	Potential impacts	Adaptive capacity	Vulnerability	Evidence	Agreement
Central hardwood-pine	Neutral-Positive	Moderate-High	Low	Medium	Medium-High
Low-elevation spruce-fir	Neutral-Negative	Moderate	Moderate-High	Medium	Medium
Lowland and riparian hardwood	Positive and Negative	Moderate-High	Moderate	Limited	Limited
Lowland mixed conifer	Neutral-Negative	Low-Moderate	Moderate-High	Limited-Medium	Medium
Montane spruce-fir	Neutral-Negative	Moderate	Moderate-High	Medium	Medium
Northern hardwood	Positive and Negative	Moderate-High	Low-Moderate	Medium	Medium
Pitch pine-scrub oak	Neutral-Positive	Moderate	Low	Medium	Medium
Transition hardwood	Positive and Negative	Moderate-High	Low-Moderate	Medium	Medium-High

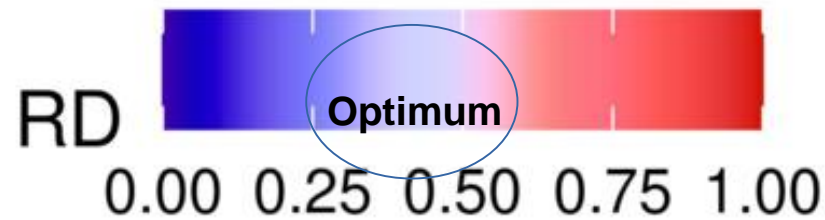
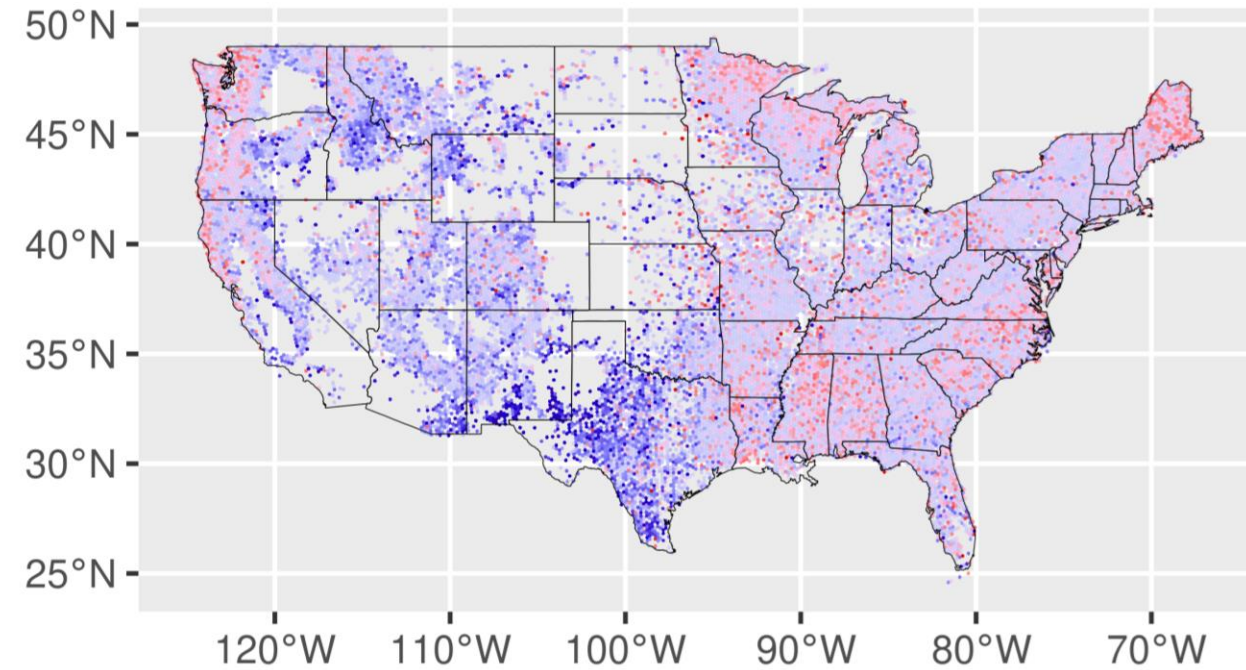
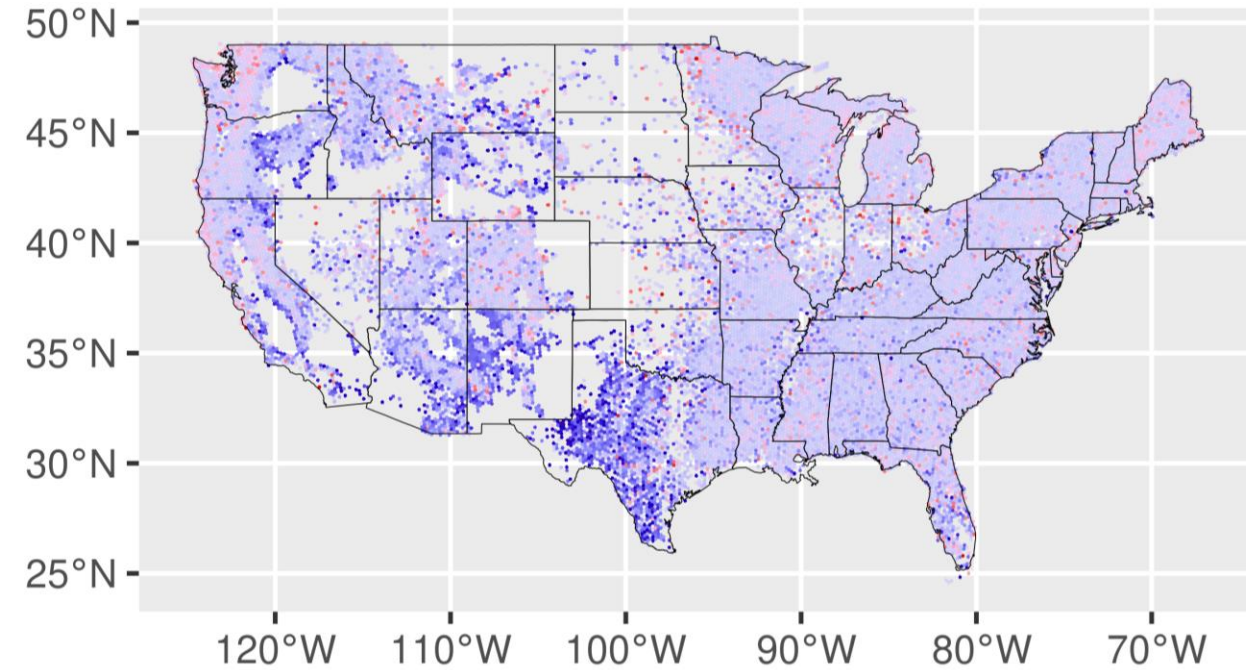
Janowiak et al. (2018)

**Climate is expected to be warmer and wetter with implications for both forest productivity and composition**

# Relative density trends in the US

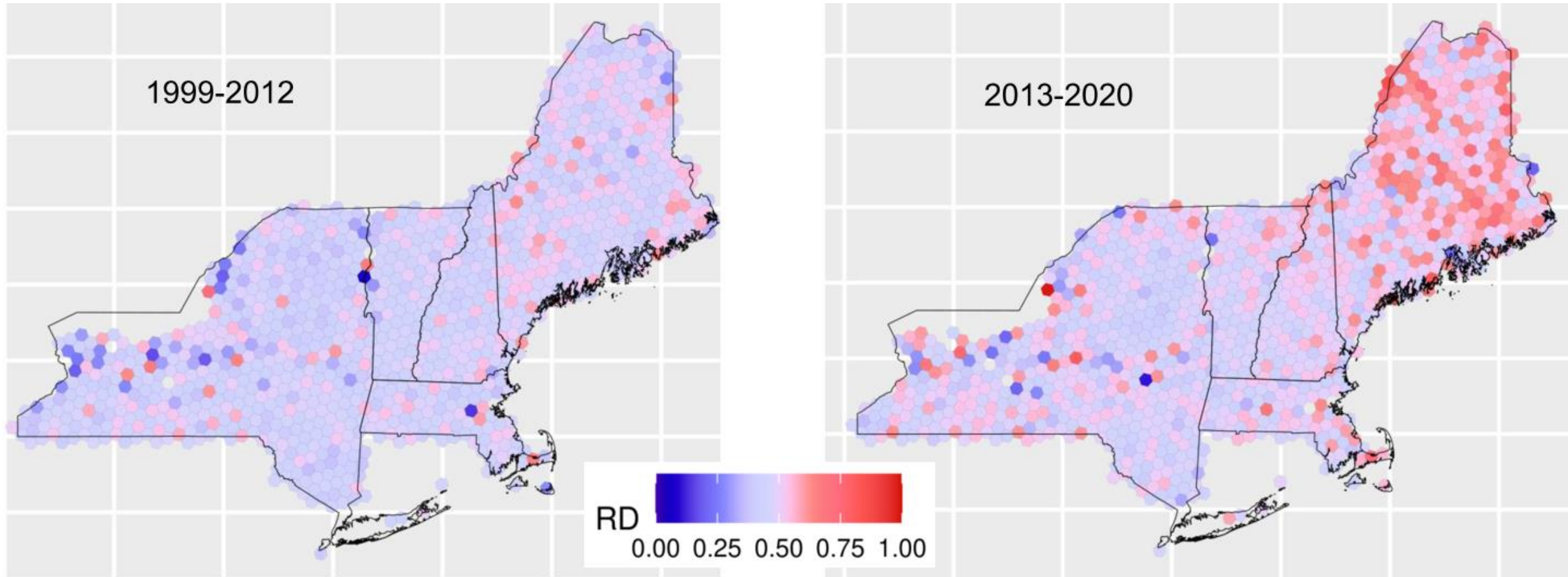
Time 1 (1999 - 2012)

Time 2 (2013-2020)






CW Woodall, AR Weiskittel (2021). Relative density of United States forests has shifted to higher levels over last two decades with important implications for future dynamics. Scientific reports 11 (1), pp. 1-12.

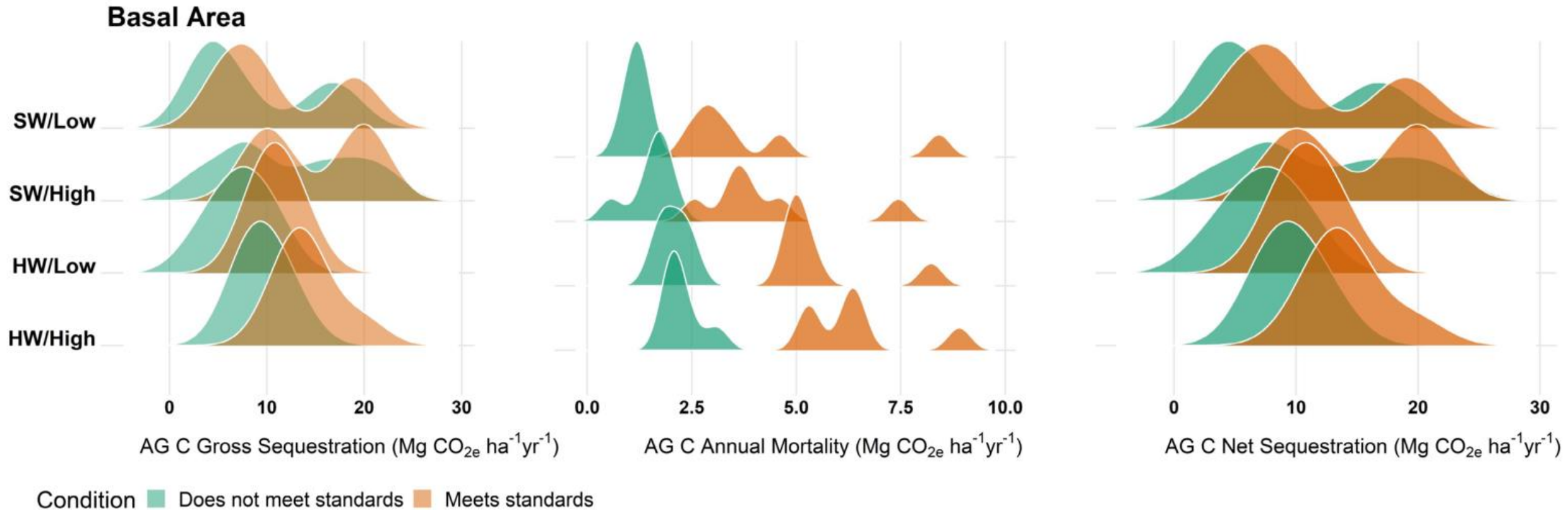
# Relative density trends in New England



**23% of Maine's forests are now outside the target 'medium' RD zone, up from 2% in 1999-2012**

# Carbon conundrums: Do United States' current carbon market baselines represent an undesirable ecological threshold?

Anthony W. D'Amato<sup>1</sup>  | Christopher W. Woodall<sup>2</sup>  | Aaron R. Weiskittel<sup>3</sup>  |  
Caitlin E. Littlefield<sup>1,4</sup>  | Lara T. Murray<sup>5</sup>



**Current baselines based on basal area result in increased annual mortality and similar net sequestration rates as forests that do not meet the standard**

# MAINE CLIMATE COUNCIL



## STRATEGY E

### Protect Maine's Environment and Working Lands and Waters: Promote Natural Climate Solutions and Increase Carbon Sequestration

Climate change and development are harming Maine's natural and working lands and waters, which are key to the state achieving its carbon neutrality commitment by 2045. Protecting natural and working lands from development maintains their potential to draw back carbon from the atmosphere, as well as provide important co-benefits. Maine's coastal and marine areas also store carbon, while supporting our fishing, aquaculture, and tourism industries.

1

#### Protect Natural and Working Lands and Waters

- Increase by 2030 the total acreage of conserved lands in the state to 30% through voluntary, focused purchases of land and working forest or farm conservation easements.
  - Additional targets should be identified in 2021, in partnership with stakeholders, to develop specific sub-goals for these conserved lands for Maine's forest cover, agriculture lands, and coastal areas.
- Focus conservation on high biodiversity areas to support land and water connectivity and ecosystem health.
- Revise scoring criteria for state conservation funding to incorporate climate mitigation and resiliency goals.
- Develop policies by 2022 to ensure renewable energy project siting is streamlined and transparent while seeking to minimize impacts on natural and working lands and engaging key stakeholders.

2

#### Develop New Incentives to Increase Carbon Storage

- DEP will conduct a comprehensive, state-wide inventory of carbon stocks on land and in coastal areas (including blue carbon) by 2023 to provide baseline estimates for state carbon sequestration, allowing monitoring of sequestration over time to meet the state's carbon neutrality goal.
- Establish by 2021 a stakeholder process to develop a voluntary, incentive-based forest carbon program (practice and/or inventory based) for woodland owners of 10 to 10,000 acres and forest practitioners.
- Engage in regional discussions to consider multistate carbon programs that could support Maine's working lands and natural-resource industries, and state carbon-neutrality goals.

3

#### Expand Outreach to Offer Information and Technical Assistance

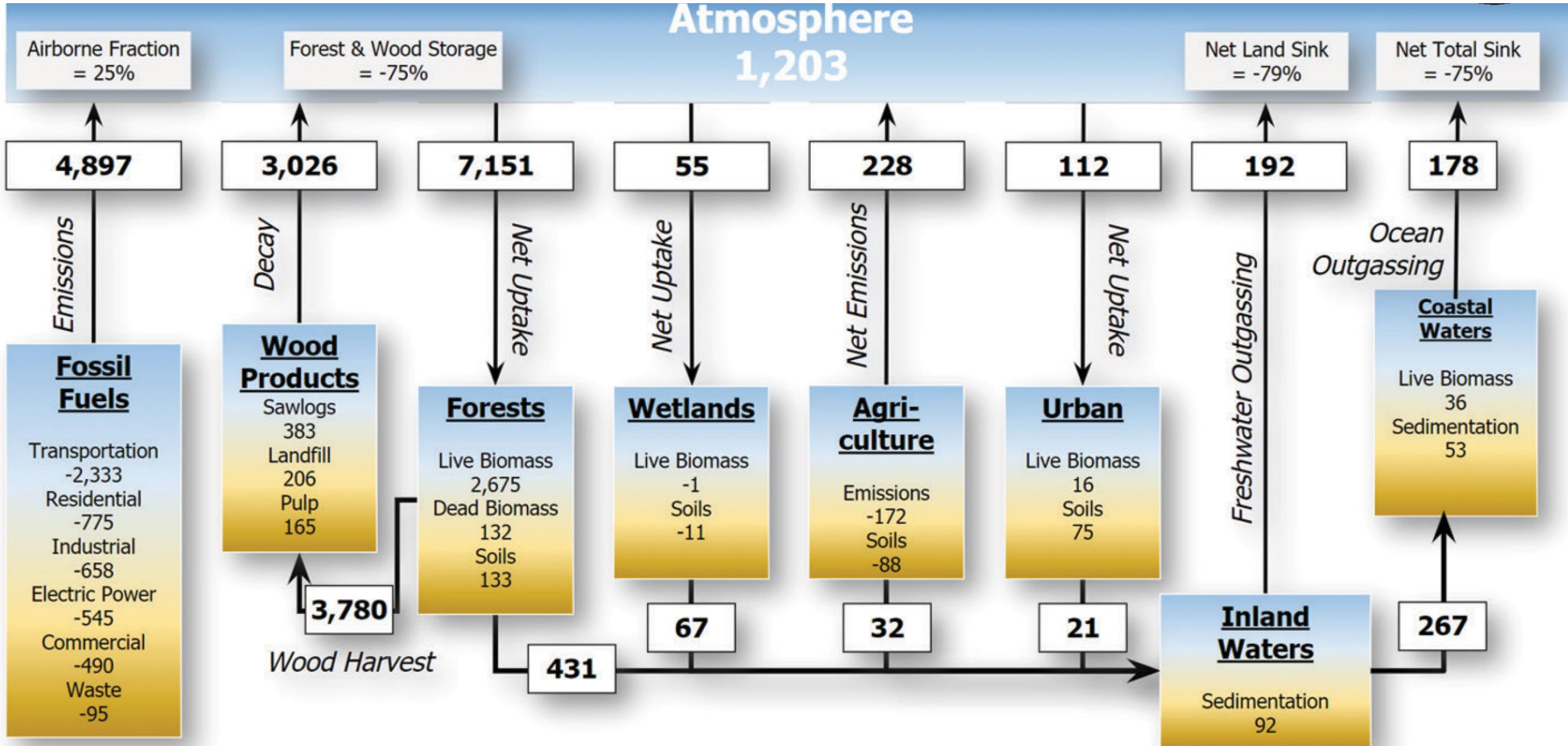
- Increase technical service provider capacity by 2024 to deliver data, expert guidance, and support for climate solutions to communities, farmers, loggers, and foresters at the Department of Agriculture, Conservation and Forestry, Maine Forest Service, Department of Inland Fisheries and Wildlife, the Department of Marine Resources, and the University of Maine.
- Launch the Coastal and Marine Information Exchange by 2024.

4

#### Enhance Monitoring and Data Collection to Guide Decisions

- Establish a "coordinating hub" with state and non-state partners for key climate-change research and monitoring work to facilitate statewide collaboration by 2024.

# Maine's First Statewide Carbon Budget

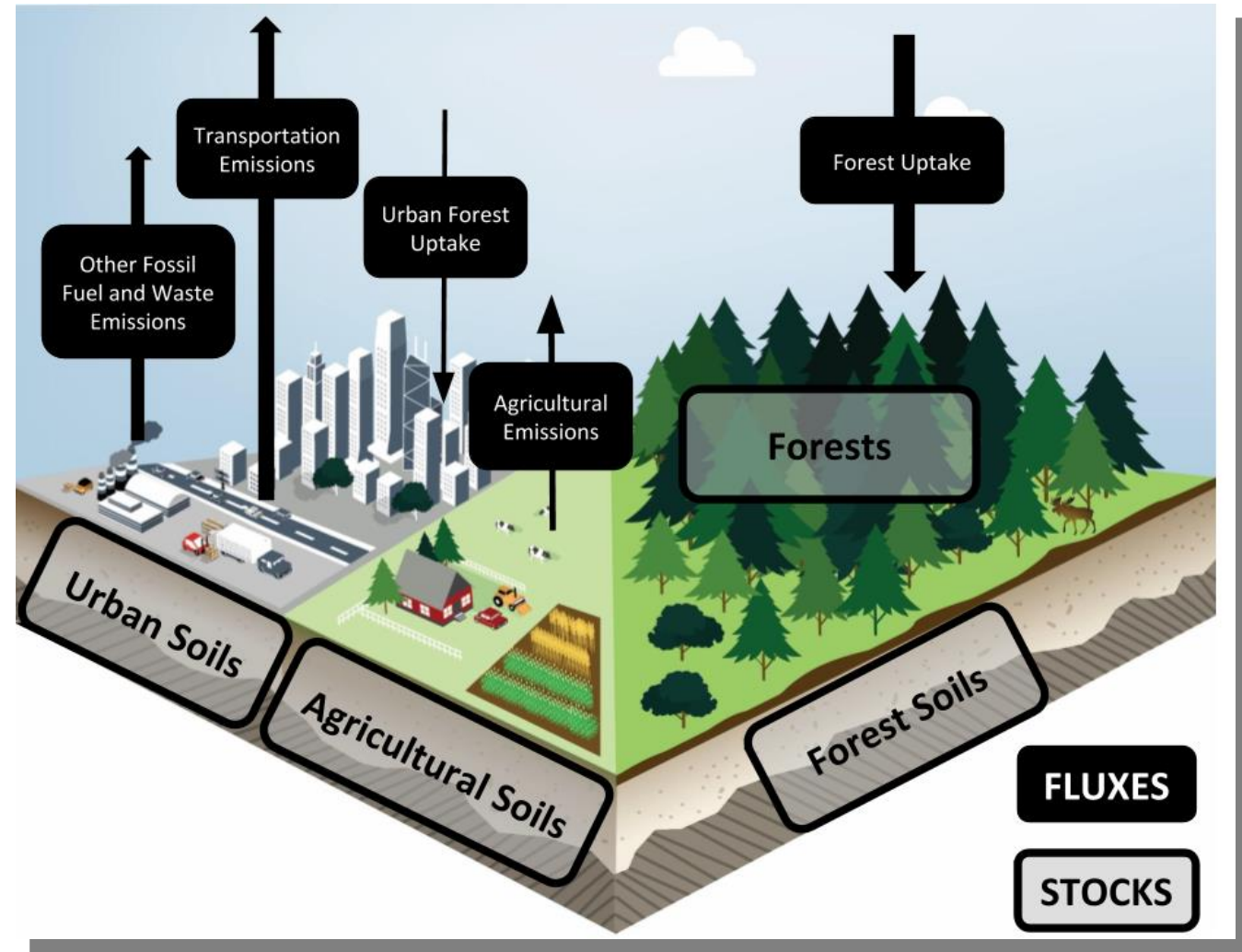


<https://crsf.umaine.edu/forest-climate-change-initiative/carbon-budget/>

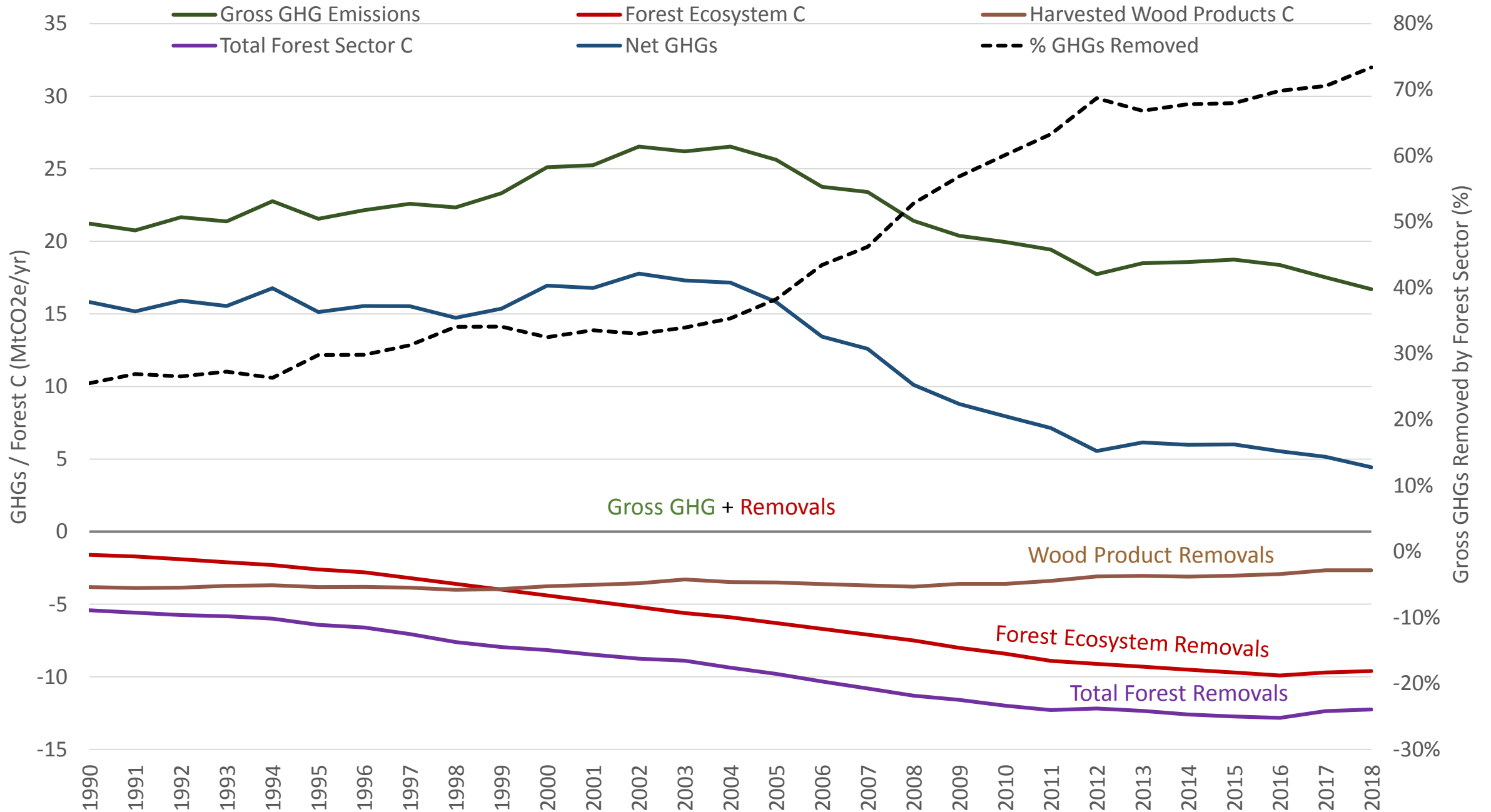


# Maine's Managed Forest Captures Carbon

Carbon Pool	% of State's Annual Fossil Fuel Emission
Forest carbon stocks + annual growth	60%
Forest products	15%
Total forestry sector	75%
Net Land Sink	78%



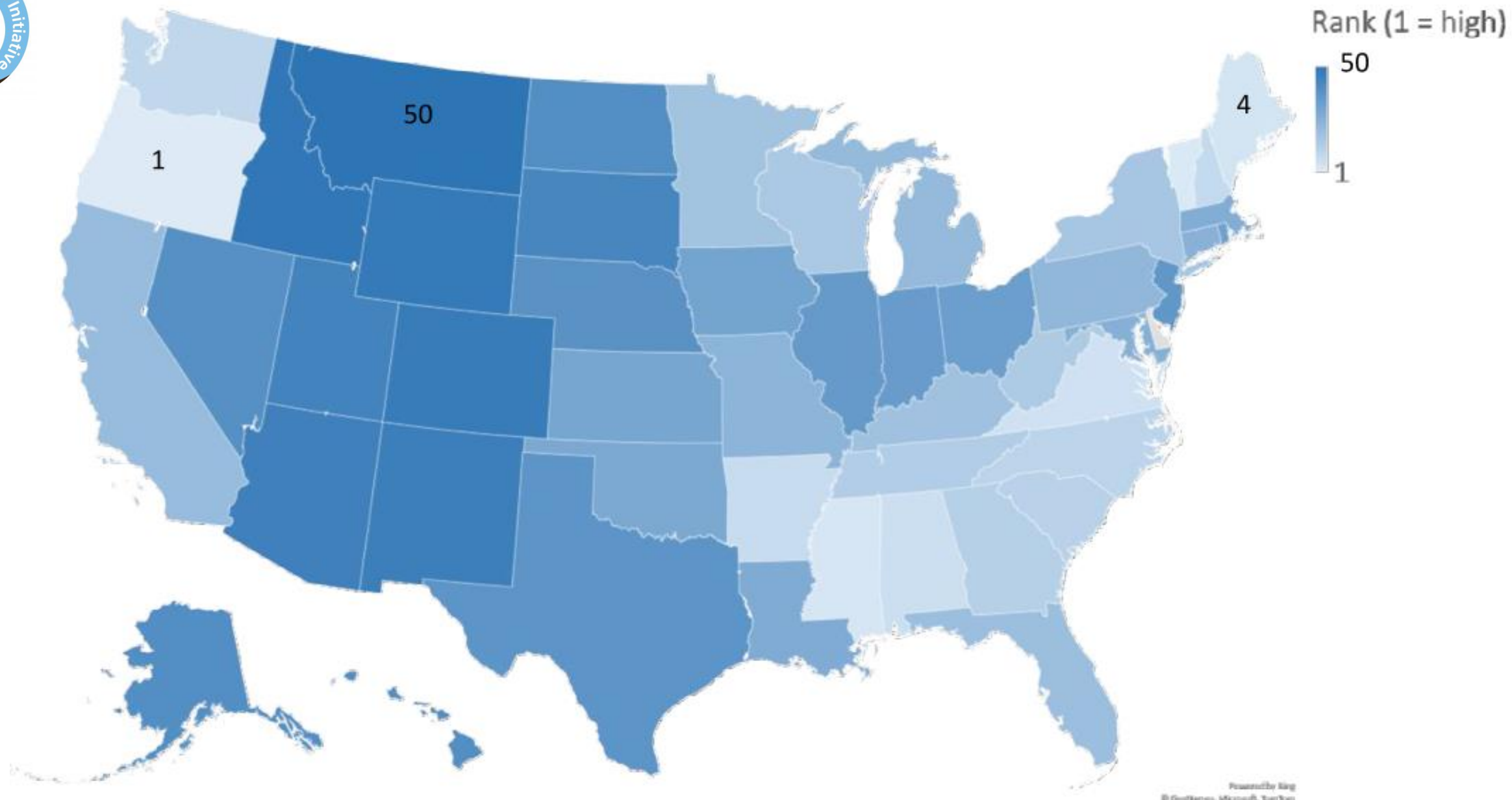
<https://crsf.umaine.edu/forest-climate-change-initiative/carbon-budget/>



**% GHG removal has increased over time yet primarily driven by forest condition and composition**

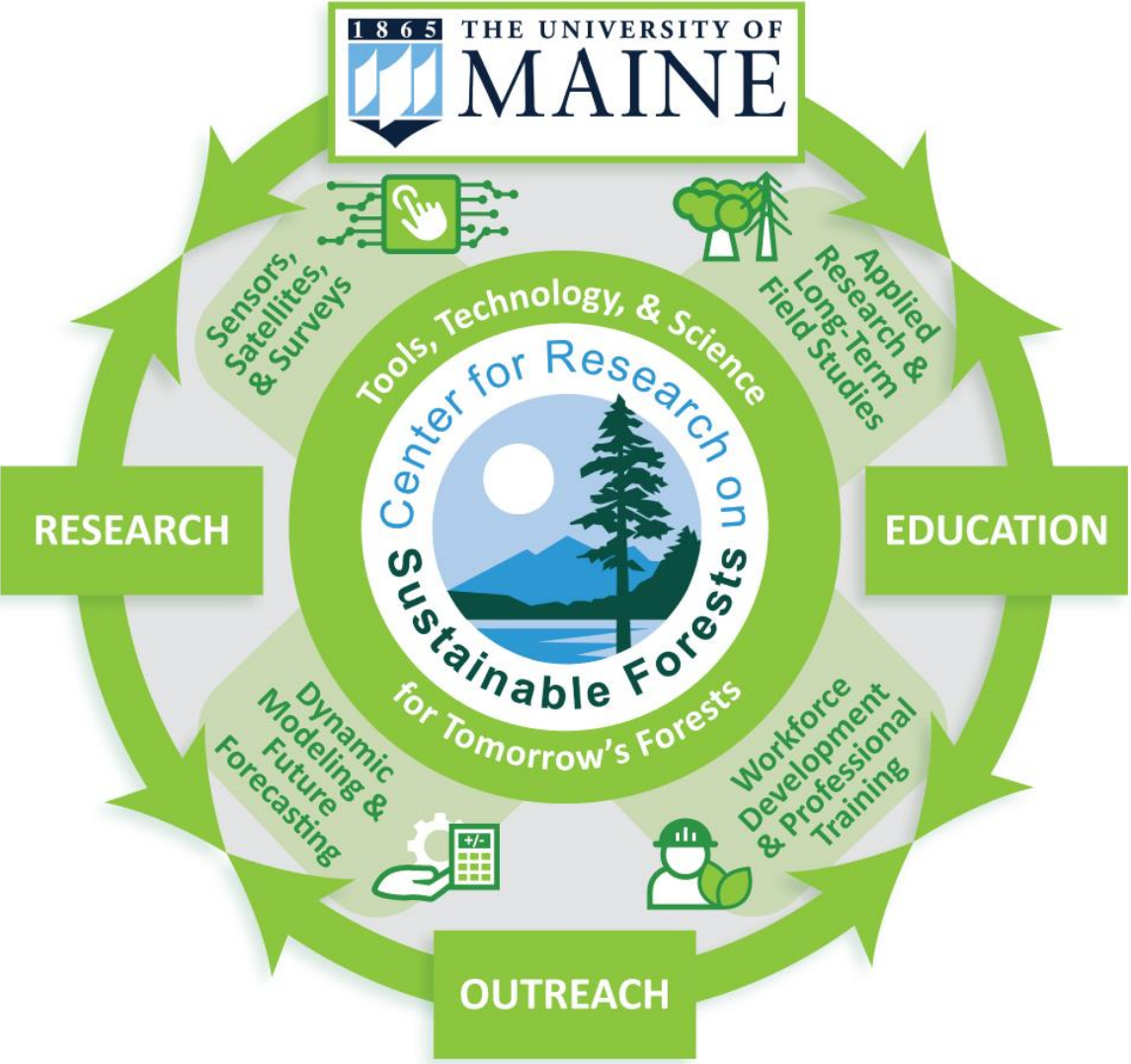


## Percent GHG removal Rank by State (2008-2018 Average)



**Maine is in the top 5 in the US for % GHG removal by forests**

# Center for Research on Sustainable Forests' Natural Climate Solutions Initiative



## Natural Climate Solutions (NCS) Initiative

The FCCI Natural Climate Solutions (NCS) Initiative was formed to evaluate the potential of alternative NCS to decrease greenhouse gas (GHG) emissions through management in forestry and agriculture. Alternatives include reforestation, planting of fast-growing tree species, and extended rotations in forests as well as no-till cultivation, cover cropping, and capturing methane from manure on farms. In particular, researchers are assessing land management strategies for Maine's farms and working forests that will optimize future carbon sequestration rates and how the price of carbon influences the outcome.

The recently released [Final Report](#) highlights the cost and effectiveness of various NCS approaches compared to standard business-as-usual practices.

The Maine NCS Initiative project seeks to:

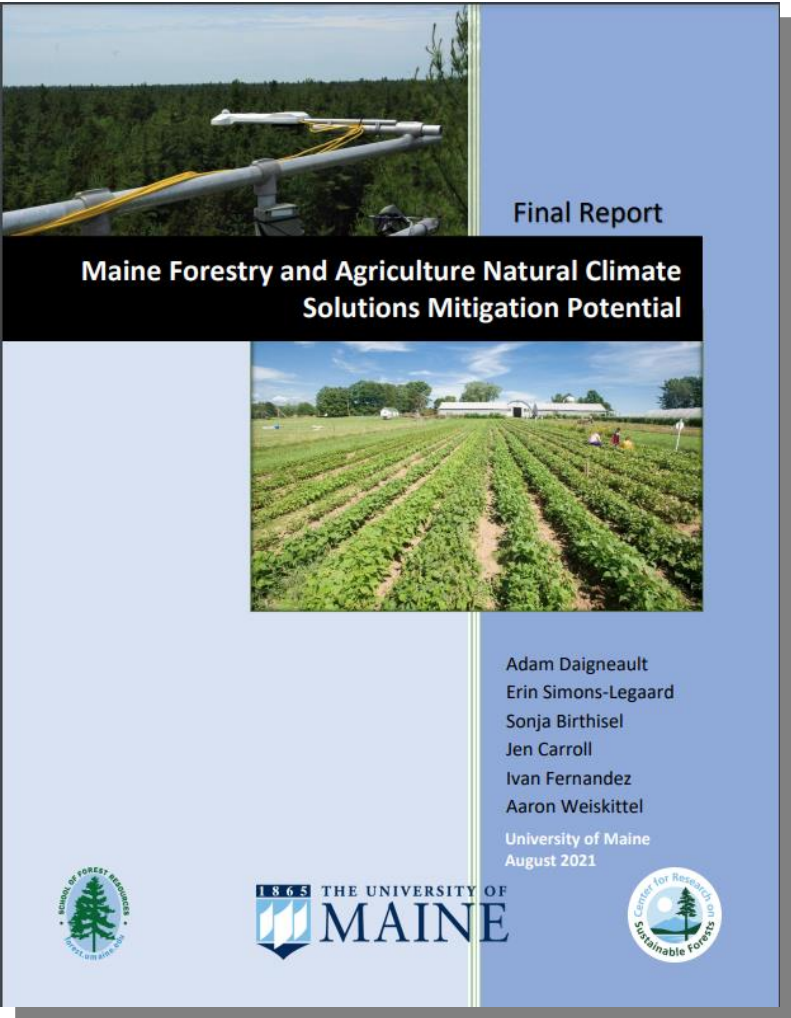
- (1) assess current practices to determine the degree to which foresters and farmers are using NCS;
- (2) determine the most cost-effective NCS for Maine;
- (3) understand key barriers to adopting NCS; and
- (4) generate information about which practices can be implemented on a broader scale.



[Download Report PDF](#)


**Stakeholder-engaged research and implementation effort**

# Center for Research on Sustainable Forests' Natural Climate Solutions Initiative






Final Report

**Maine Forestry and Agriculture Natural Climate Solutions Mitigation Potential**

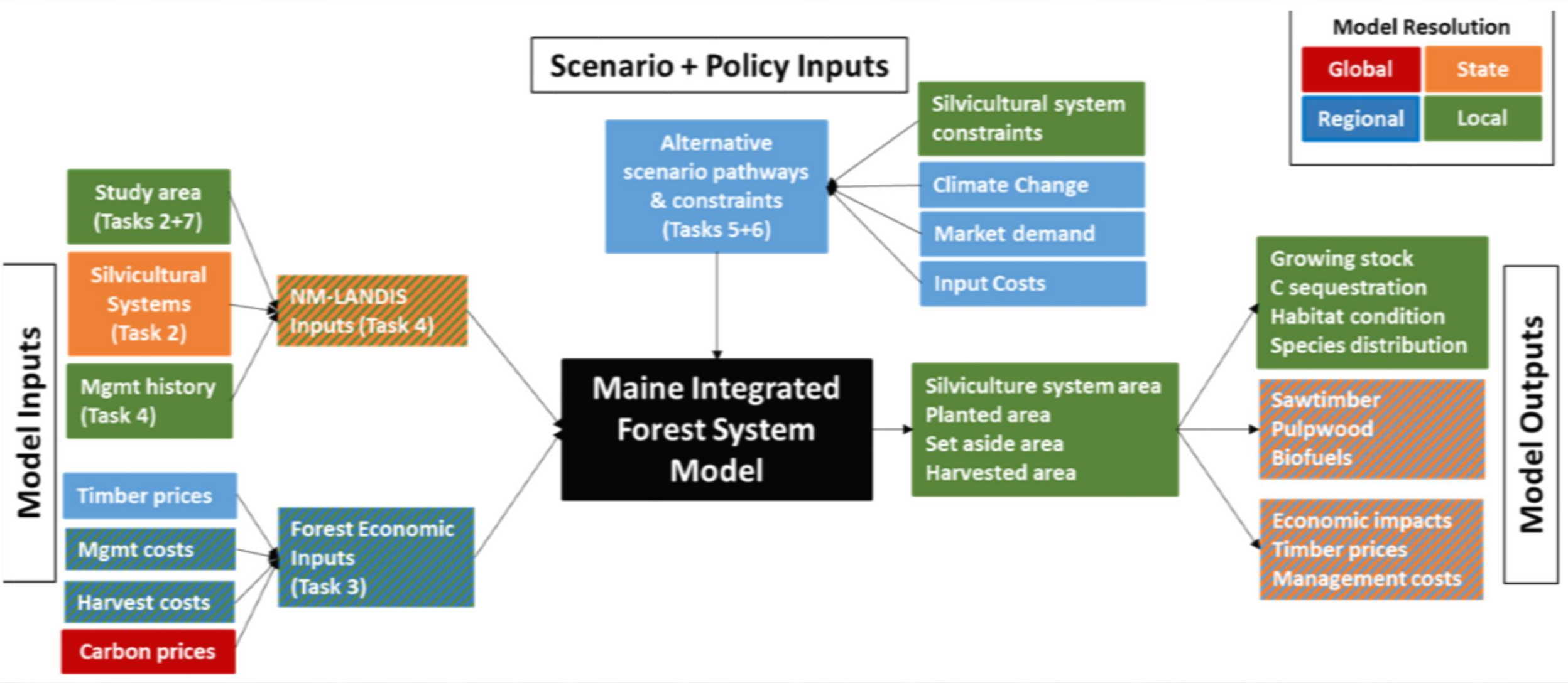


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Sonja Birthisel  
Jen Carroll  
Ivan Fernandez  
Aaron Weiskittel  
University of Maine  
August 2021



<https://crsf.umaine.edu/forest-climate-change-initiative/ncs/>

# Integrated and linked biophysical & economic modeling framework



**Final Report**  
**Maine Forestry and Agriculture Natural Climate Solutions Mitigation Potential**

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 University of Maine  
 August 2021

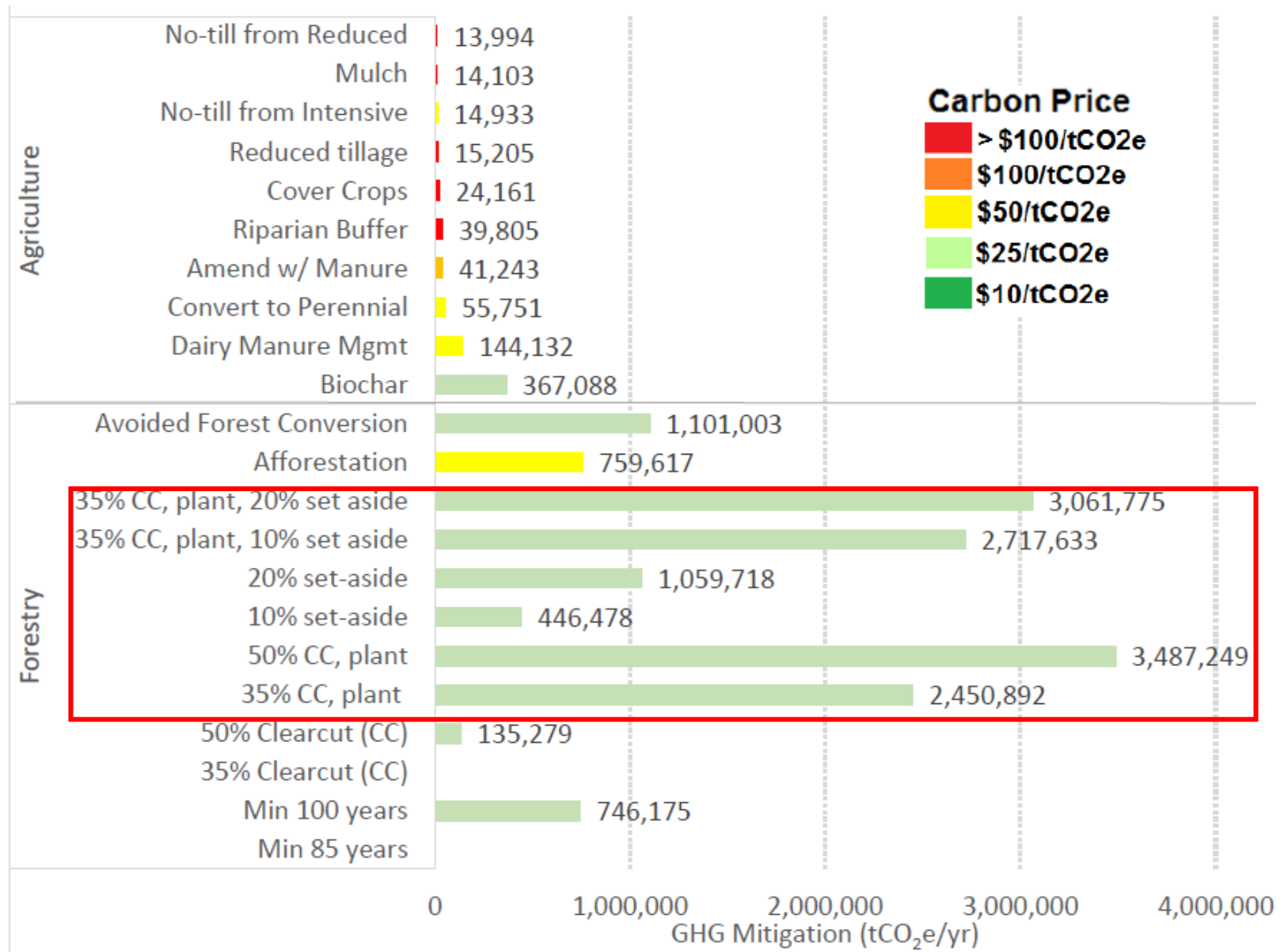


Figure 1. Summary of Maine NCS mitigation potential (tCO<sub>2</sub>e/yr) and break-even carbon price (\$/tCO<sub>2</sub>e).

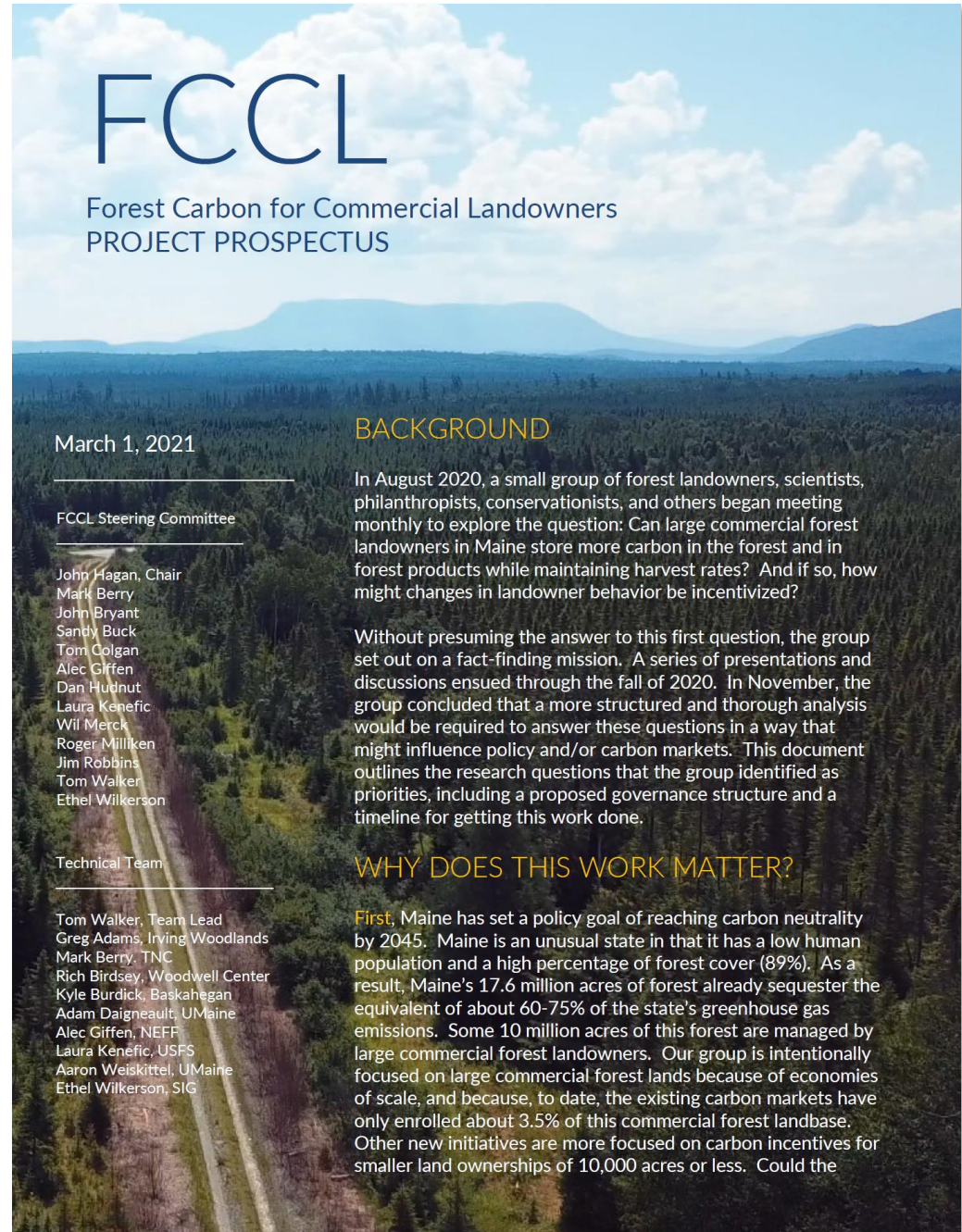
**Mixture of forest management approaches achieved highest mitigation potential with modest carbon prices**

*Coming in December 2022*

# Forest Carbon for Commercial Landowners Project (FCCL)

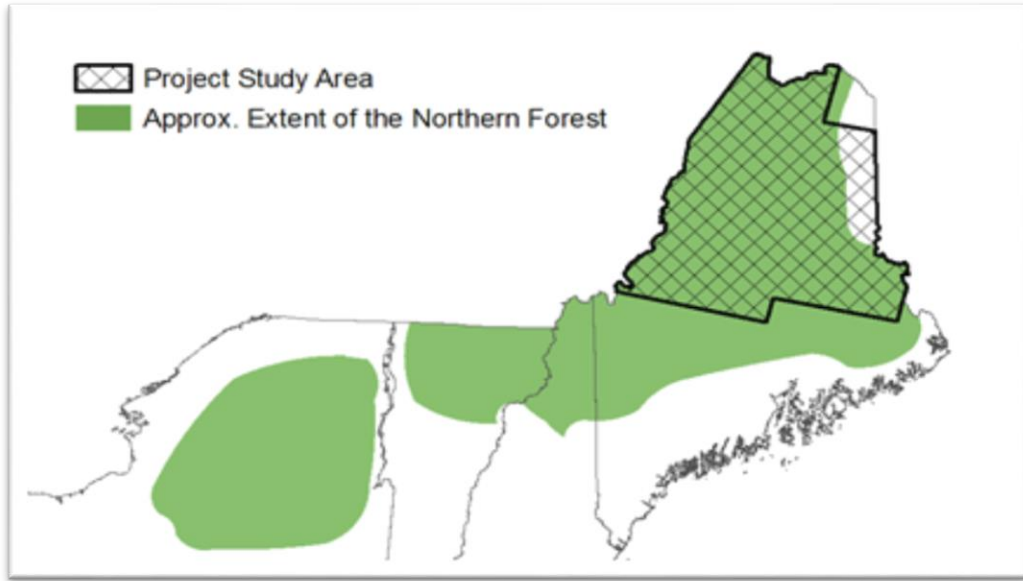
**“Can Northern Maine’s Commercial Forests Store More Carbon Without Reducing Harvests?”**

A study led by Tom Walker and Adam Daigneault (UMaine)

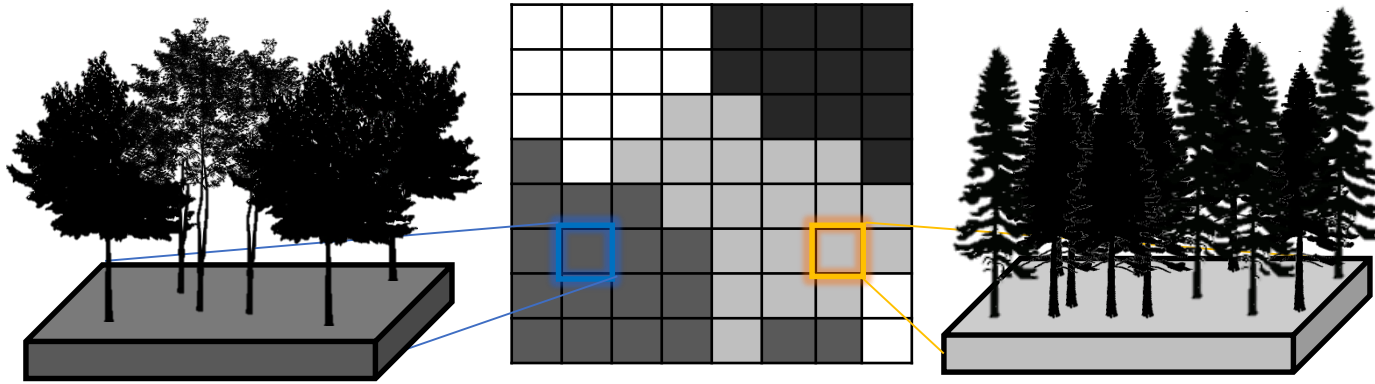
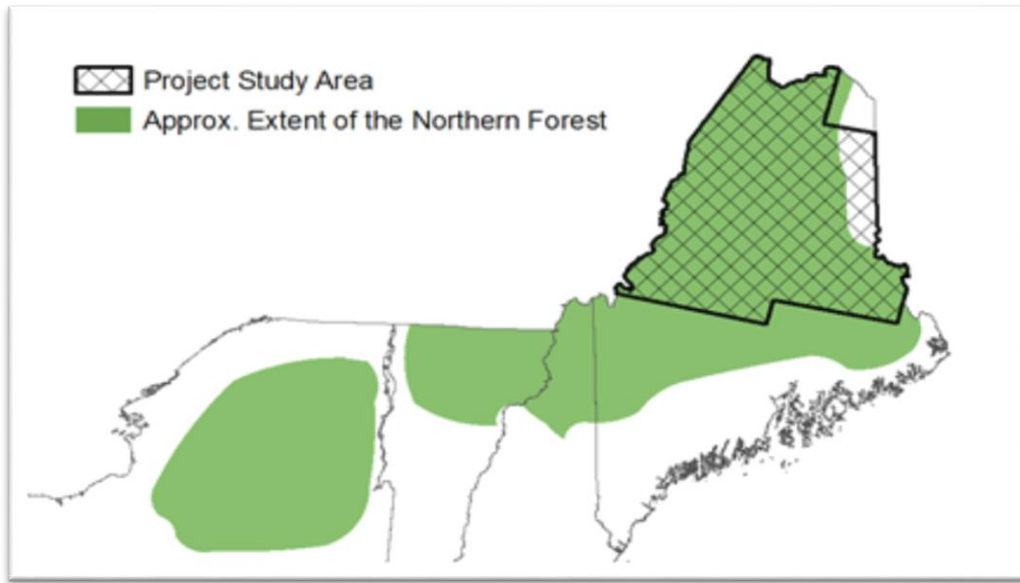




# LANDIS-II forest landscape model



# LANDIS-II forest landscape model



*Figurative example of the cell-based system used by LANDIS-II.  
Stands are formed by groups of like cells.*


Intelligent GeoSolutions - Center x +

crsf.umaine.edu/forest-research/igs/


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## Intelligent GeoSolutions Research Team



**Kasey Legaard**  
Remote Sensing  
[kasey.legaard@maine.edu](mailto:kasey.legaard@maine.edu)




**Erin Simons-Legaard**  
Landscape Ecology  
[erin.simons@maine.edu](mailto:erin.simons@maine.edu)  
[SFR Faculty webpage](#)



**Aaron Weiskittel**  
Forest Biometrics  
[aaron.weiskittel@maine.edu](mailto:aaron.weiskittel@maine.edu)  
[SFR Faculty webpage](#)

### IGS Resources



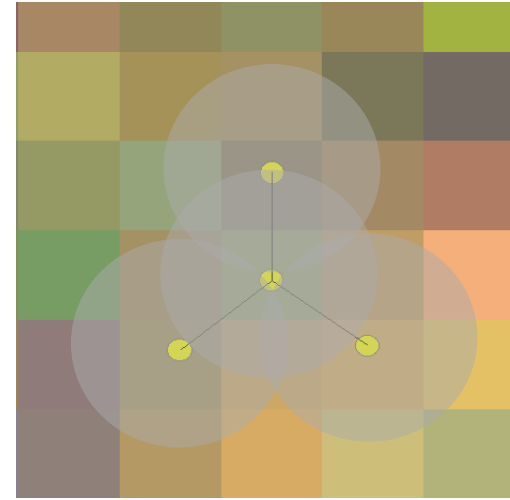
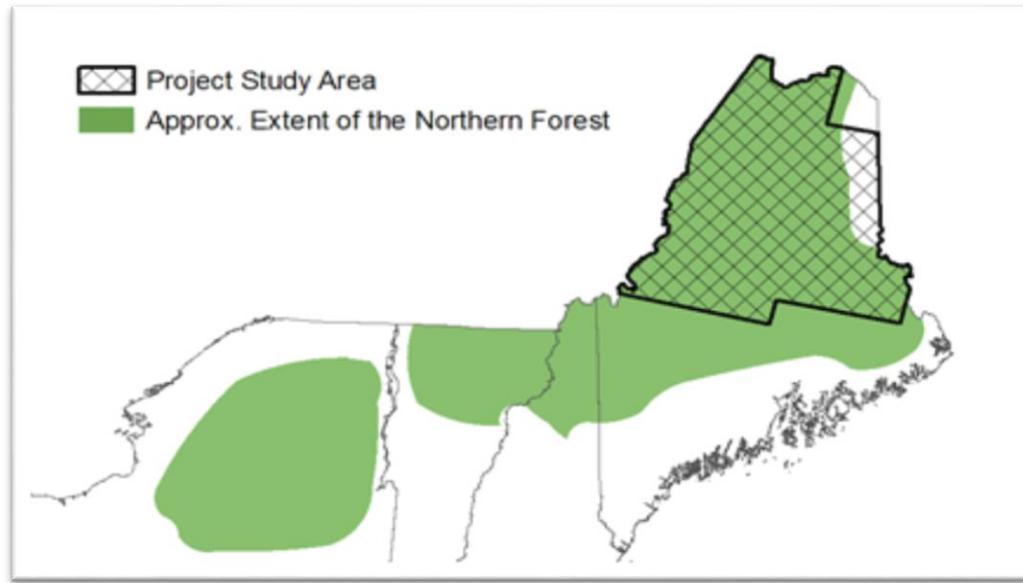
**Northeast Forest Information Source**

[Intelligent GeoSolutions Overview](#): Presentation at land cover mapping workshop, August 14, 2019.

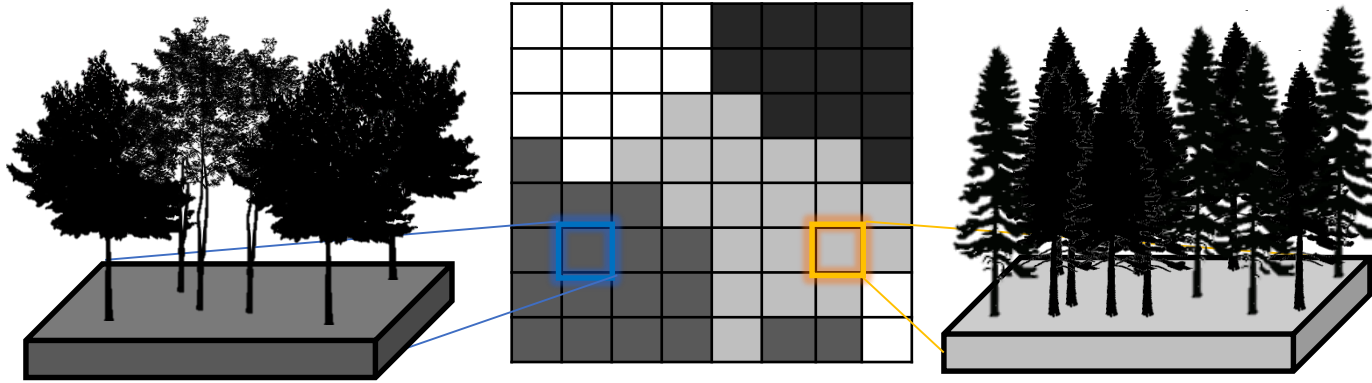
[Mapping Maine's Land Cover: A New Approach](#). Position paper on the how a next-generation land cover mapping project for the state of Maine be approached as a partnership between state and federal agencies, the University of Maine, and other private stakeholder organizations.

TOP

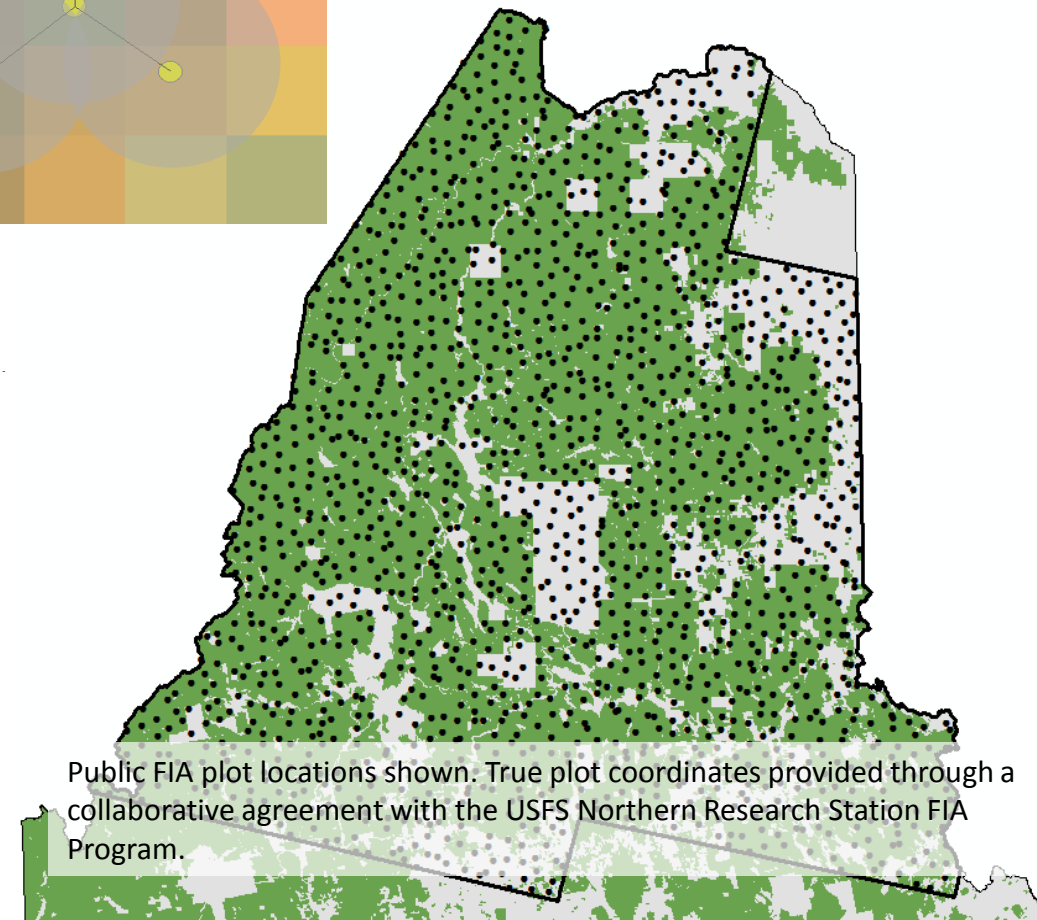
# Model initialization



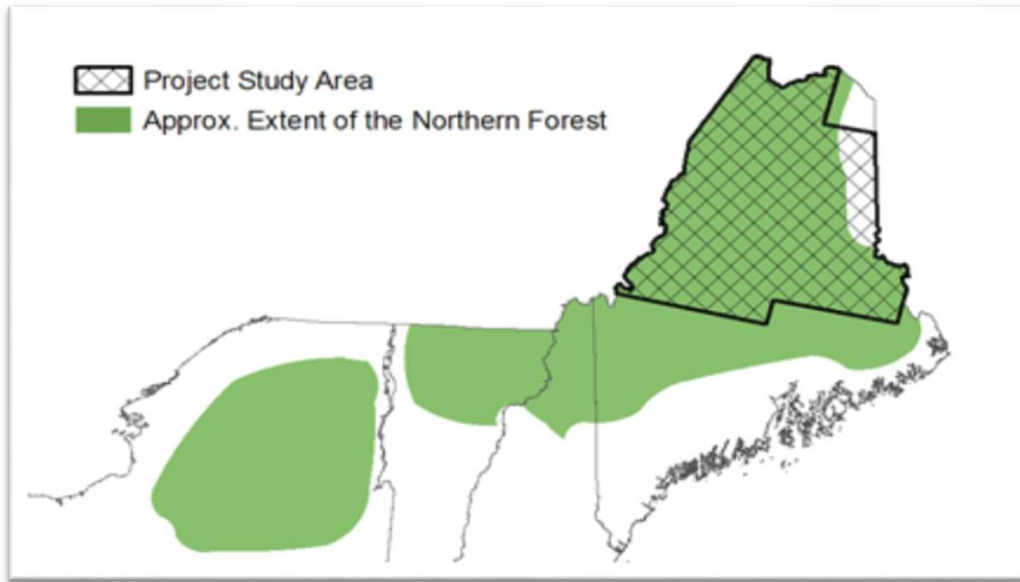
FIA plot (+ location error), superimposed over 30 m pixels:



*Figurative example of the cell-based system used by LANDIS-II.  
Stands are formed by groups of like cells.*

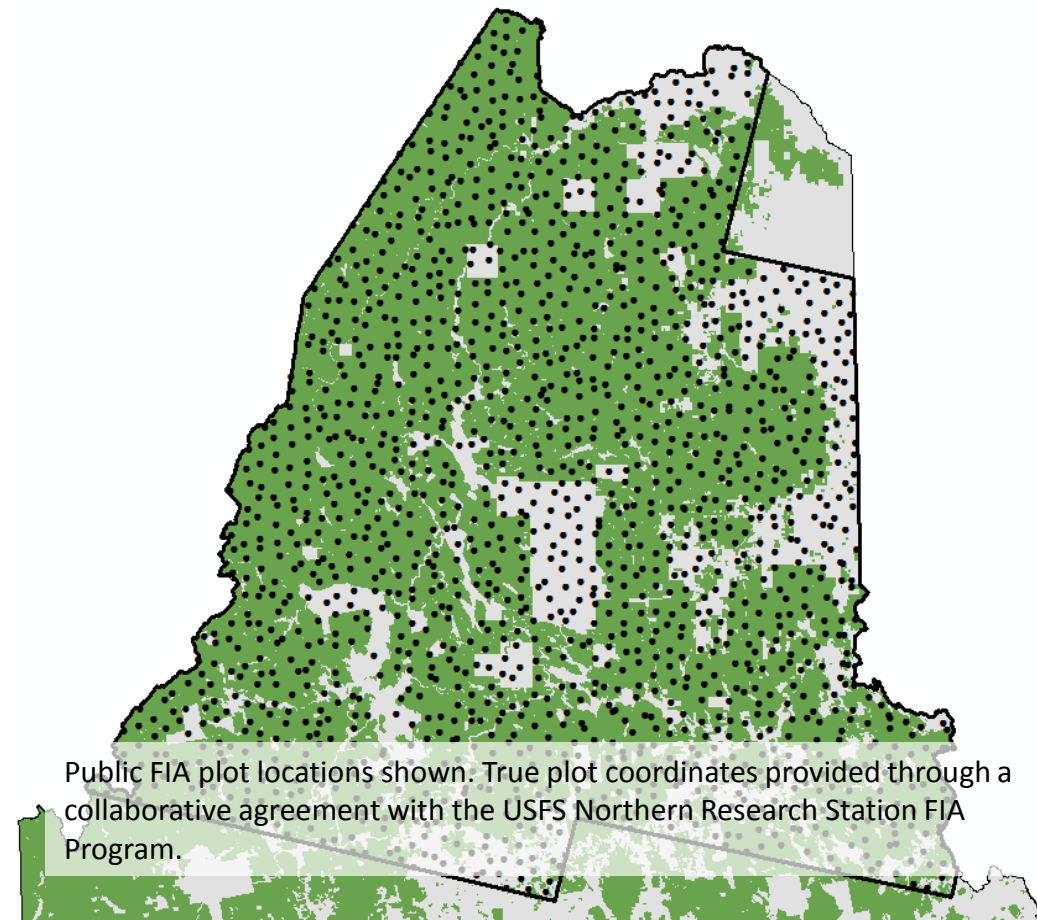


# Model initialization

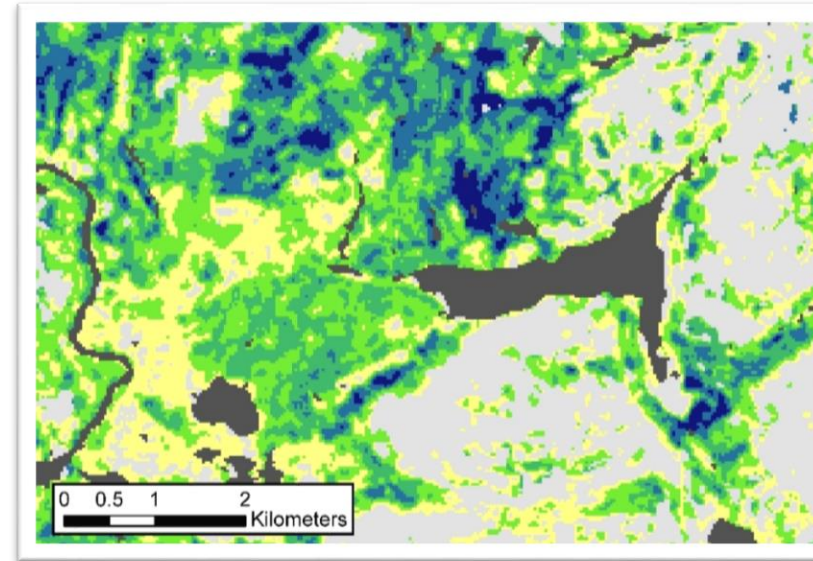
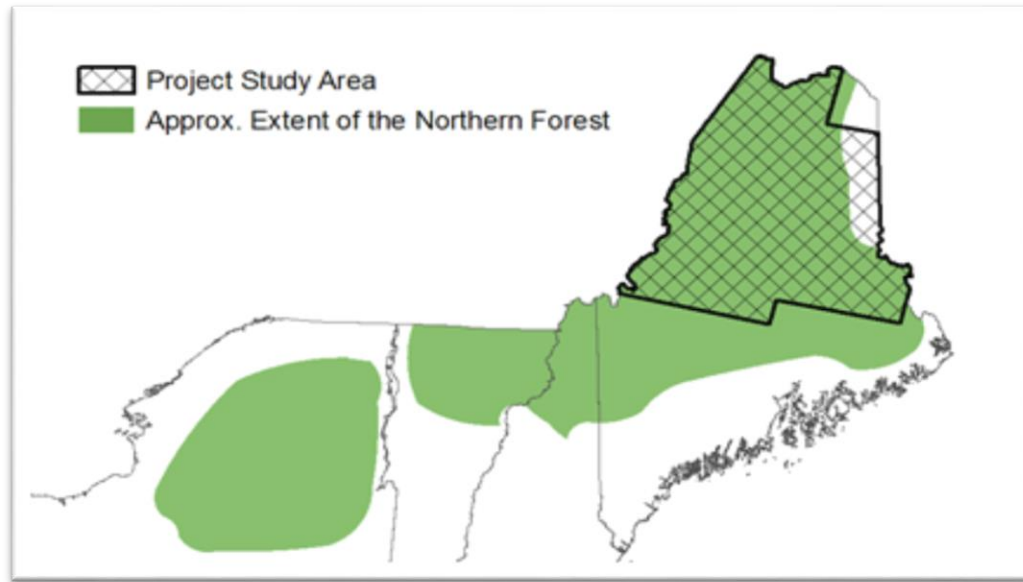


Species with relative abundance > 10% biomass:

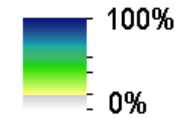
- Balsam fir
- Red, white, black spruce
- E. White pine
- N. White cedar
- Sugar and Red maple
- E. Hemlock
- American beech
- Yellow birch
- Paper birch
- White ash



# Model initialization



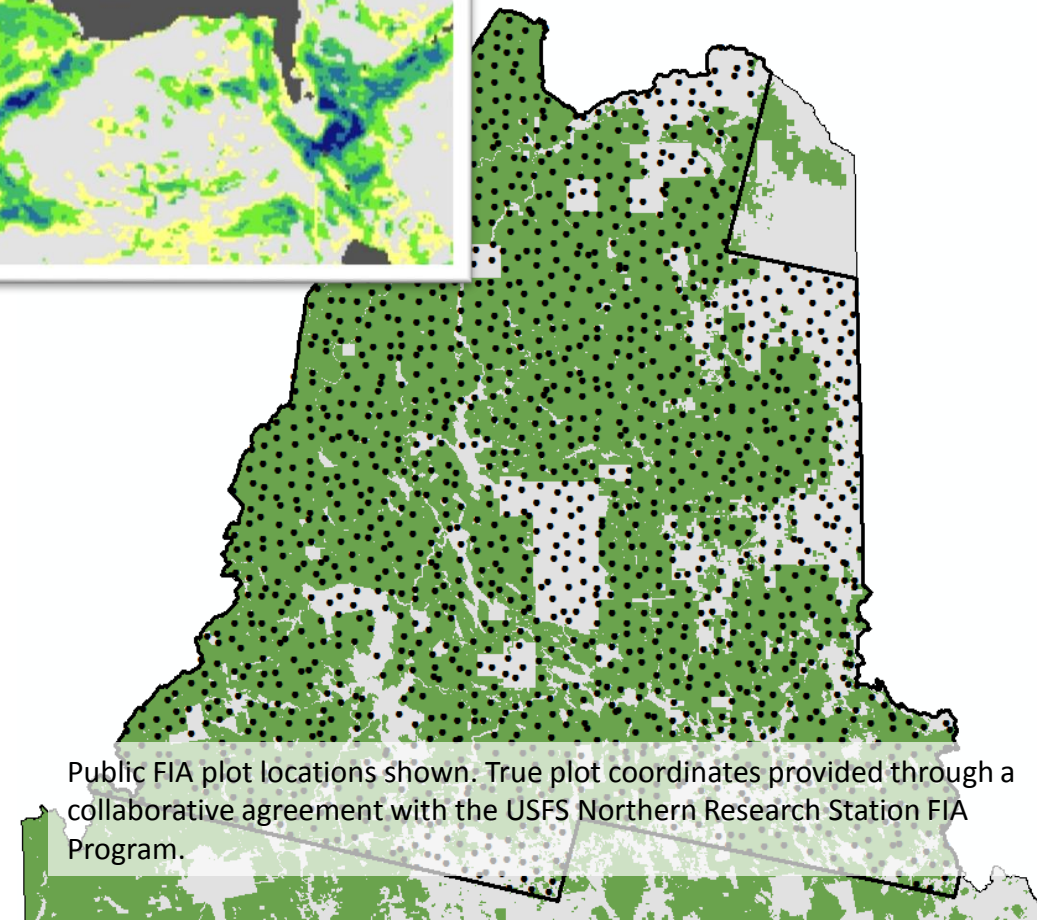
**Balsam Fir**  
(% live biomass)



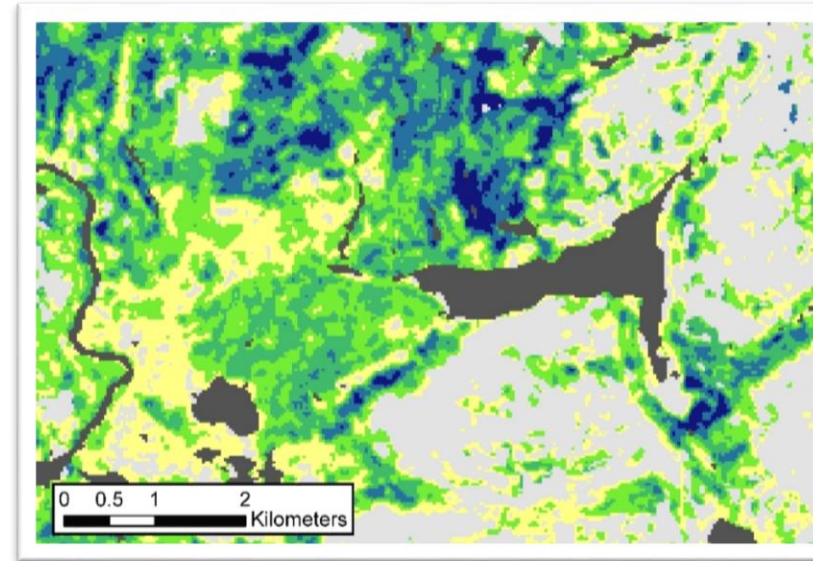
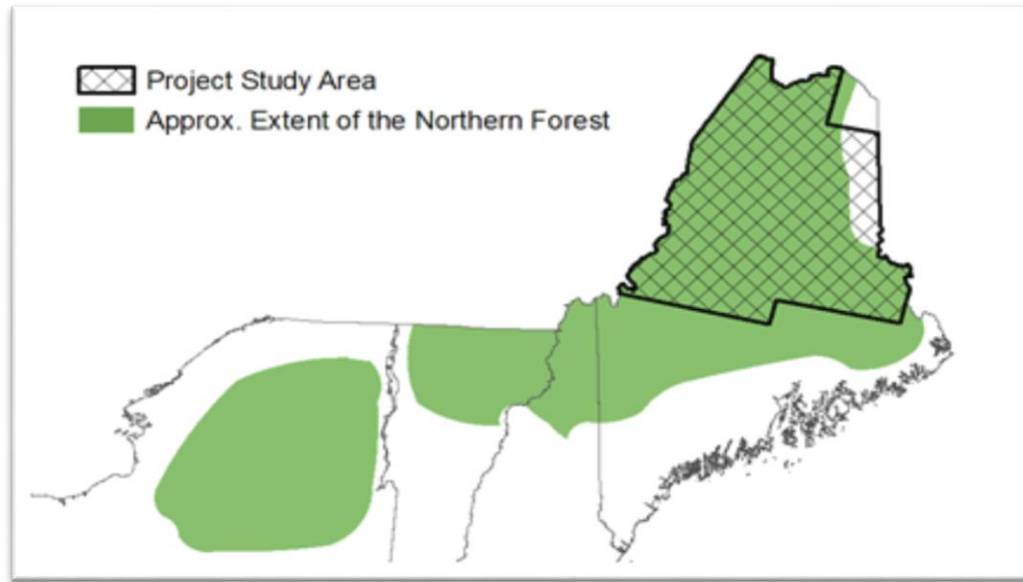
Non-forest

Species with relative abundance > 10% biomass:

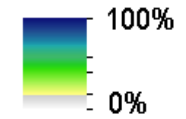
- Balsam fir
- Red, white, black spruce
- E. White pine
- N. White cedar
- Sugar and Red maple
- E. Hemlock
- American beech
- Yellow birch
- Paper birch
- White ash



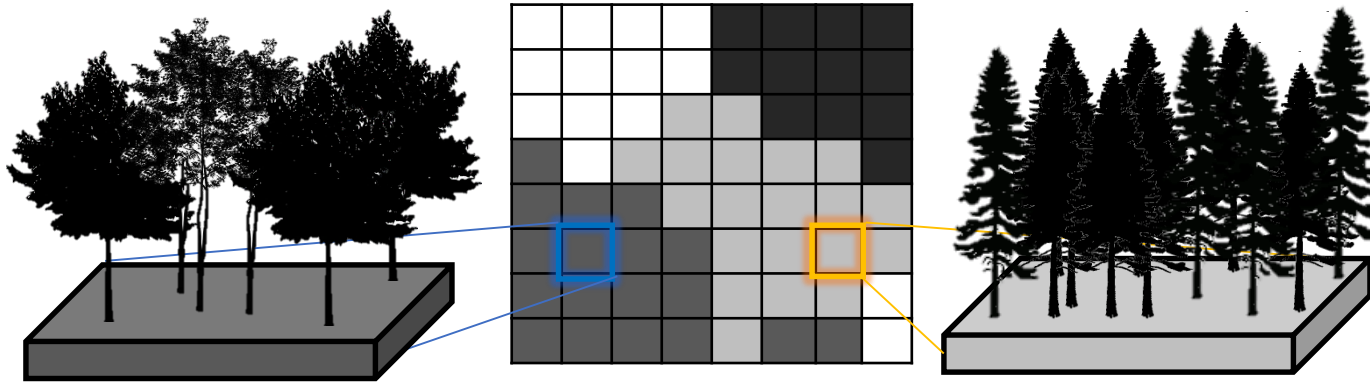
# Model initialization



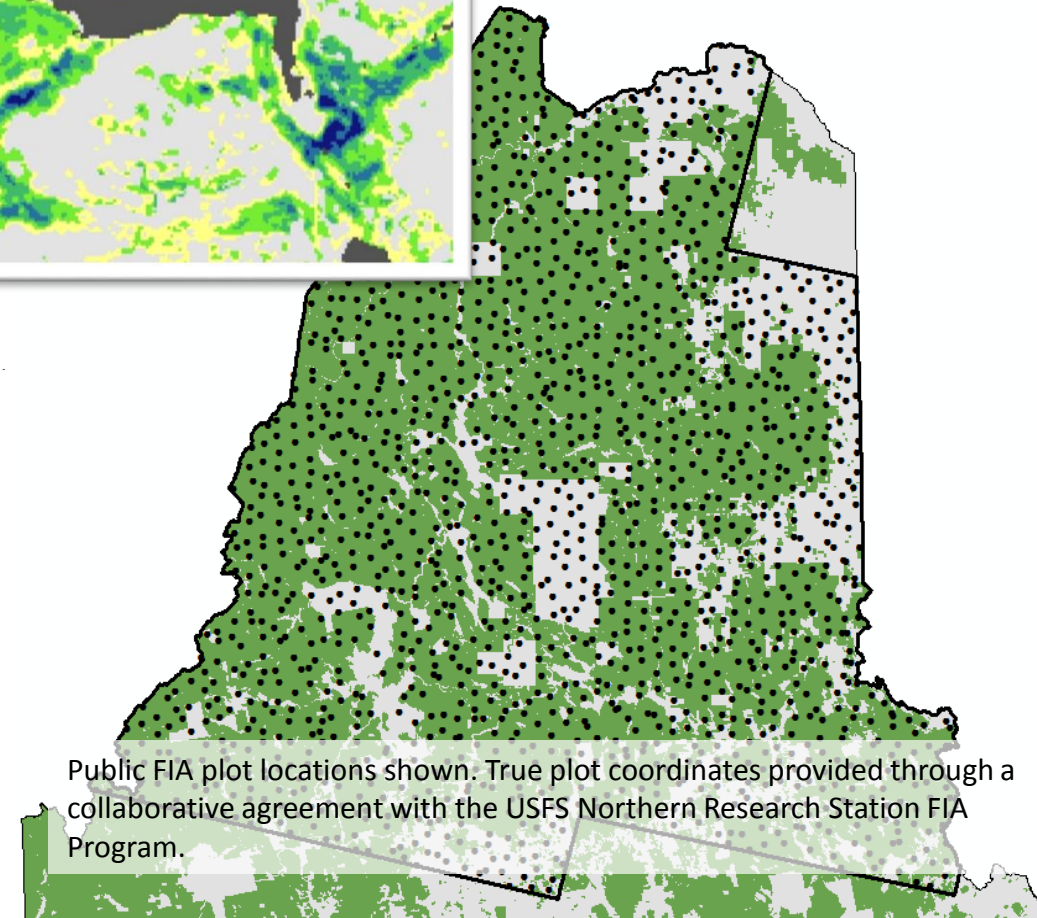
Balsam Fir  
(% live biomass)



Non-forest

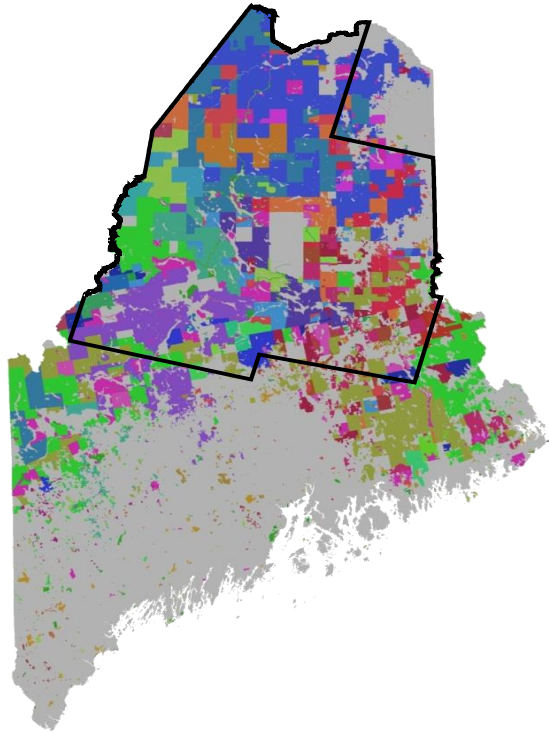


*Figurative example of the cell-based system used by LANDIS-II.  
Stands are formed by groups of like cells.*

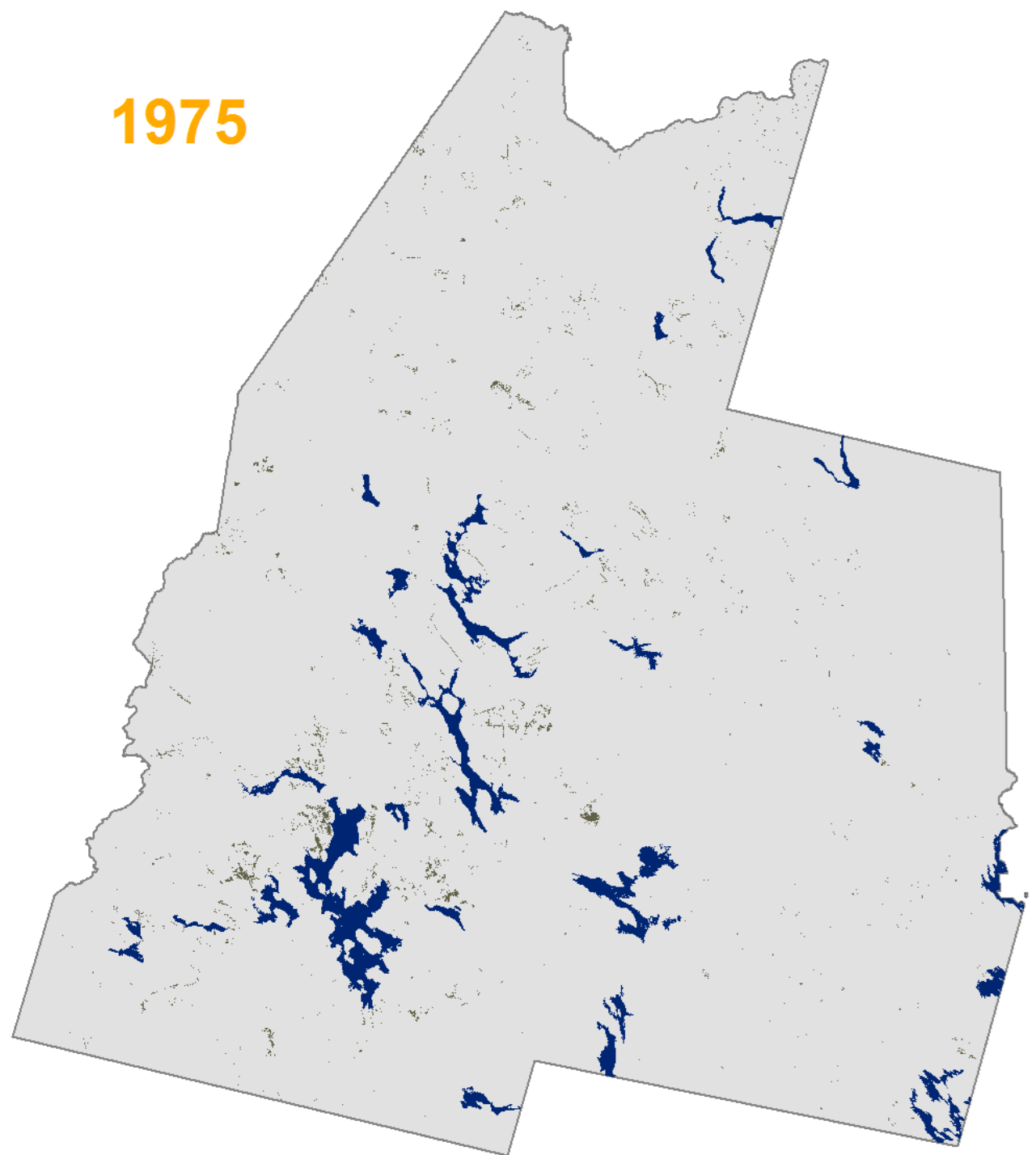


# Disturbance history

across a diverse ownership



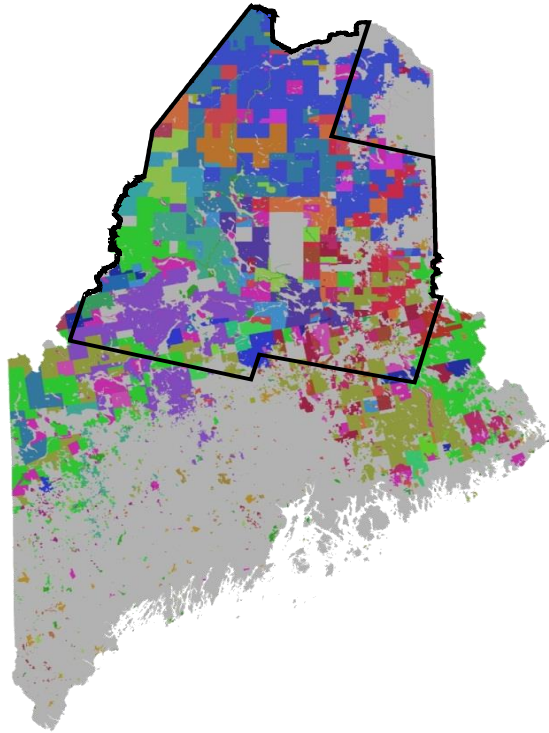
1975



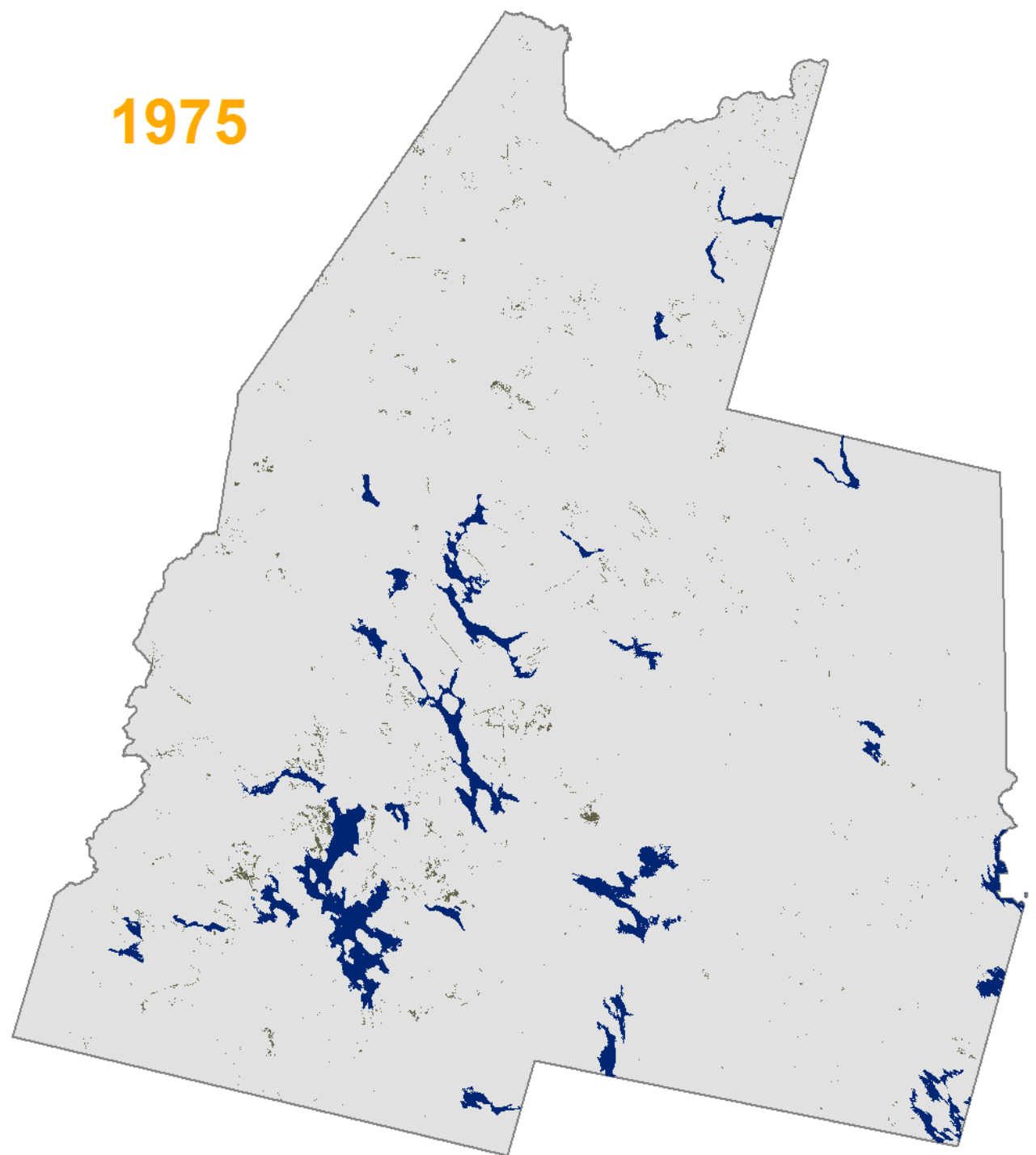


# Disturbance history

across a diverse ownership

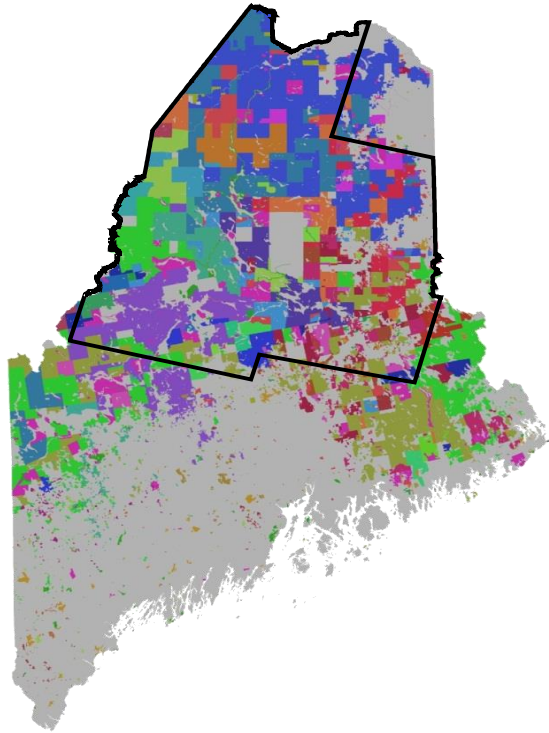


1975

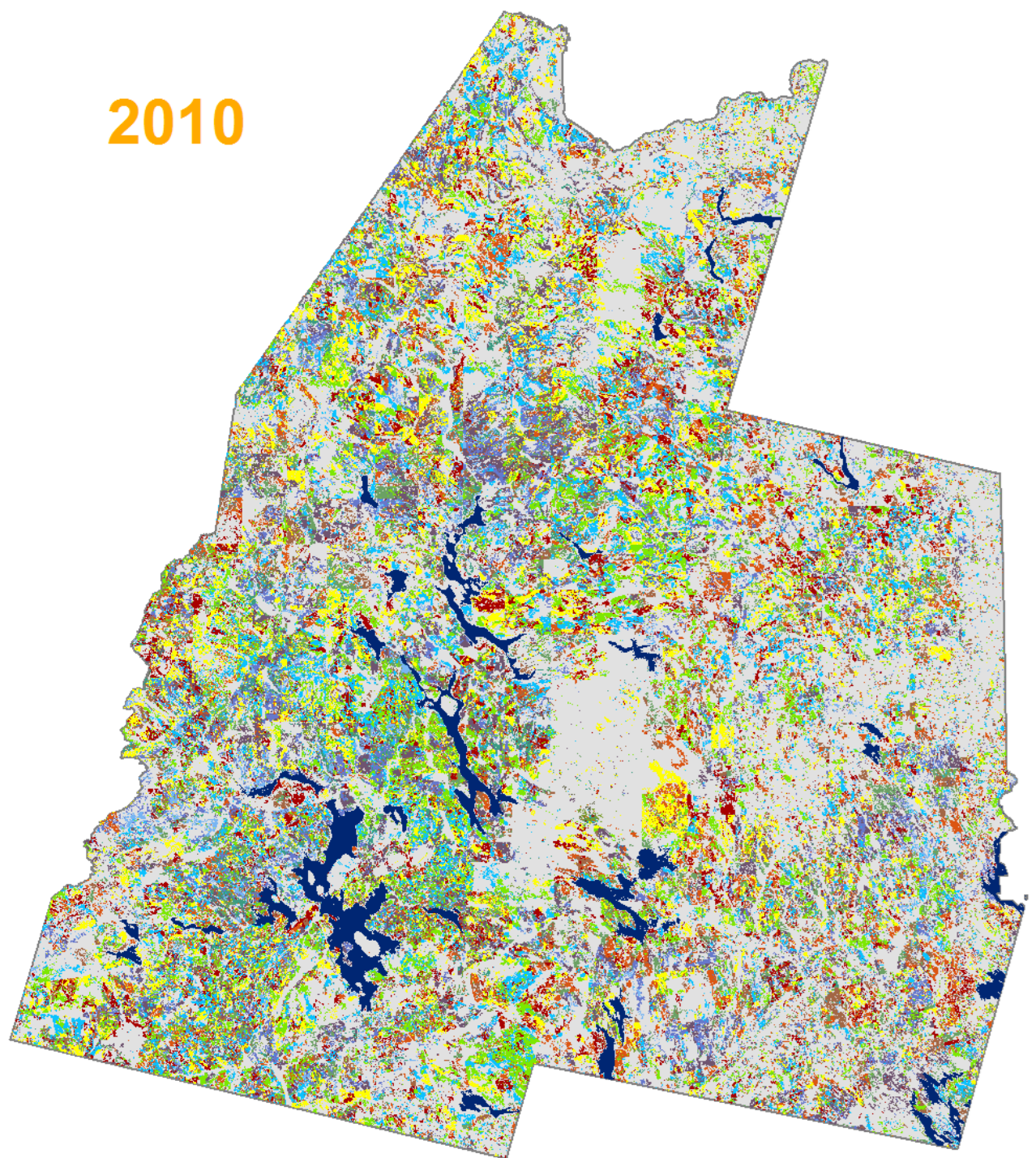


# Disturbance history

across a diverse ownership

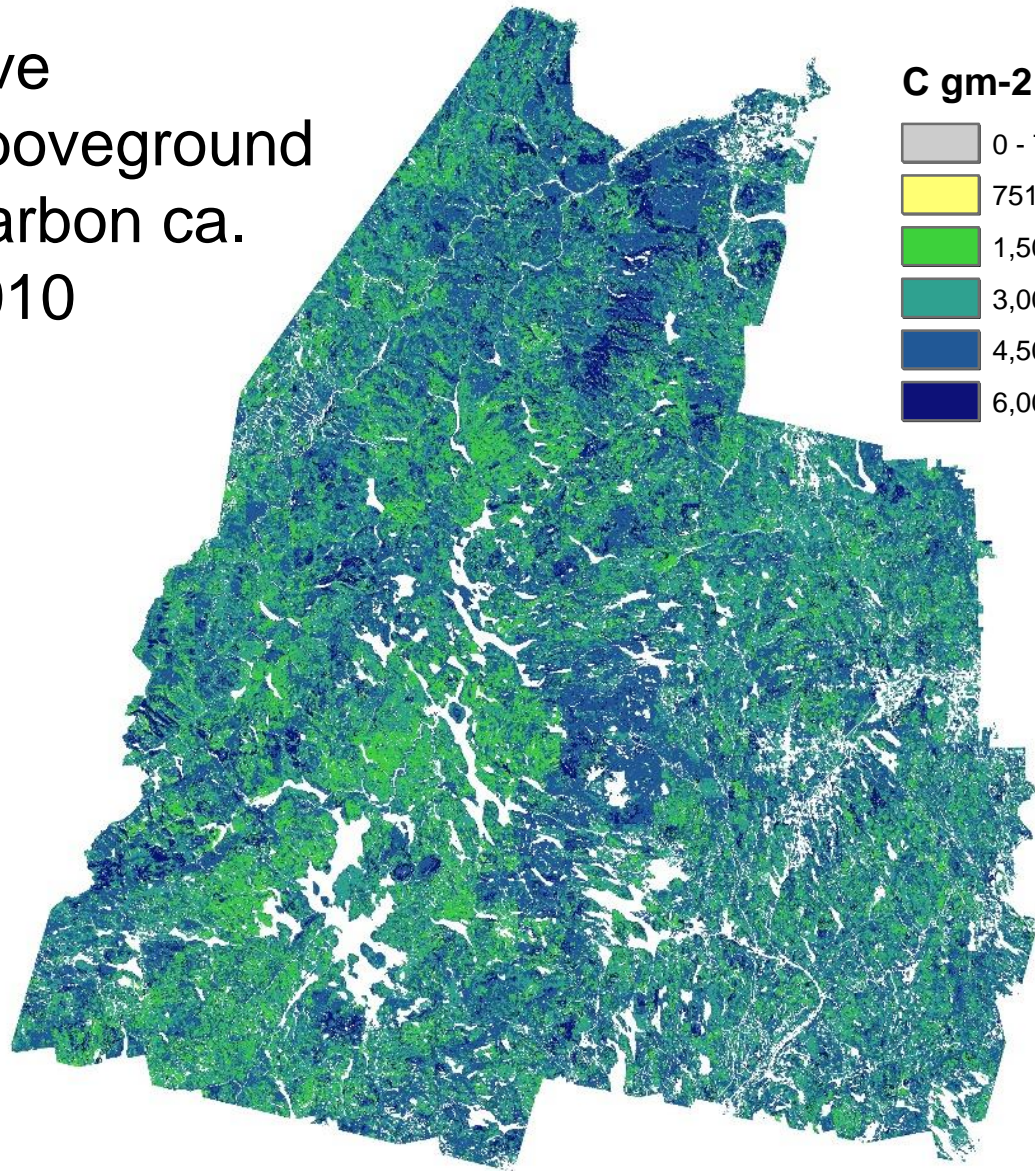


2010

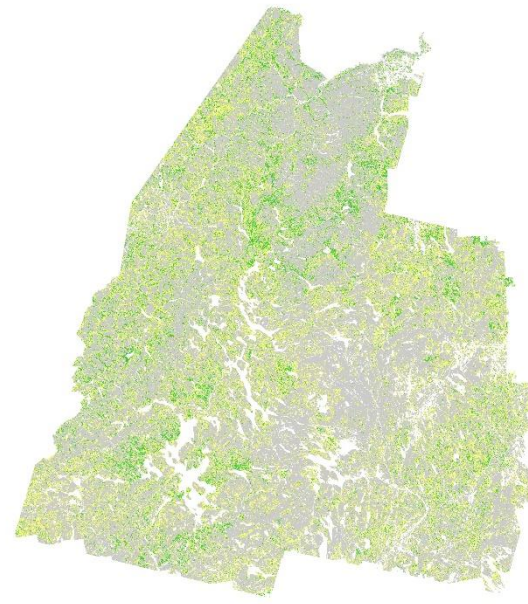
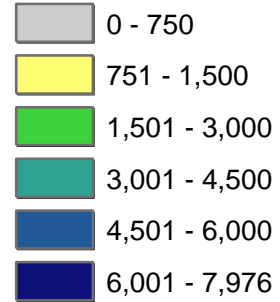


# Initial Carbon Density

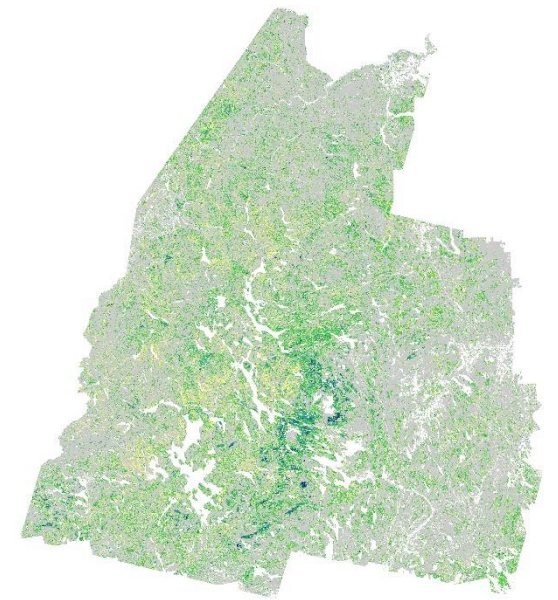
Live  
Aboveground  
Carbon ca.  
2010



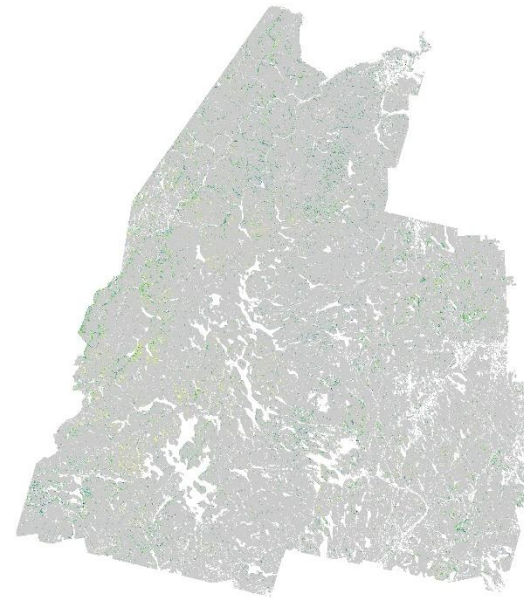
**C gm-2**



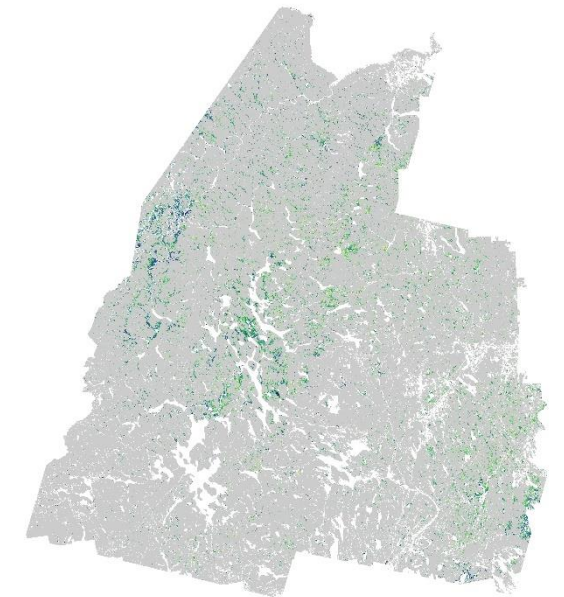
Balsam fir



Red spruce



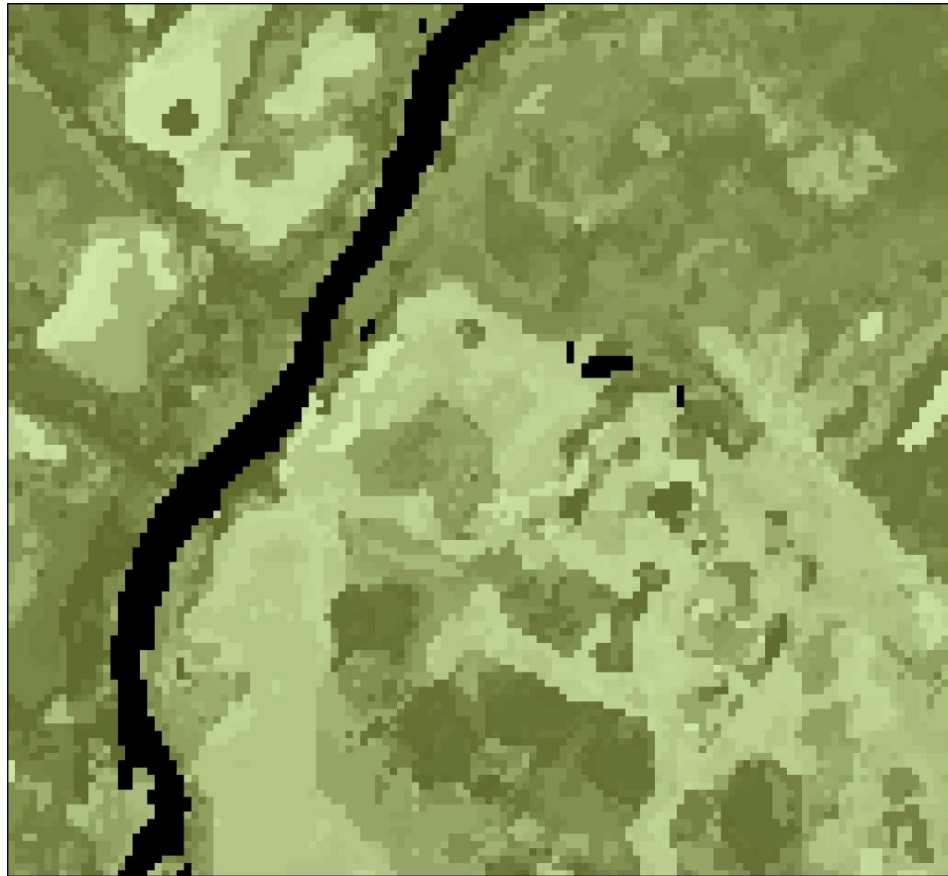
White spruce



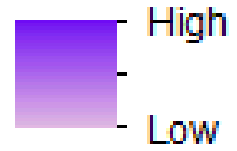
Black spruce

# Landscape simulation

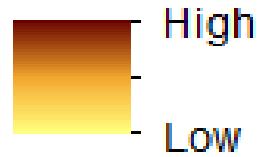
of current disturbance regime



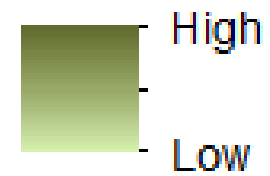
## Harvest



## Wind

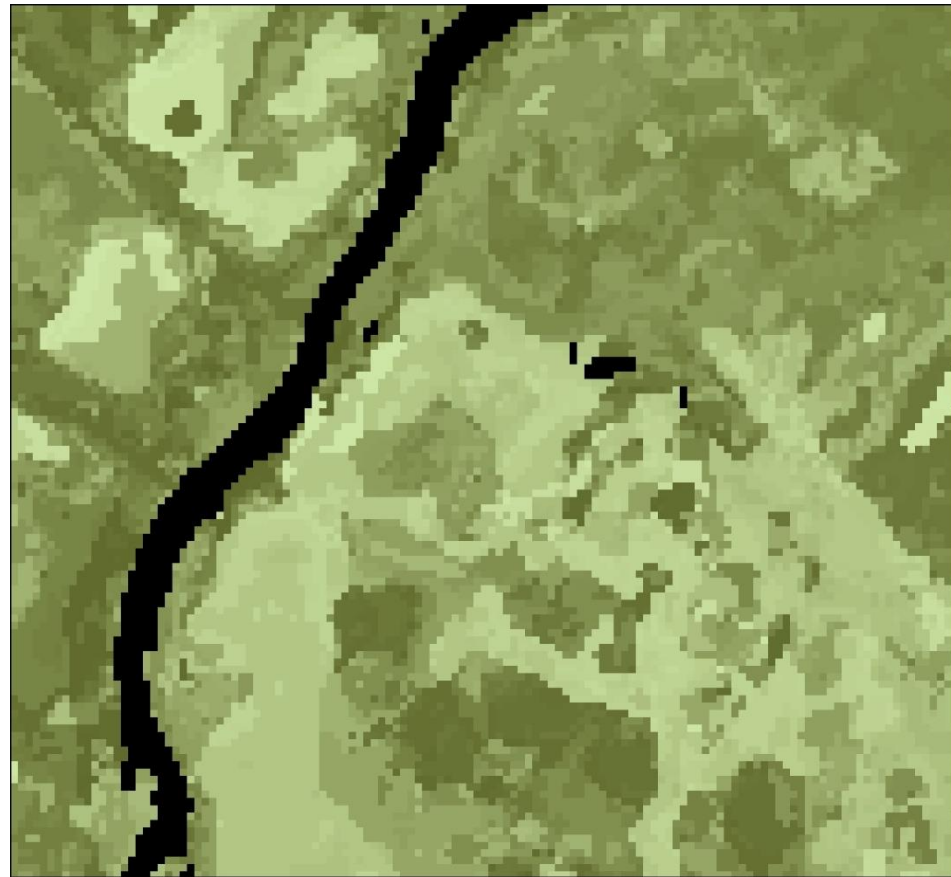


## Biomass



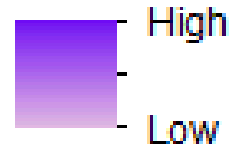
# Landscape simulation

of current disturbance regime



2010

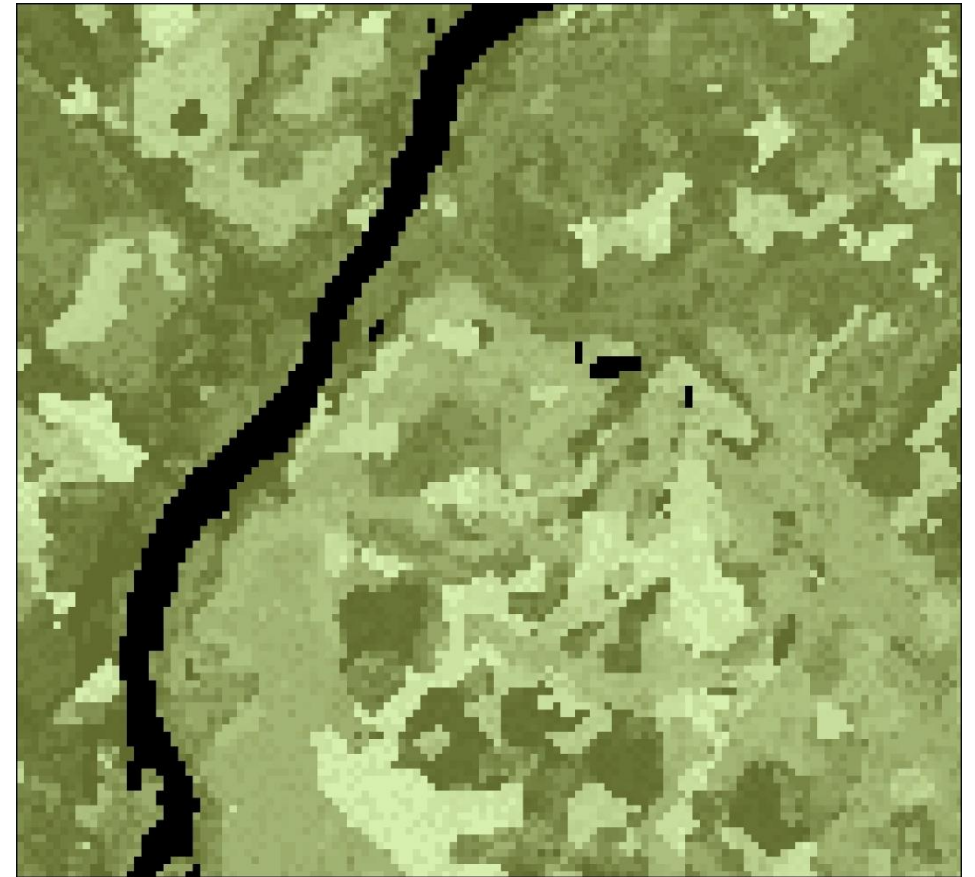
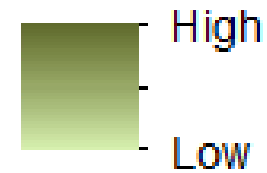
**Harvest**



**Wind**



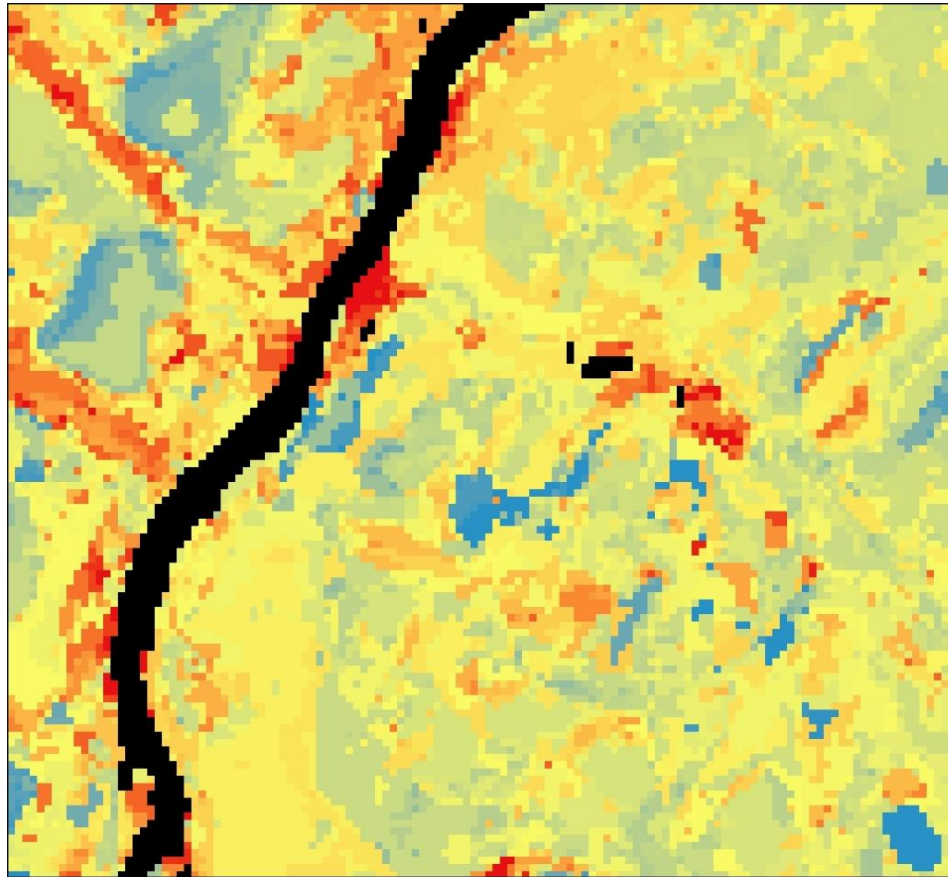
**Biomass**



2020

# Landscape simulation

of current disturbance regime

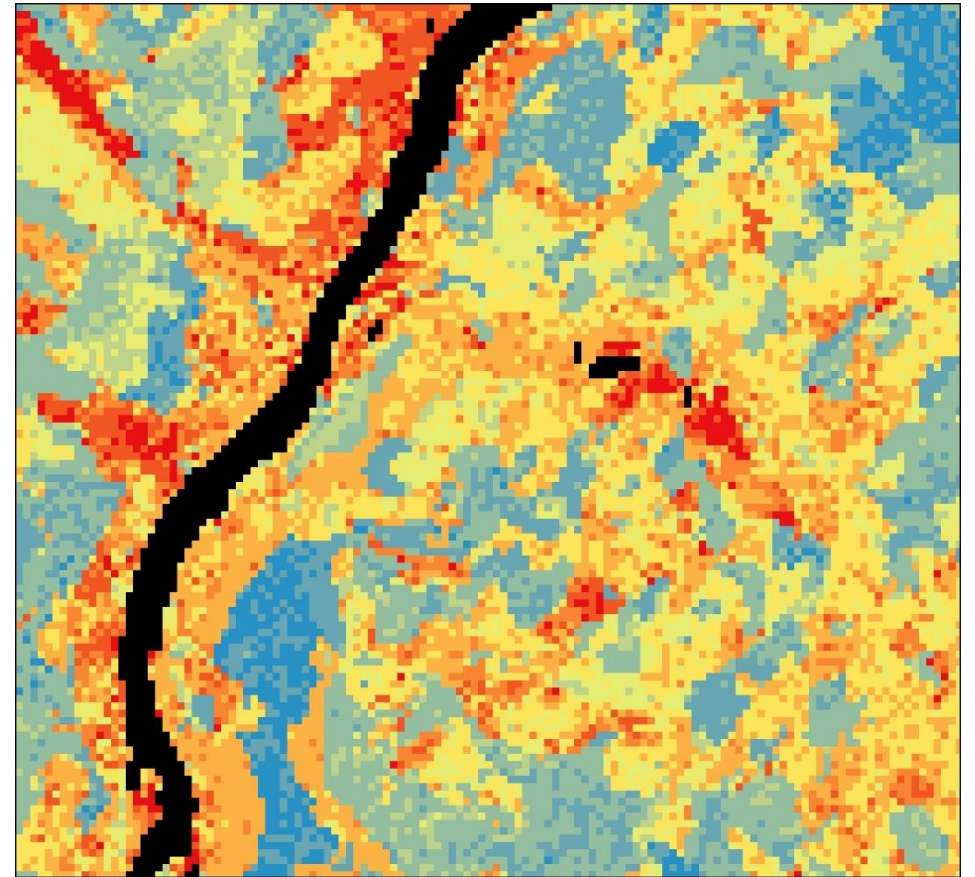


**NPP**



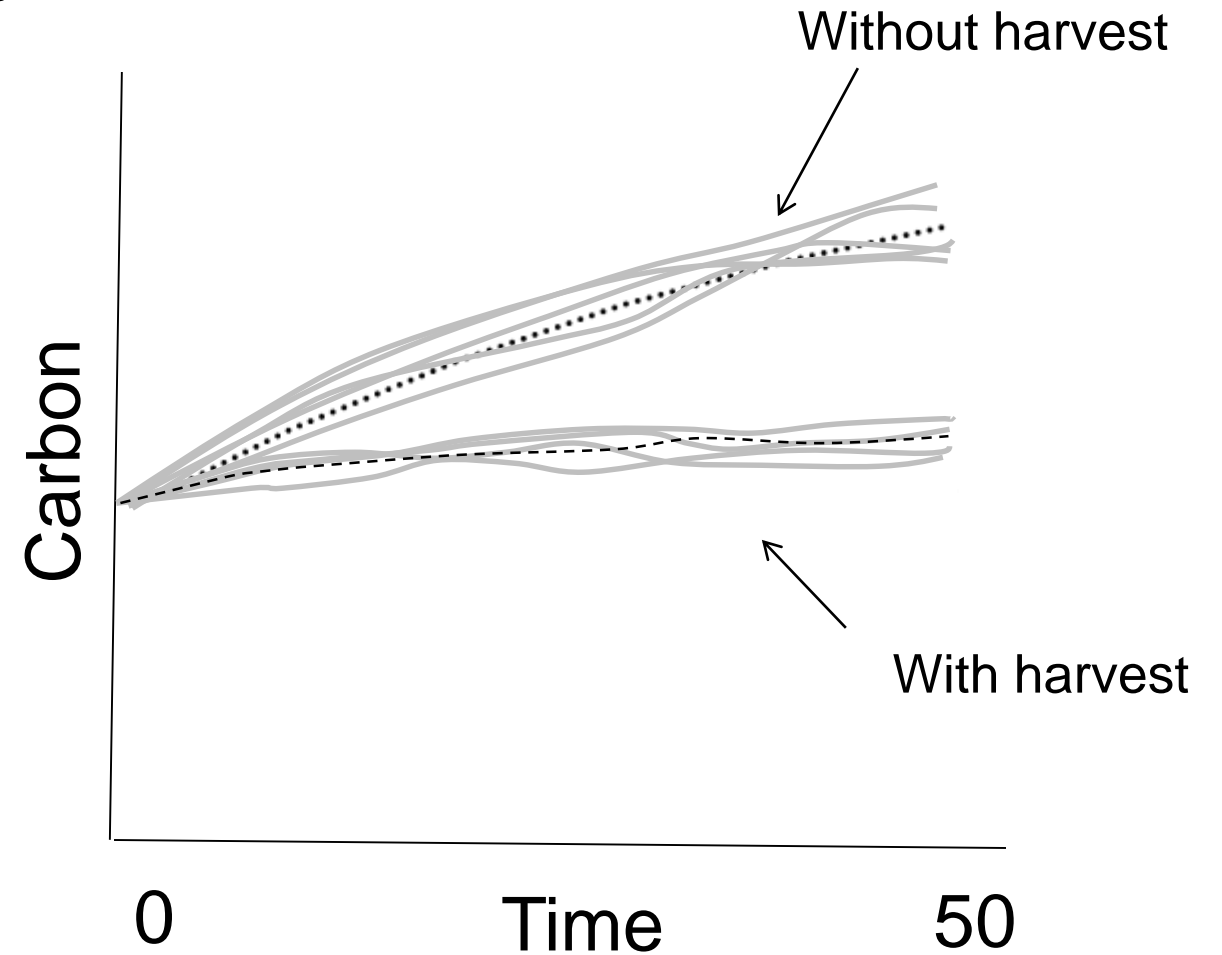
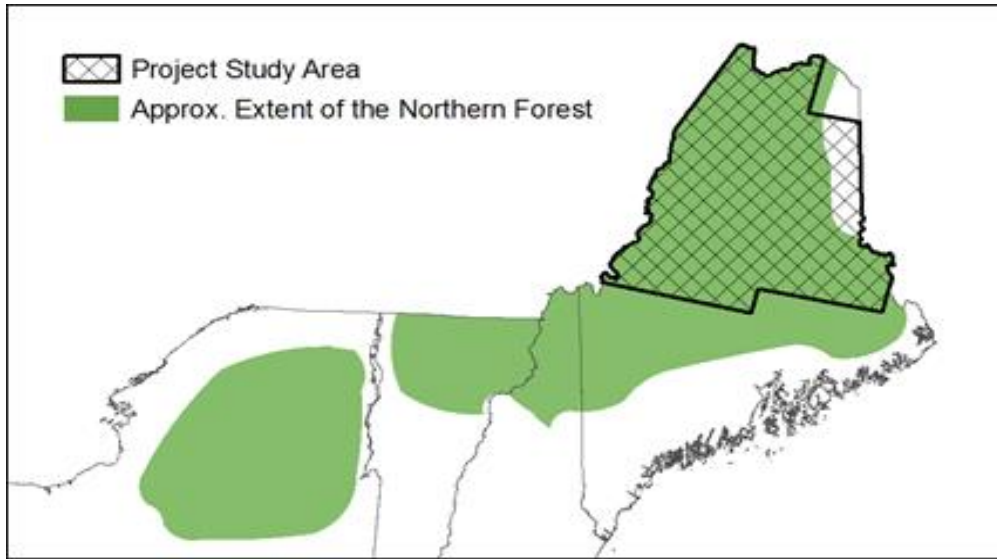
High

Low



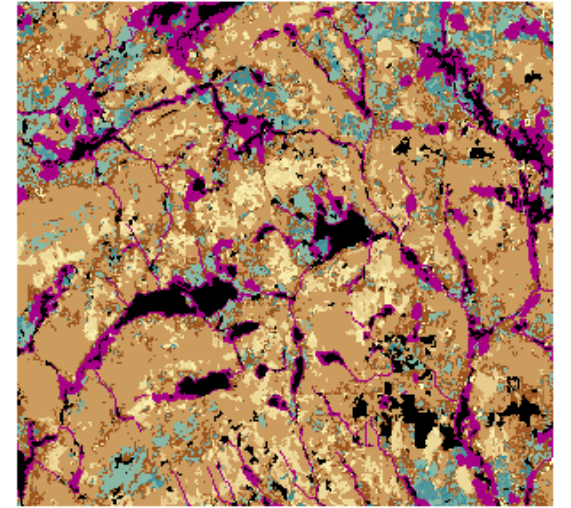
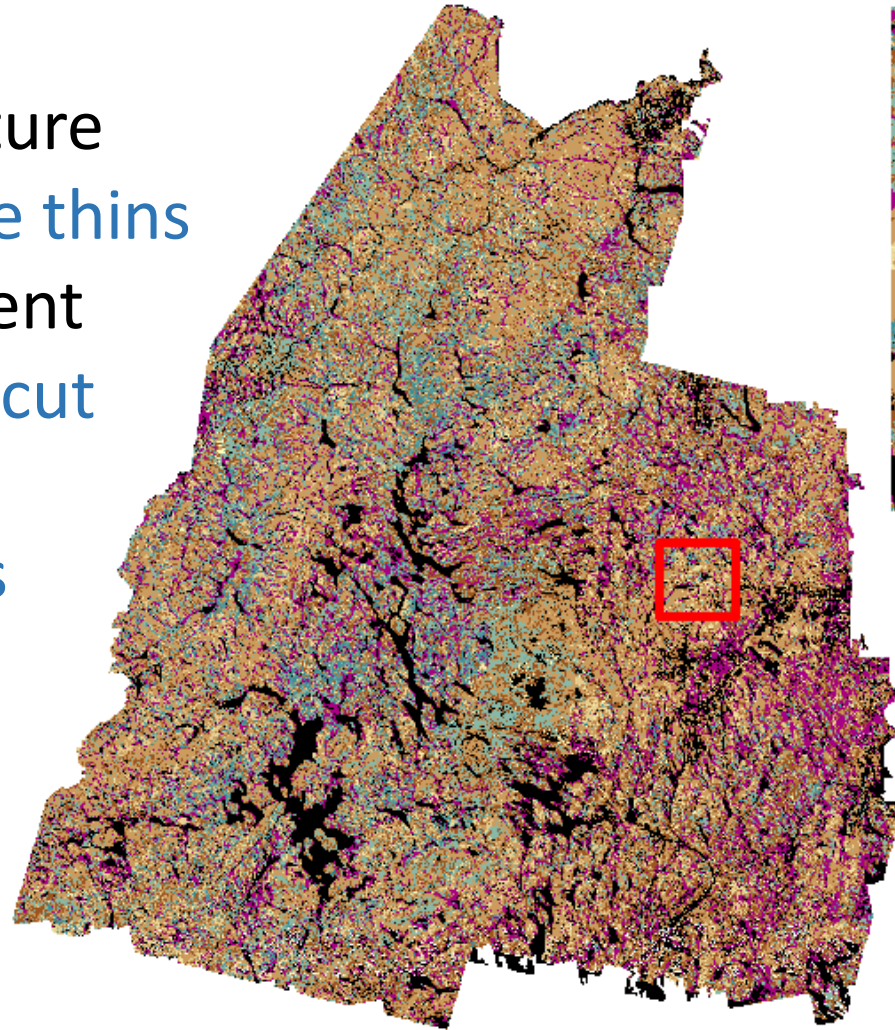
# Large area application

assuming recent climate and harvesting trends



# Climate-smart adaptation strategies

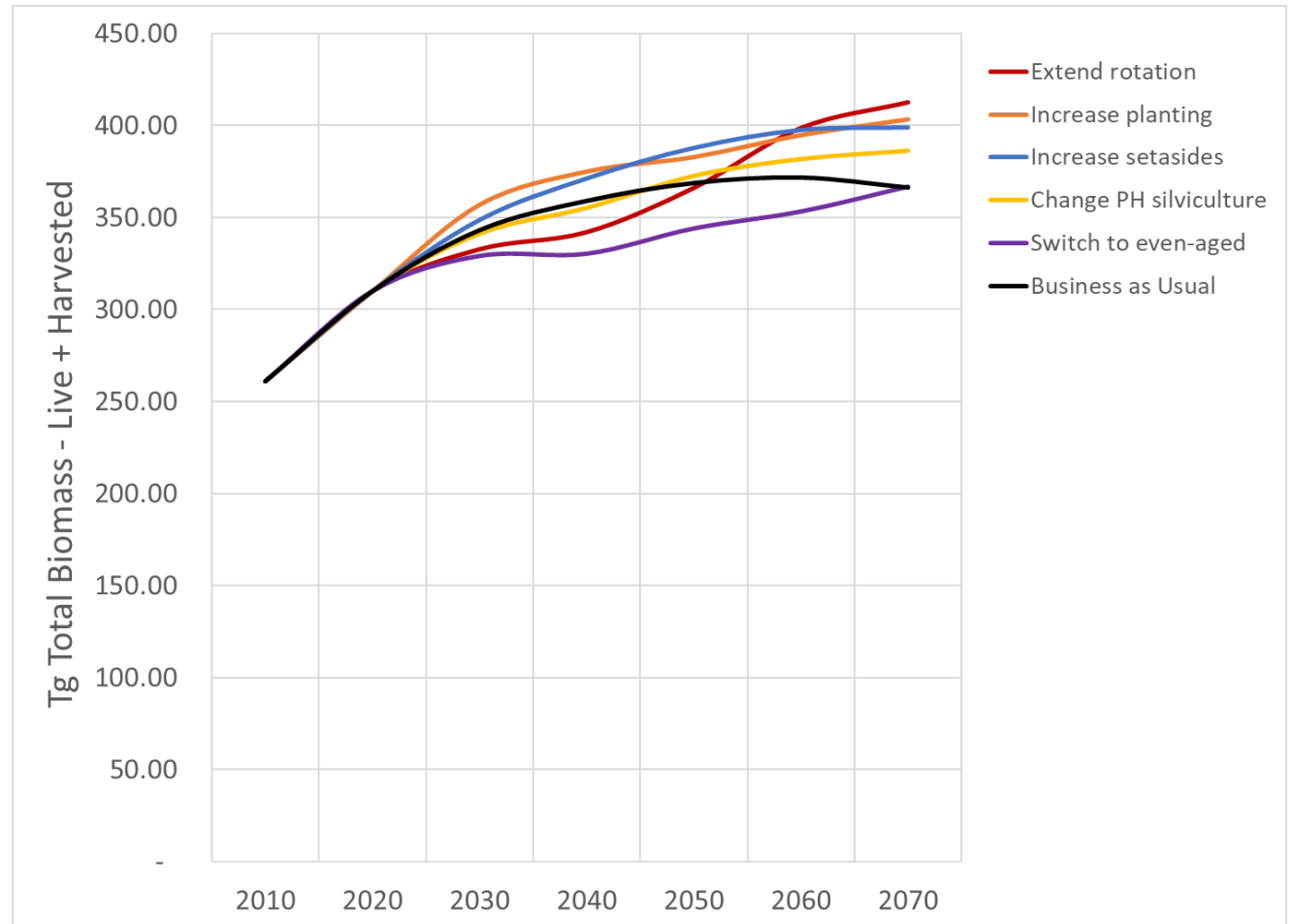
- Extend rotation
  - from 50 to 100 years
- Change partial harvest silviculture
  - to repeat light/moderate thins
- Increase even-aged management
  - percent harvest by clearcut
- Increase plantations
  - plant spruce in clearcuts
- Increase setasides
  - to 20% of the landbase





# Climate-smart adaptation strategies

- Extend rotation
- Change partial harvest silviculture
- Increase even-aged management
- Increase plantations
- Increase setasides



# Climate-smart adaptation strategies

Tradeoffs  
ca. 2070  
Relative to BAU

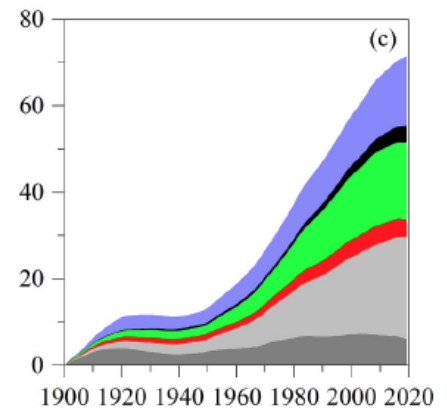
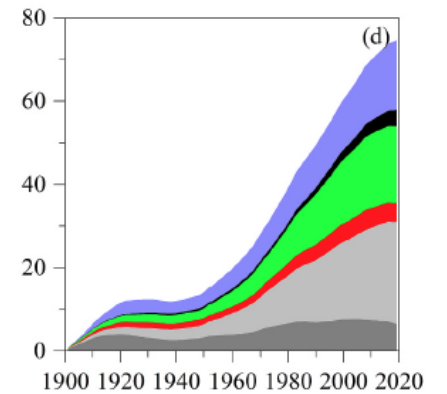
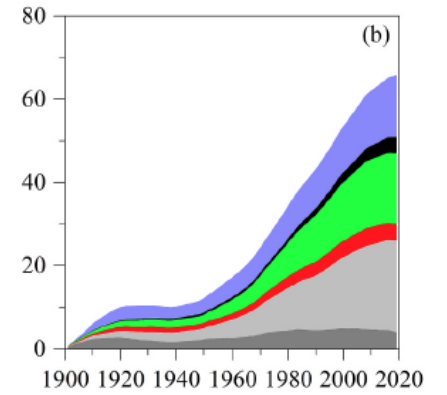
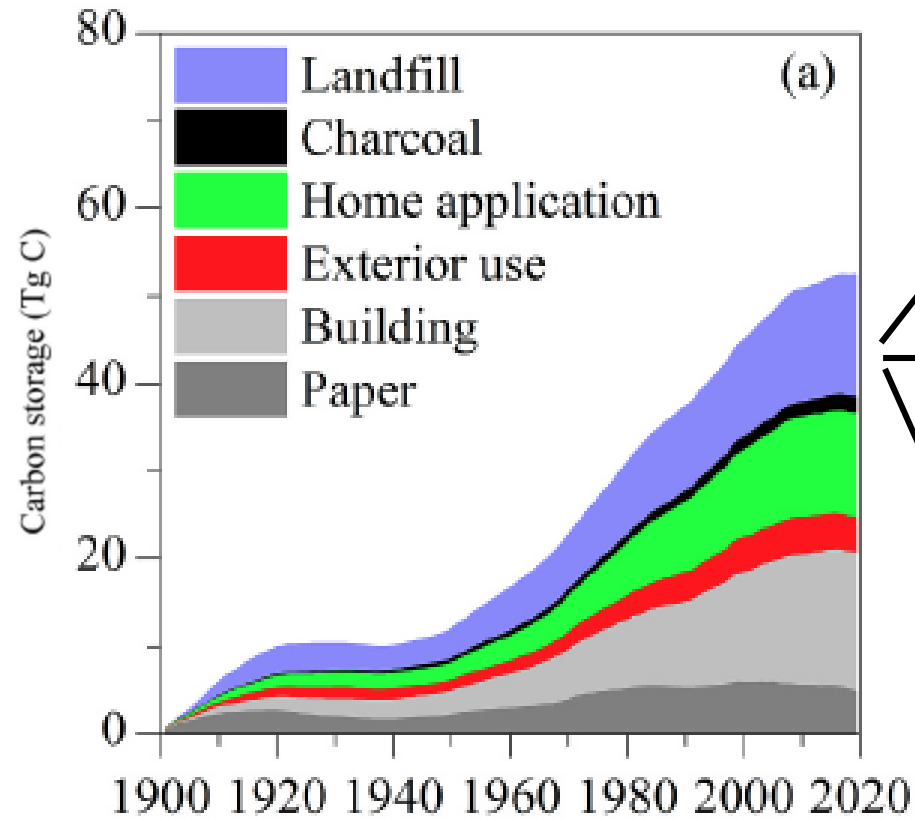
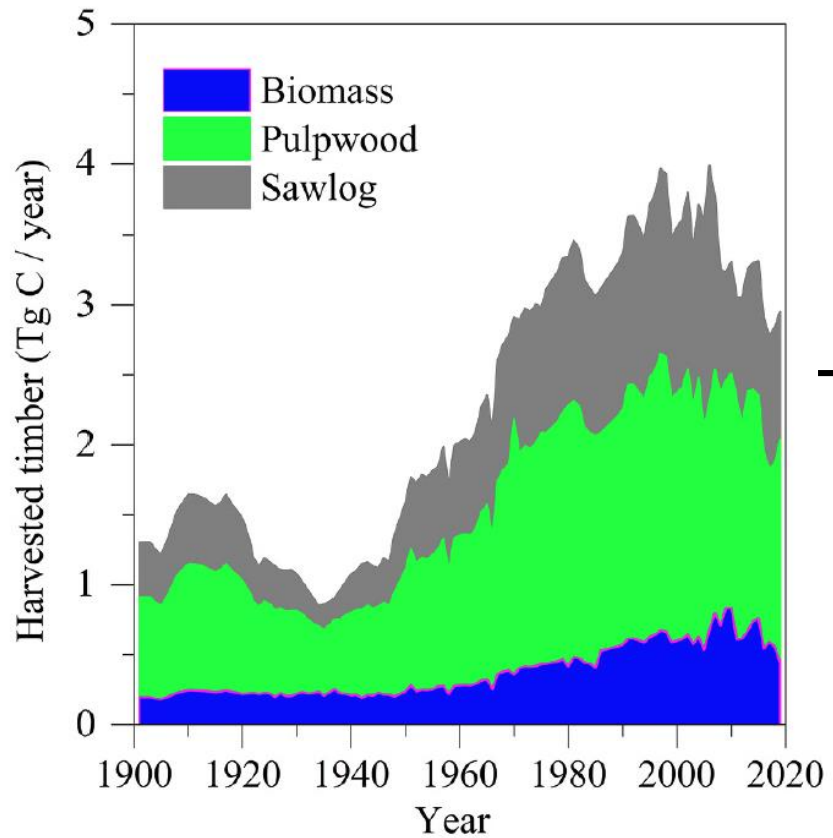
Reduction

Increase



Scenario	Total harvest	Late-Successional Forest		Lynx habitat	Marten habitat
		Spruce-Fir	N. Hardwood		
Extend rotation	-2%	1%	1%	8%	-4%
Change PH silviculture	-7%	5%	80%	-94%	13%
Increase even-aged management	-5%	-61%	-12%	>100%	-38%
Increase plantations	+18%	-60%	-7%	>100%	-53%
Increase setasides	-18%	2%	9%	-26%	2%

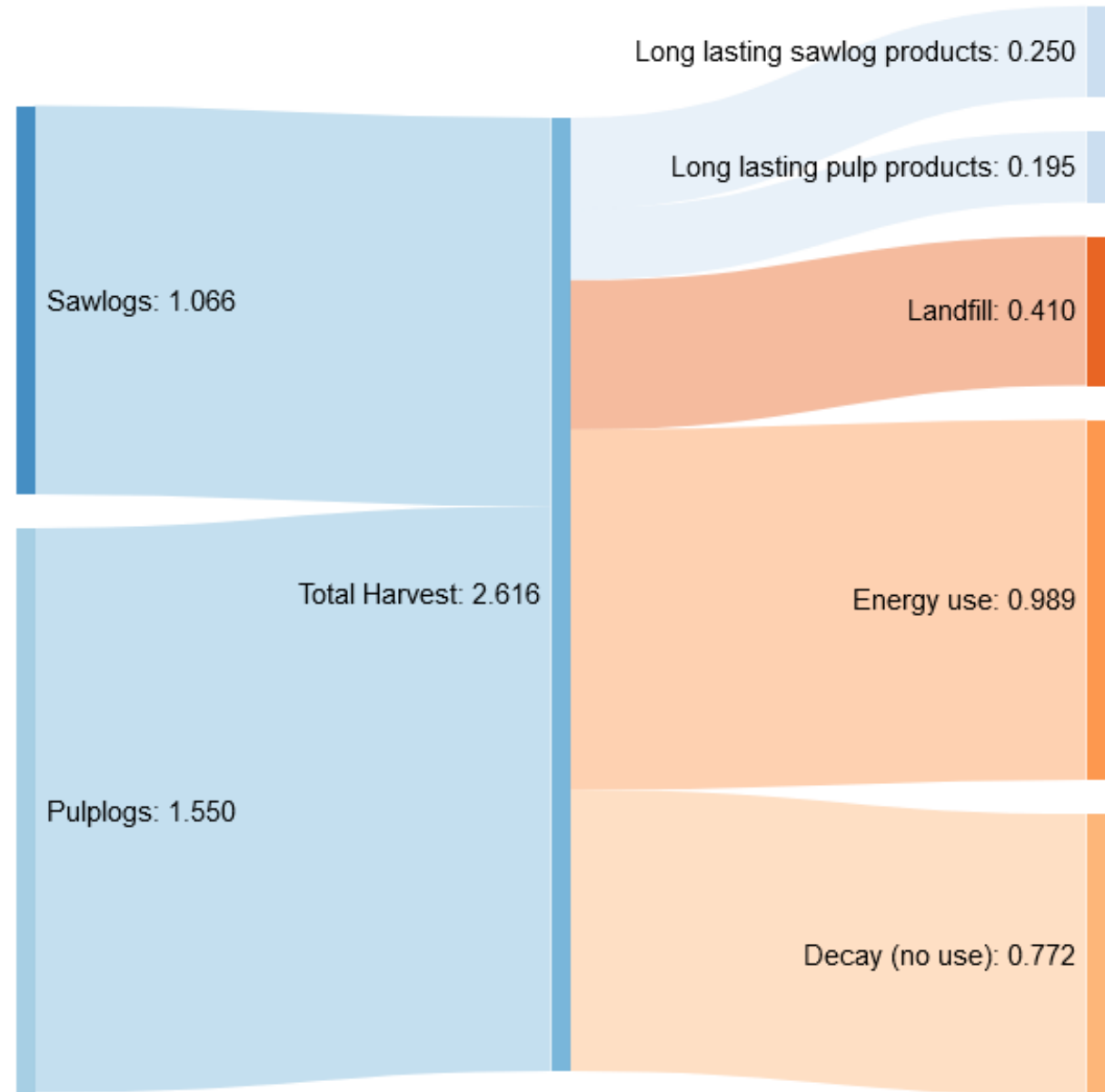
# End product effects on carbon



Li et al. 2022. Technological advancement expands carbon storage in harvested woods products in Maine, USA. Biomass and Bioenergy 161:106457

# Current challenges

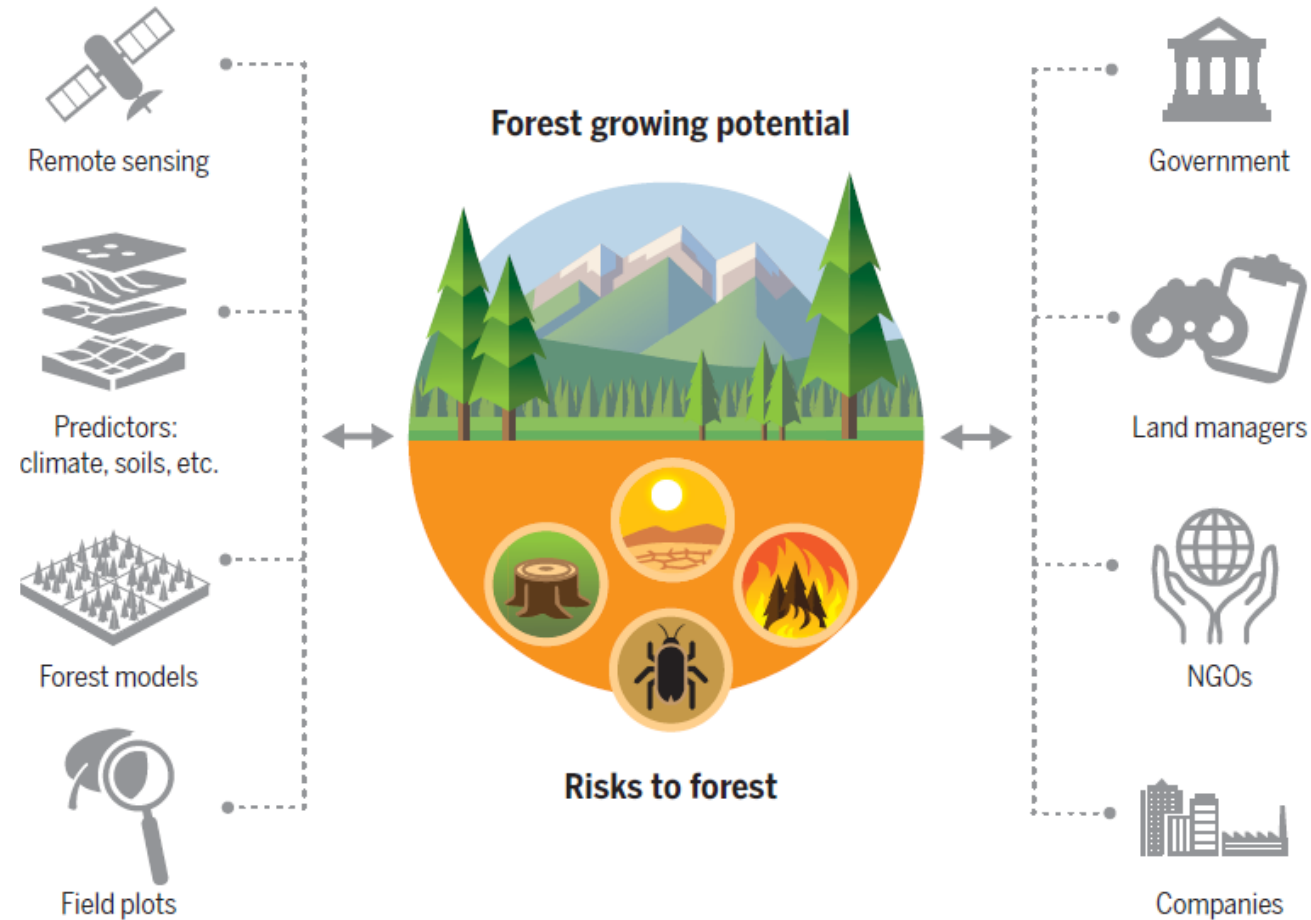
- Intra- and inter-model uncertainty
- Interactive effects of climate change
- Availability of robust economic data and pricing forecasts
- Changing policy and potential market demands
- Technological advances in harvesting & transport



Maine 100-yr HWP C Flow (MtC)

# Summary

- Tradeoffs associated with different climate-smart management strategies
- Mixture of management methods (intensive, extensive, conservation) is most effective in complex landscapes
- Incentives (policy/financial) may be necessary for implementation



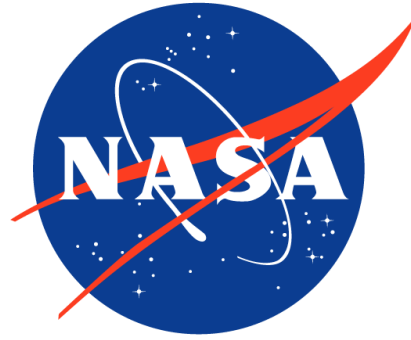
# Acknowledgments

- Data

- US Forest Service
- Maine Forest Service
- NASA

- Funding

- National Science Foundation
- NCASI
- Forest Carbon for Commercial Landowners
- Cooperative Forestry Research Unit
- NASA
- The Nature Conservancy



The Nature  
Conservancy  
Protecting nature. Preserving life.

NCASI



THE UNIVERSITY OF  
**MAINE**

An aerial photograph of a dense forest, likely in Maine, during the autumn season. The trees are mostly green, but some are showing early signs of color change, with hints of yellow and red. In the distance, a range of mountains is visible under a dramatic sky with scattered clouds, suggesting a sunset or sunrise. The overall scene is serene and expansive.

# Questions?

Aaron Weiskittel

[aaron.weiskittel@maine.edu](mailto:aaron.weiskittel@maine.edu)

Erin Simons-Legaard

[erin.simons@maine.edu](mailto:erin.simons@maine.edu)