Does New York's Path to 'Net Zero' Go Through the Catskills?

Mapping & Monitoring Climate Benefits of Catskill Forests & Their Role in Achieving Statewide Carbon Neutrality

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SUNY College of Environmental Science & Forestry

Catskills Environmental Research & Monitoring
2025 Conference
22 Oct 2025

Overview

Purpose & Approach

- Objectives
- Approach

Functions & Outputs

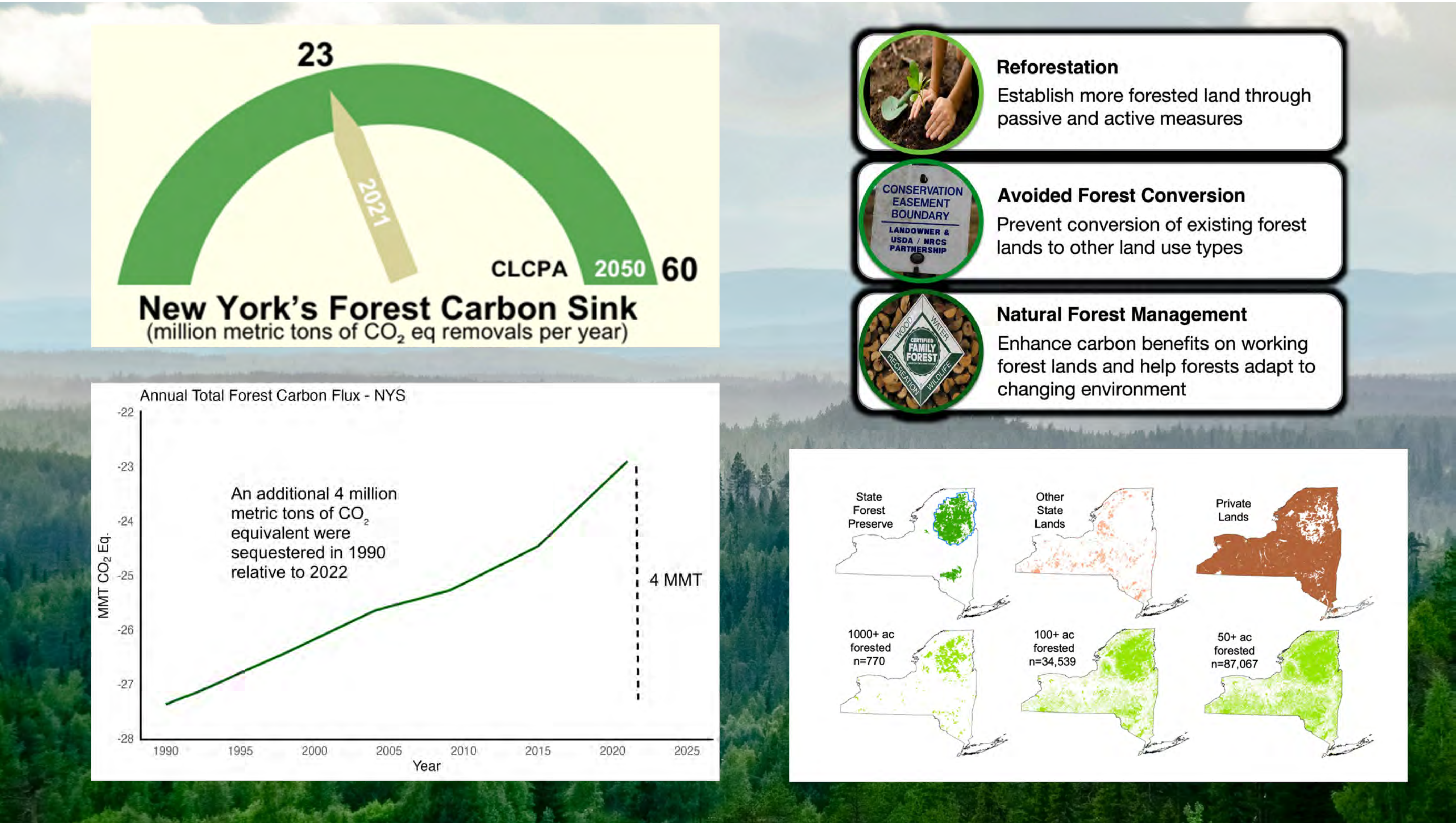
- Biomass & C Stocks
- Stock-Change
- Monitoring
- GHG Inventory
- Uncertainty

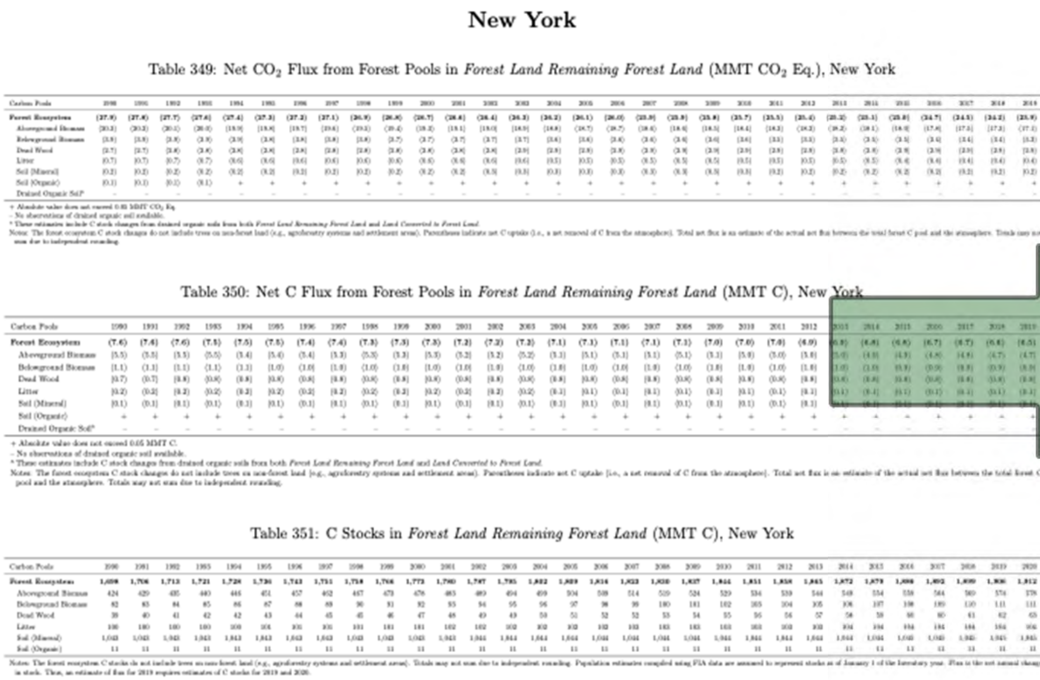
Insights on Catskills

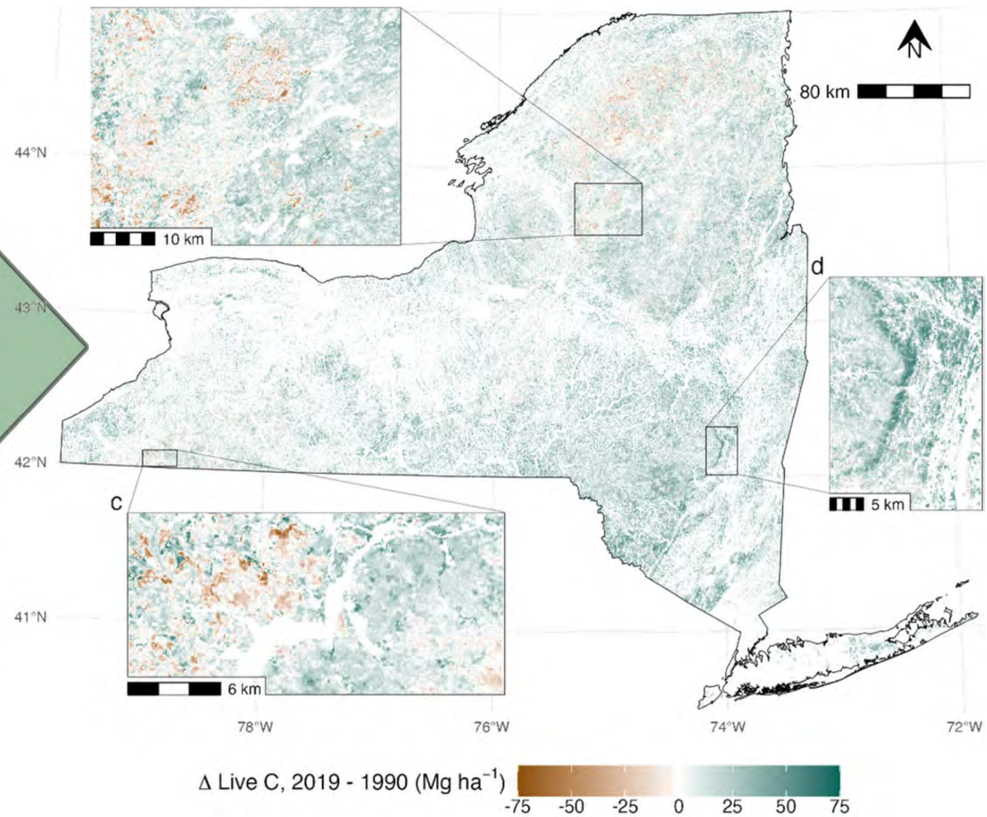
- C Stocks & Changes
- Catskills Park & FP Lands
- Role in NYS Forest C Sink
- ‘Top Tier’ Parcels

Applications & Data Products

- Climate solutions planning
- Parcel-level MMRV
- NY Solar Scorecard
- 2024 NYS-wide update


23
2021
CLCPA
2050
60
New York's Forest Carbon Sink
(million metric tons of CO_2 eq removals per year)
Reforestation
Establish more forested land through passive and active measures
CONSERVATION EASEMENT BOUNDARY
LANDOWNER & USDA / NRCS PARTNERSHIP
Avoided Forest Conversion
Prevent conversion of existing forest lands to other land use types
WOOD
WATER
RECREATION
WILDLIFE
CERTIFIED FAMILY FOREST
Natural Forest Management
Enhance carbon benefits on working forest lands and help forests adapt to changing environment
Annual Total Forest Carbon Flux - NYS
-22
-23
-24
-25
-26
-27
-28
MMT CO_2 Eq.
An additional 4 million metric tons of CO_2 equivalent were sequestered in 1990 relative to 2022
4 MMT
1990
1995
2000
2005
2010
2015
2020
2025
Year
State Forest Preserve
Other State Lands
Private Lands
1000+ ac forested n=770
100+ ac forested n=34,539
50+ ac forested n=87,067





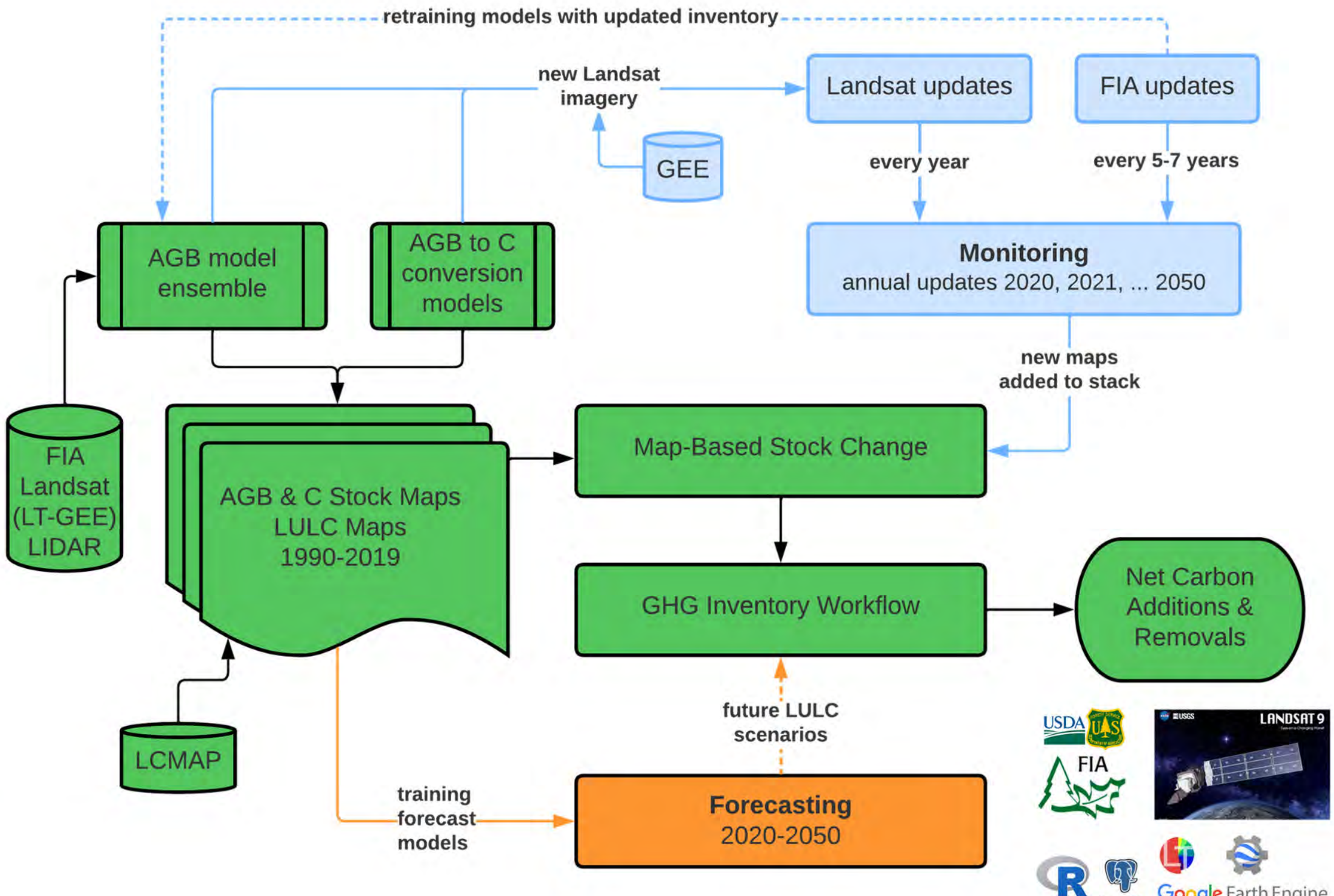
Objective

To translate FIA's stock-change methodology for forest GHG inventory into fine-resolution (30m, annual) maps and data for New York State

Integrated basis for

- **AGB & C Mapping**
- **Stock Change**
- **GHG Inventory**
- **Monitoring**
- **Forecasting**

Built on freely available data* and open-source computational tools



Framework

*excludes FIA plot coordinates!

Train machine-learning models on systematic field inventory and existing leaf-off LIDAR

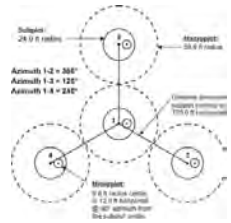
Airborne LIDAR available in a spatiotemporal patchwork

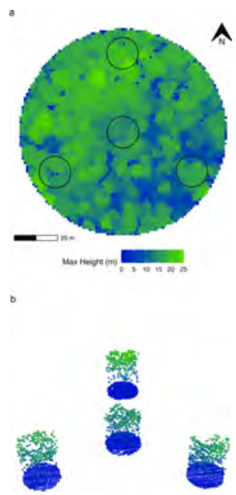
Aligning FIA plot inventory and LIDAR coverages to maximize model obs. was challenging

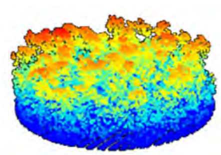
Predictors derived from LIDAR point clouds gridded to 30 m

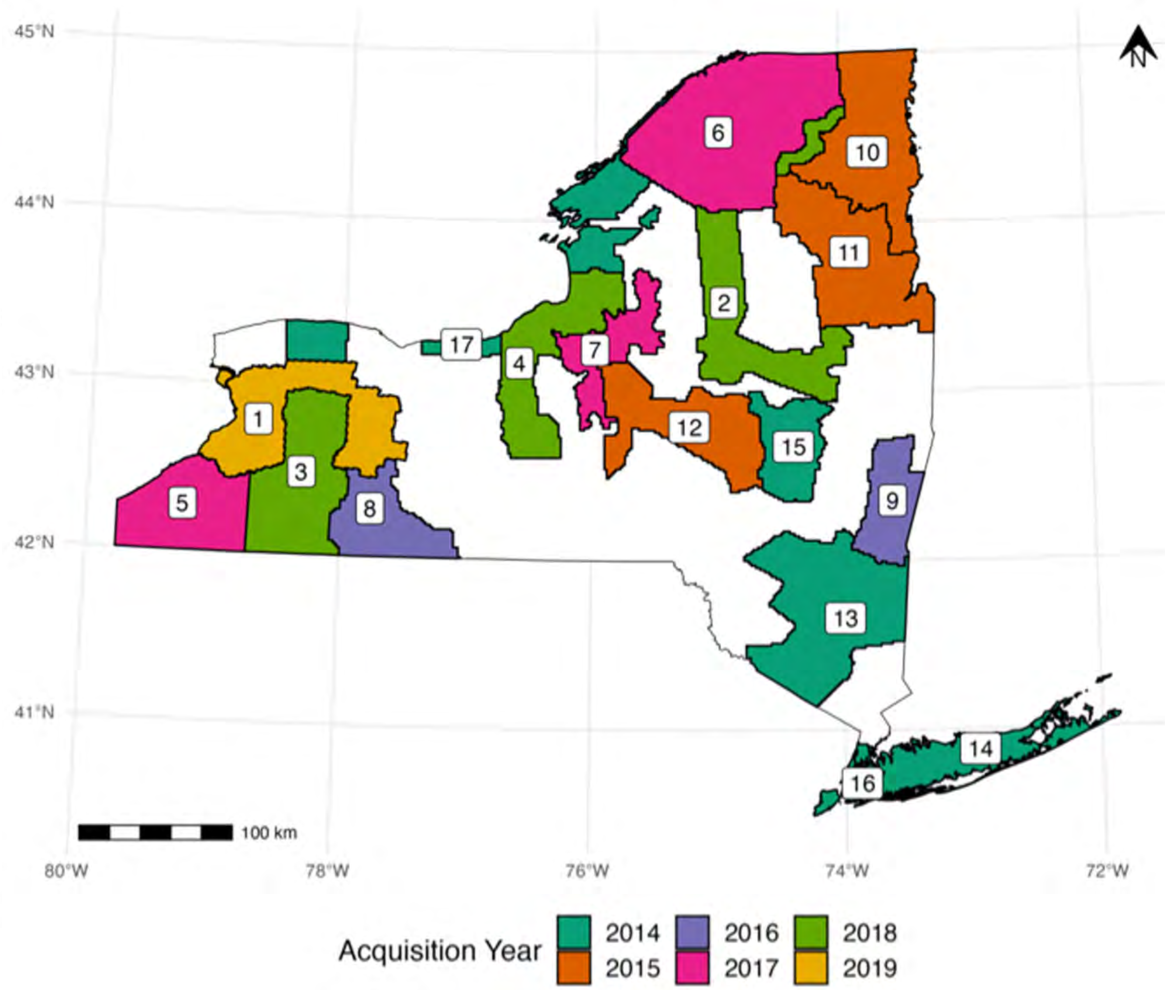
Use ML models to map forest aboveground biomass (AGB) for LIDAR year at 30m resolution

AGB & C Mapping









Trained Landsat-based models:

- Directly on FIA plots
- Indirectly on LIDAR-AGB prediction surfaces (maps)

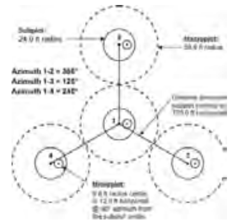
AGB/C models typically have saturation thresholds: cannot predict above a 'false ceiling'

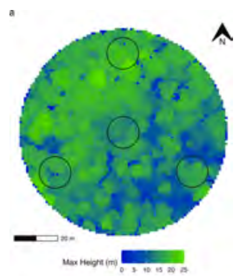
- LIDAR ~300 Mg ha^{-1} (<1% NYS)
- Landsat ~220 Mg ha^{-1} (~4% NYS)

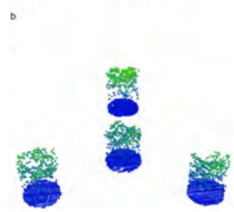
Training on LIDAR-AGB also improves fine-scale patterns

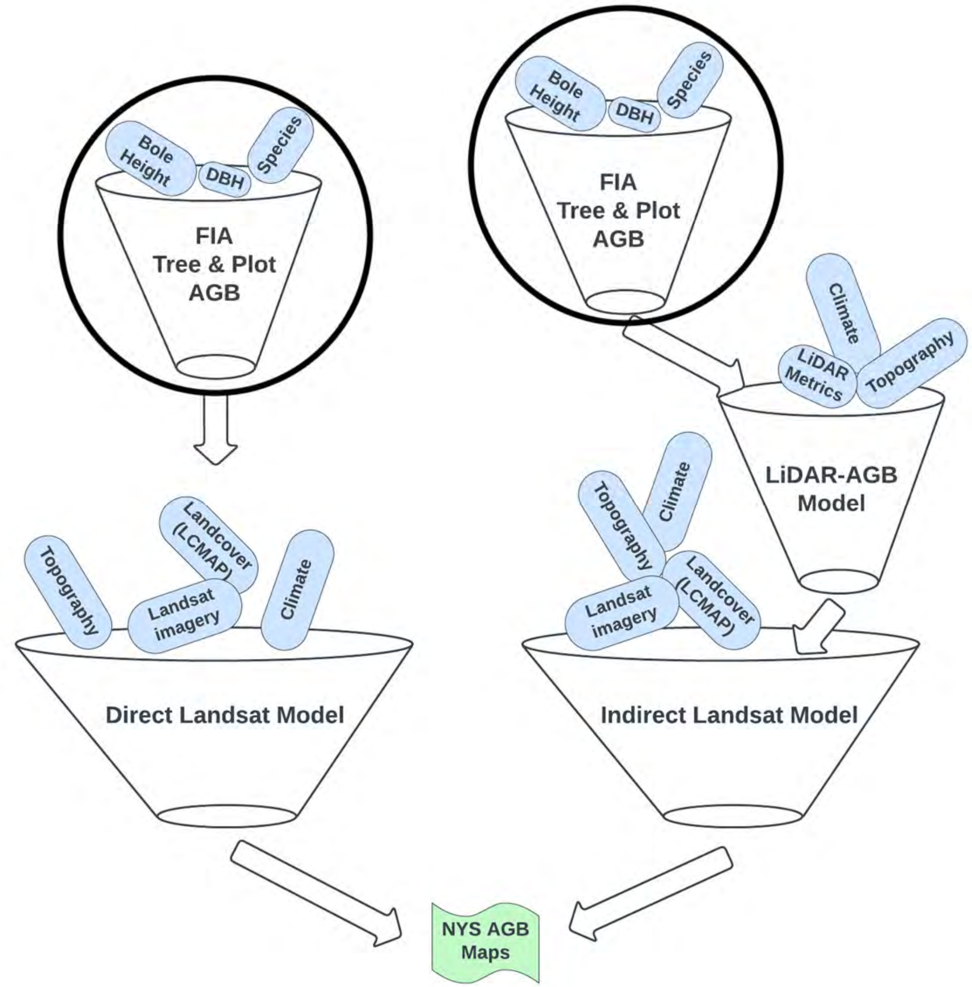
We combined models into an ensemble that has a prediction ceiling of ~280 Mg ha^{-1} (<2% NYS)

AGB & C Mapping









Ensemble machine-learning models, trained on FIA plots and EO data (LIDAR, Landsat, LT-GEE)

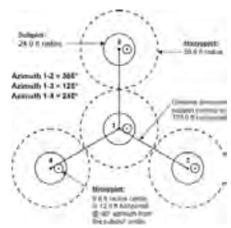
Version 1.x: 30m annual AGB maps from 1990 to 2019, AGB estimates converted to AGC, BGC pools.

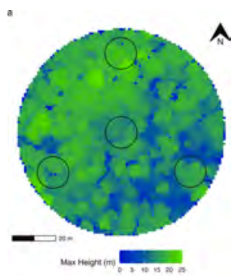
Version 2.0: AGB, AGC, BGC predictions based on FIA NSVB, LIDAR, Landsat-c2, 1990-2023

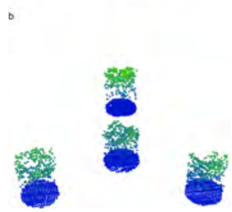
Soil, litter, deadwood C pools mapped using models trained on FIA Phase 3 and EO data

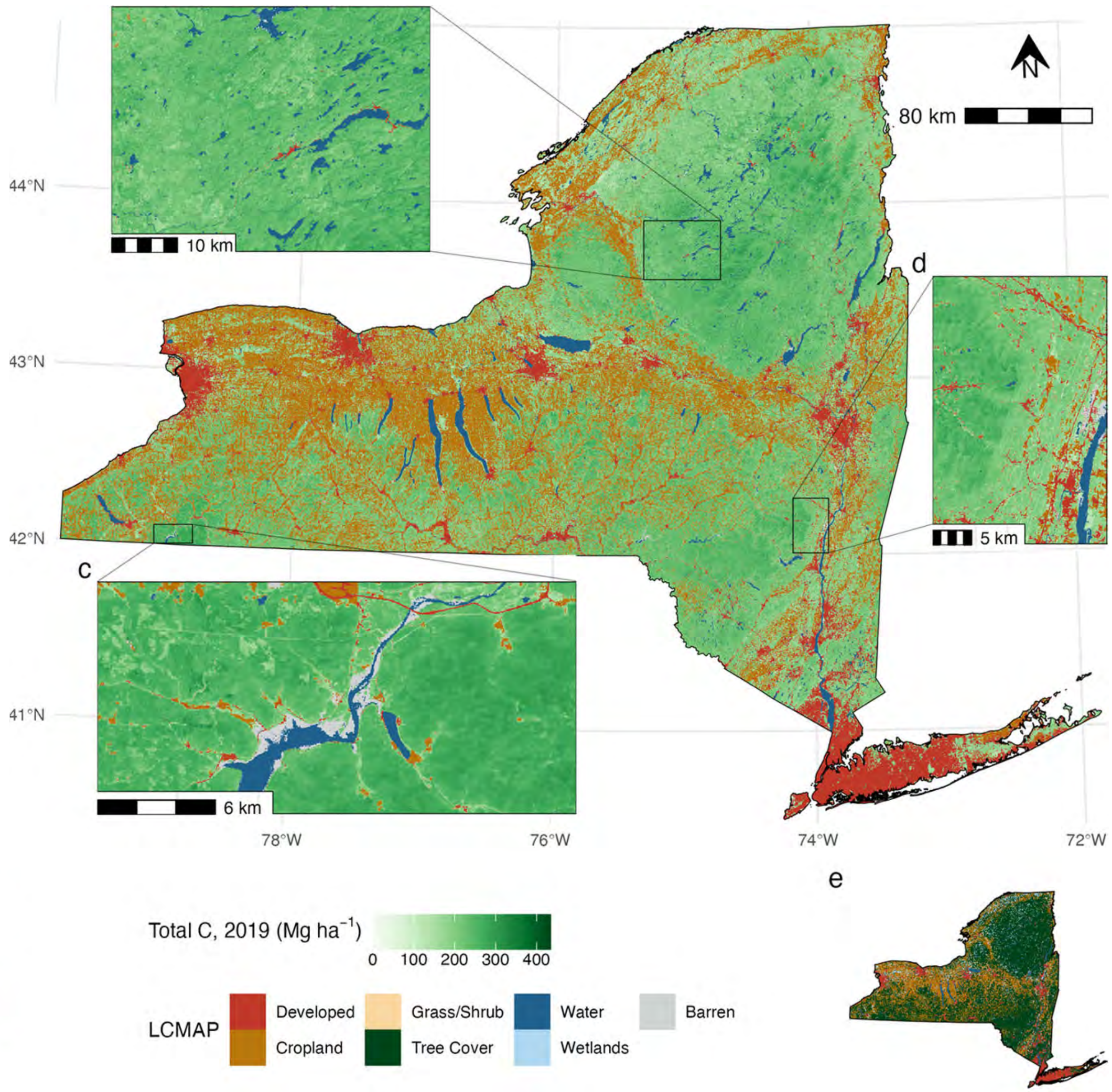
Annual statewide 30m maps of C pools for all forested lands

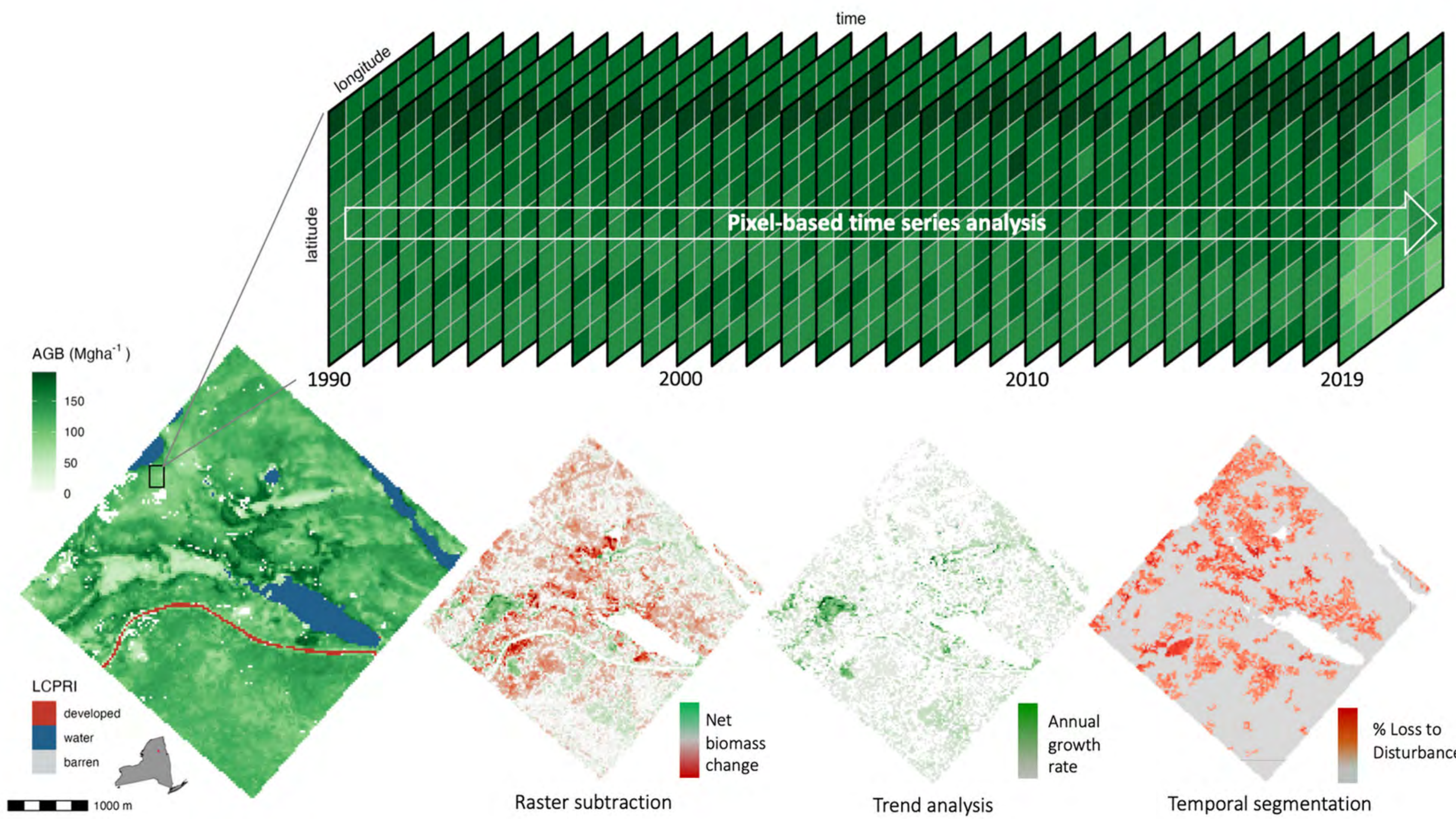
AGB & C Mapping







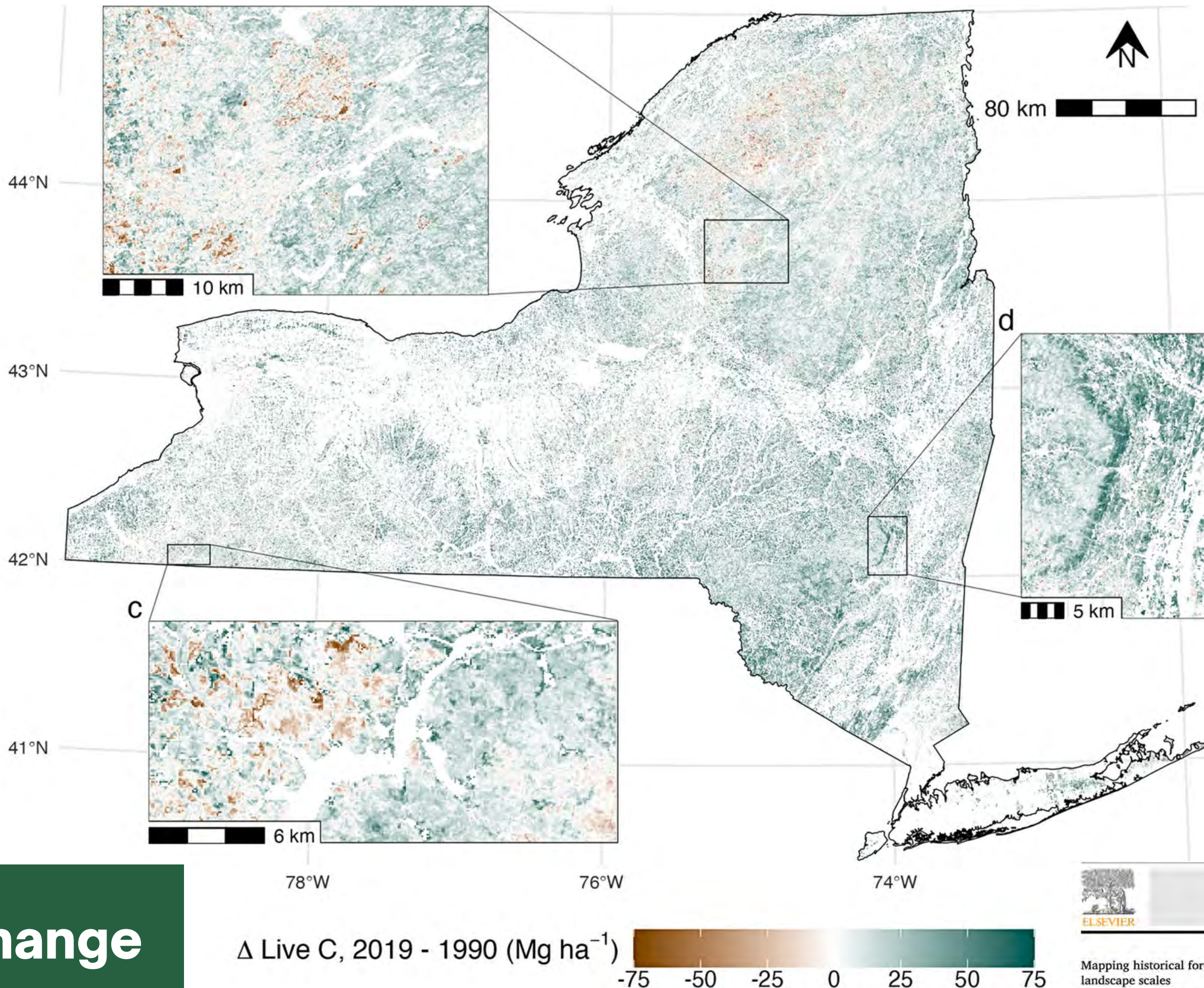




Stock-Change

We compile 'raster stacks' of 30m annual AGB/C and LULC maps, providing a flexible basis for stock-change analysis using raster operations, such as:

- simple differencing
- trend analysis
- temporal segmentation



Stock-Change

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

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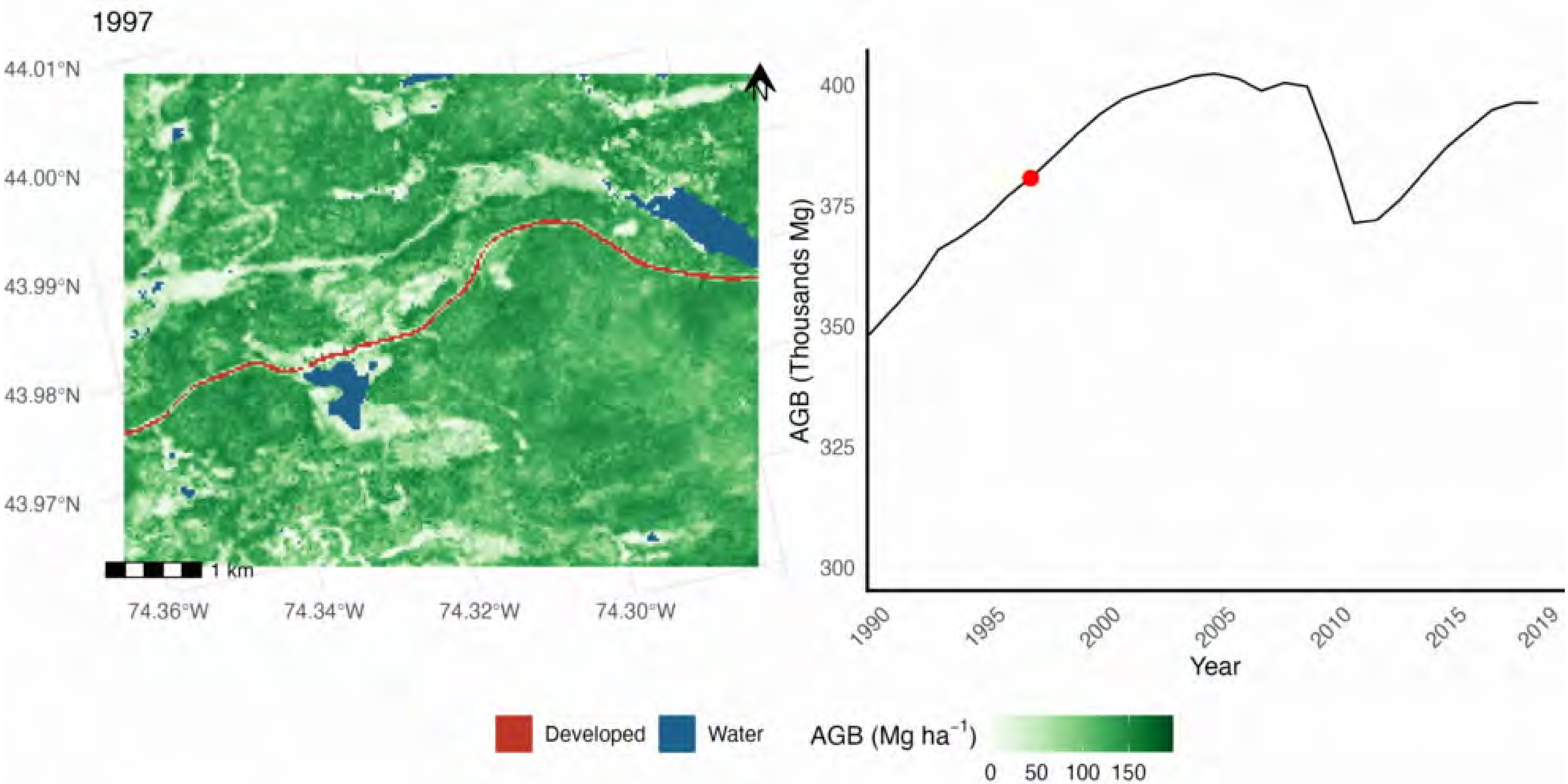
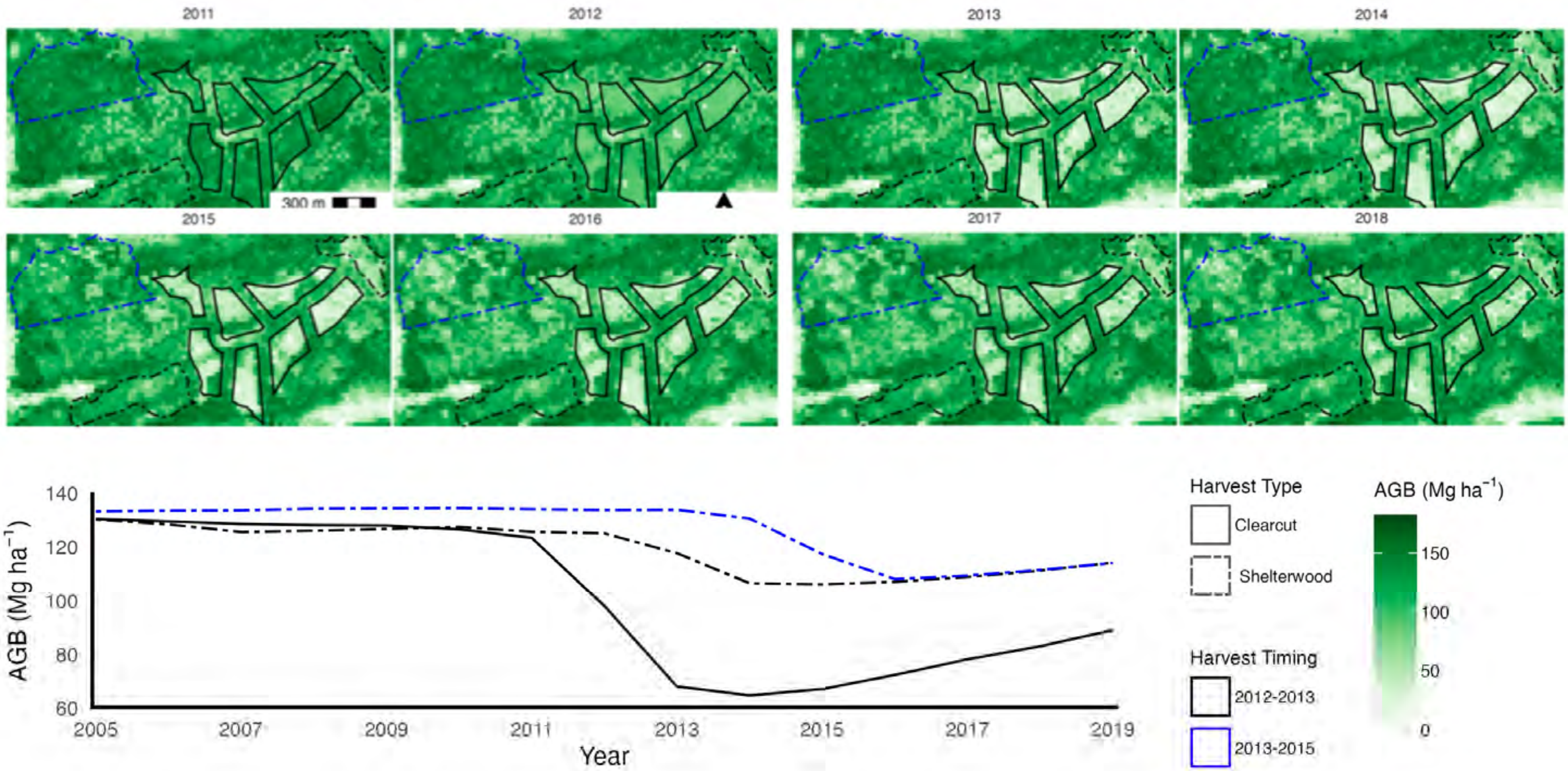
Mapping historical forest biomass for stock-change assessments at parcel to landscape scales

Lucas K. Johnson[a,*], Michael J. Mahoney[a], Madeleine L. Desrochers[b], Colin M. Beier[b]



Monitoring

As Landsat imagery collections are updated annually with new imagery, we use our models to produce 'annual update' maps of AGB and C stocks. New maps are added to raster stacks and stock-change metrics are recalculated for ongoing monitoring.



Monitoring

Map time-series accurately represent known patterns of disturbance, such as harvesting, in terms of timing, location, and relative magnitude (of volume removals). Modeled biomass recovery rates from 1-14 years post-harvest are faster than field-based estimates, but becomes consistent with field-derived growth curves at 15+ years after harvesting.

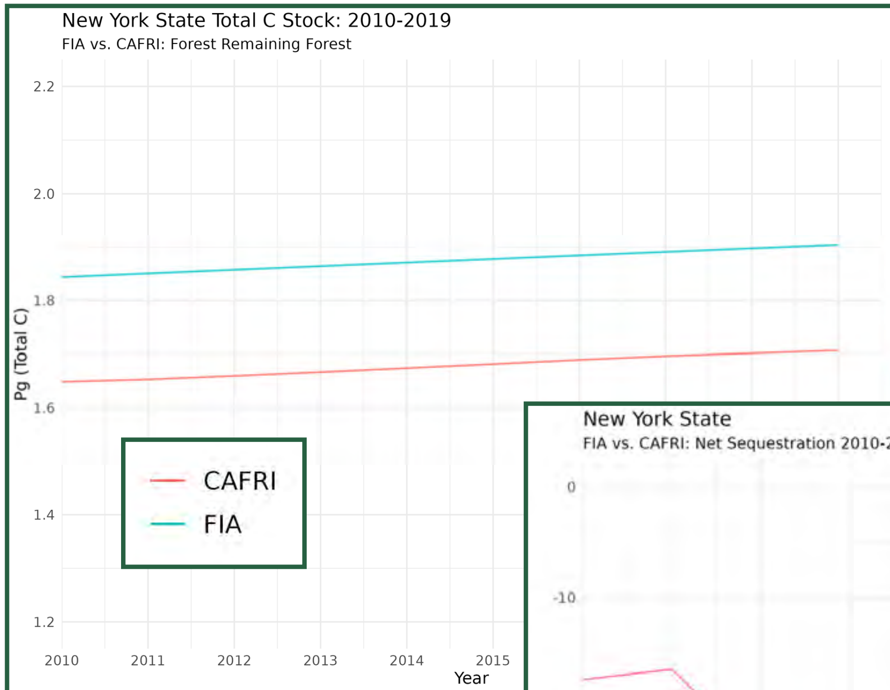
Carbon accounting workflow combines our C stock-change rasters, annual LULC products (LCMAP) and reference data for conversions (FIA, IPCC)

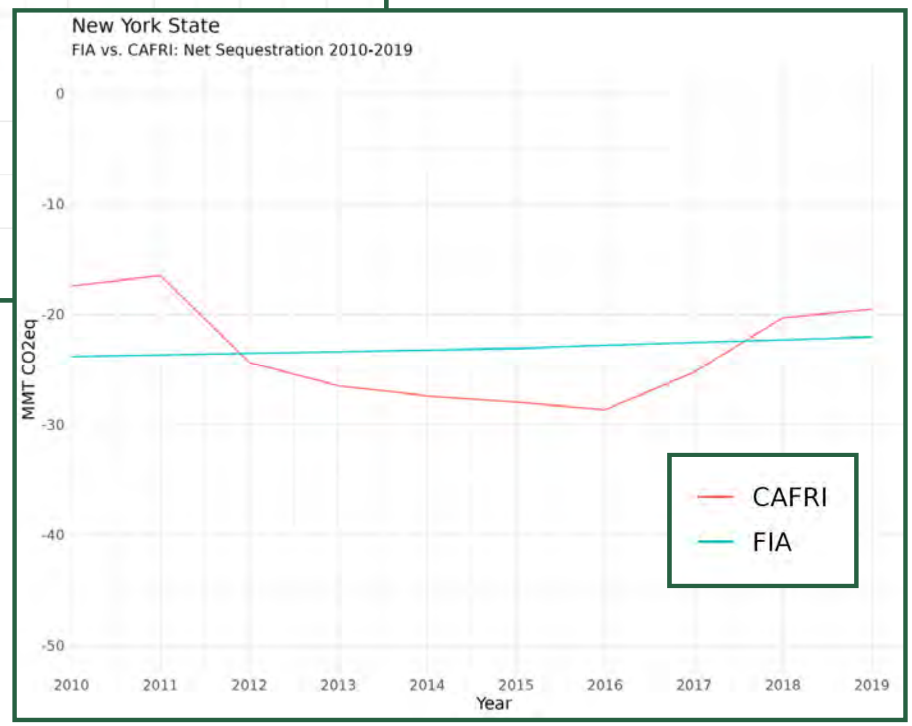
Replicates IPCC's AFOLU Tier-3 Stock-Change methodology used by EPA GHG Reporting Program

Highest confidence in live C accounting on forest lands remaining forest

Soil C spatially resolved, but can only change over time due to LULC conversions (forested land loss and gain)

GHG Inventory





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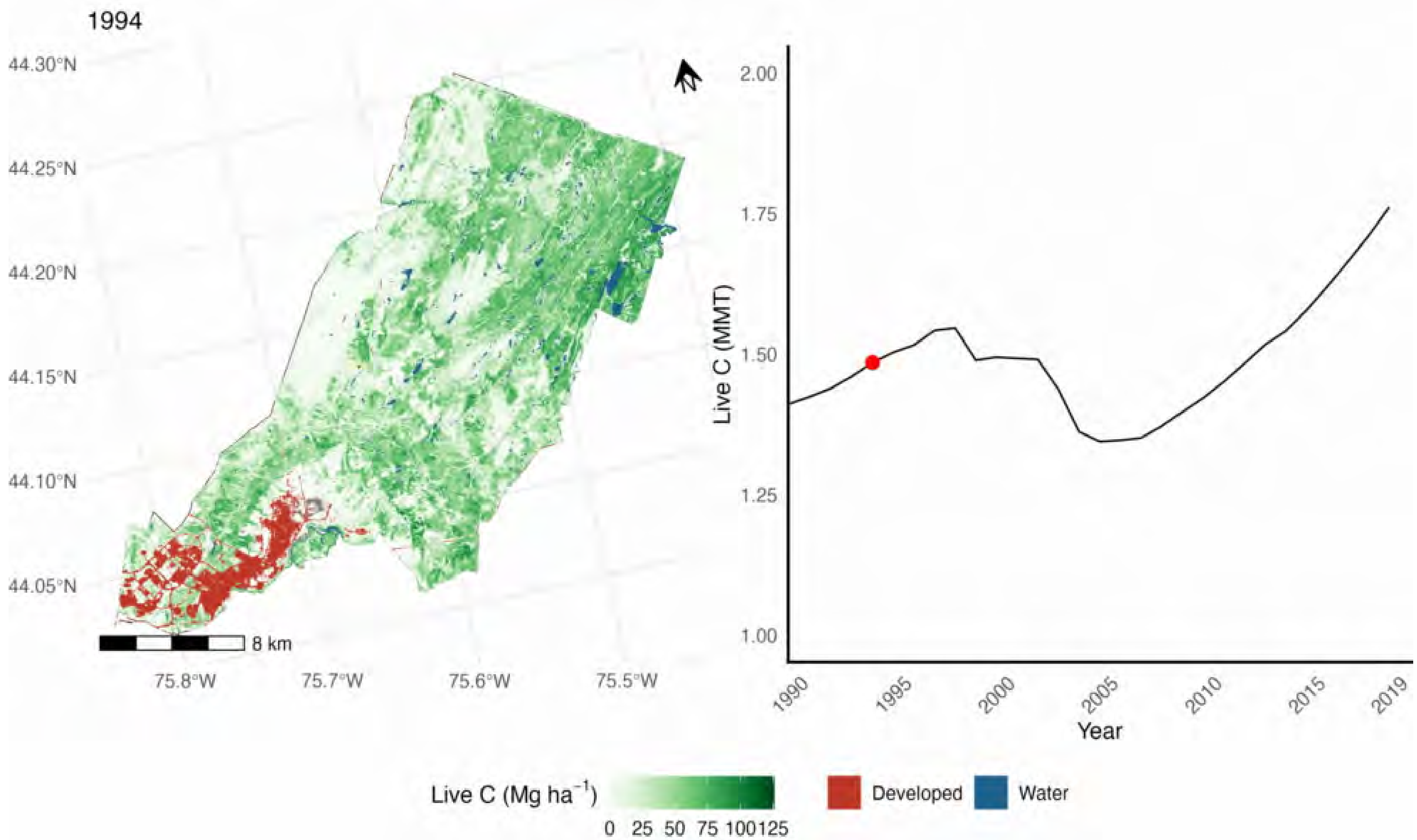
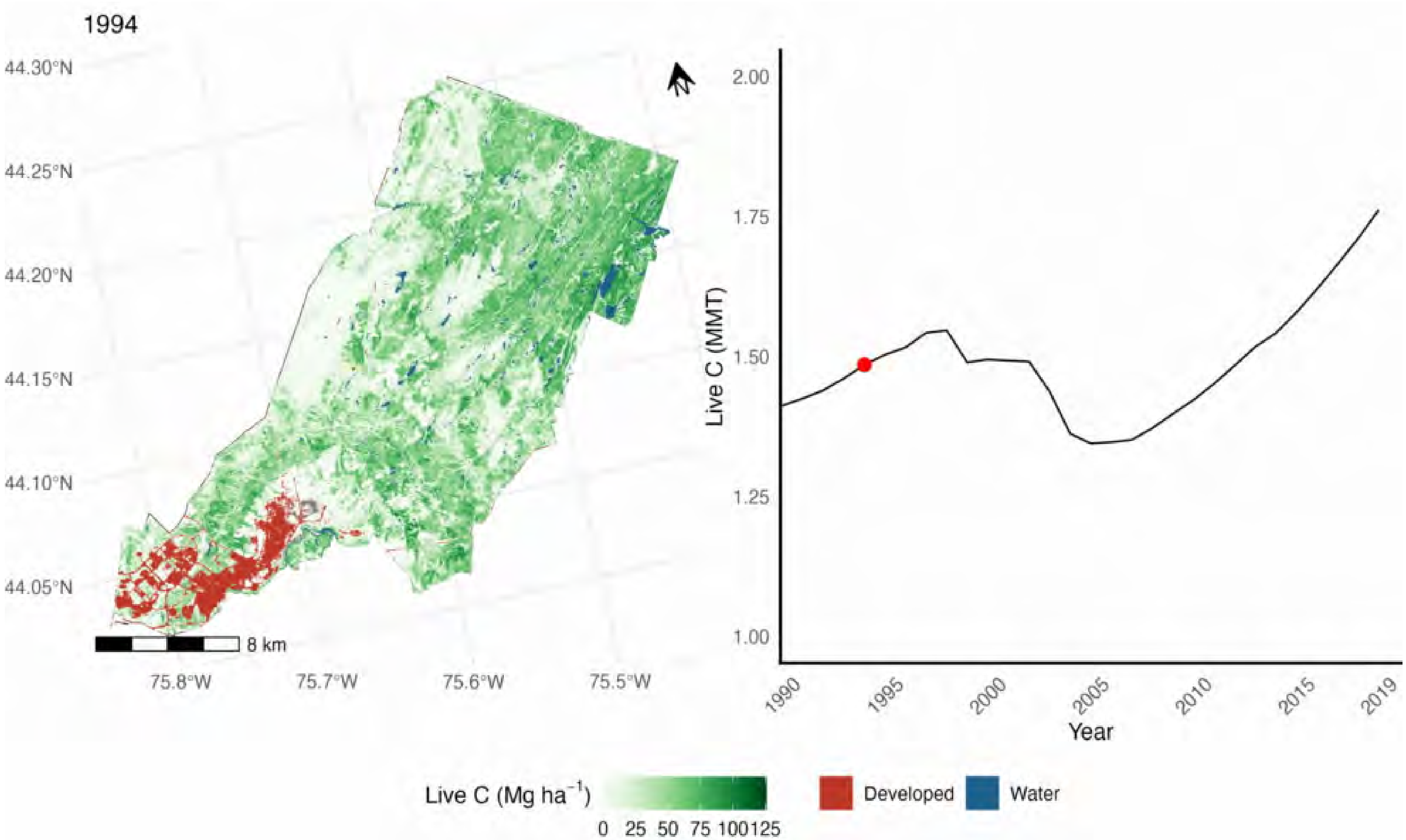


GHG Inventory



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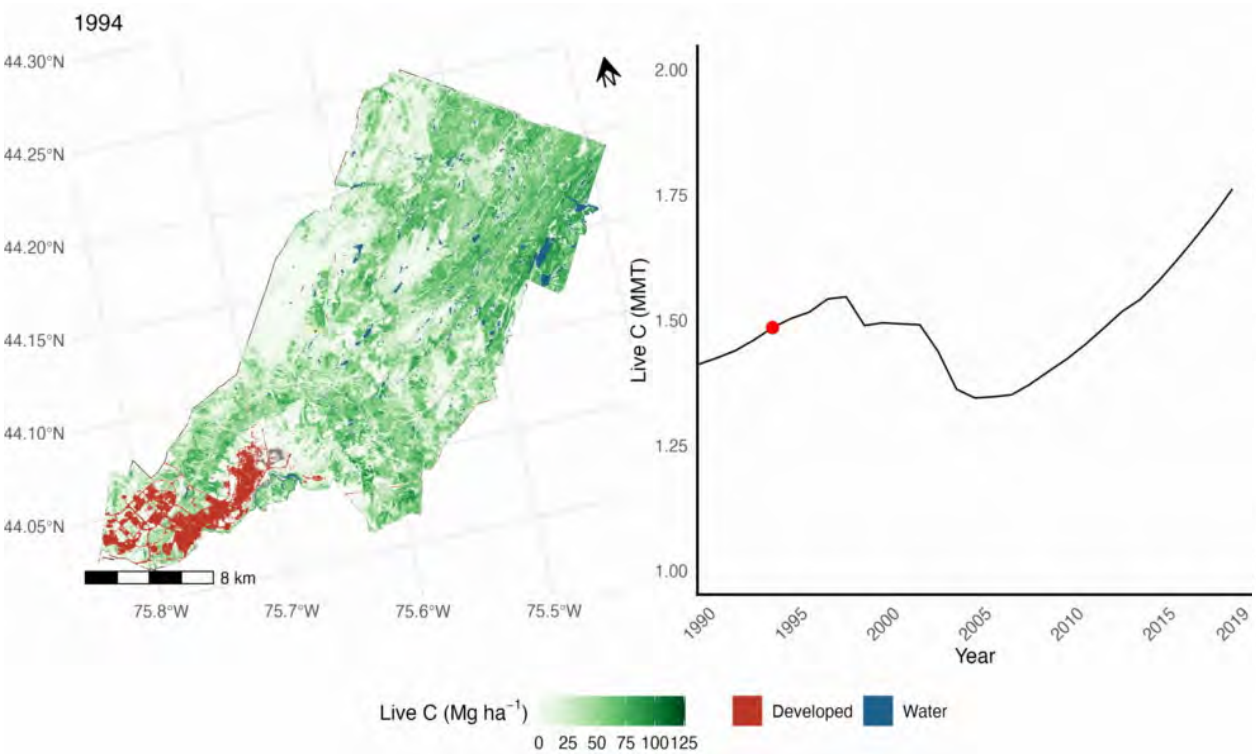

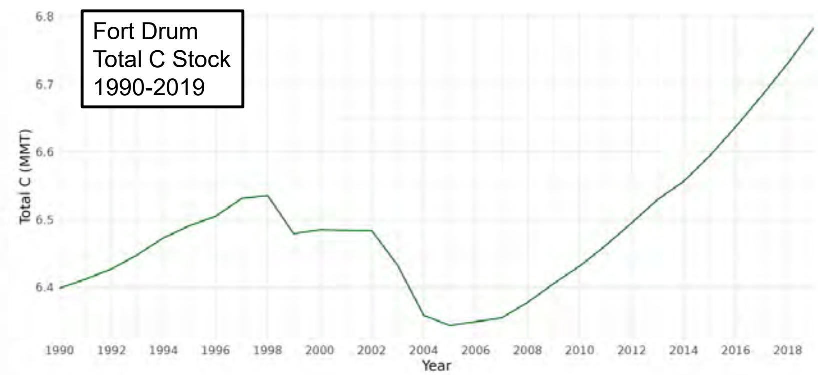

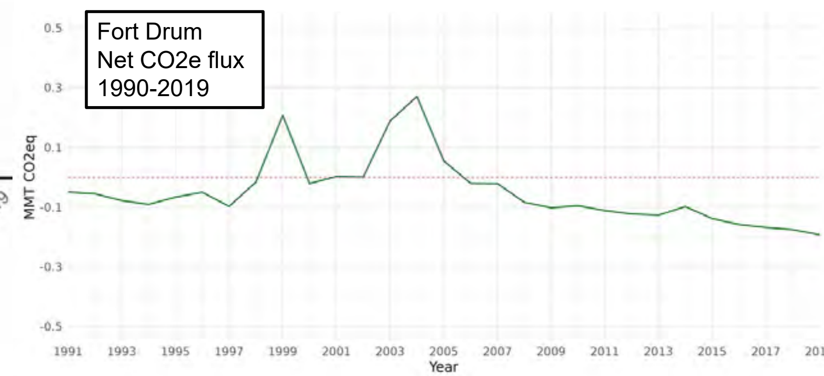

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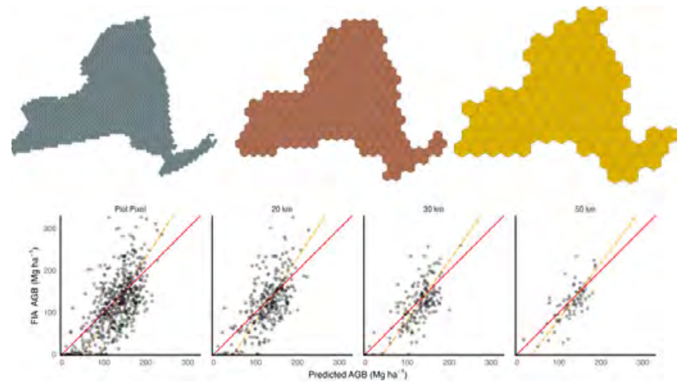
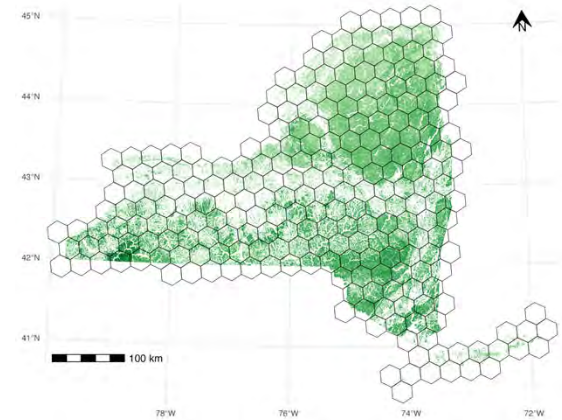
Model

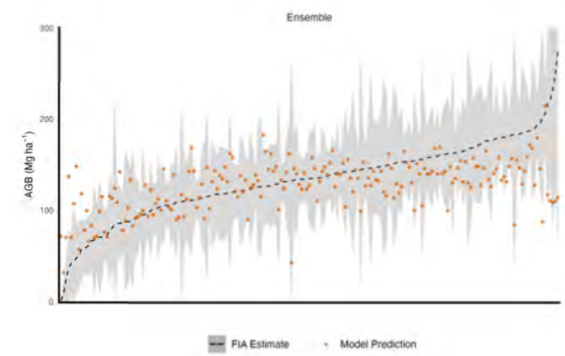
Prediction accuracy on 70/30 training holdout plots; k-fold cross-validation, hyperparameter tuning; ensembling





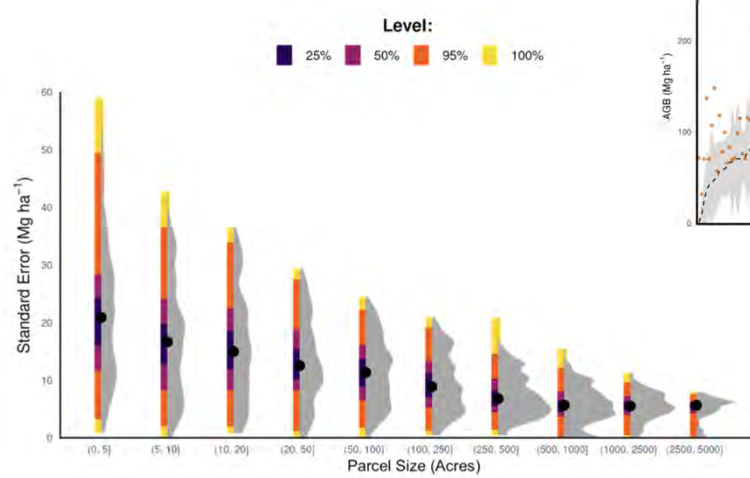
Map

Plot-to-pixel comparisons aggregated to variable scales (Riemann et al. 2010); LULC-corrected validation vs FIA small-area hexagons (Menlove & Healey 2021)

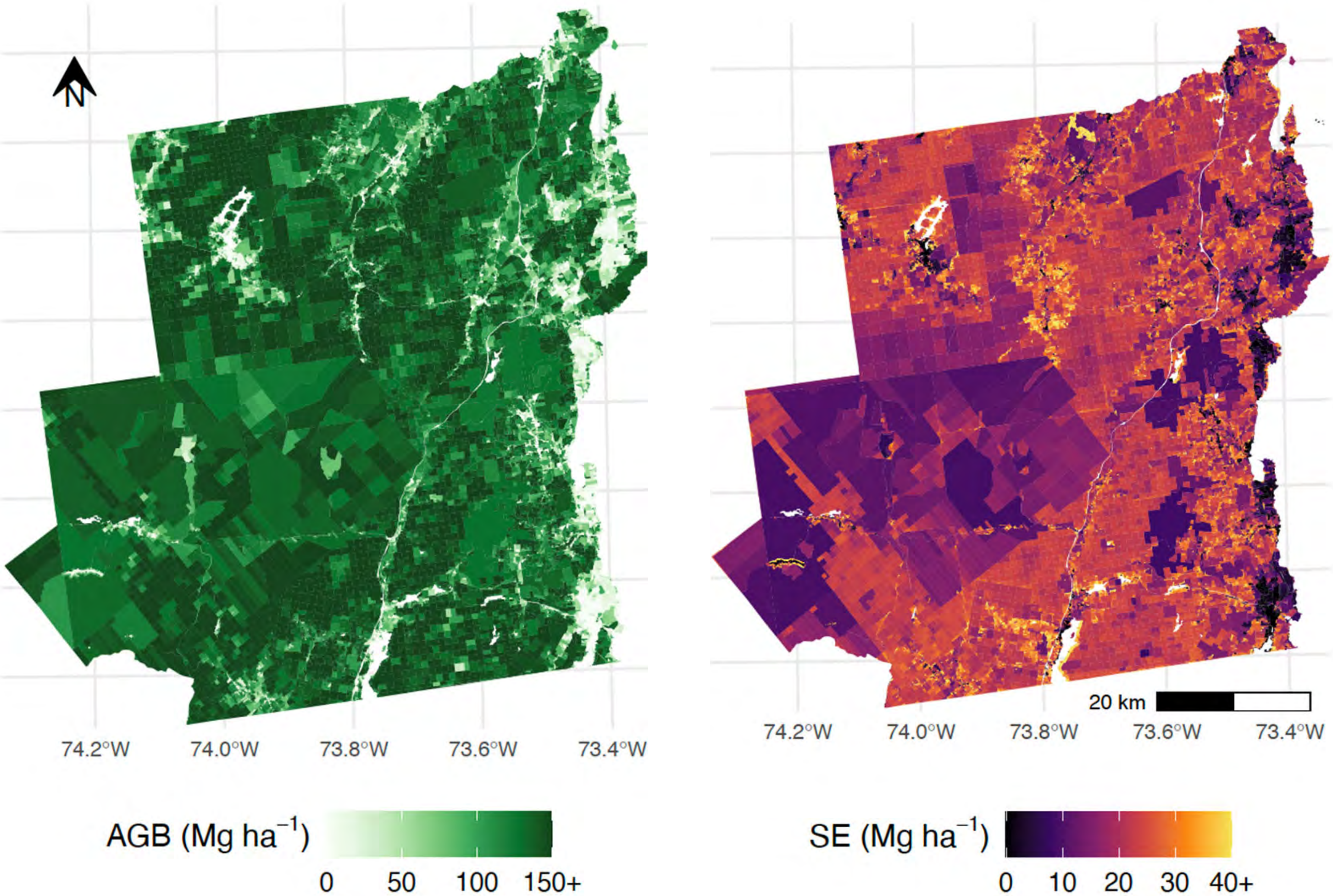


Scale

Bootstrapped cumulative uncertainty from reference plots, model residuals, spatial autocorrelation, etc. provides estimate of standard error per parcel



Uncertainty



Uncertainty

Continuous maps summarized by parcel boundaries = property-level estimates

Map uncertainty is related to parcel size, shape, prediction range, % forest, etc

Can now estimate parcel-level standard error of map data (Johnson et al. 2025 RSE)

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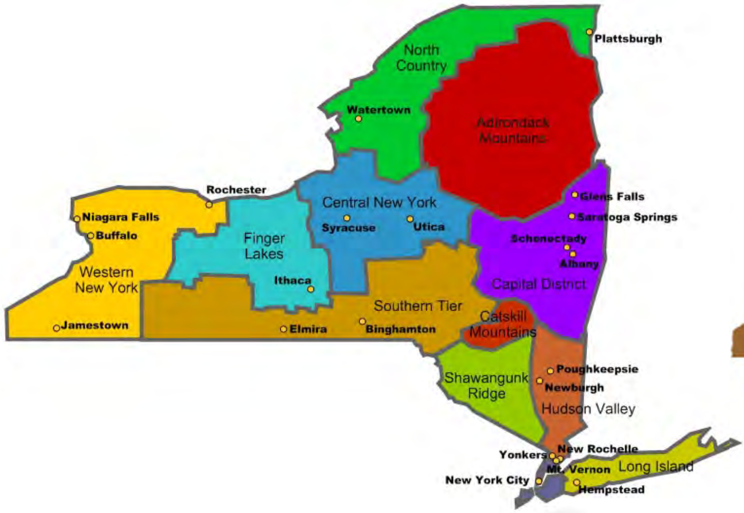
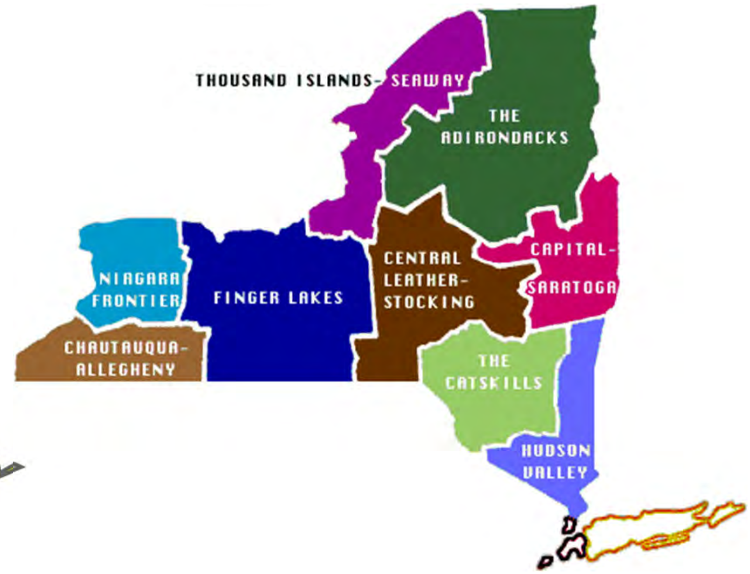
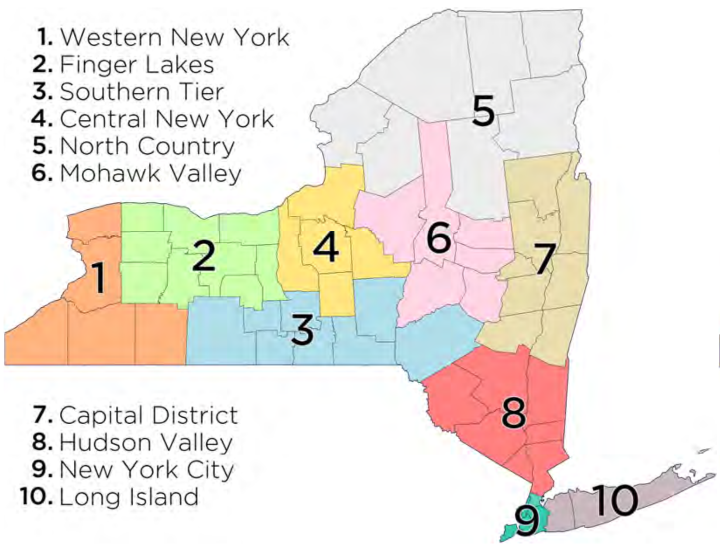

North Country
Plattsburgh
Watertown
Adirondack Mountains
Rochester
Niagara Falls
Buffalo
Western New York
Jamestown
Finger Lakes
Central New York
Syracuse
Utica
Ithaca
Glens Falls
Saratoga Springs
Schenectady
Albany
Capital District
Southern Tier
Elmira
Binghamton
Catskill Mountains
Shawangunk Ridge
Poughkeepsie
Newburgh
Hudson Valley
Yonkers
New Rochelle
Mt. Vernon
Long Island
New York City
Hempstead


THOUSAND ISLANDS-SEAWAY
THE ADIRONDACKS
NIAGARA FRONTIER
FINGER LAKES
CENTRAL LEATHER-STOCKING
CAPITAL-SARATOGA
CHAUTAUQUA-ALLEGHENY
THE CATSKILLS
HUDSON VALLEY


Upstate
Not upstate


1. Western New York
2. Finger Lakes
3. Southern Tier
4. Central New York
5. North Country
6. Mohawk Valley
7. Capital District
8. Hudson Valley
9. New York City
10. Long Island
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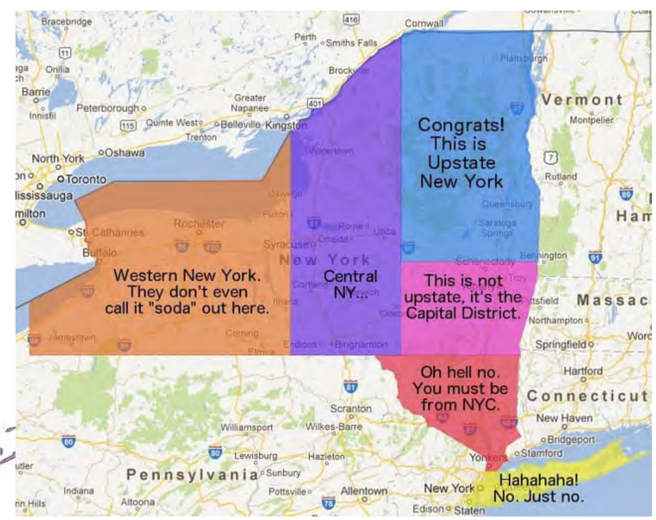
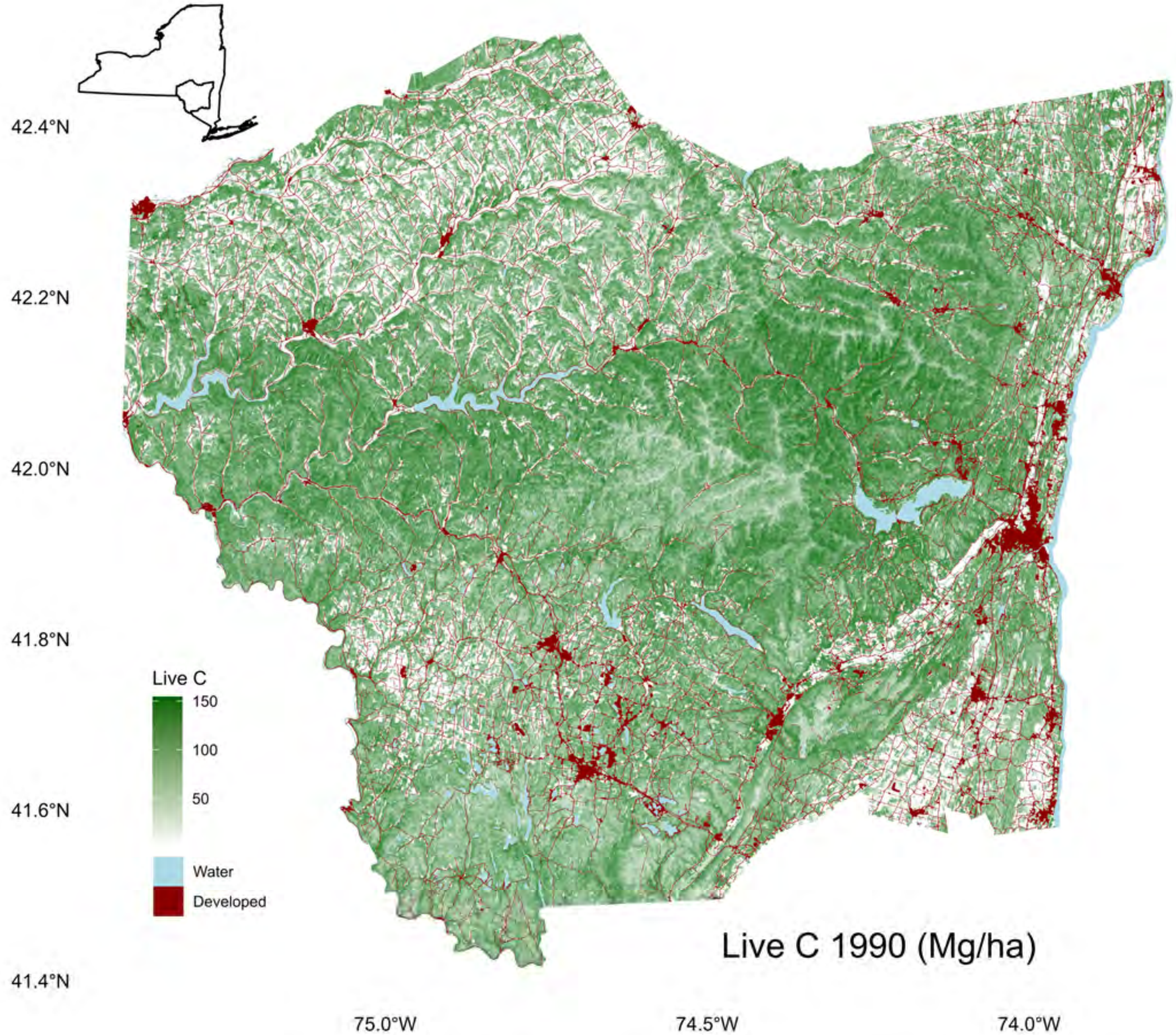
10


Regions of New York State
www.ExploringUpstate.com
Adirondack Region
Capital Region
Catskills Region
Central NY Region
Chautauqua-Allegheny Region
Finger Lakes Region
Hudson Valley Region
Long Island
New York City
Niagara Frontier Region
Thousand Island - Seaway Region


Congrats! This is Upstate New York
Western New York. They don't even call it "soda" out here.
Central NY...
This is not upstate, it's the Capital District.
Oh hell no. You must be from NYC.
Hahahaha! No. Just no.
Vermont
Connecticut
Pennsylvania
New York

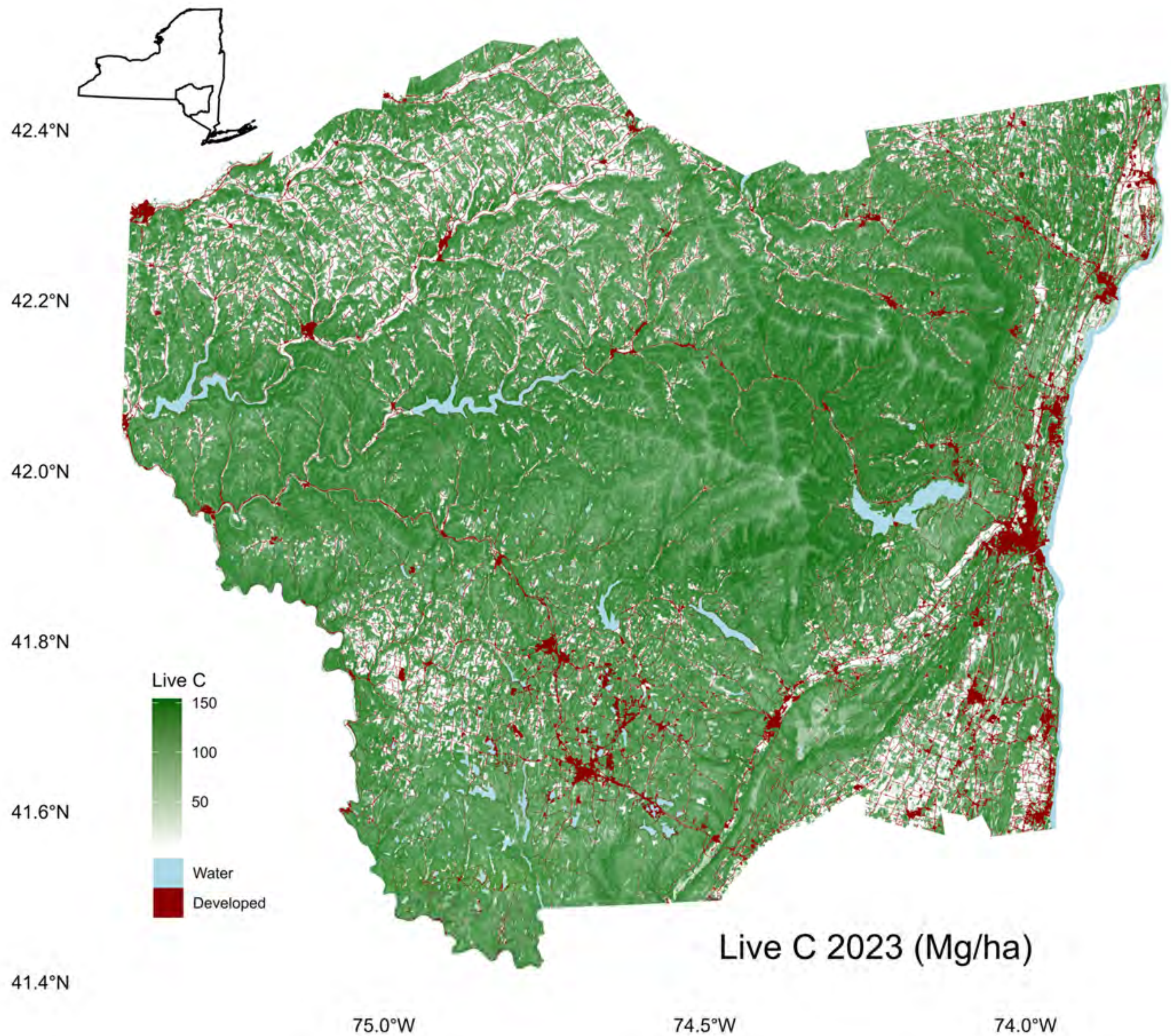
Biomass, live carbon (C) stocks have grown regionally since 1990



C Stocks & Changes

Biomass, live carbon (C) stocks have grown regionally since 1990

Land use and topography drive patterns in live C density and net gains/losses in live C stocks



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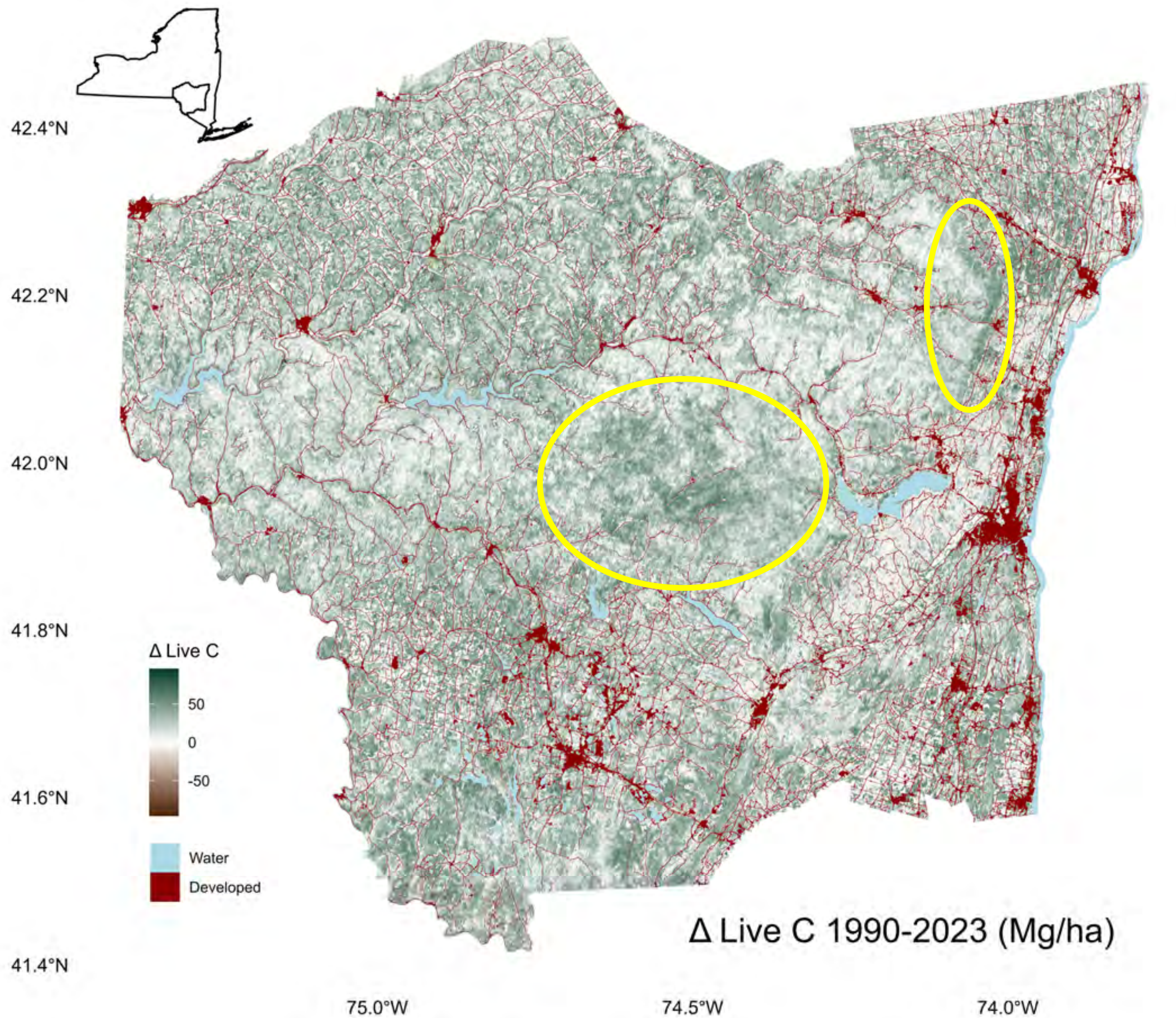
Regional carbon sink includes contiguous tracts within reserves (southcentral, northeast C. Park)



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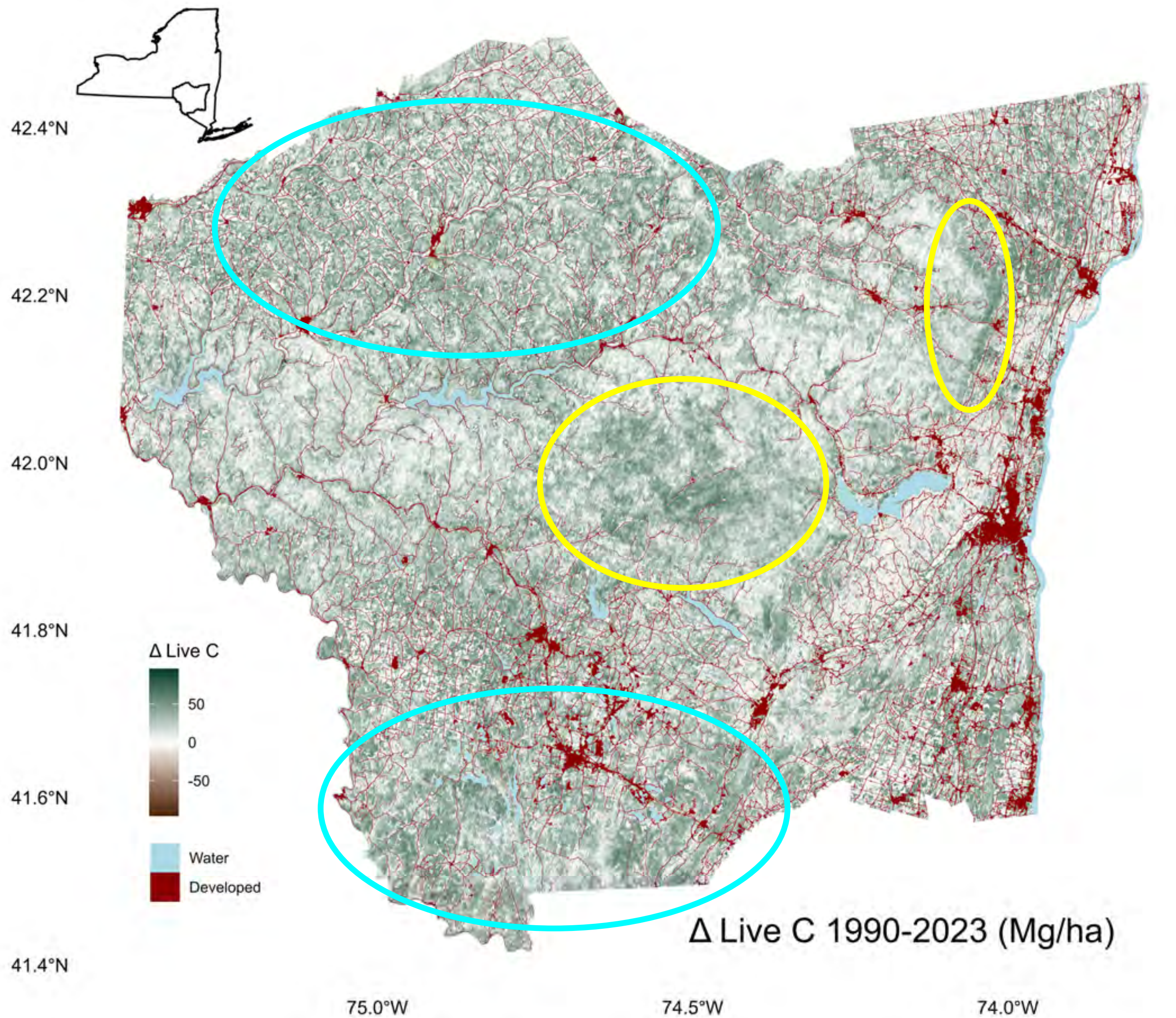
...and many smaller fragmented patches in more developed areas (Delaware, Sullivan Co.)

C Stocks & Changes



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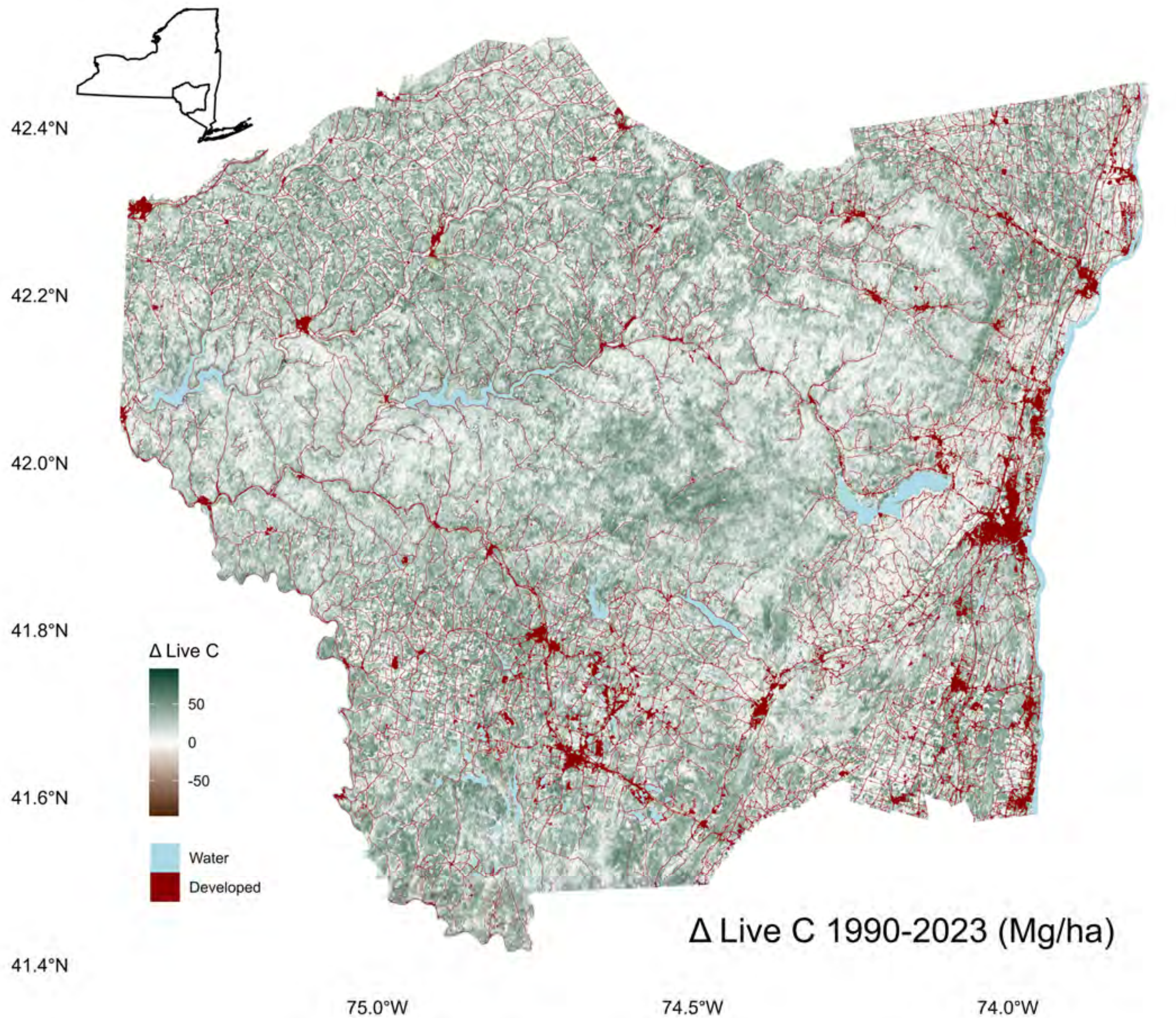
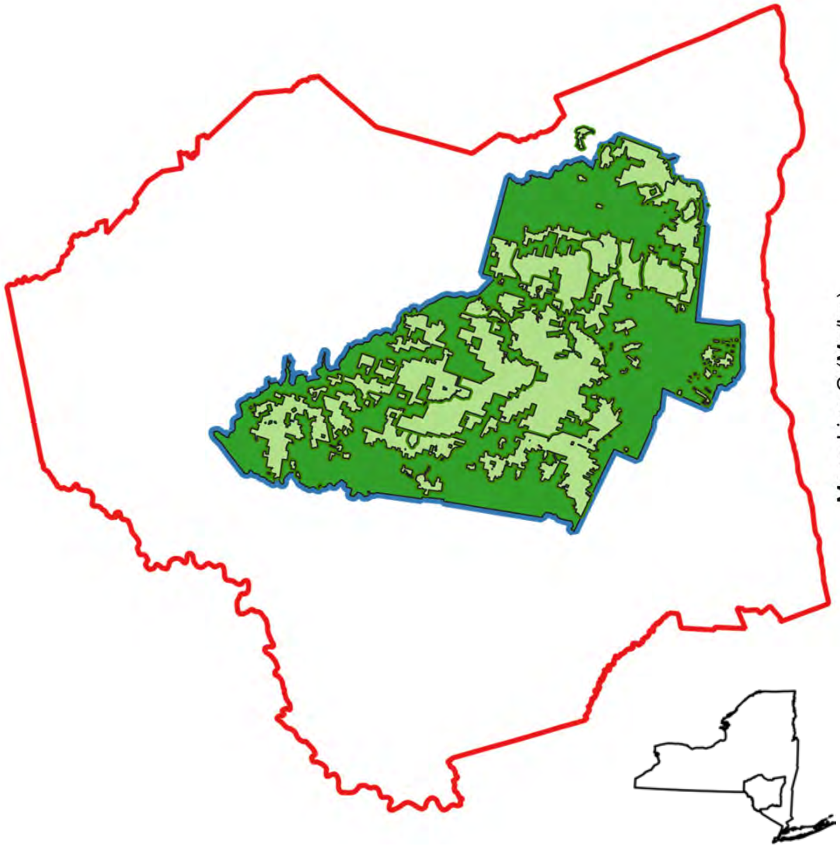
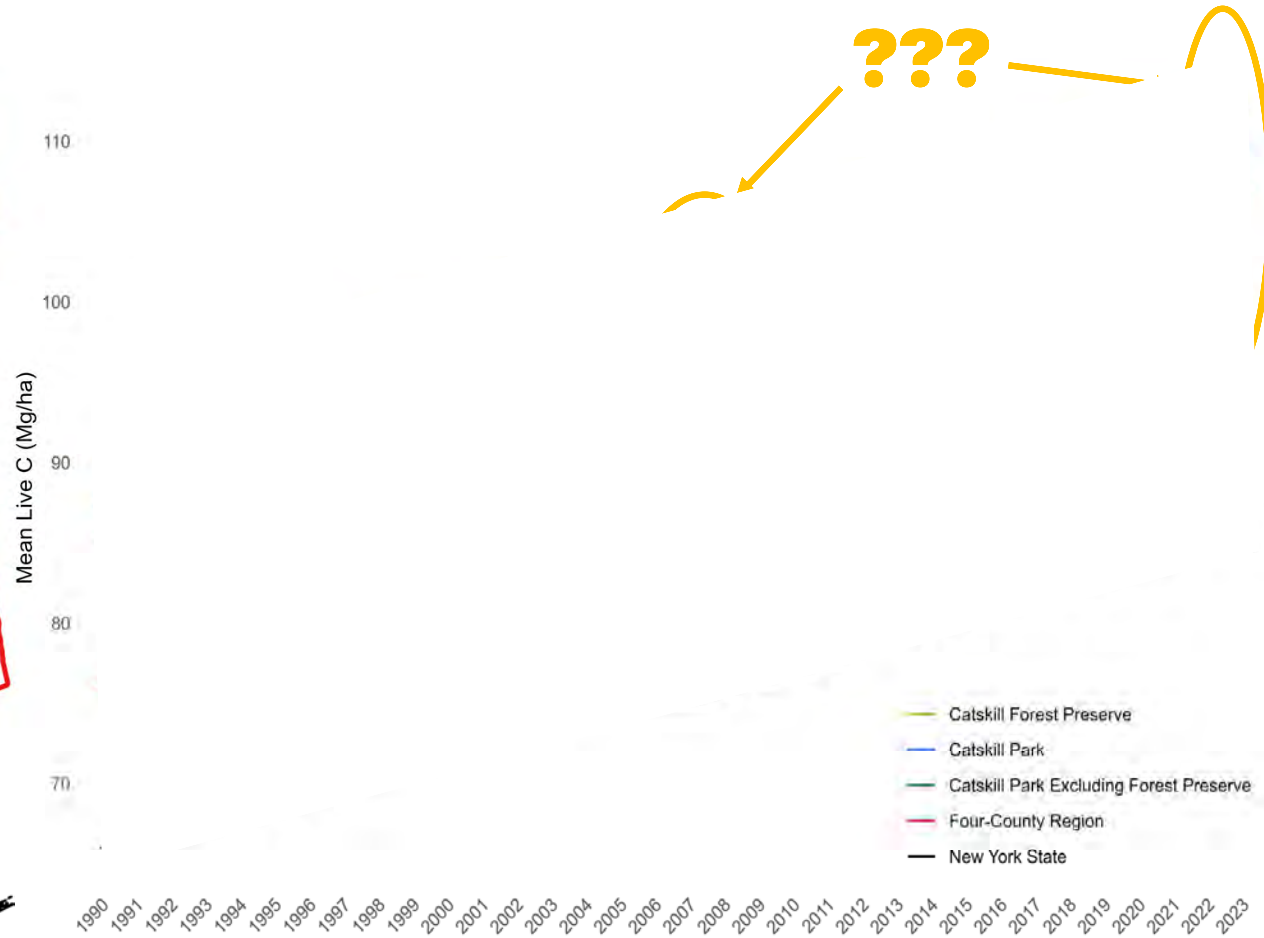
Most forest conversion due to development in peri-urban areas

C Stocks & Changes

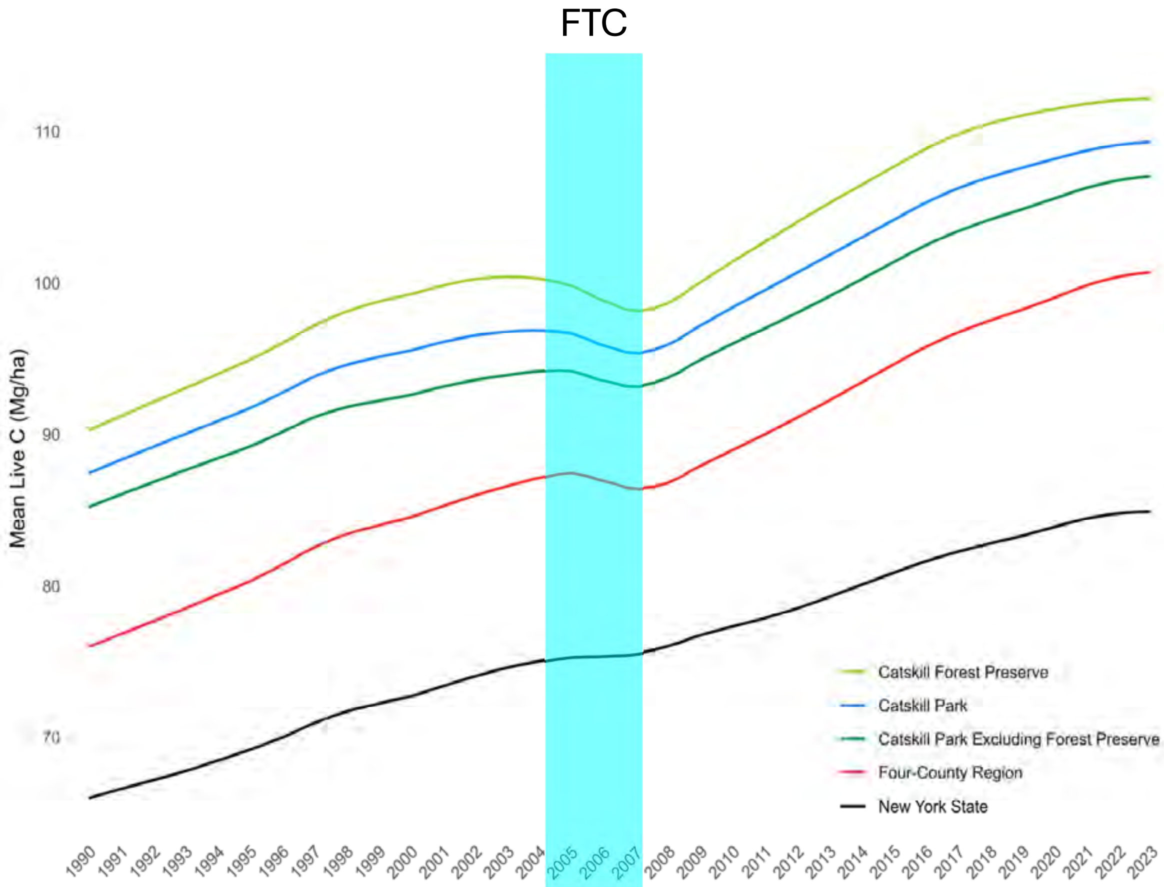


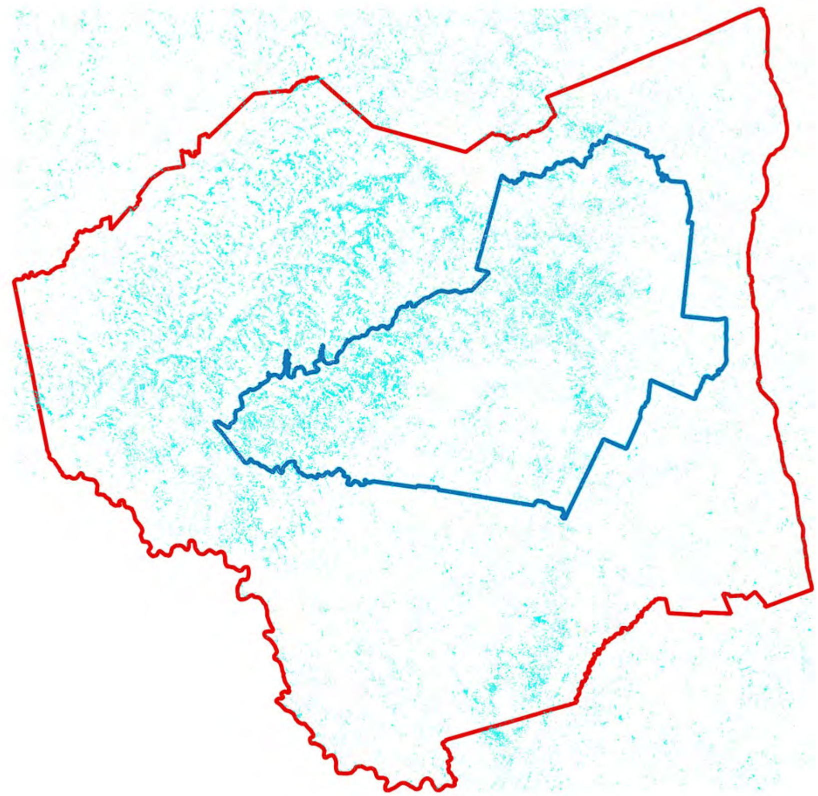




Insights

- Catskills Park and Forest Preserve have higher average live C density than rest of region and state
- Similar patterns of live C stock-change over 30+ years = similar rates of C sequestration
- Within region, live C max ~170 Mg/ha, suggesting ample ‘room’ for future growth (and C seq)

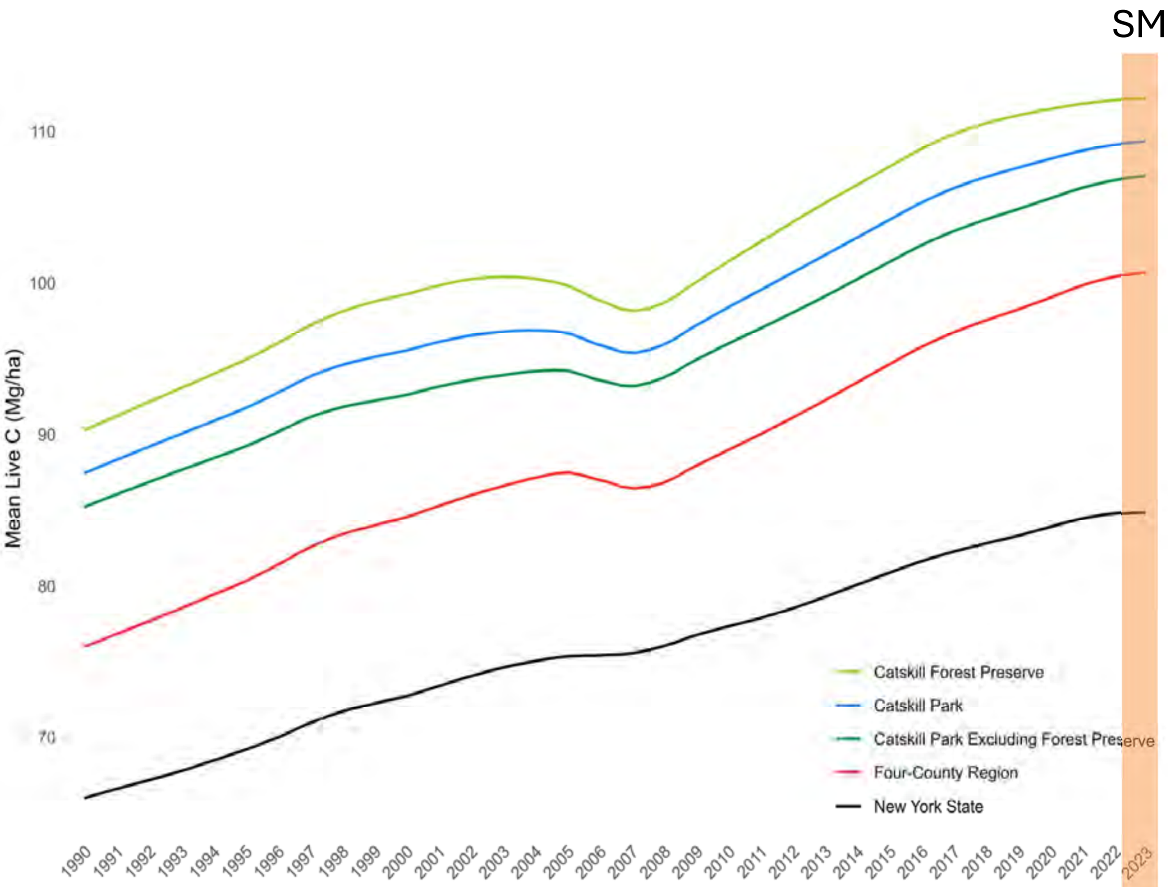


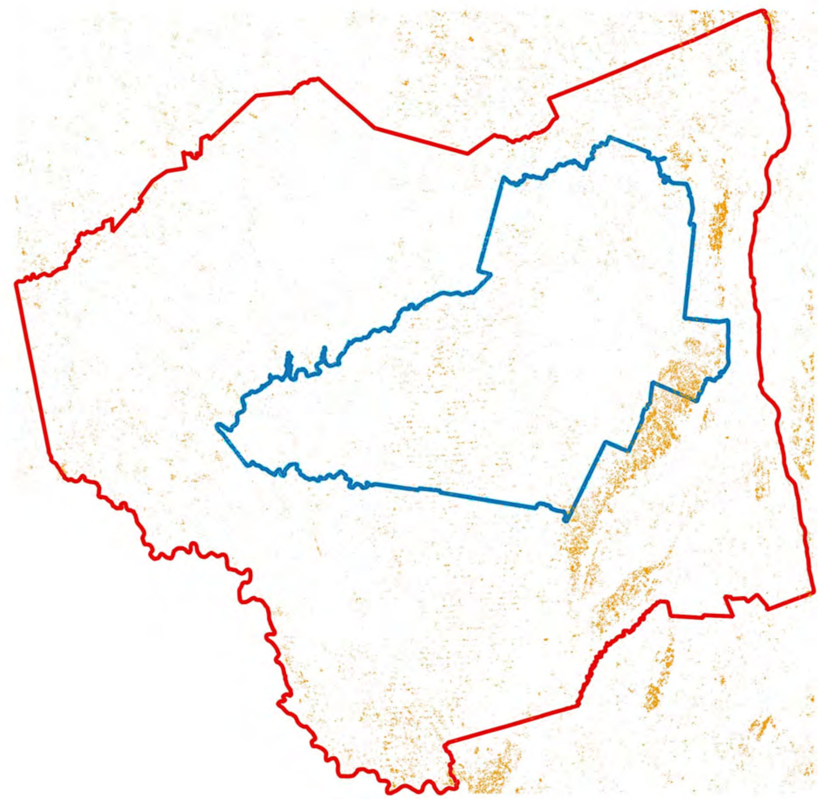


Malacosoma disstria

Insights

2005-2007: outbreaks of forest tent caterpillar (FTC; *Malacosoma disstria*) across NYS and broader region. Catskills were extensively impacted, especially in the cooler N-facing and mid-elevation habitats where northern hardwoods (maple-beech-birch) are common.

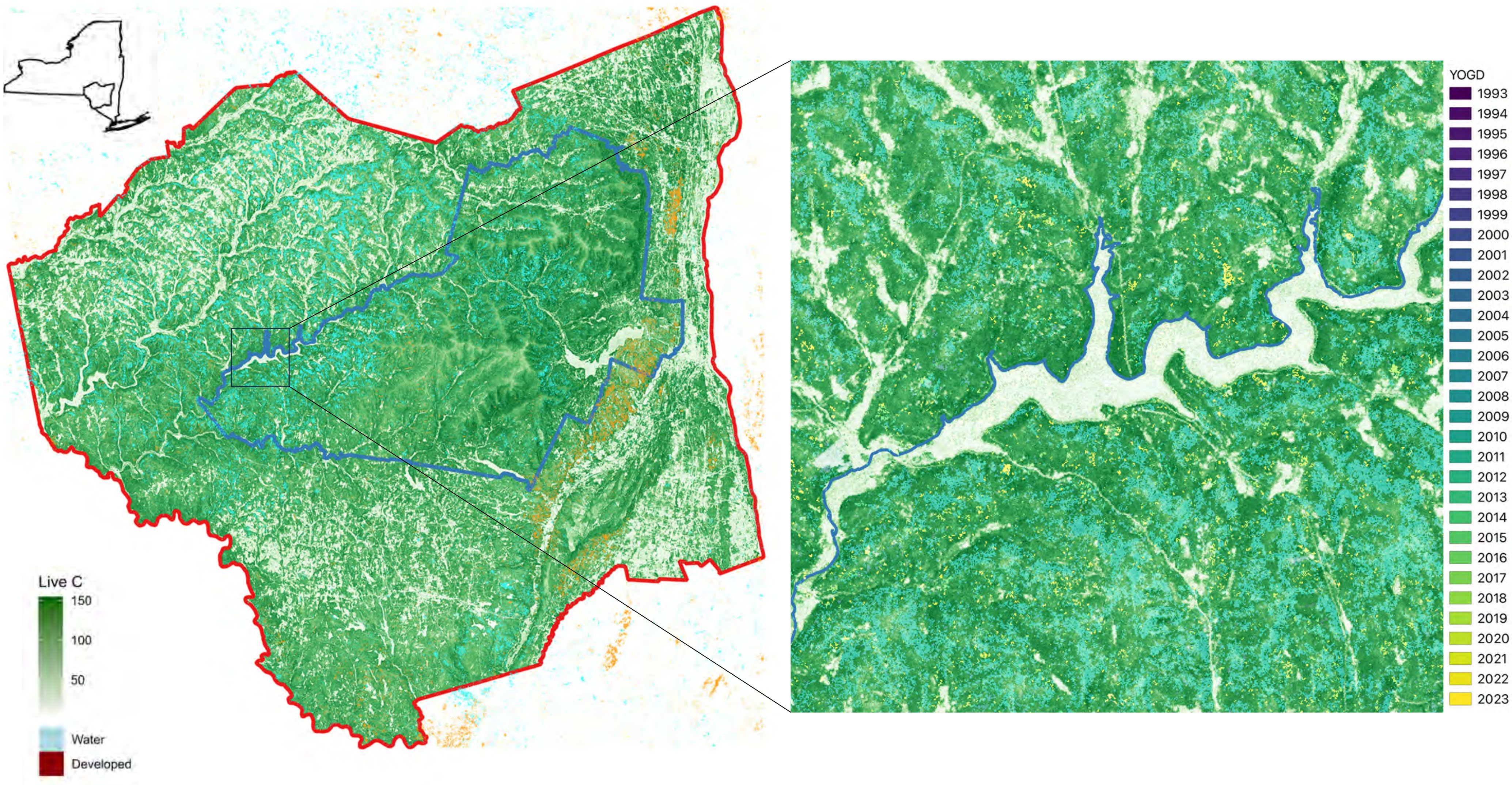




Lymantria dispar

Insights

2023: outbreaks of spongy moth (SM, *Lymantria dispar*) reported across lower Hudson Valley and Catskills. Areas of heavy defoliation were mainly located on warmer, S-facing slopes, escarpments, and valleys consistent with oak-hickory and mixed hardwood forests.



Live C
150
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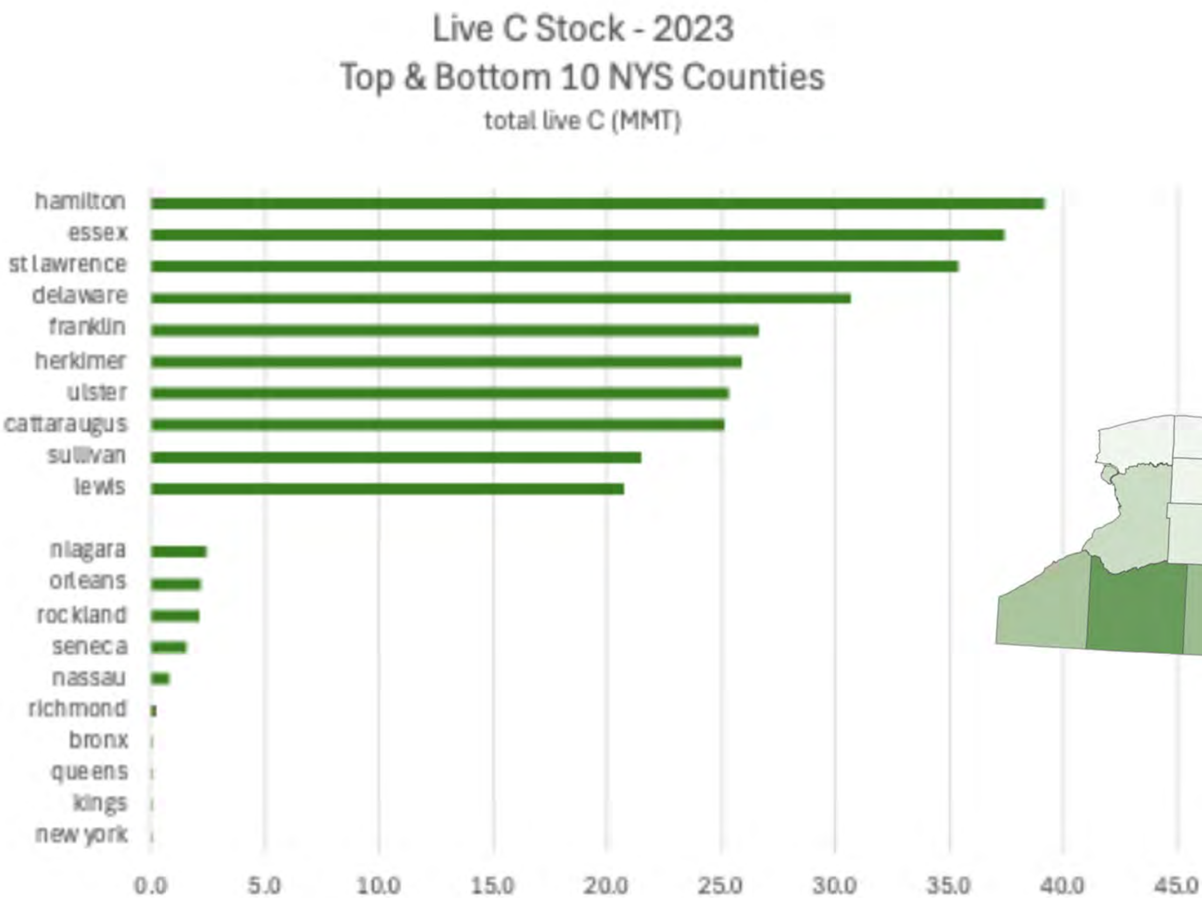
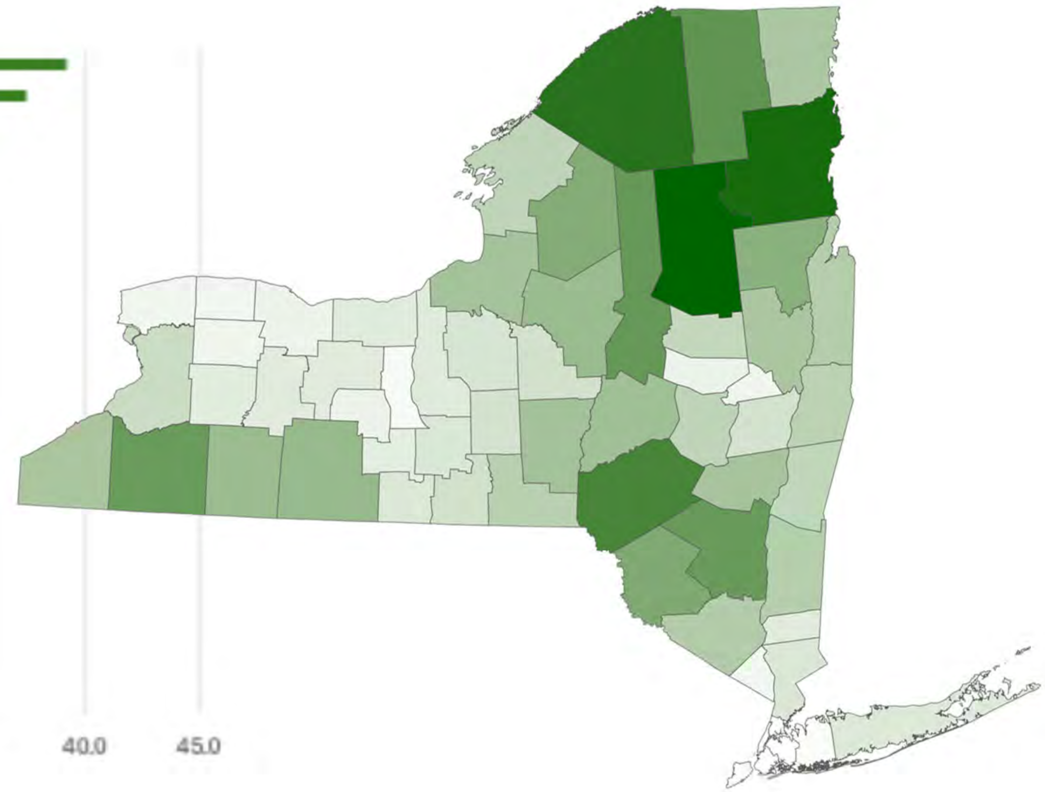
2022
2023

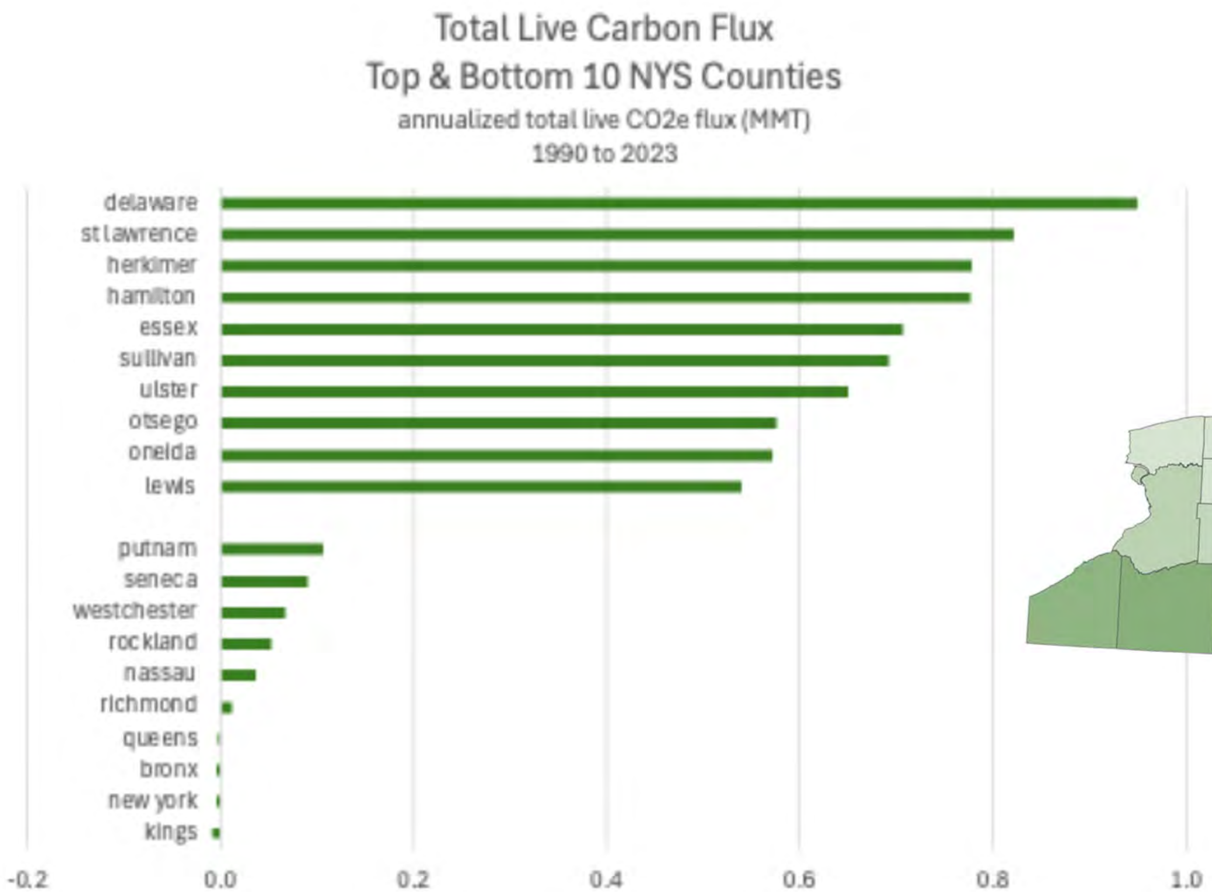


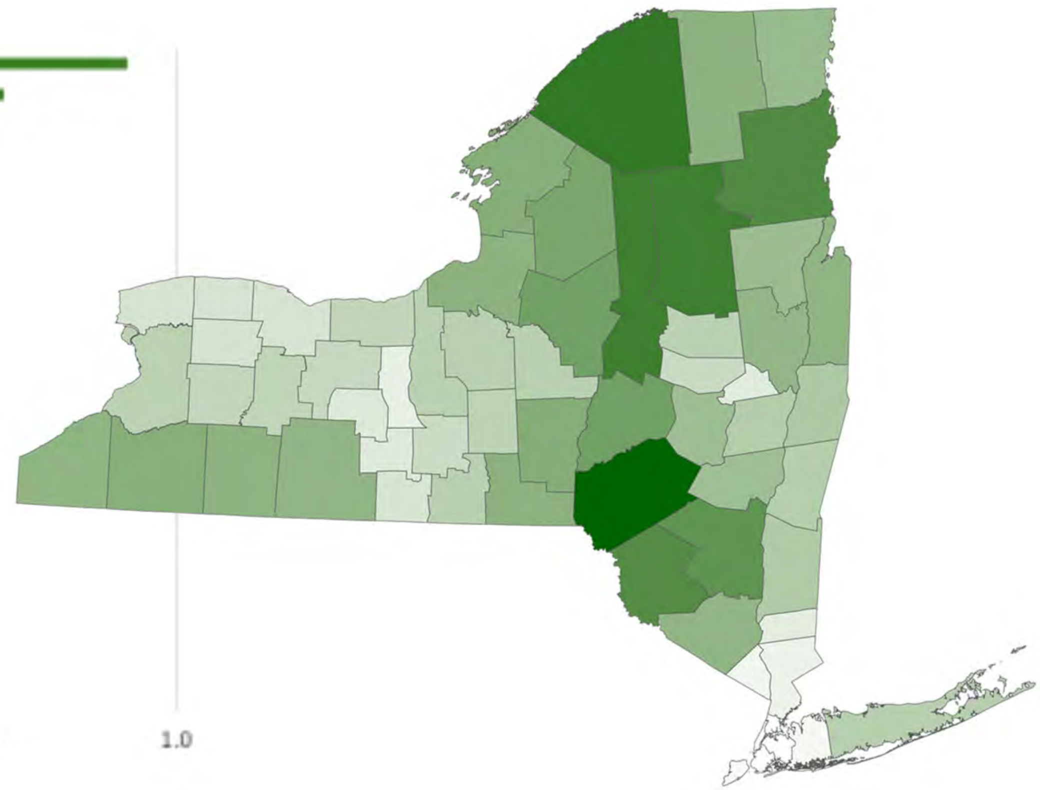


Role of Catskills in NYS Carbon Sink

Four-county Catskills region is 8.8% of NYS land area but represents:

- 13.4% of statewide live C stocks (2023)





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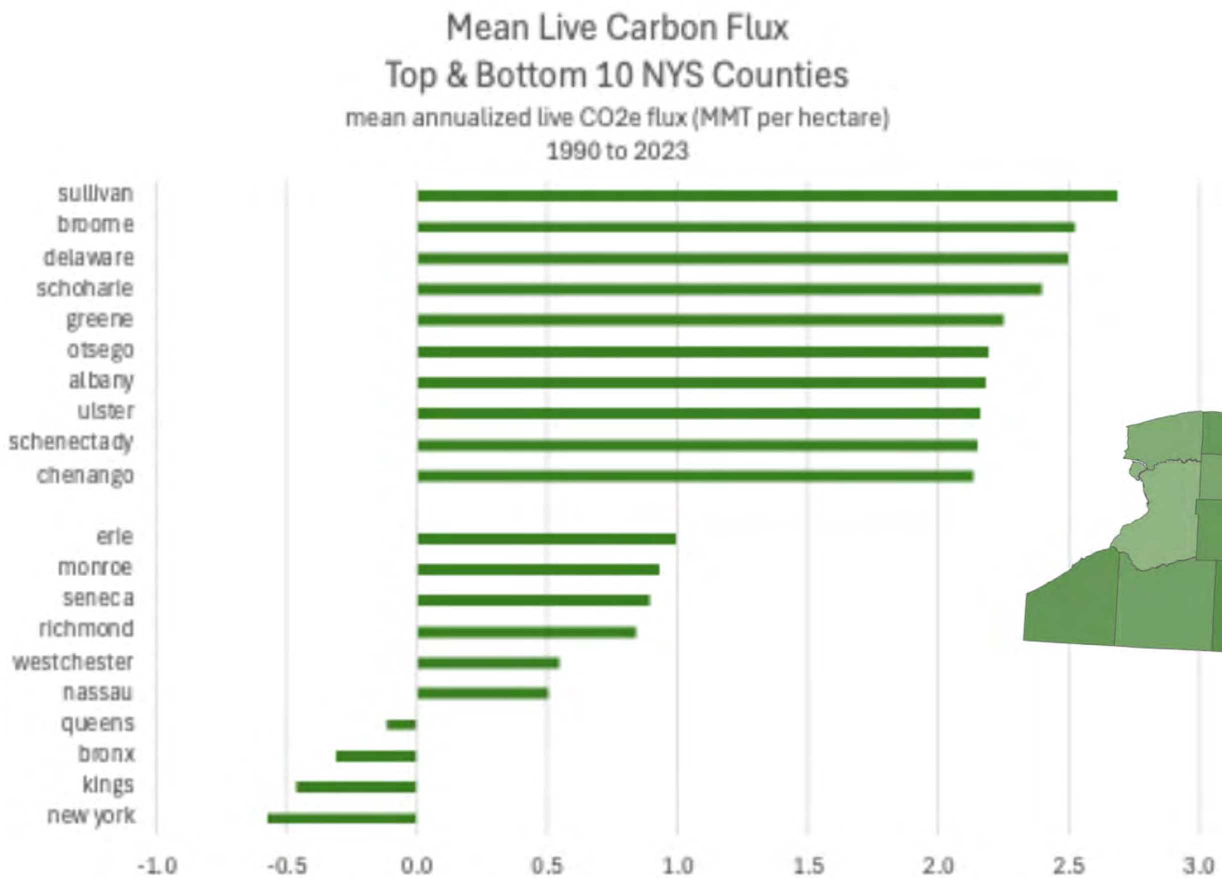
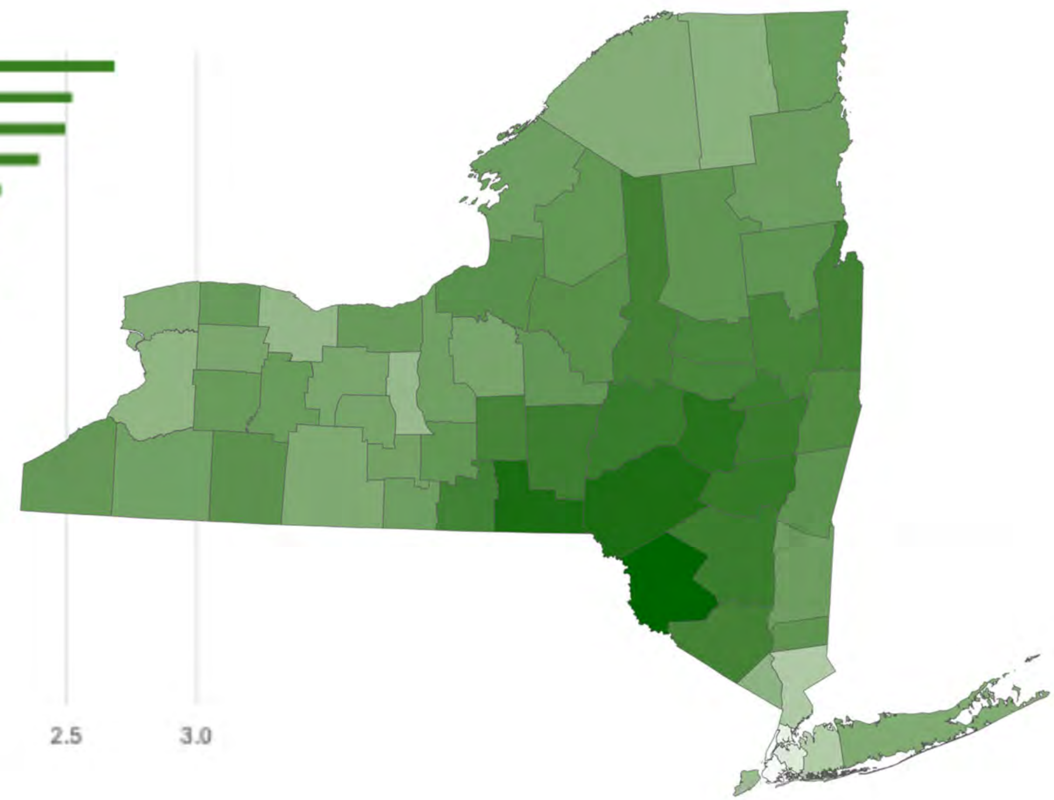
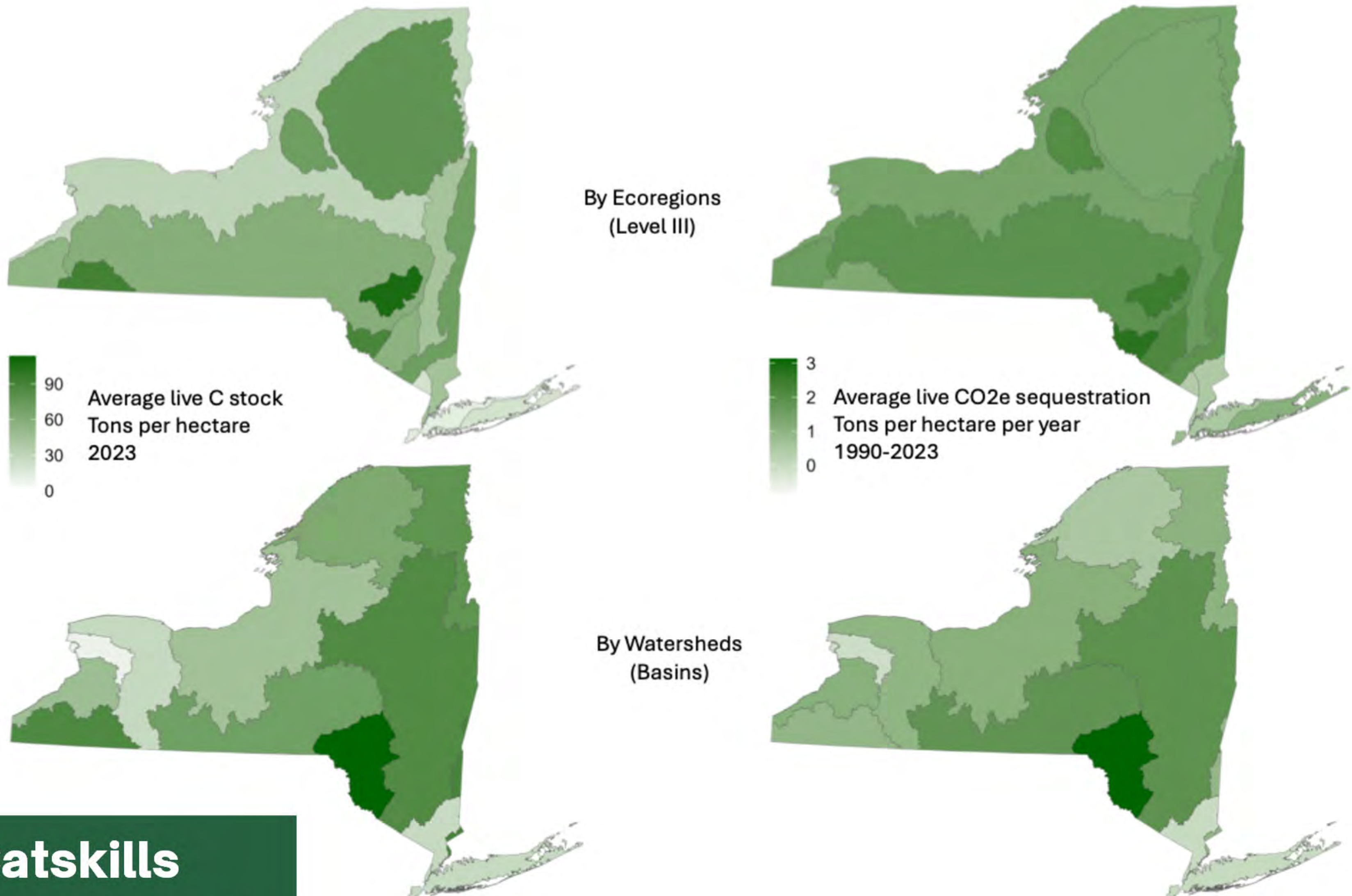




Role of Catskills in NYS Carbon Sink

Four-county Catskills region is 8.8% of NYS land area but represents:

- 13.4% of statewide live C stocks (2023)
- 14.9% of statewide annual net C sequestration (1990-2023)
- 1^{st} & 3^{rd} top-ranked counties: average C sink strength per acre forest land



Role of Catskills in NYS Carbon Sink

Continuous high-res maps can be summarized by geographic areas into discrete estimates

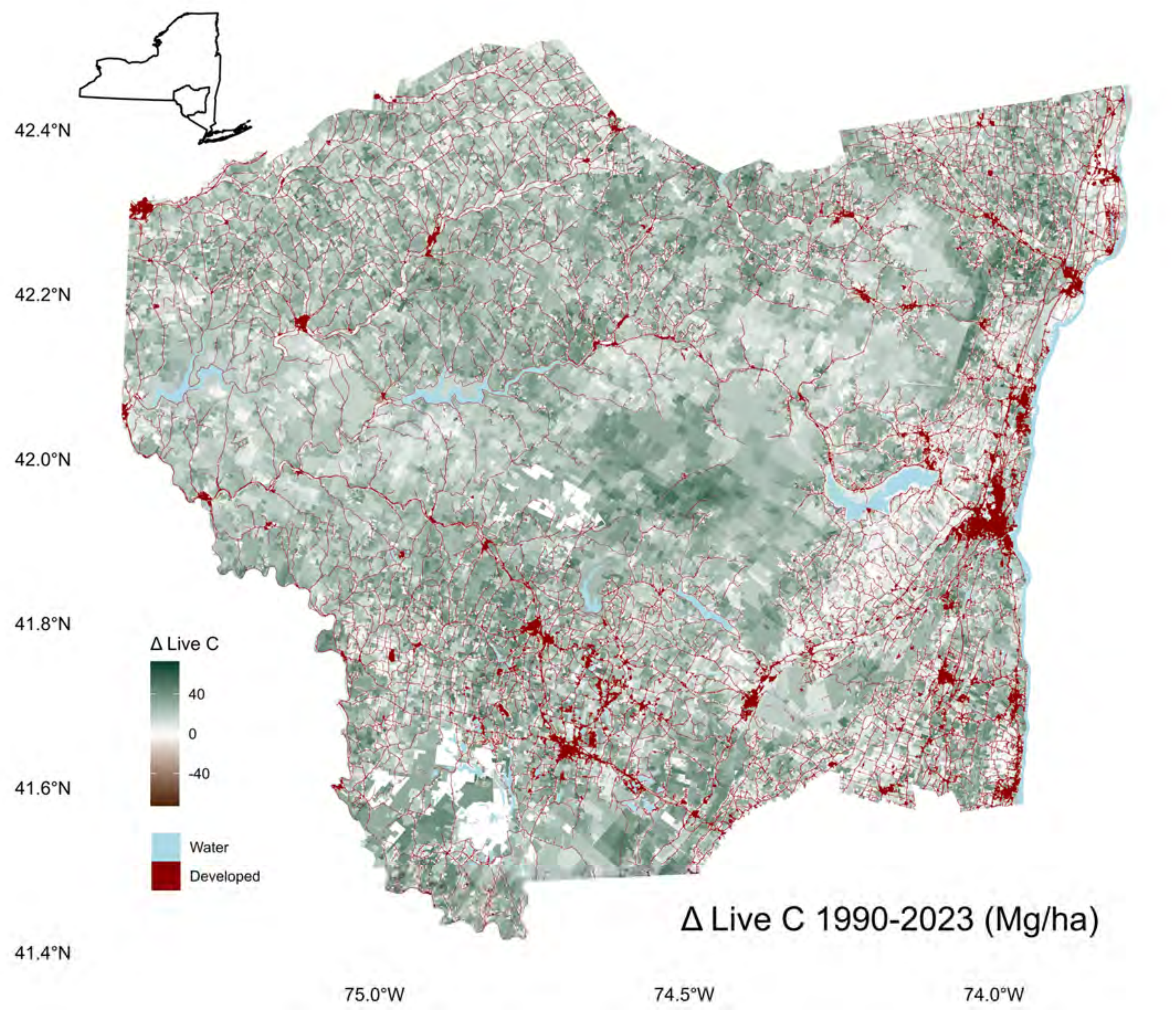
On public lands: management units and other designations

On private lands: parcels represent scale at which landowners make decisions

Parcel boundaries can be useful for understanding spatial patterns related to historical land use

Parcel boundaries subject to change (subdivision) over time, can be updated annually

Insights



Most parcels in Catskills Park rank in top 20% for live C density statewide

Relatively few of these 'high C stock' parcels also rank top 20% statewide for live C seq (during 1990-2023)

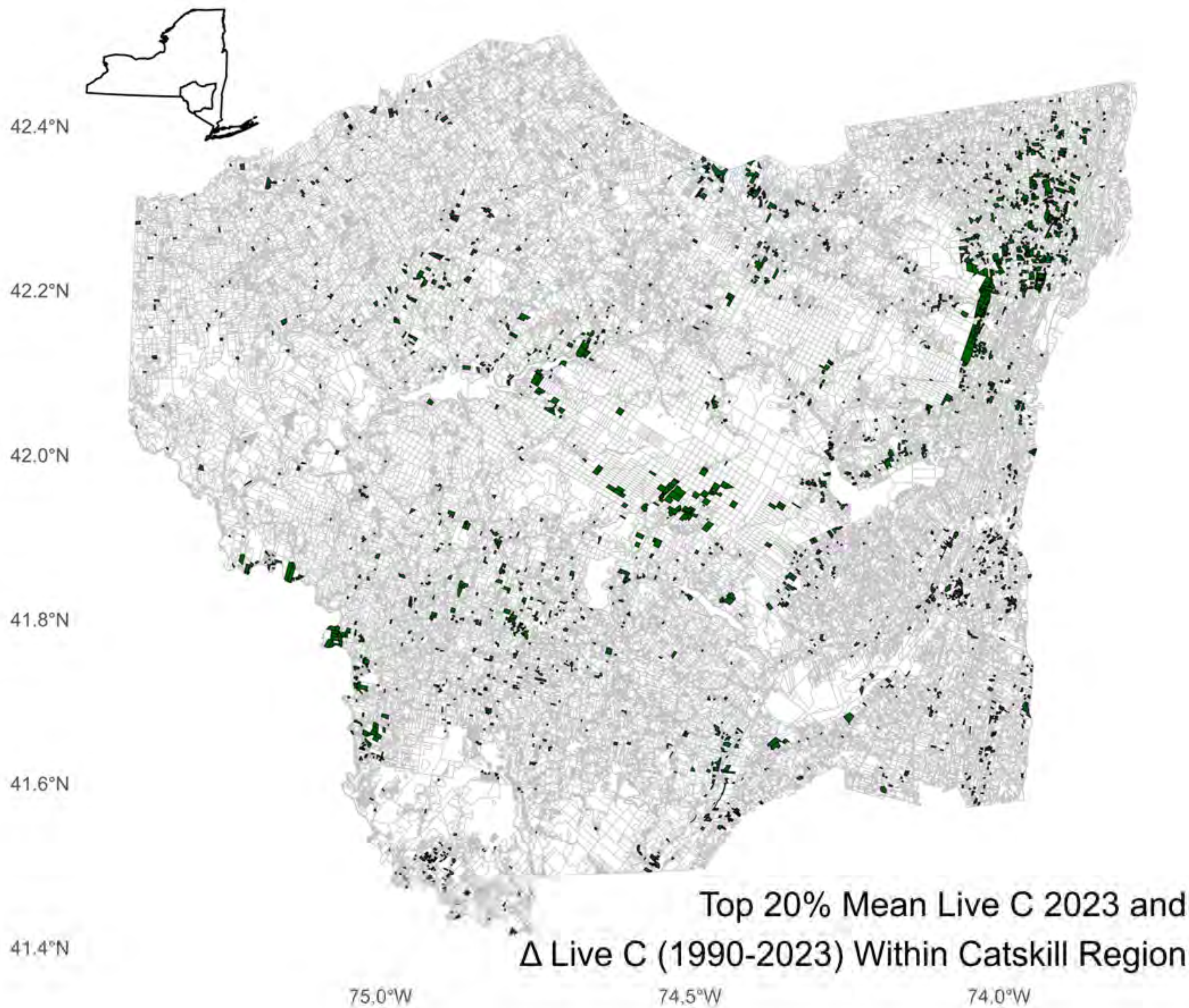
Catskills Park represents about 1/4th of the regional C sink...

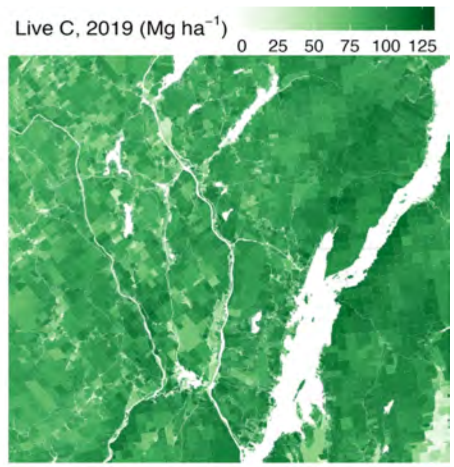
...its older forests may have slower C seq rates than younger regenerating forests outside of the Park...

...or our models are not fully capturing growth in older forests.

Parcels high in both C stocks and C seq rates = maximum climate ROI

'Top Tier' Parcels





Parcel-level carbon stocks

Carbon stock density

Estimates CO_2 emissions that would occur due to forest land conversion

Development Pressure

Forecast maps of future land use change under different scenarios

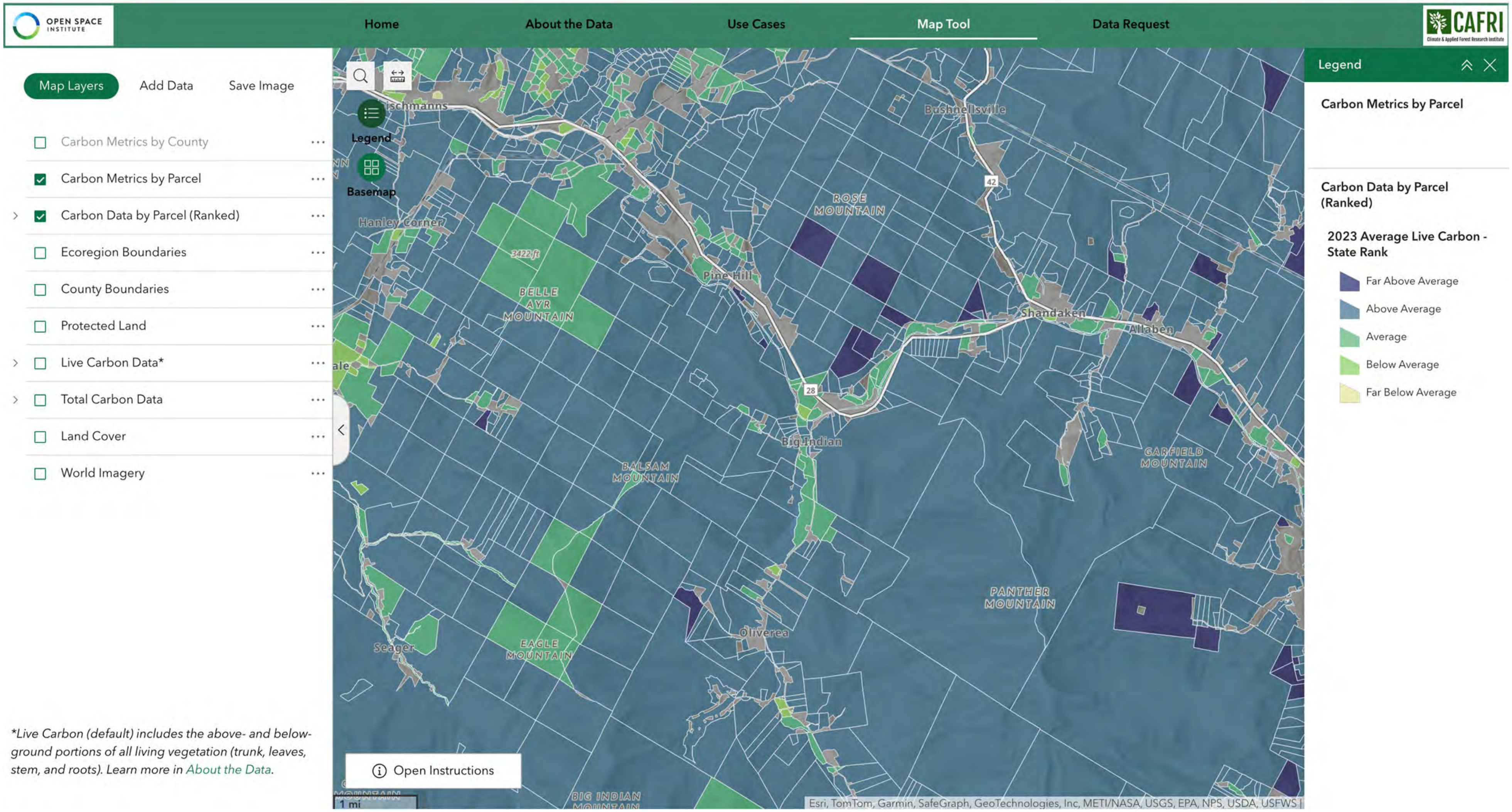
At-Risk Forest Carbon Stocks

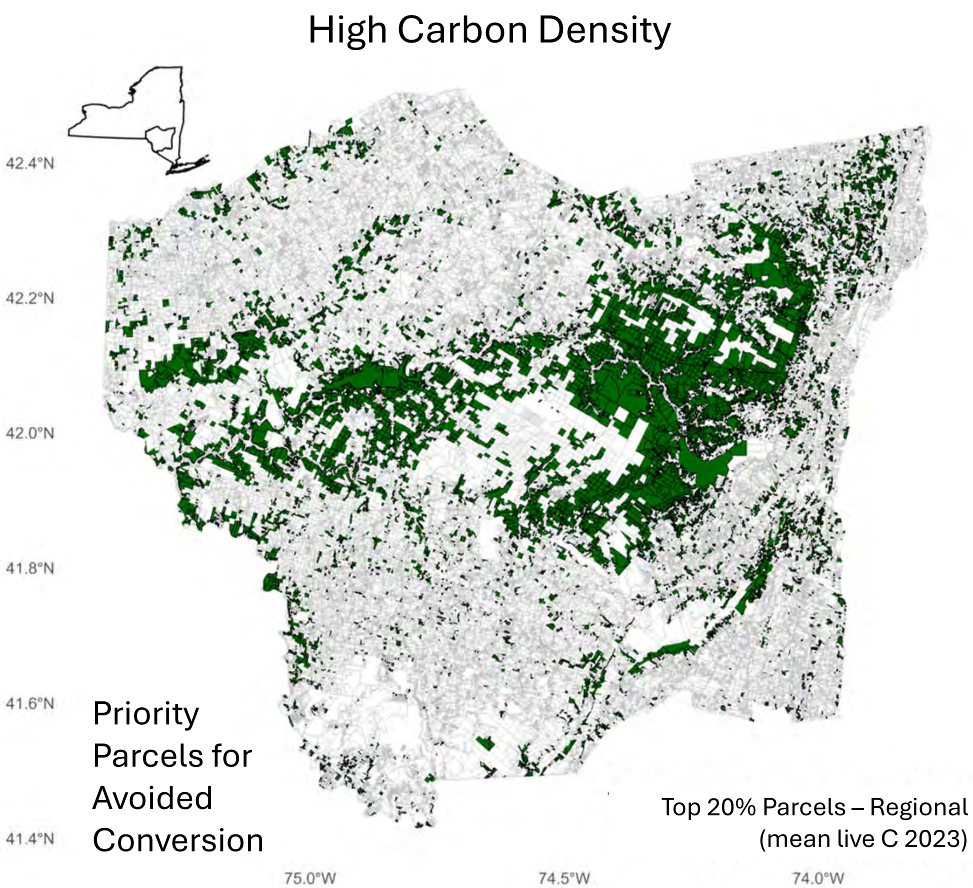
Target land acquisitions to protect C stocks

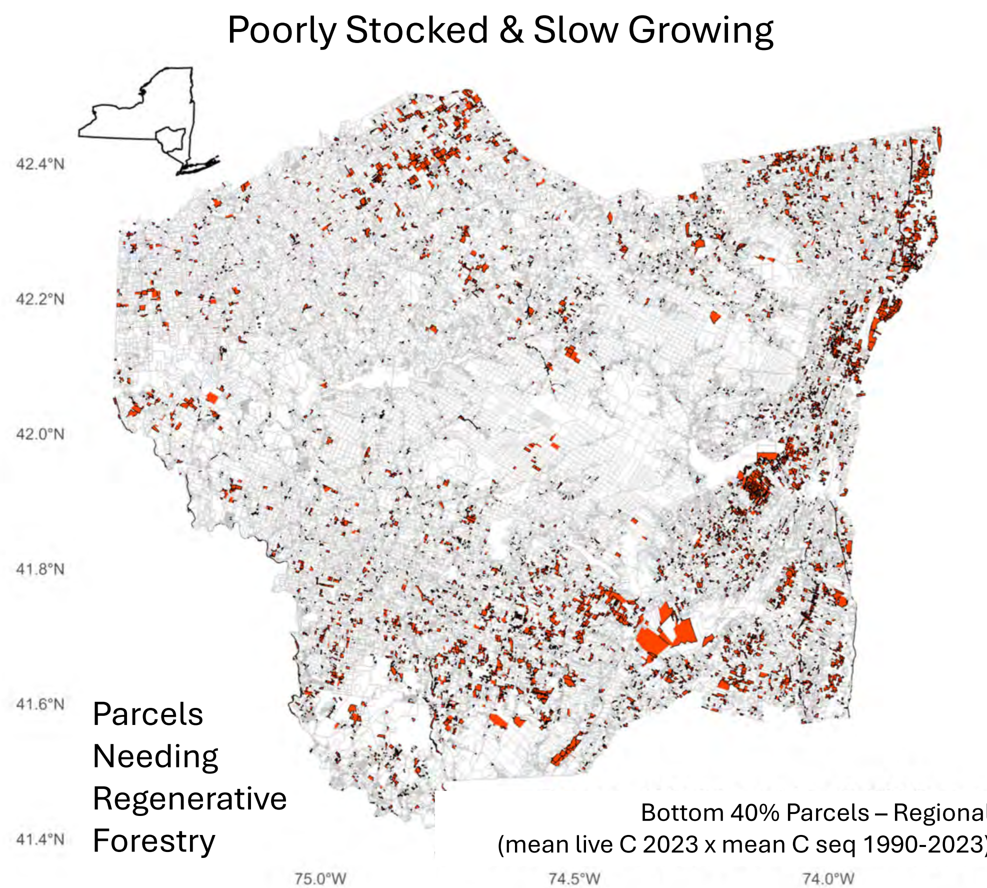
Applications: Avoiding Conversion

Combining maps of current forest C stocks and forecasts of future land use change can support targeted conservation actions (fee purchase, easements) that maximize overall climate benefits. Future land use is very difficult to predict – scenarios can help explore this uncertainty.

OSI-CAFRI New York Forest Carbon Map







Applications: Screening & Prioritizing Forest Parcels

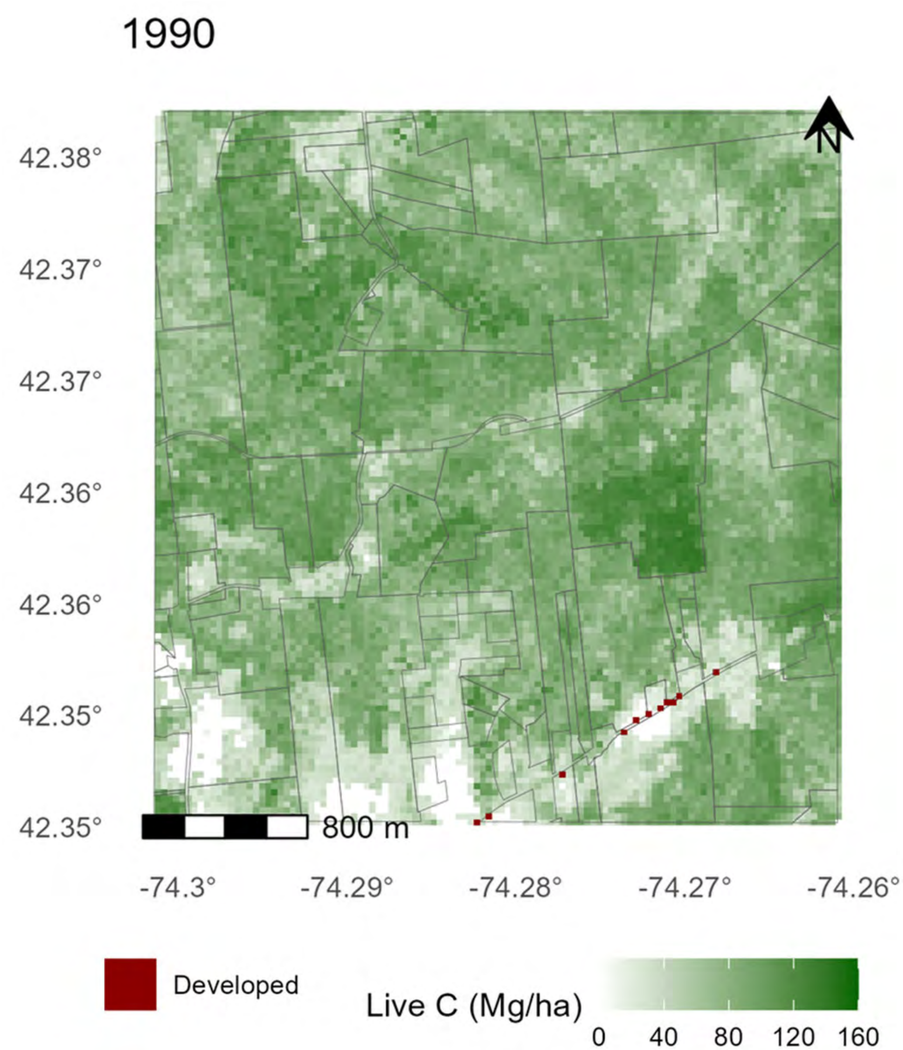
Parcels

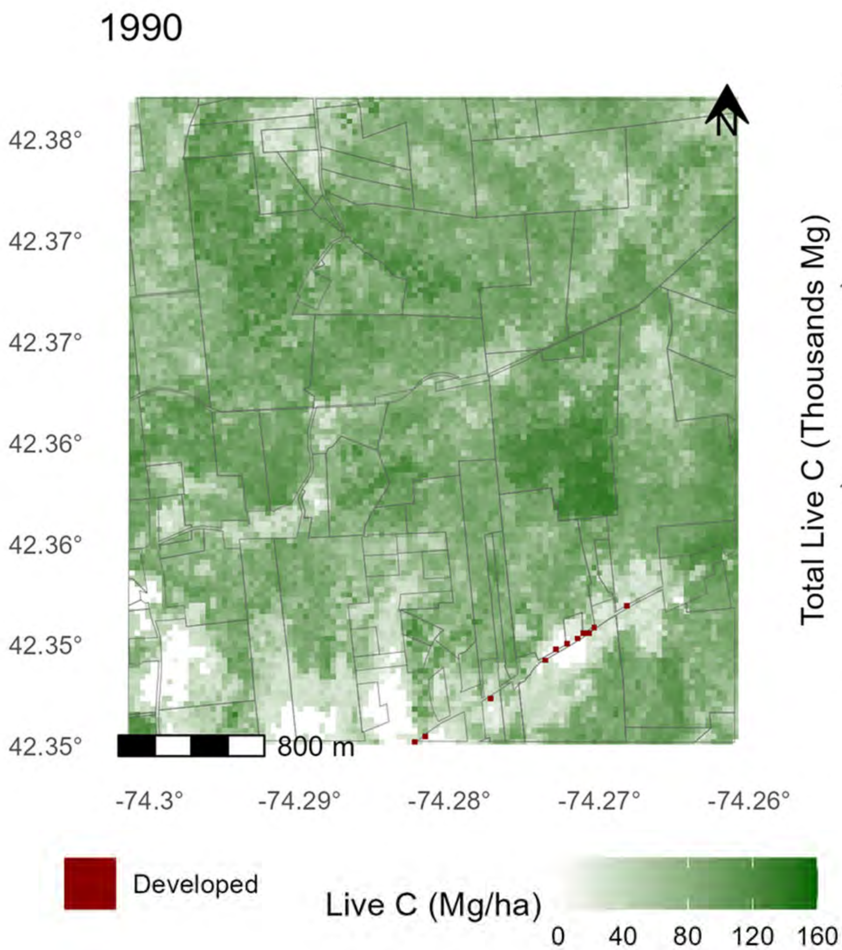
Screening and prioritizing forest parcels for enrollment in voluntary programs, conservation easements, land trust acquisitions, offsets, etc.

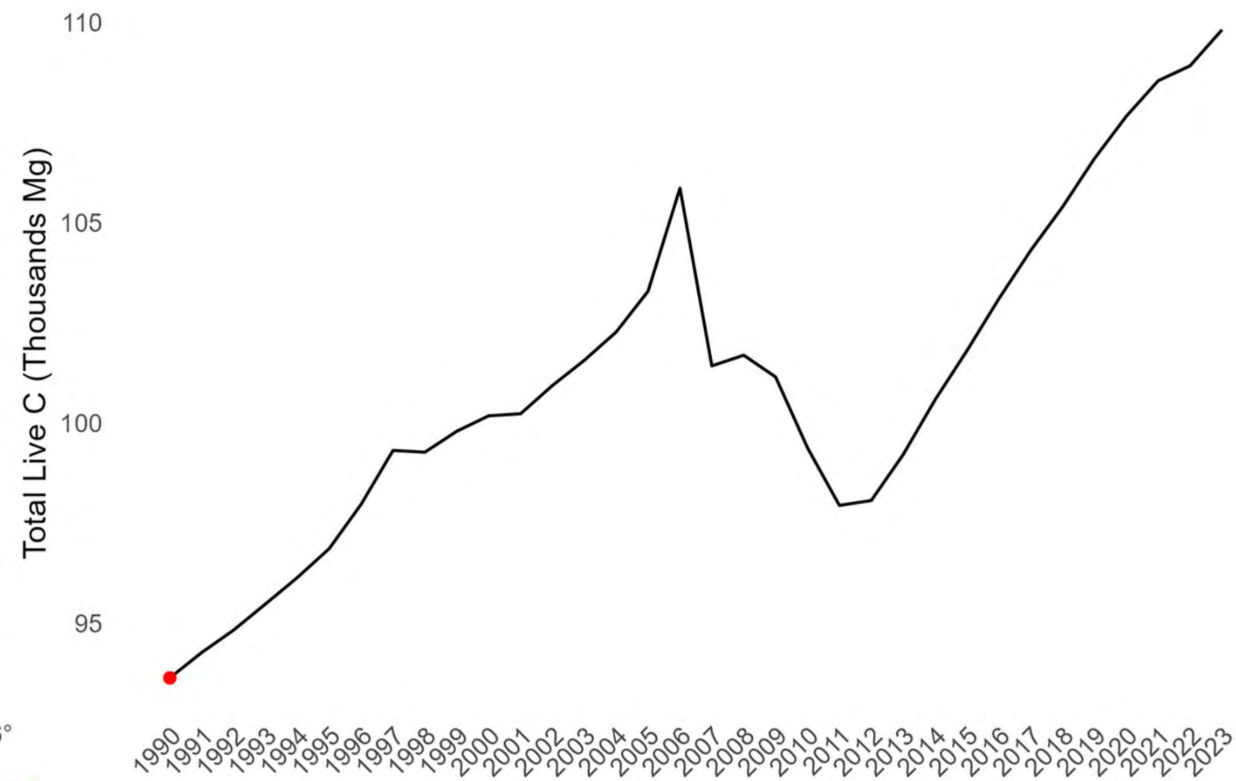
MMRV

Statewide monitoring provides an efficient basis for tracking C benefits and parcel-level compliance with easements, C offsets, tax abatement programs, etc.

Applications: Climate Solutions







Applications: Parcel-level MMRV

- Detection of harvest vs non-harvest disturbances vs land use change
- Estimate harvest volumes, assess post-harvest regeneration vs conversion
- Broad set of applications to support existing and emerging programs

Recent history of forest conditions and land use/land cover changes at parcel scales

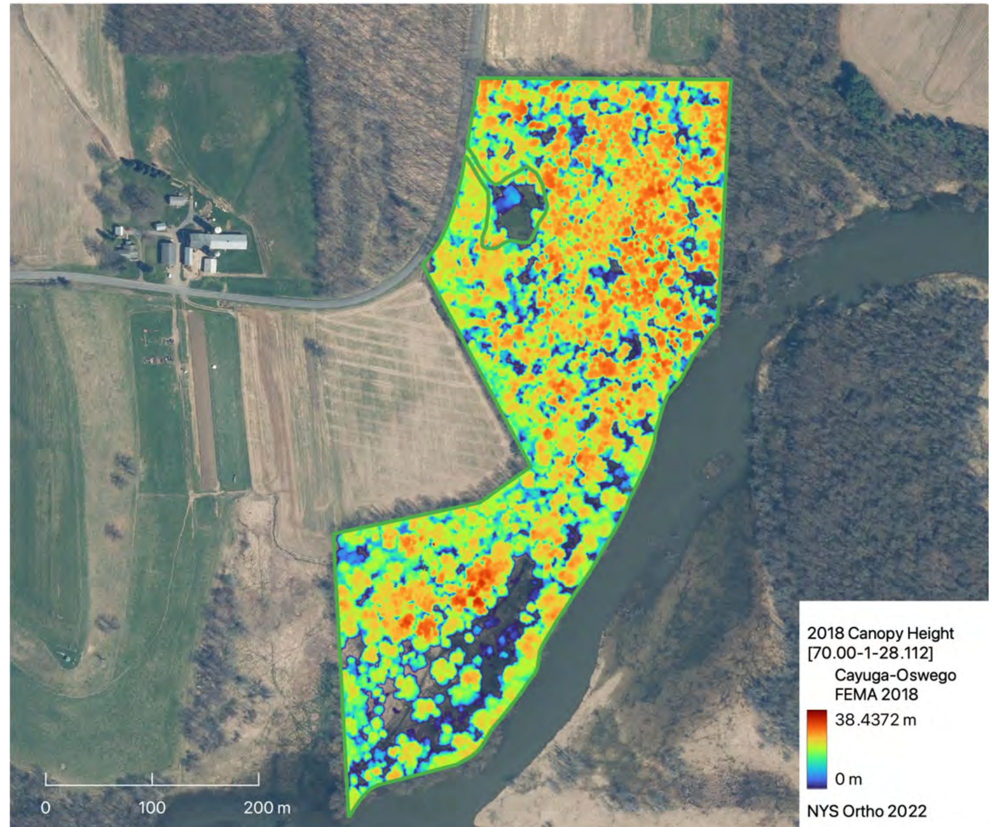
Provides efficient and consistent high-level monitoring to assess program outcomes and prioritize DEC's on-ground compliance efforts

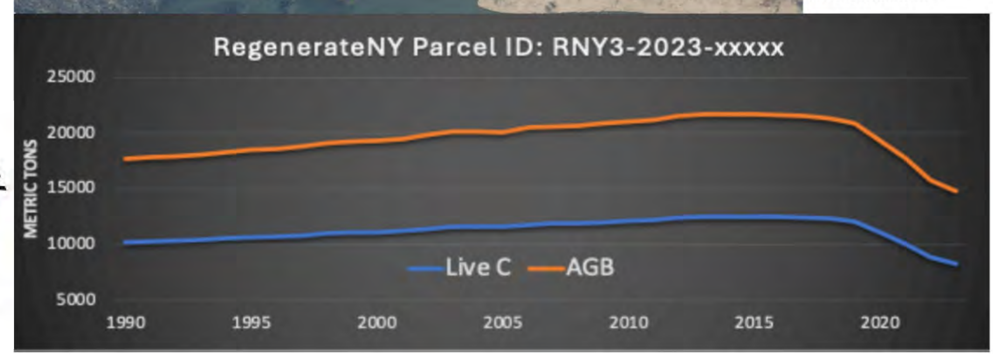
Forest Tax Law 480a: verify forest management practices (timing, location, type) and identify any land use conversions in non-compliance

Regenerate NY: estimate climate benefits of regenerative forestry practices and monitor progress in reforested areas

Provide landowners and consulting foresters with maps, data products, and annual monitoring updates for enrolled properties

Applications: Parcel-level MMRV





Parcels

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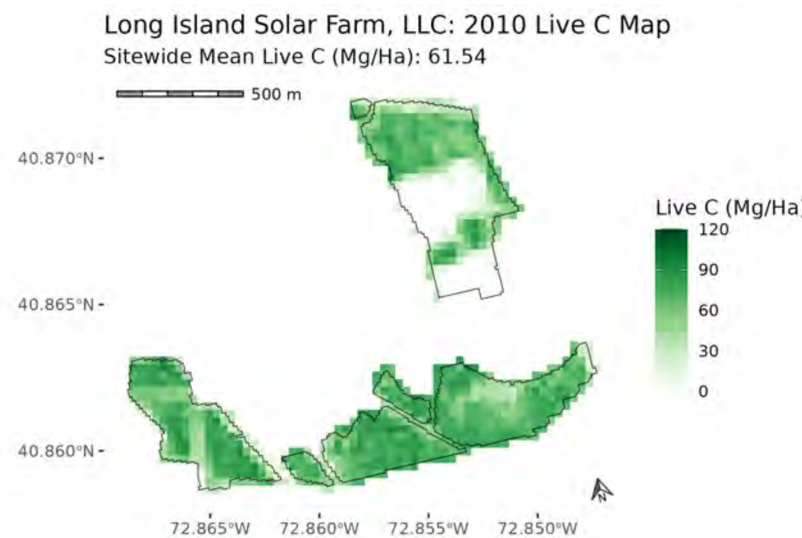
MMRV

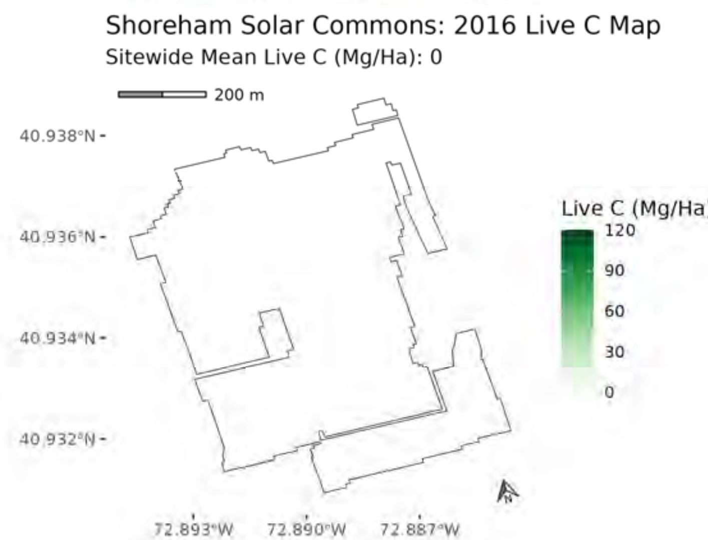
Statewide monitoring provides an efficient basis for tracking C benefits and landowner compliance with easements, C offsets, tax abatement programs, etc.

Solar

Rapid assessment of proposed solar facilities for New York's Solar Scorecard, to minimize forest loss, C emissions from land clearing for solar farms

Applications: Climate Solutions



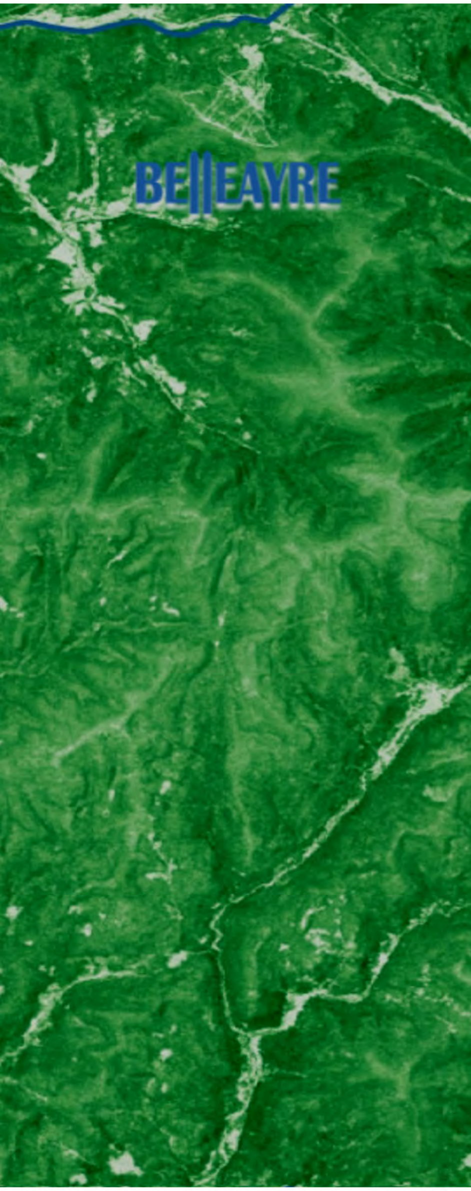


Data Product	Coverage	Resolution	Availability
Aboveground Biomass (AGB)	NYS 1990-2023	30m, annual	✓
Forest carbon pools • Live C (AGC+BGC) • Soil, Litter, Dead Wood	NYS 1990-2023	30m, annual	✓
Stock change metrics • AGB • Live C	NYS 1990-2023	30m, annual	✓
Monitoring updates (AGB, C) • New AGB/C maps • Updated stock-change	NYS 2024	30m, annual	Dec 2025
Forecast maps • AGB & Live C • Carbon Stock-Change • NYS Reference Level	NYS 2020-2050	30m, annual	✓
Shrubland probability	NYS 2019	30m, single year	✓
Canopy height models	LIDAR-specific	1m, variable year	Varies by region

Data Products

NOW AVAILABLE:

Model versions 2.0 (AGB, AGC, BGC)
- **‘new’ FIA datasets (NSVB)**
- **Landsat collection 2**



Summary

Catskills region is essential to current and future NYS carbon sink.

Many areas of secondary forest in region ‘hit their stride’ in terms of growth and **C sequestration** over the last few decades.

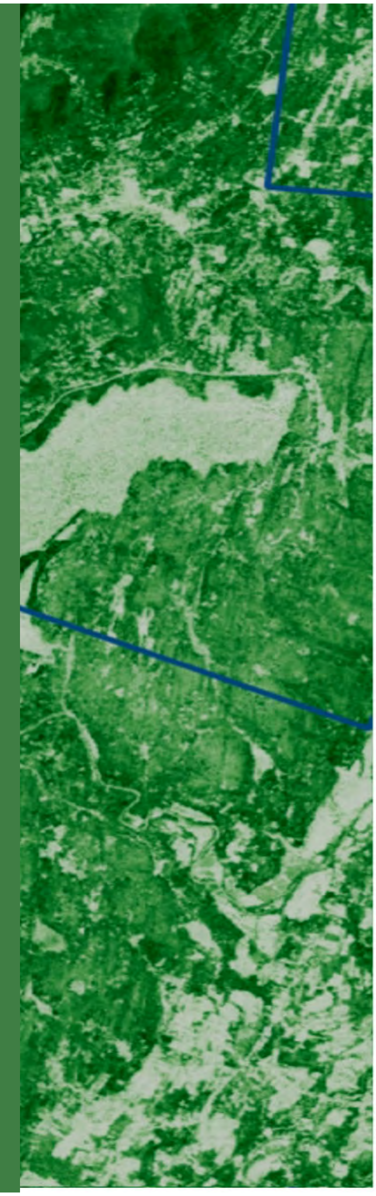
Moderate-to-high carbon density forests with ample potential for future sequestration exist on **both public and private lands**.

Younger ‘patchy’ forests on private lands contribute much to regional C sink, but are also more **vulnerable** to degradation/loss.

Regenerative forestry needed to grow and sustain future regional C sink beyond 2050… while providing many other co-benefits.

Avoiding conversion is first priority… then local **stewardship** to sustain productivity, address threats, build adaptive capacity.

Data products & tools **available now** … and more in the works.



Thanks. Questions?

Collaborators

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Partners

NYS DEC, US Forest Service, Lyme Adirondack Forest Co, F&W Forestry, NYS Geospatial Services

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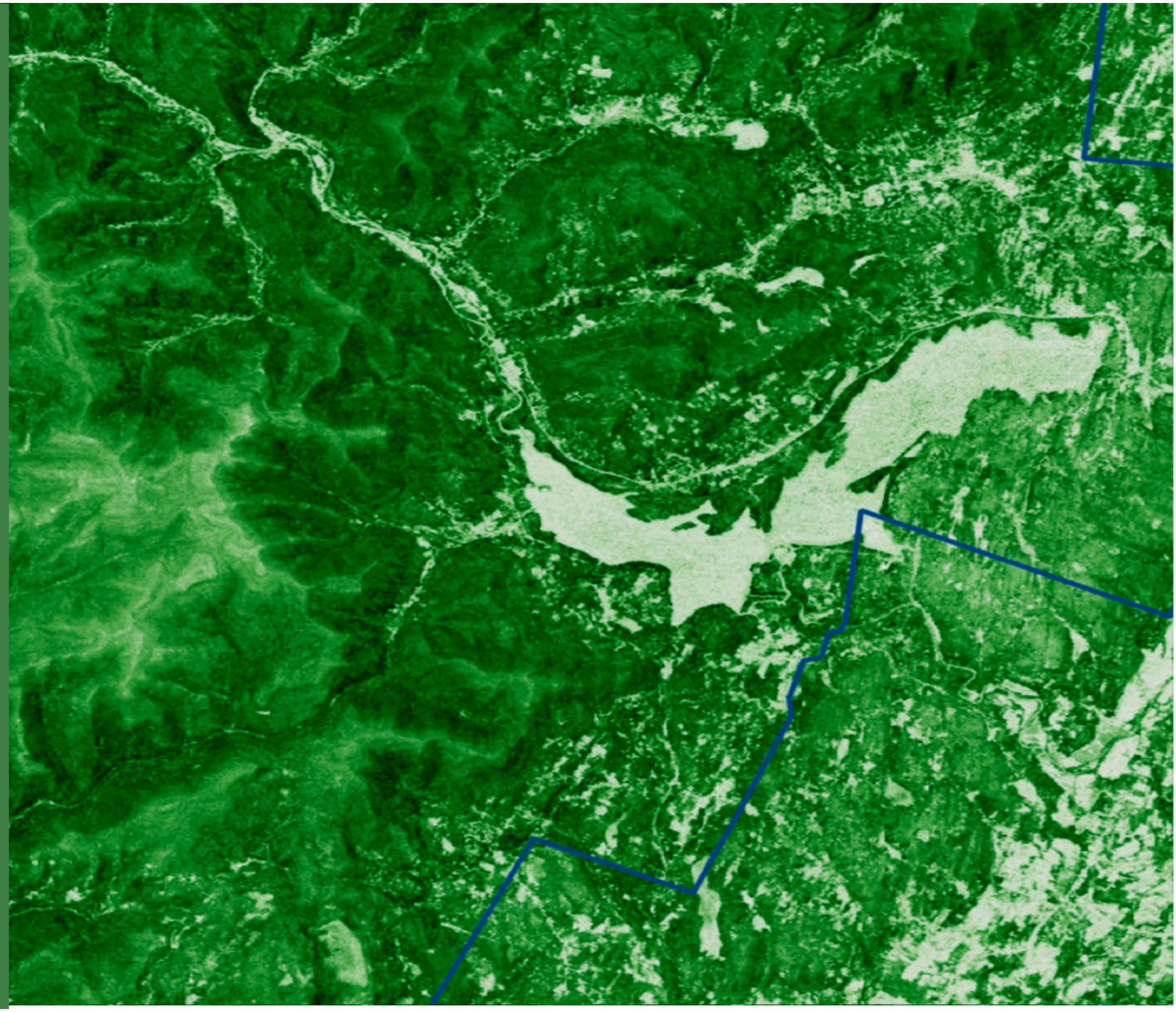
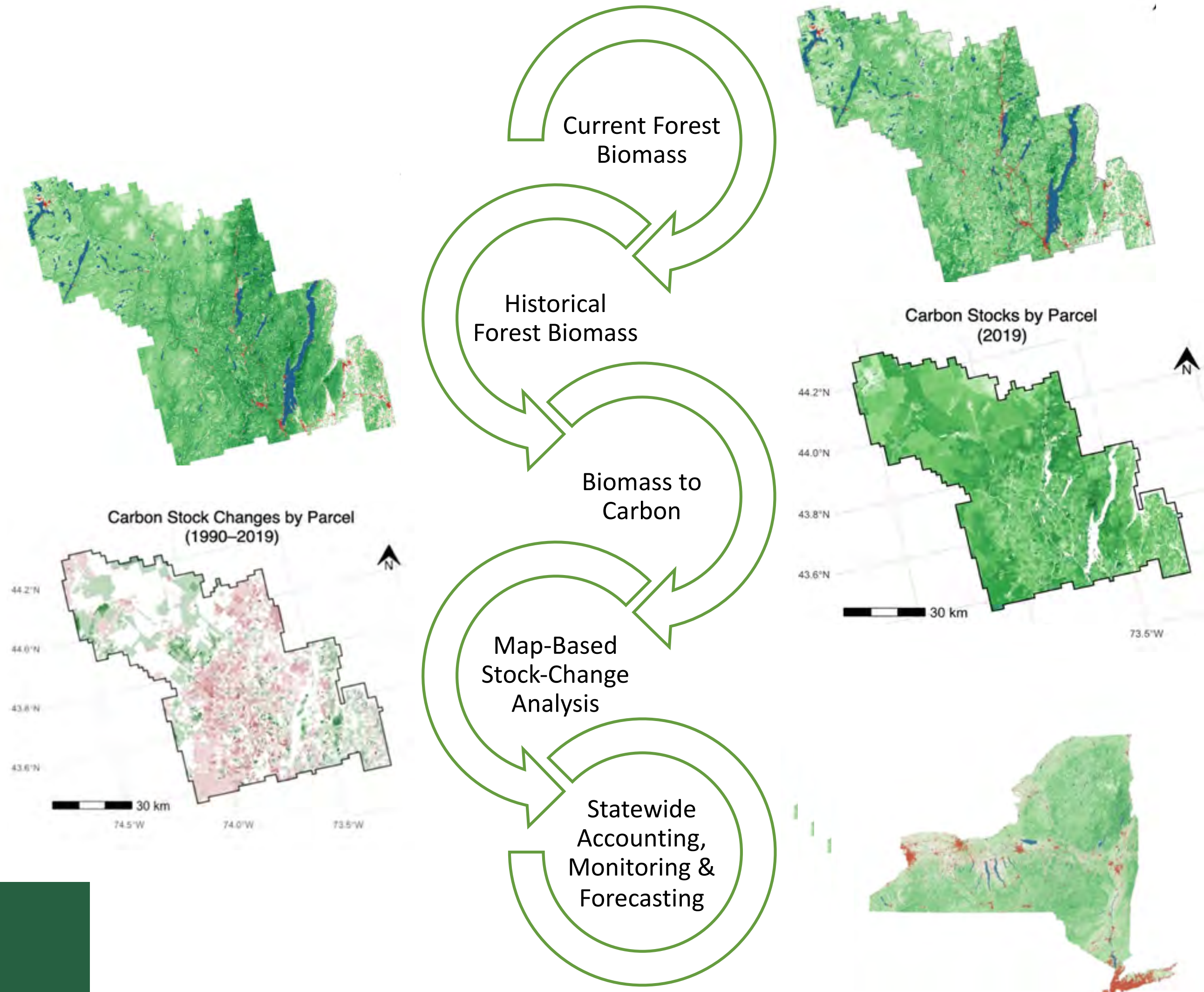



CAUTION!! This talk was produced in a facility built to support science-based decision-making and may contain:
1. (Very) Applied Research
2. Data Mining (Modeling for Prediction)
3. Limited Gory Details


Current Forest Biomass
Historical Forest Biomass
Biomass to Carbon
Map-Based Stock-Change Analysis
Statewide Accounting, Monitoring & Forecasting
Carbon Stock Changes by Parcel (1990–2019)
30 km
Carbon Stocks by Parcel (2019)
44.2°N
44.0°N
43.8°N
43.6°N
30 km
73.5°W

Approach

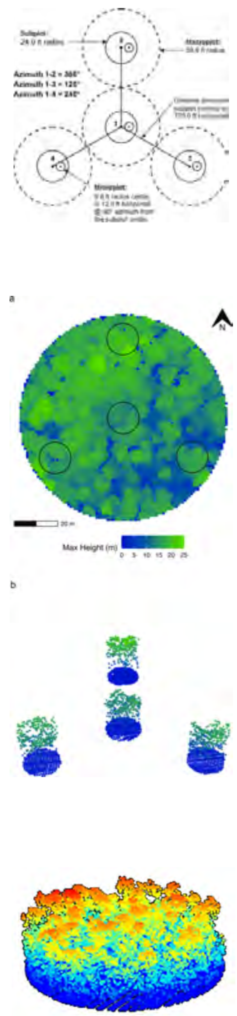
Use ML models to map forest aboveground biomass (AGB) for LIDAR year at 30m resolution

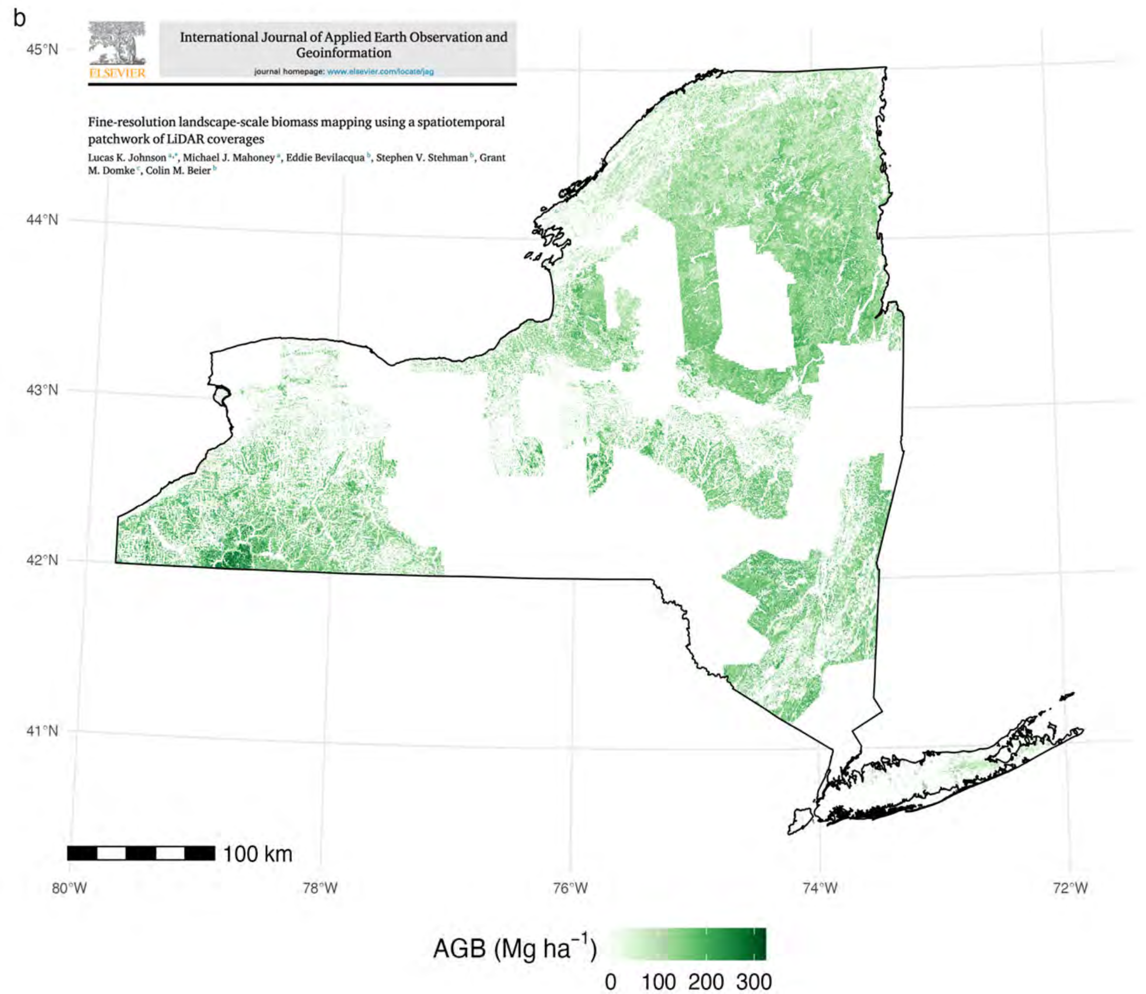
LIDAR offers highest accuracy at landscape scales, however:

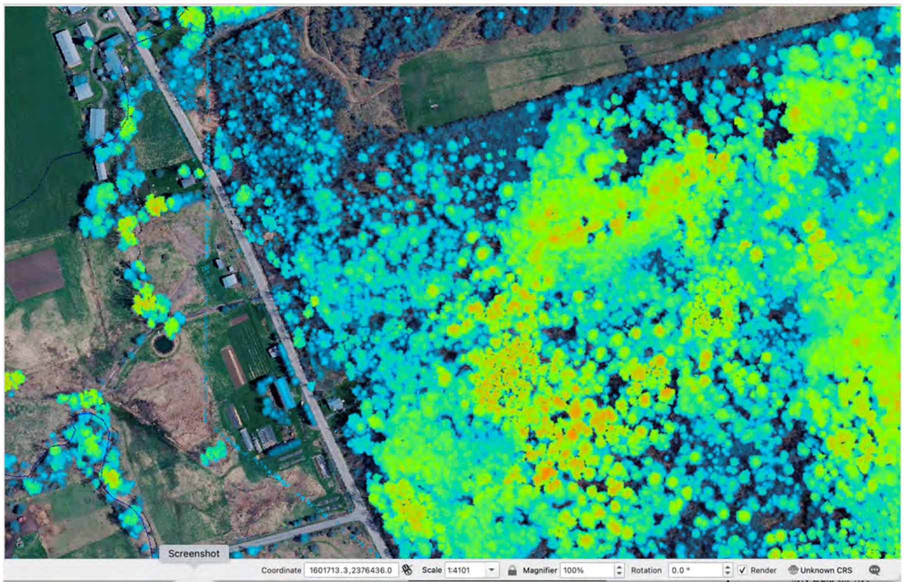
- Snapshot in time
- Disparity among sensors, mission parameters, etc. can result in ‘lost’ info
- Very limited areas with multitemporal coverage
- Computationally intensive

LIDAR maps alone not sufficient for stock-change analysis or related needs & applications

AGB & C Mapping



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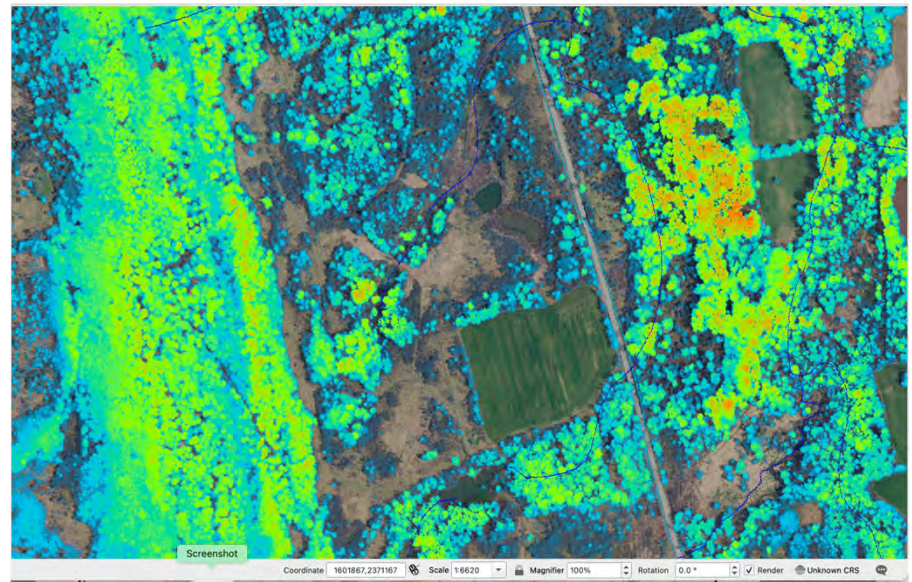
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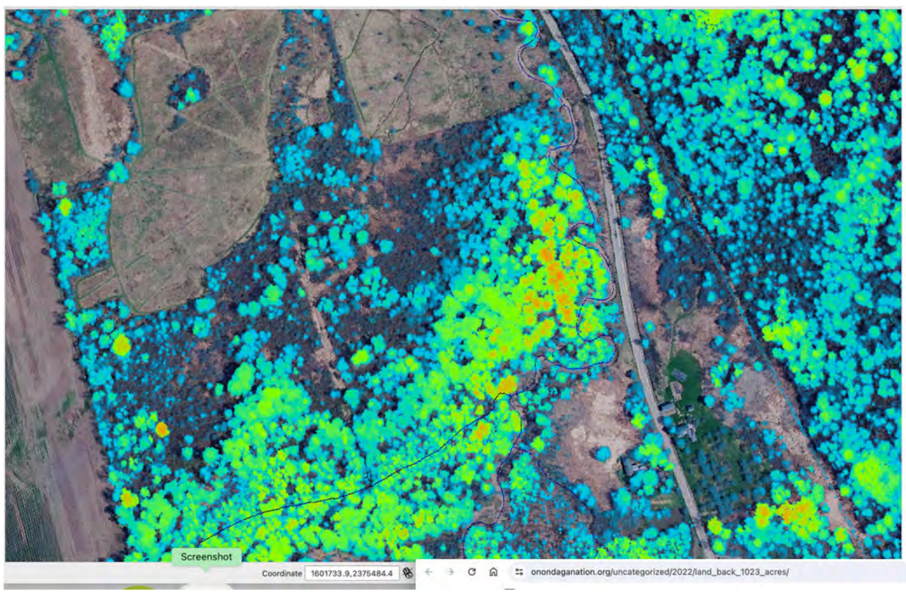
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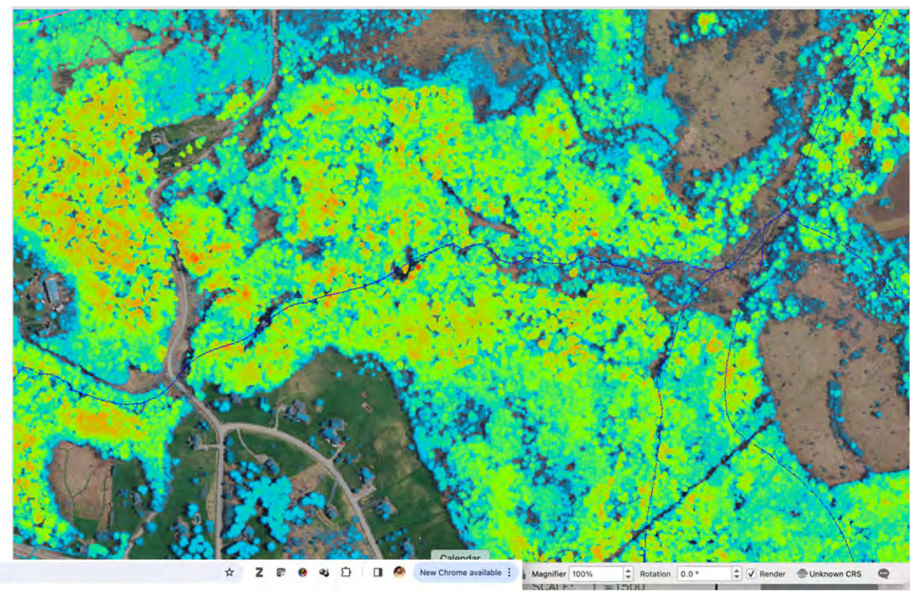
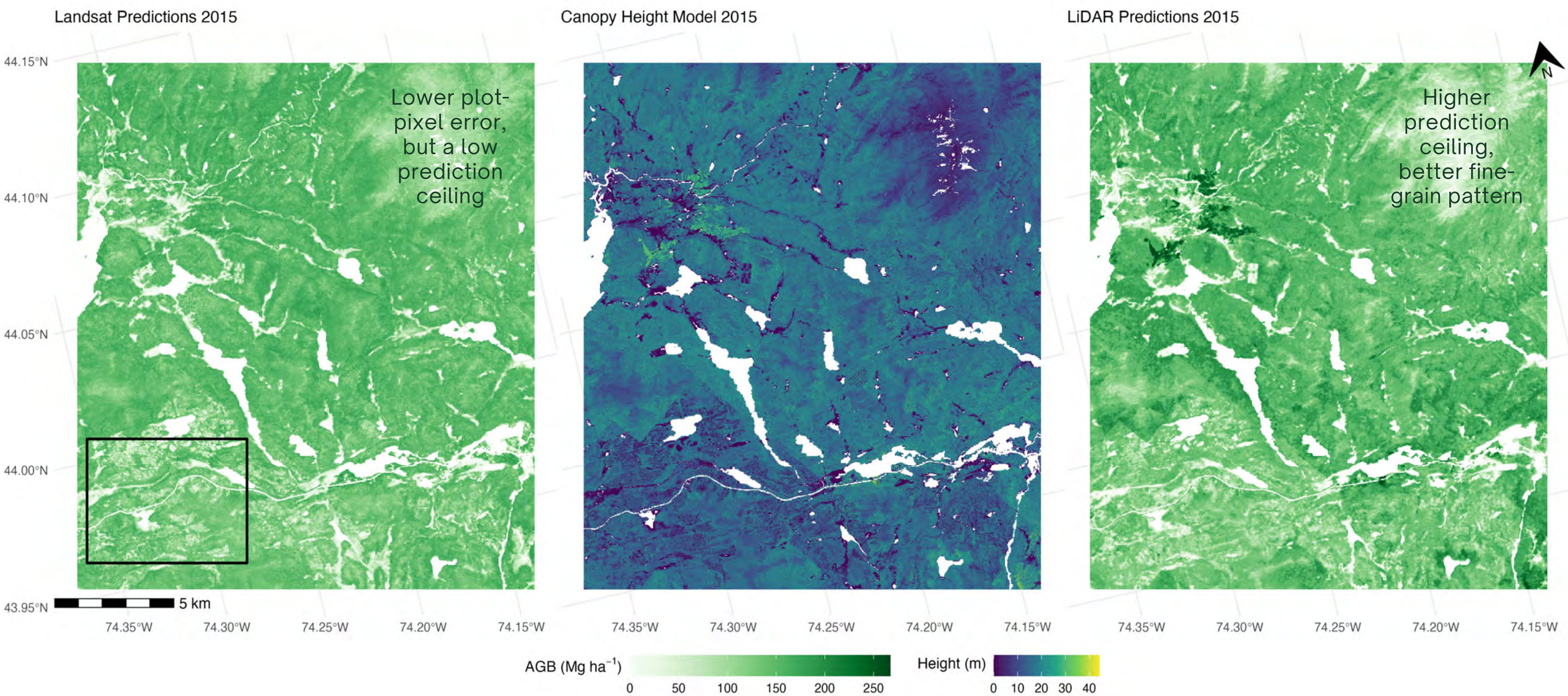
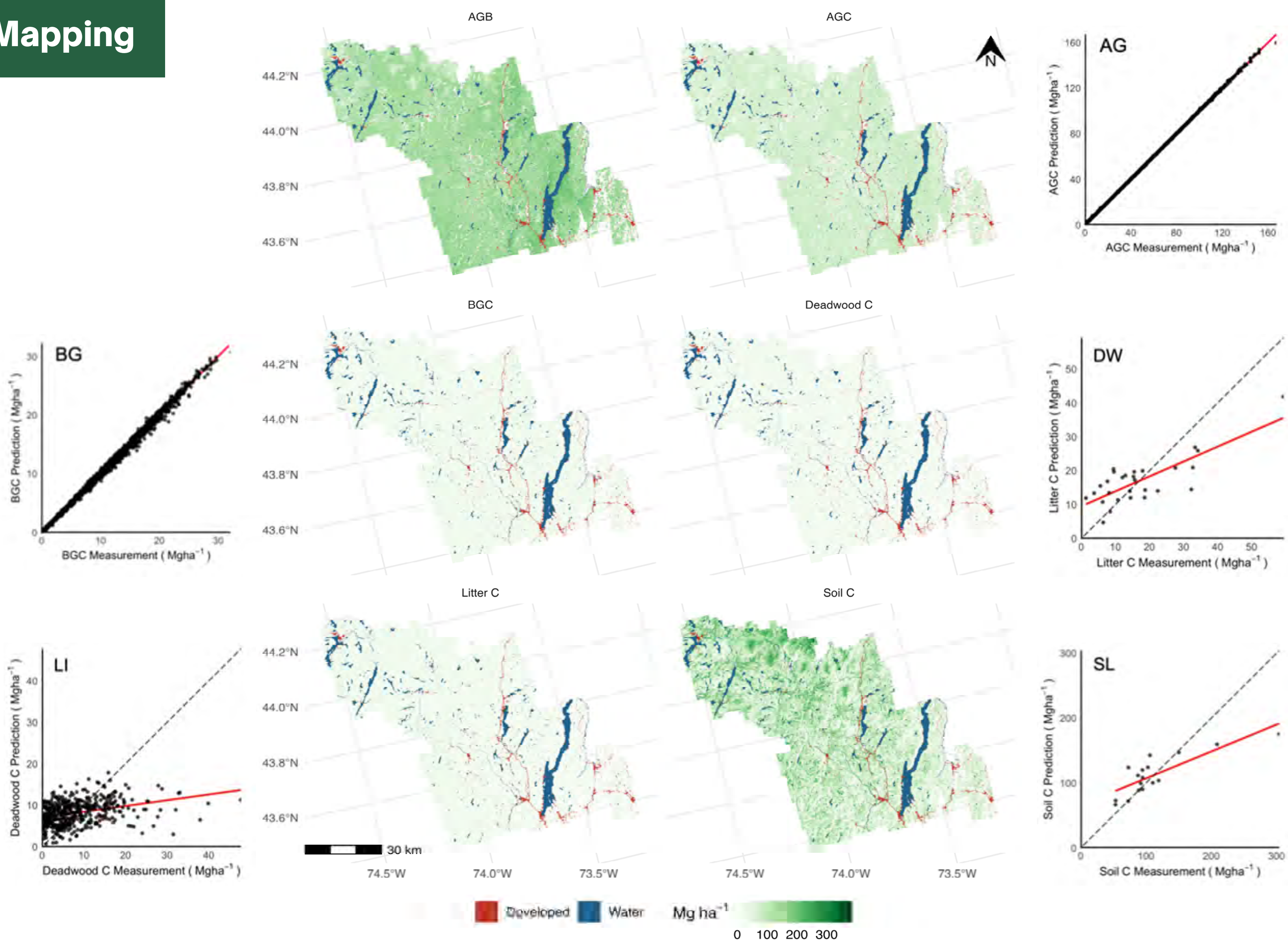

onondaganation.org/uncategorized/2022/land_back_1023_acres/
New Chrome available
Magnifier 100%
Rotation 0.0 °
Render
Unknown CRS

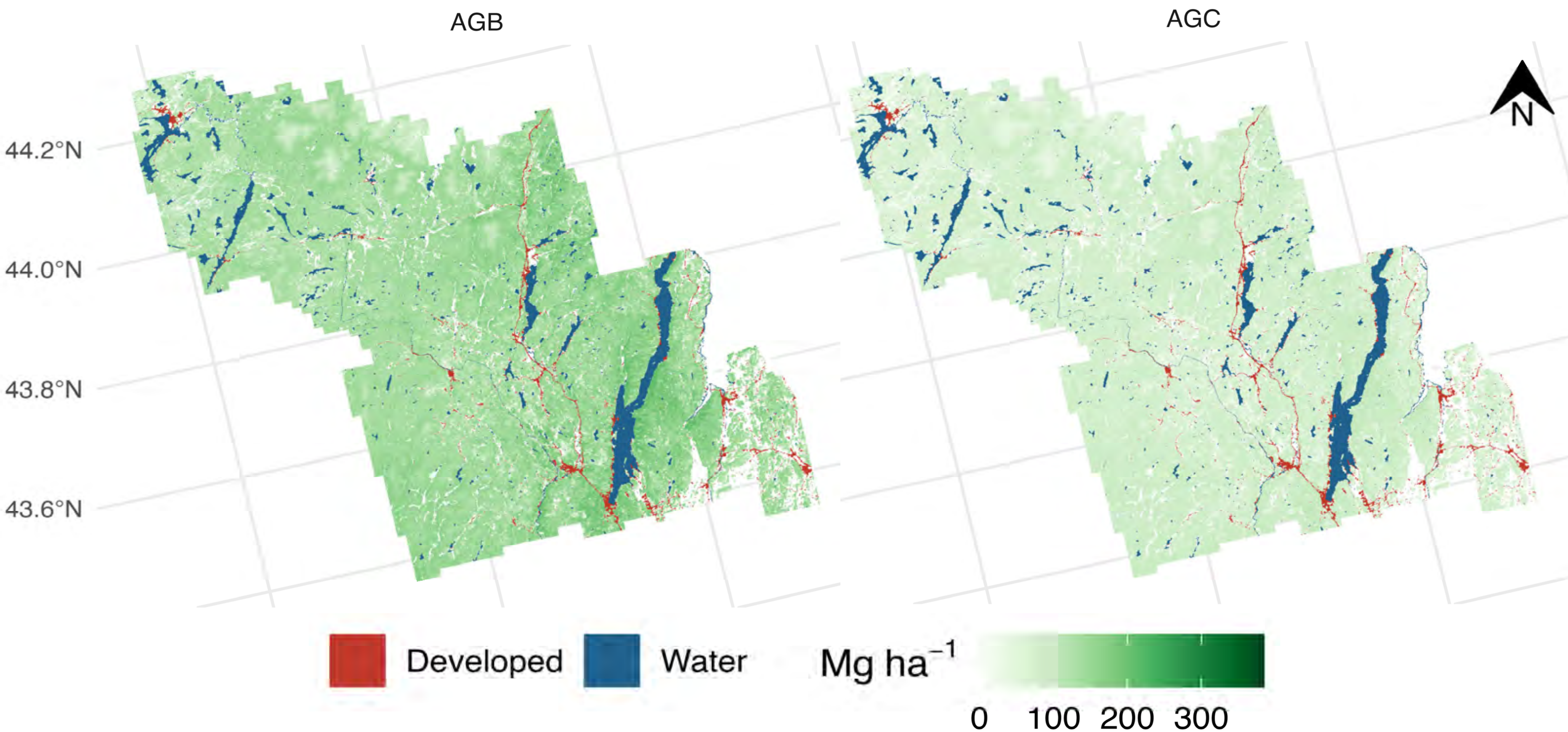


AGB & C Mapping

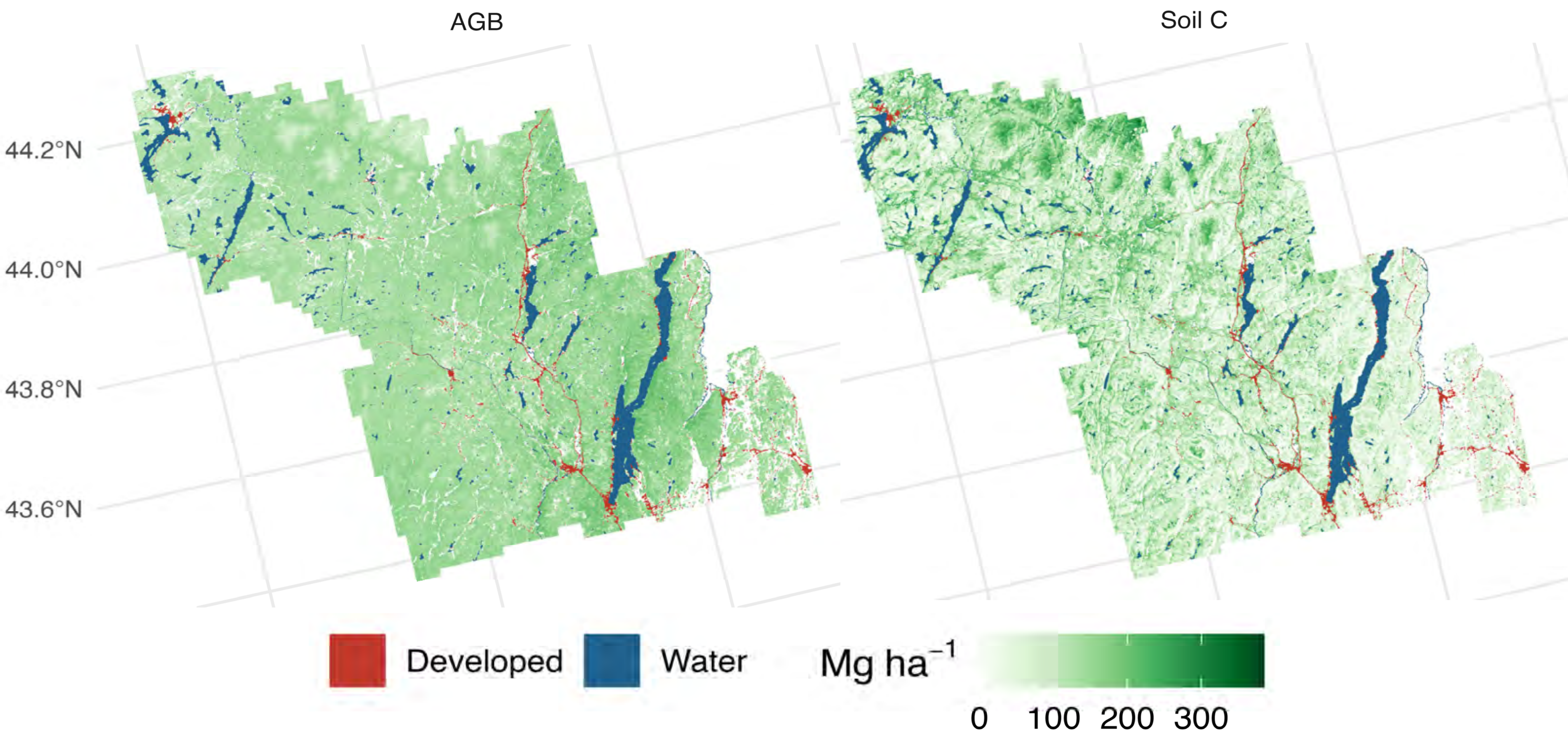
Hybrid ensembles combine direct (Landsat x FIA) and indirect (Landsat x LIDAR-AGB) using a common set of LT-GEE derived predictors to achieve a good balance between overall accuracy, prediction ceiling and fine-grain patterns.

AGB & C Mapping

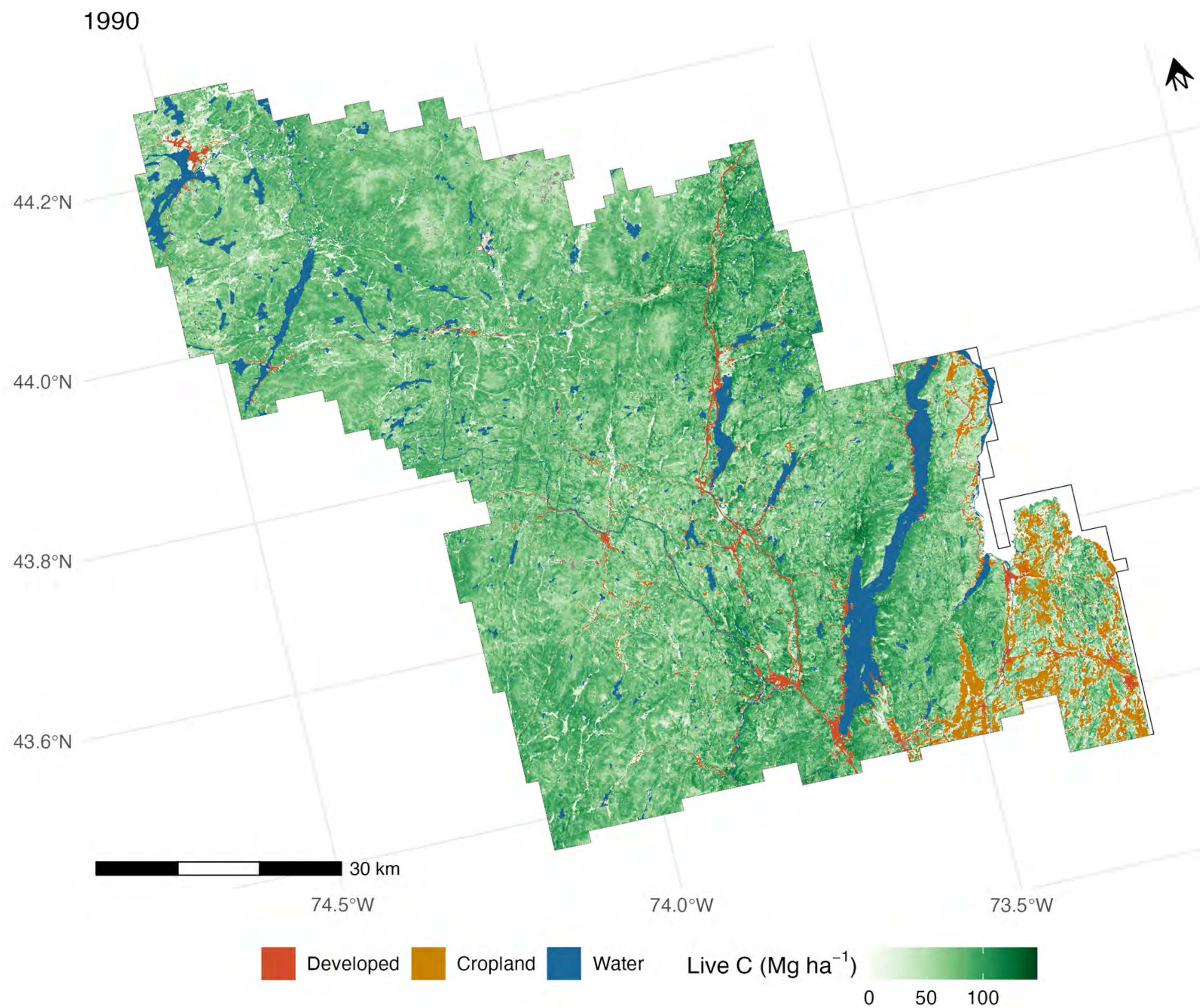




AGB & C Mapping



AGB & C Mapping


1990
44.2°N
44.0°N
43.8°N
43.6°N
30 km
74.5°W
74.0°W
73.5°W
Developed
Cropland
Water
Live C (Mg ha^{-1})
0
50
100

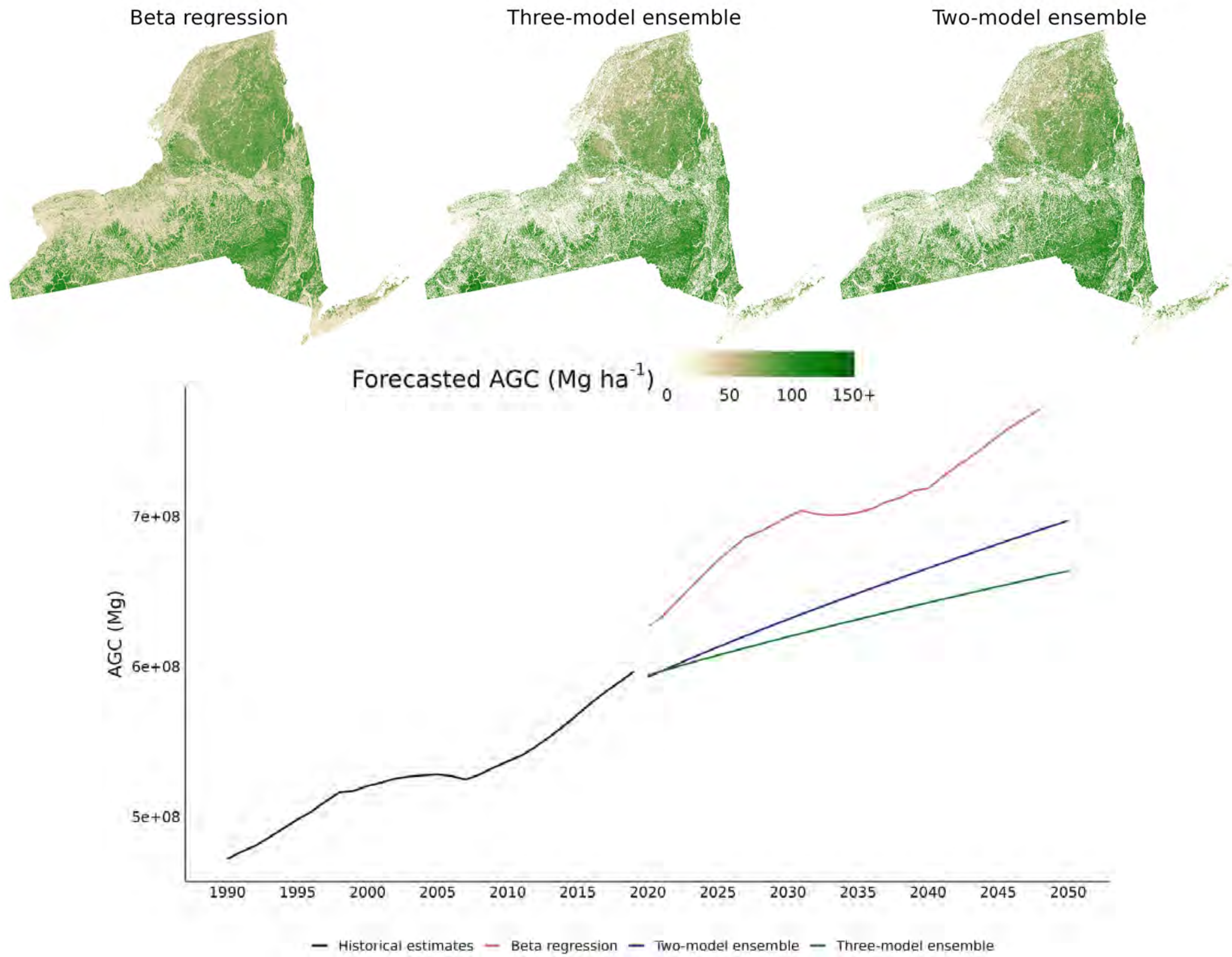
Time-series forecasting models trained on historical map series at pixel level

Baseline or 'business as usual' map forecasts of potential future C seq

Many forecasts possible...

Can incorporate future LULC maps and model scenarios

Next step: integrate stand-level simulations (FVS) into mapping framework



Forecasting

Compiled most known sources of uncertainty in modeling framework:

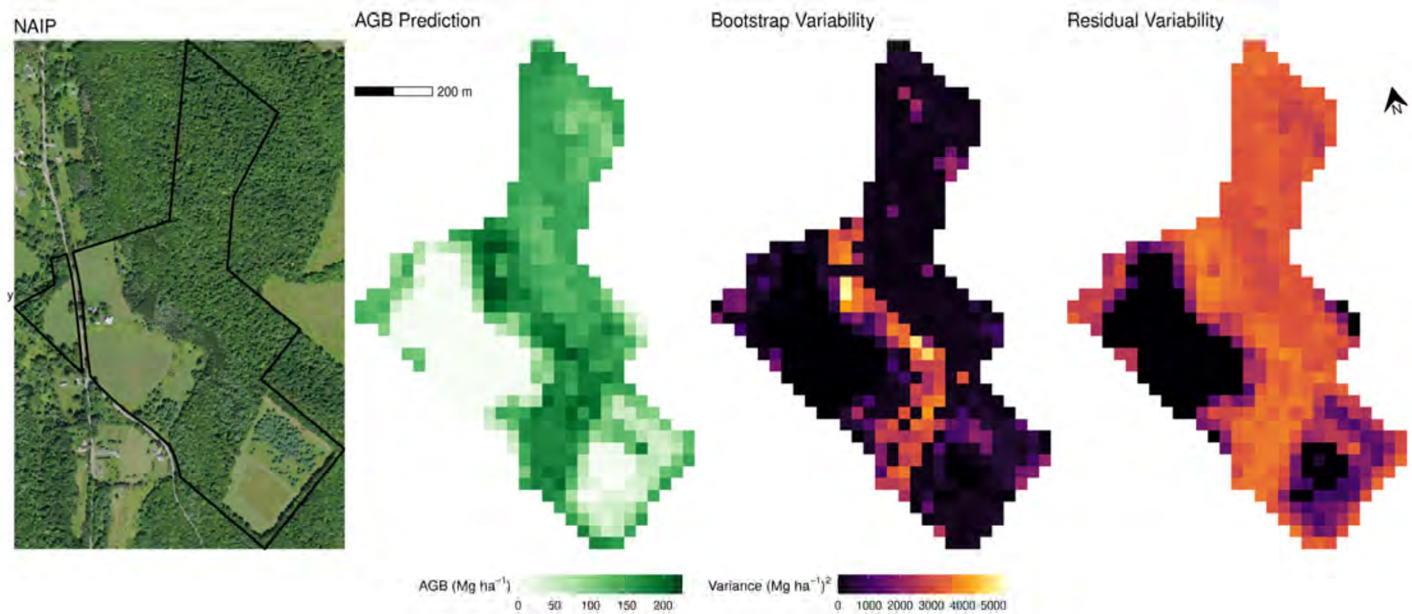
- Inventory plot location
- Plot measurement error
- Allometric models
- Spatial model residuals
- Spatial covariance

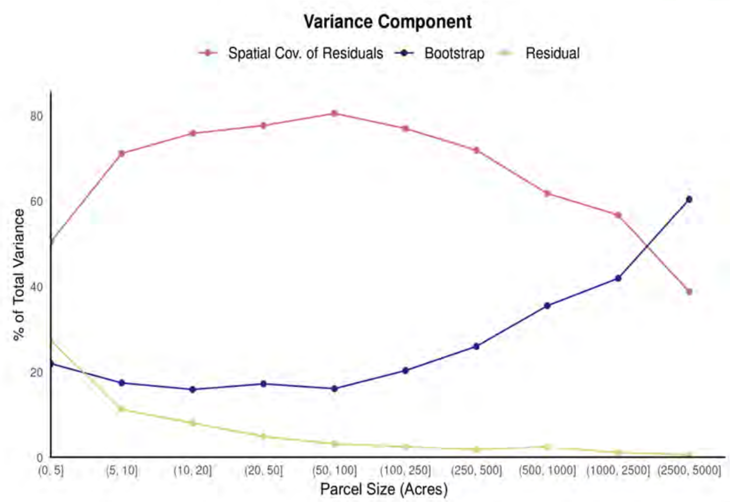
Error propagation through 'daisy-chain' of models

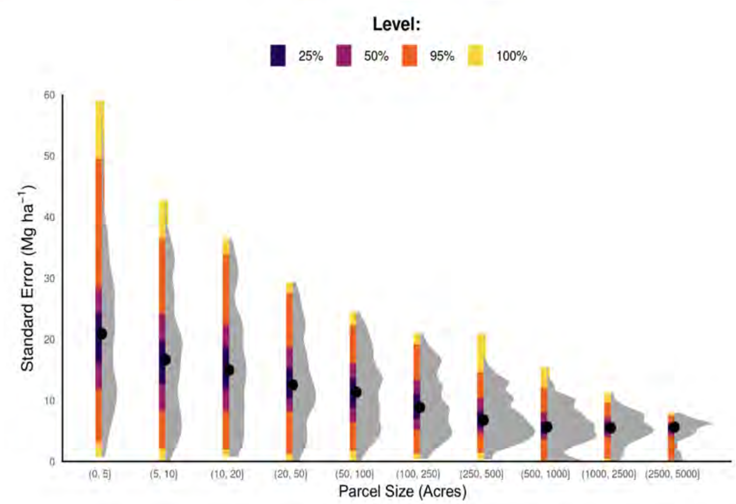
Provides pixel-level estimates of variability for map products

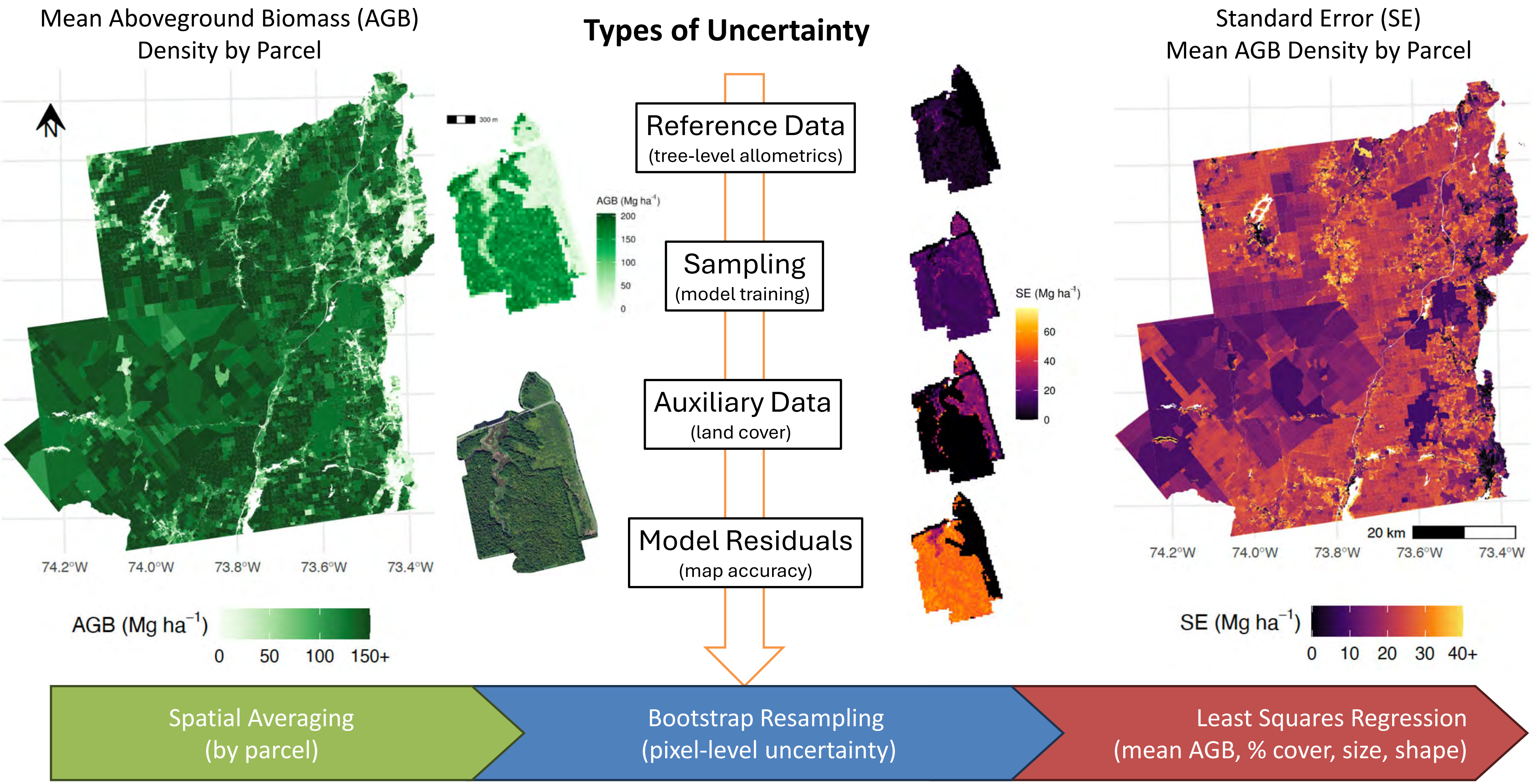
Scaleable uncertainty estimation for arbitrary map areas (groups of pixels)

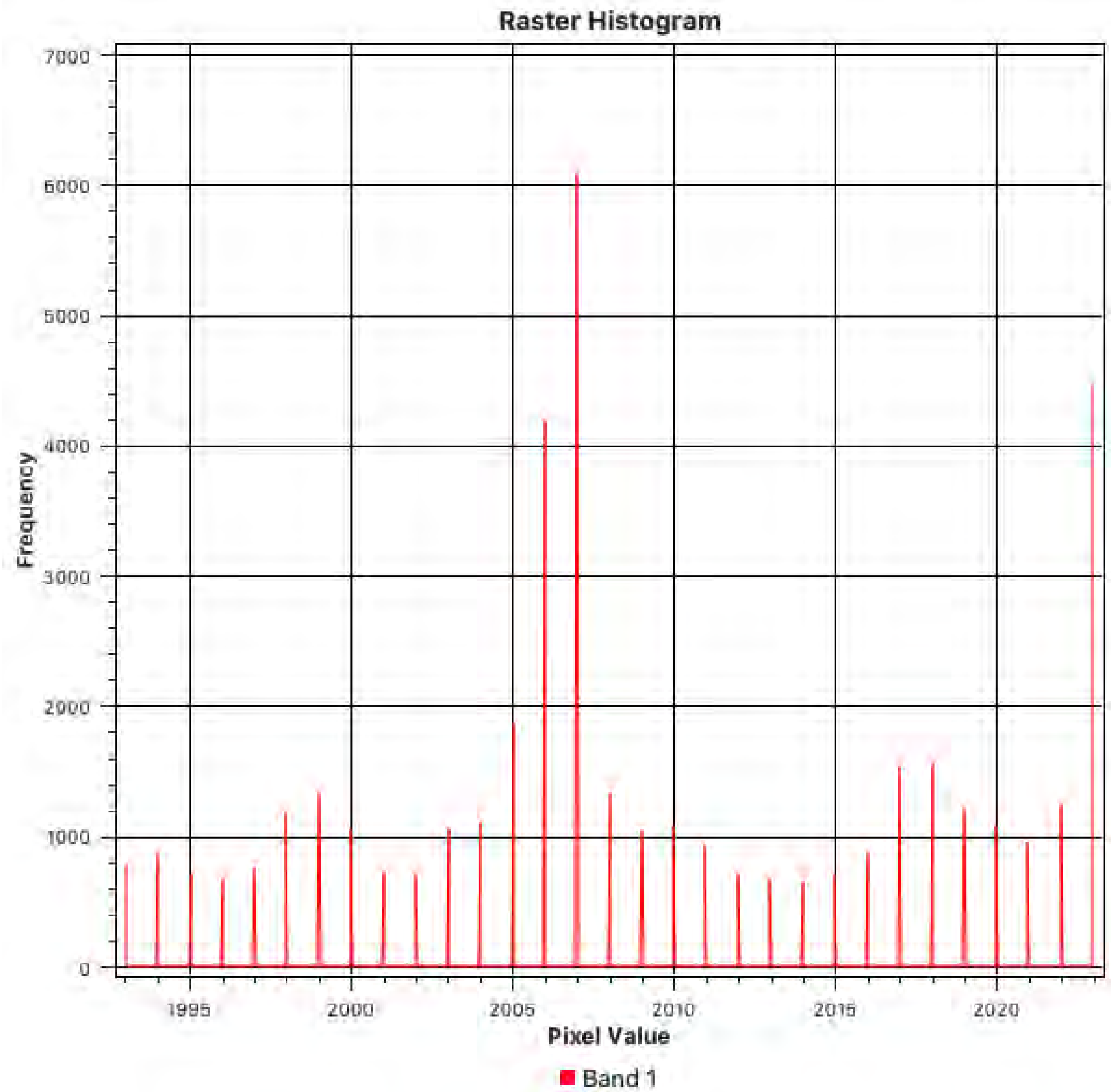
Uncertainty







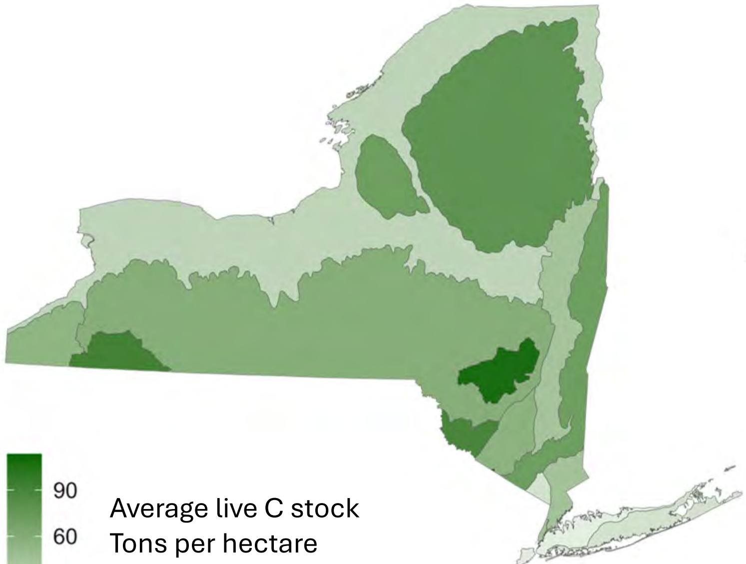

Mean Aboveground Biomass (AGB)
Density by Parcel
Types of Uncertainty
Standard Error (SE)
Mean AGB Density by Parcel
N
300 m
AGB (Mg ha-1)
200
150
100
50
0
Reference Data
(tree-level allometrics)
Sampling
(model training)
Auxiliary Data
(land cover)
Model Residuals
(map accuracy)
SE (Mg ha-1)
60
40
20
0
74.2°W
74.0°W
73.8°W
73.6°W
73.4°W
20 km
AGB (Mg ha-1)
0 50 100 150+
SE (Mg ha-1)
0 10 20 30 40+
Spatial Averaging
(by parcel)
Bootstrap Resampling
(pixel-level uncertainty)
Least Squares Regression
(mean AGB, % cover, size, shape)

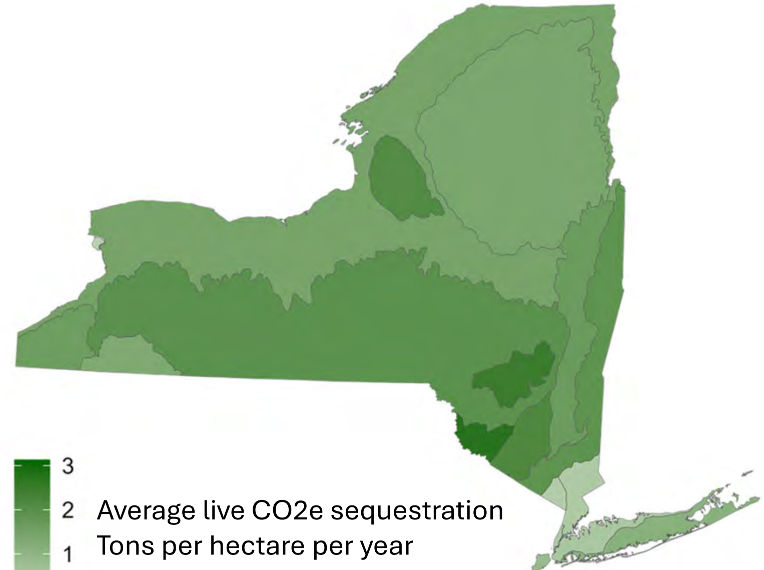


Raster Histogram
Frequency
7000
6000
5000
4000
3000
2000
1000
0
1995
2000
2005
2010
2015
2020
Pixel Value
Band 1

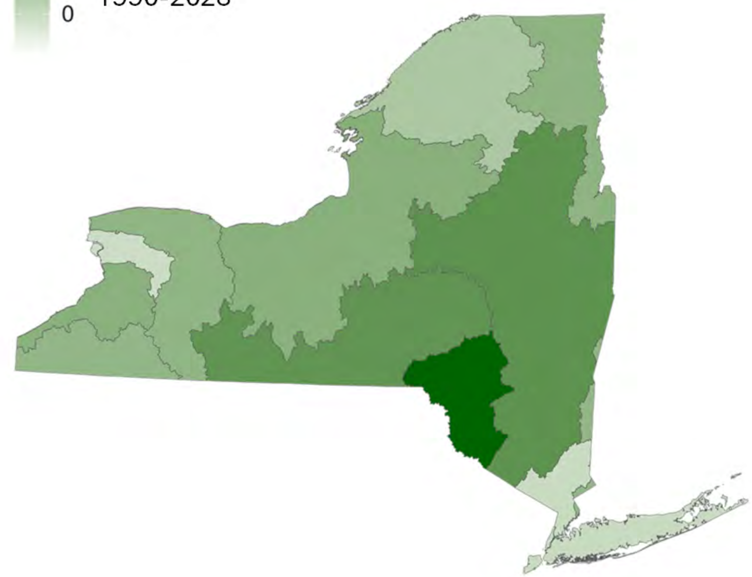
Role of Catskills in NYS Carbon Sink

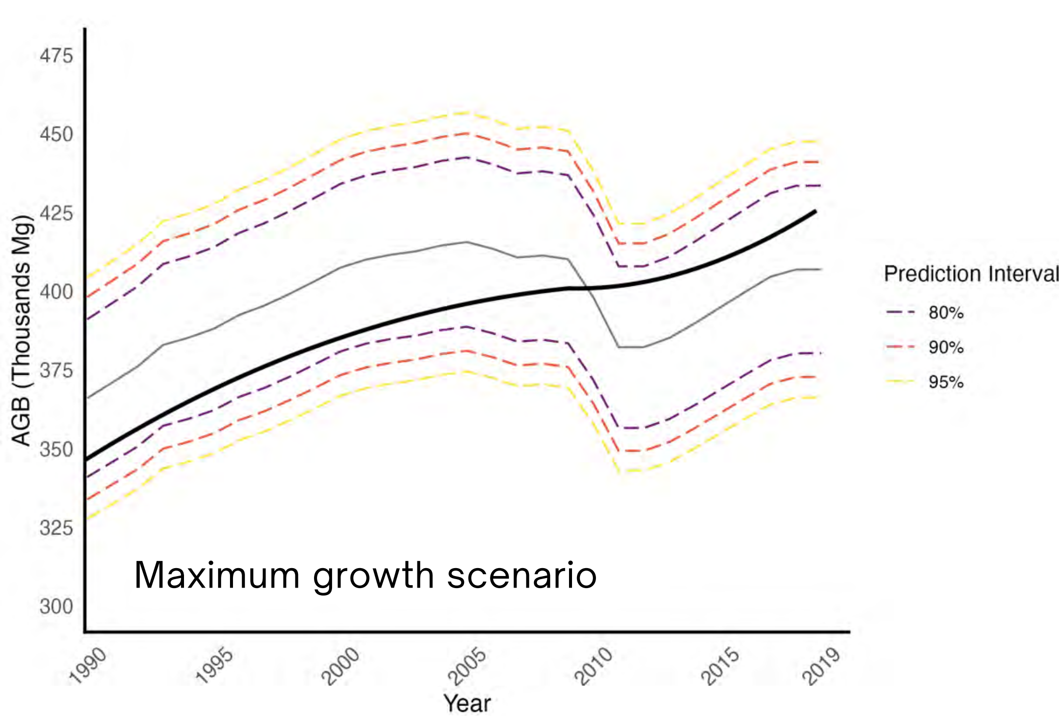
By Ecoregions
(Level III)





By Watersheds
(Basins)



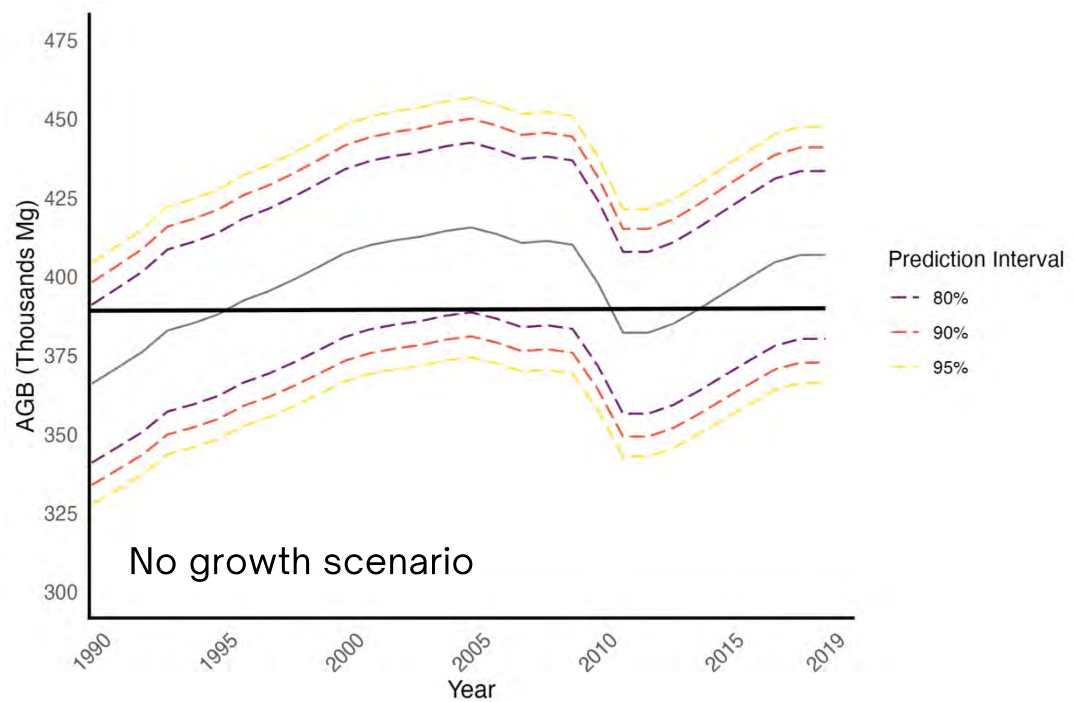


Uncertainty

Can we reliably estimate stock-changes when uncertainty > rate of change?

Even with ”best in class” models (h/t: J. Battles) there is room for interpretation

Room for improvement: reducing uncertainty, ‘green up’ vs ‘grow up’, etc.



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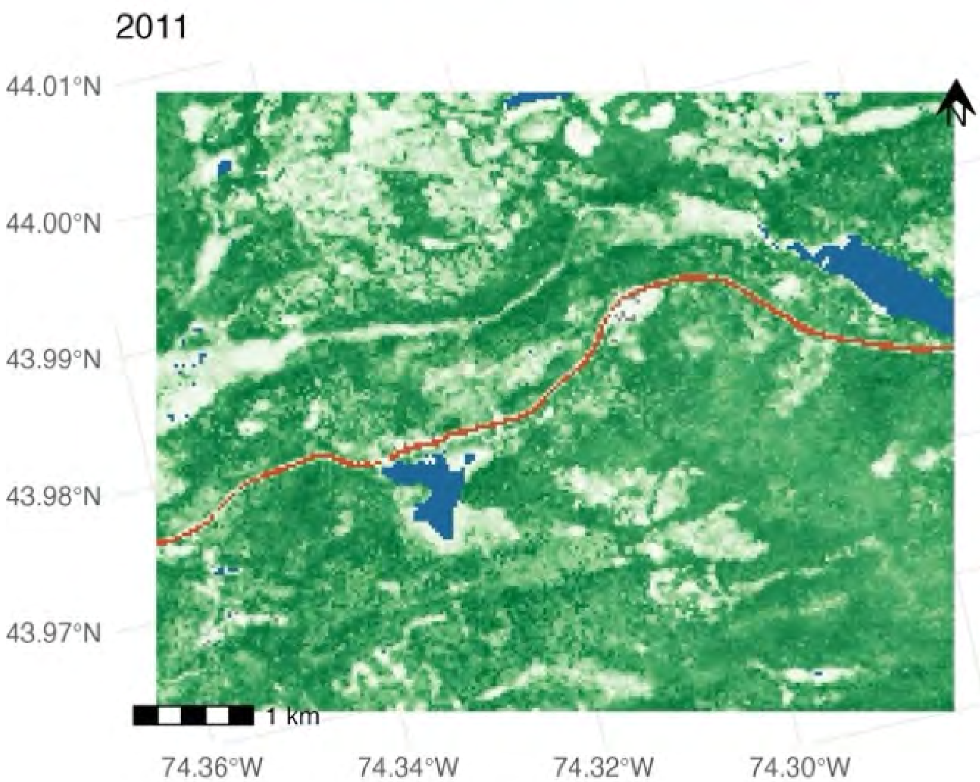

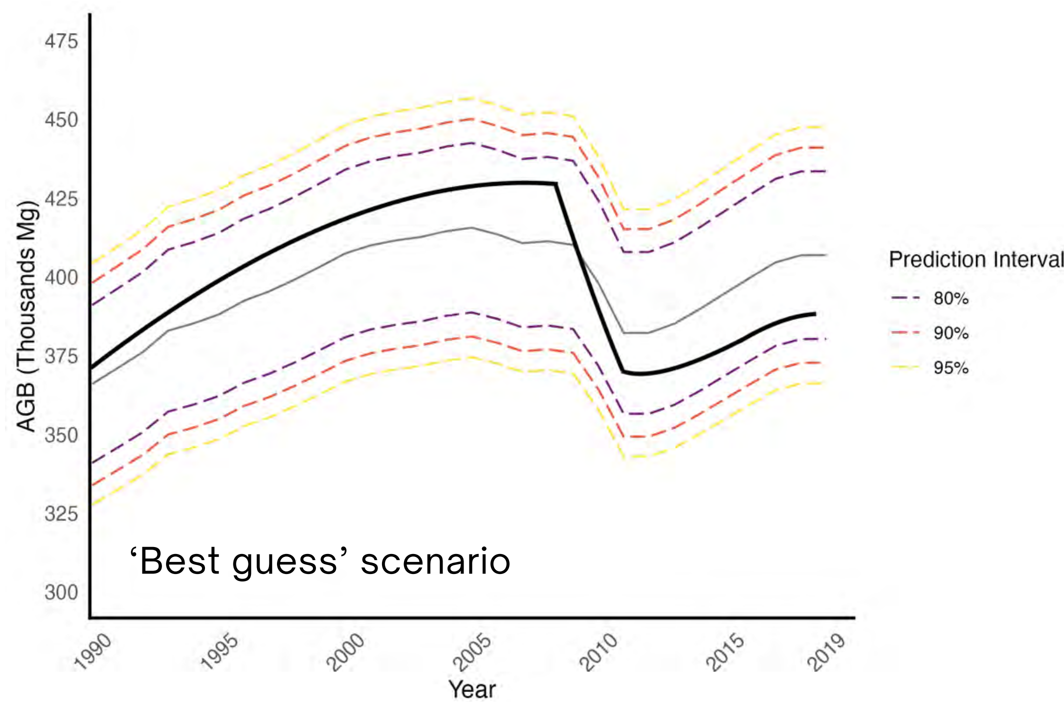

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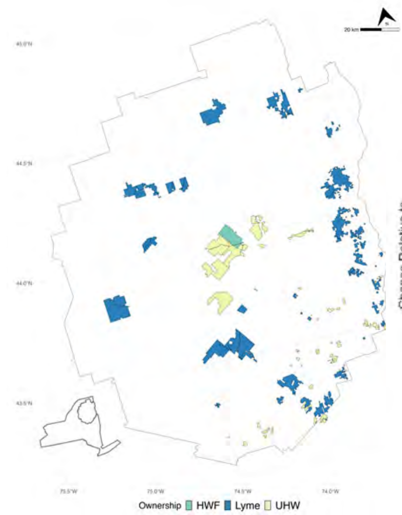
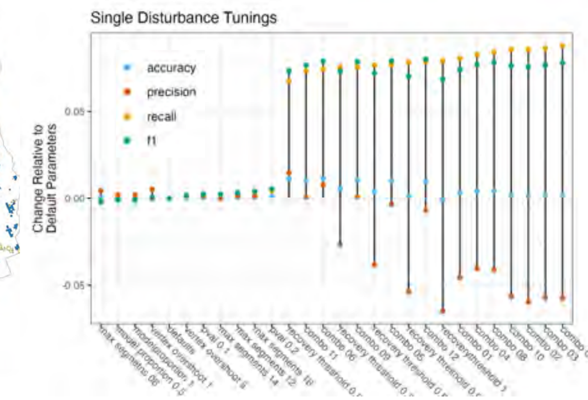
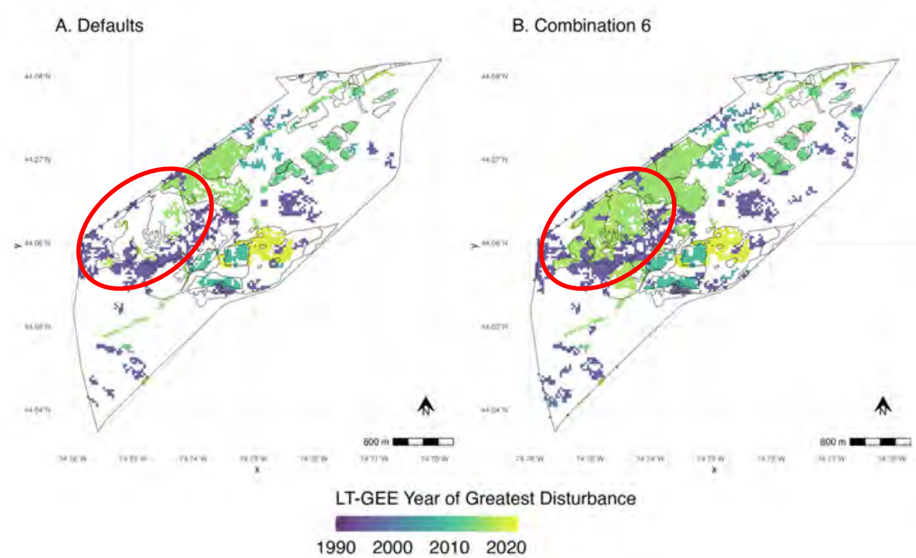
Room for improvement: reducing uncertainty, ‘green up’ vs ‘grow up’, etc.

Detection

Multiple ‘tunings’ of LT-GEE based on extensive harvest records; provides statewide high-res data on disturbance timing, location, magnitude back to 1990







Applications: Landscape Change

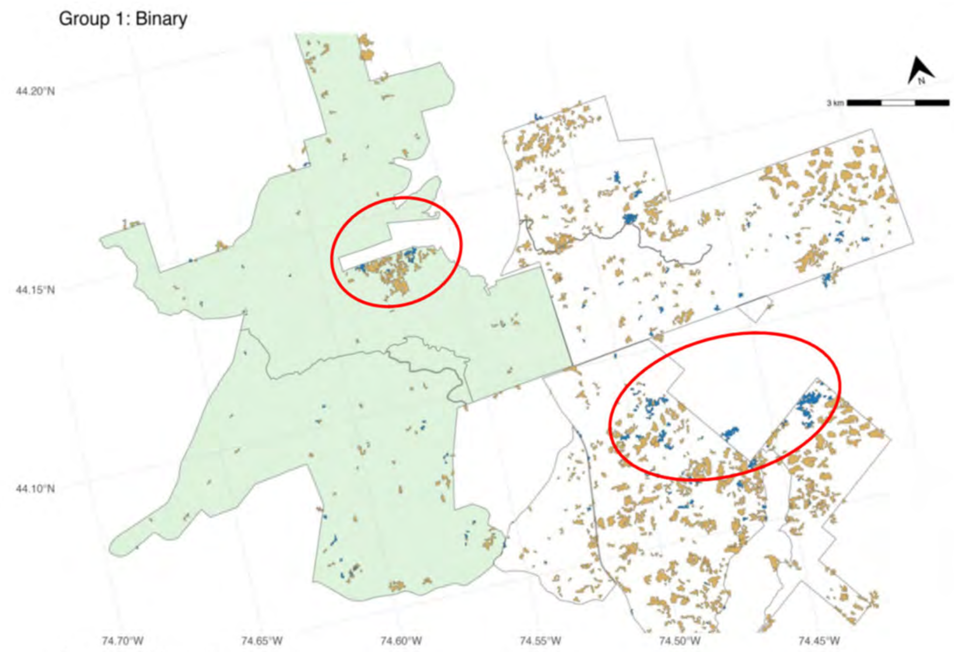
Detection

Multiple ‘tunings’ of LT-GEE based on extensive harvest records; provides statewide high-res data on disturbance timing, location, magnitude back to 1990

Attribution

Patch level classification of harvest vs non-harvest disturbances based on spectral, spatial properties of LT-GEE outputs

Applications: Landscape Change



Accuracy	Precision	Recall	Specificity	F1	ROC AUC
0.926	0.937	0.937	0.908	0.937	0.969

	Land Designation	Total Area (ha)	Percentage Total Area Disturbed	Disturbed Area Classified as Harvest
Group 1	Private	10,498	12.06%	850 (67.1%)
	Public	10,692	2.45%	30 (11.5%)
Group 2	Private	28,639	17.39%	3,339 (67.0%)
	Public	28,343	3.34%	260 (27.5%)

Applications: Landscape Change

Detection

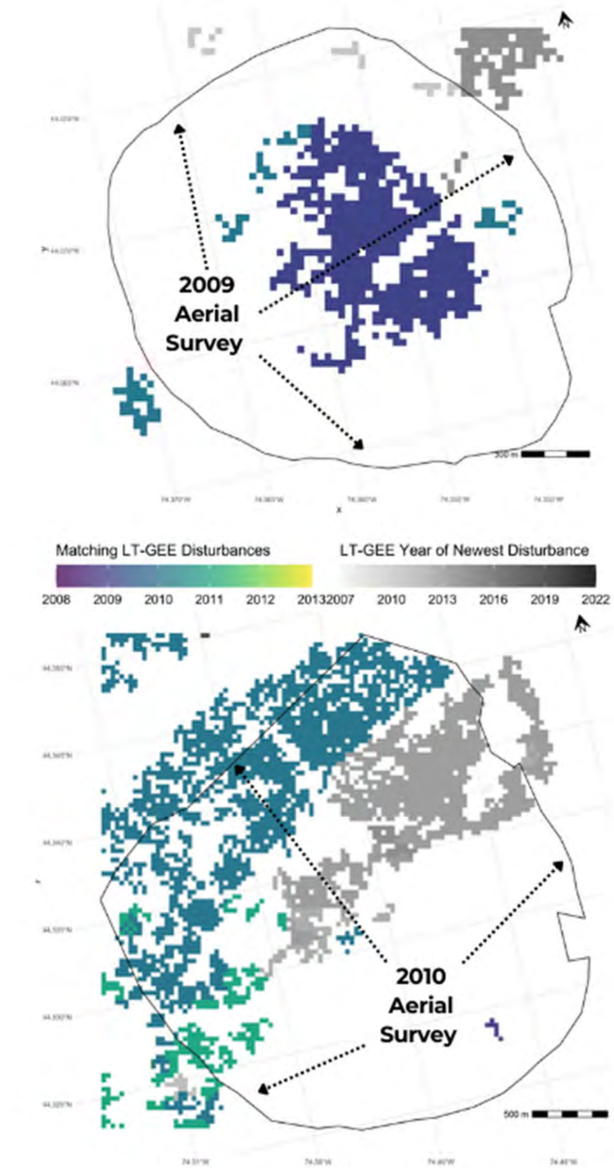
Multiple ‘tunings’ of LT-GEE based on extensive harvest records; provides statewide high-res data on disturbance timing, location, magnitude back to 1990

Attribution

Patch level classification of harvest vs non-harvest disturbances based on spectral, spatial properties of LT-GEE outputs

Forest Health

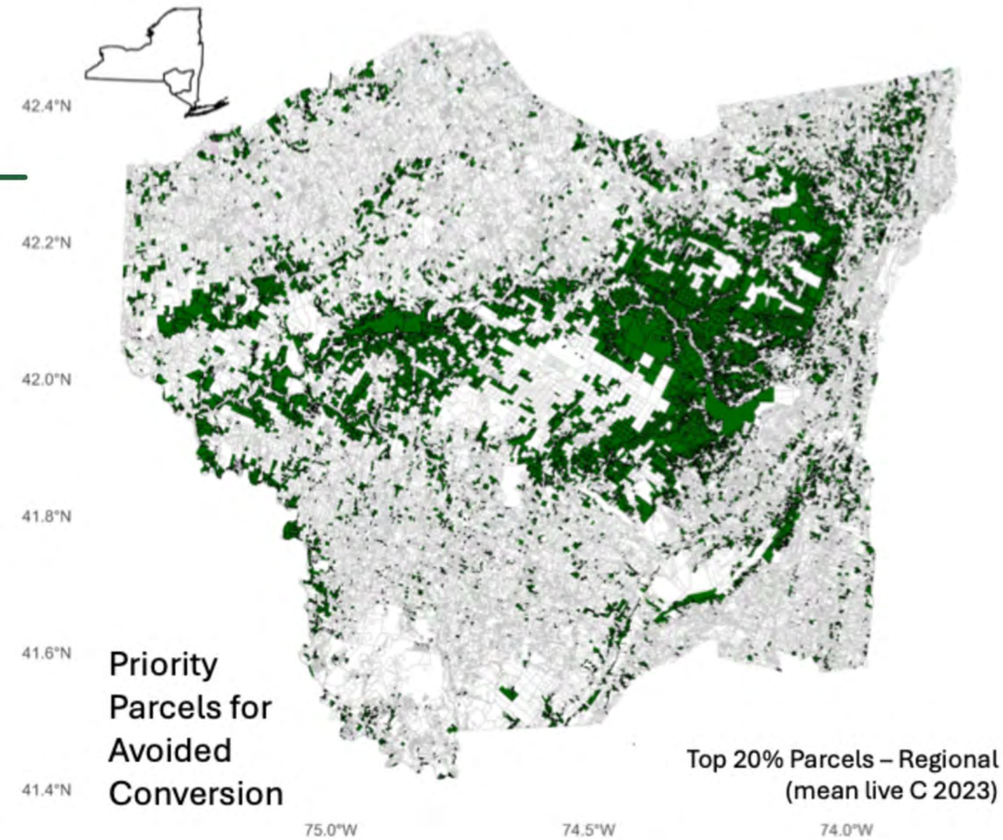
Cross validation of DEC aerial forest health maps; mapping insect outbreaks and pathogen impacts, defoliation events, etc.



Parcels

Screening and prioritizing forest parcels for enrollment in voluntary programs, conservation easements, land trust acquisition, offsets, etc.

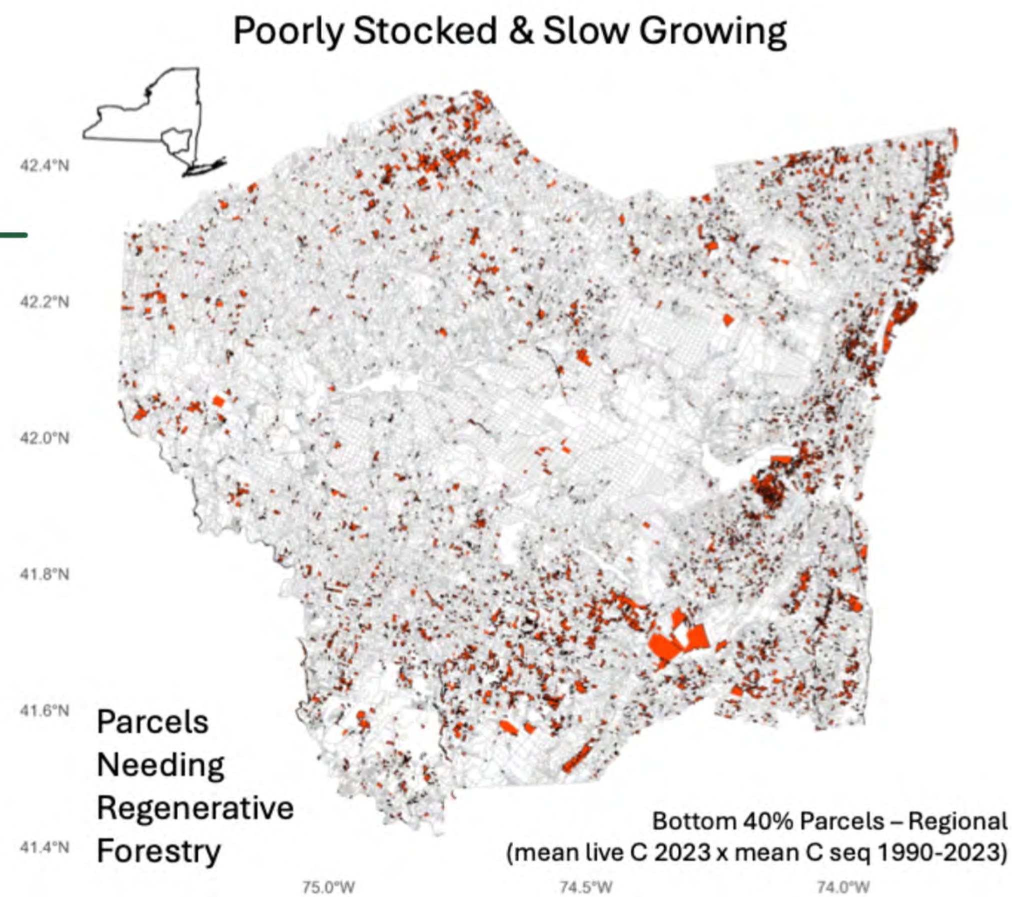
High Carbon Density



Applications: Climate Solutions

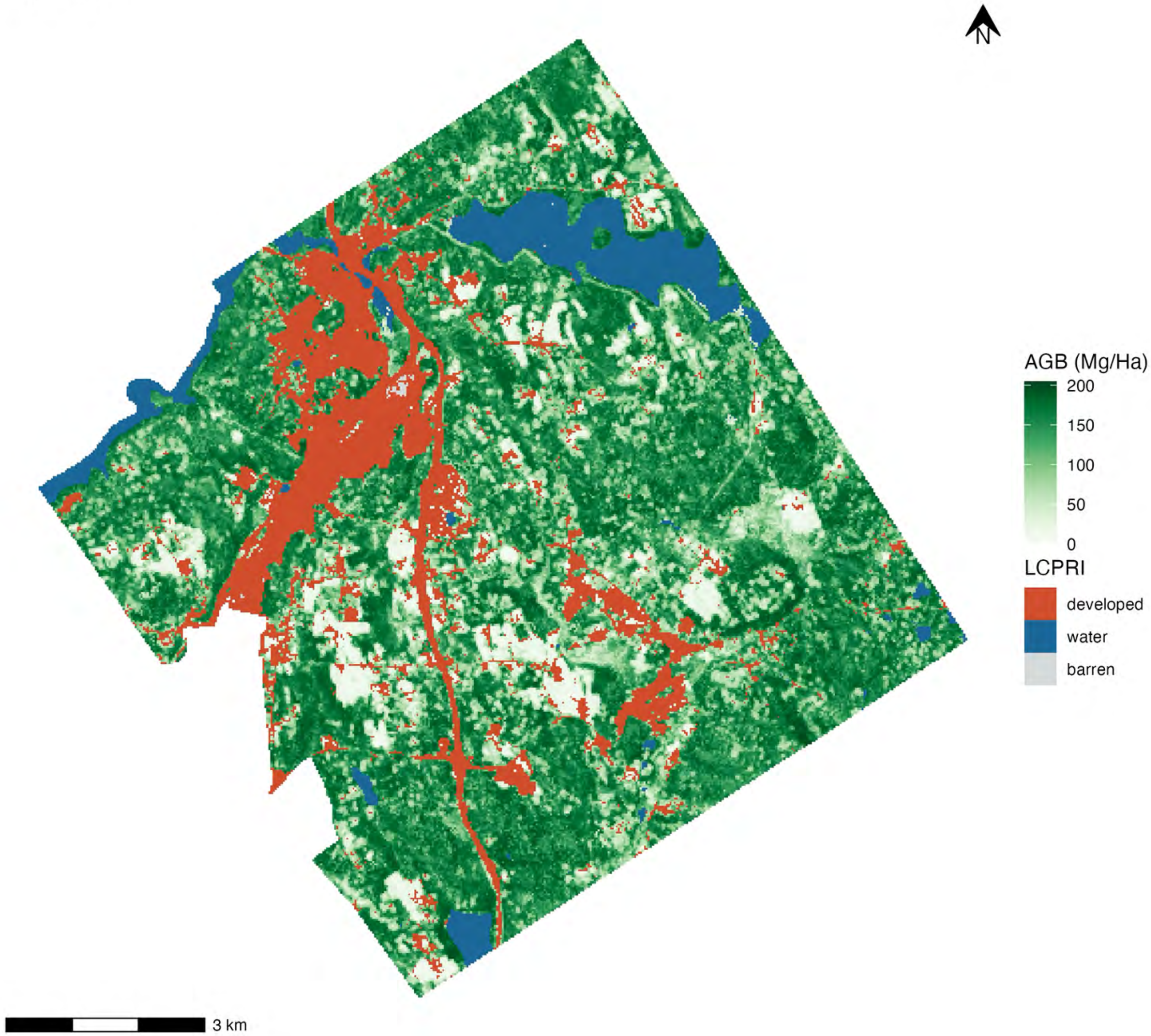
Parcels

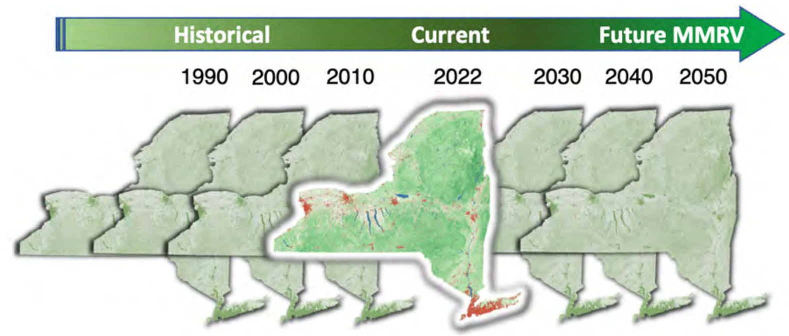
Screening and prioritizing forest parcels for enrollment in voluntary programs, conservation easements, land trust acquisition, offsets, etc.



Applications: Climate Solutions

Target 1990





USDA

FIA

R

PostgreSQL

Google Earth Engine

Applications: marginal & transitional lands

Upstate NY is mostly a post-agricultural landscape

Old-fields in many areas are not going through succession as expected

Invasive shrubs are creating persistent shrub/scrub habitats

'Novel' ecosystems and cover types for NYS

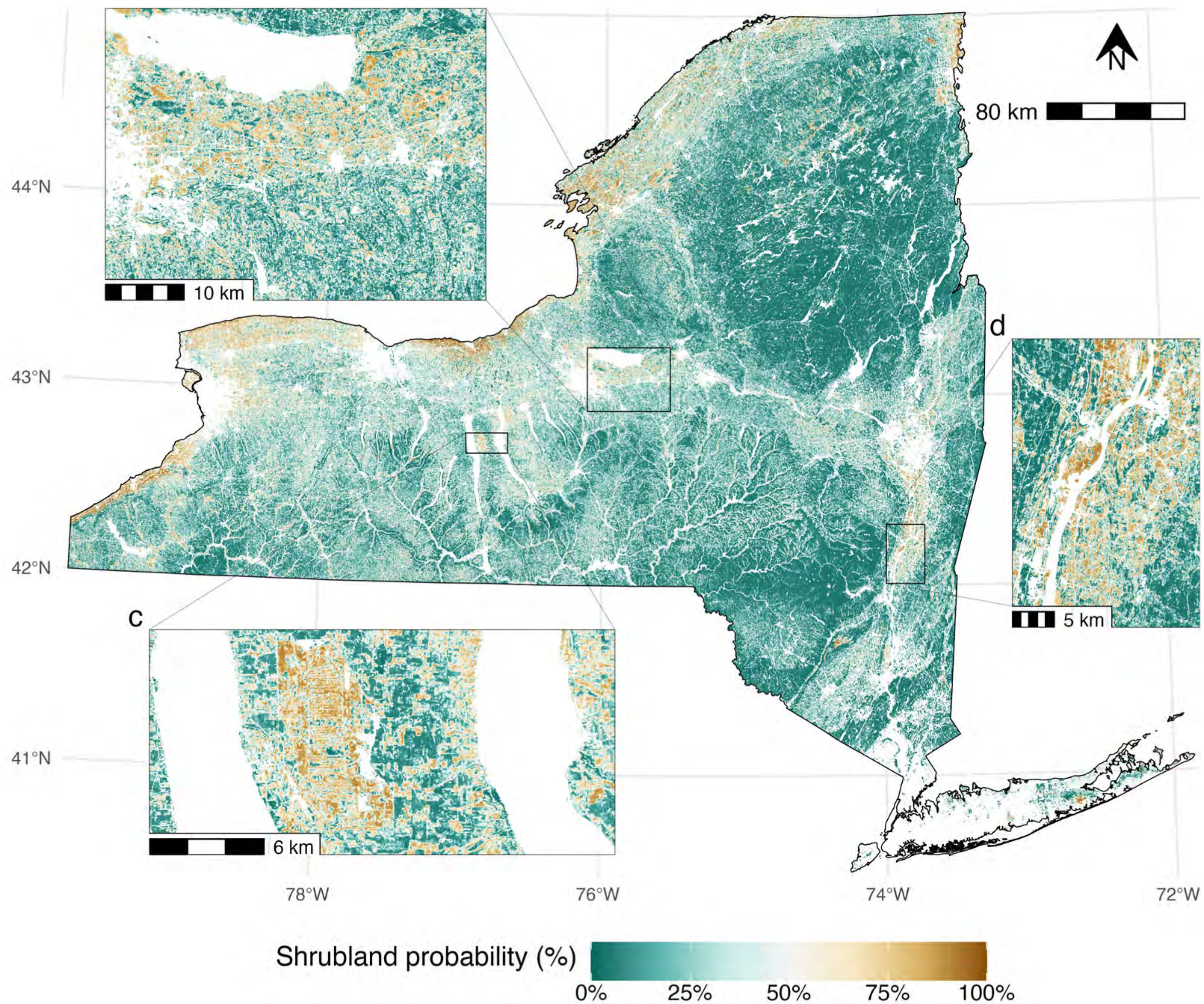
Applications: marginal & transitional lands

Combined LiDAR and Landsat to map low-statured vegetation (1-5m tall) at 30m

~1.4 million acres of 'shrublands' across NYS

Long-term carbon benefits and co-benefits are limited relative to forests

Ideal sites for reforestation, bioenergy crops, solar/wind facilities, silvopasture, etc.



Applications: urban forests & green spaces

We initially assumed that our LIDAR-AGB models would perform poorly in urban settings

A closer look suggests models can parse out built environment from urban tree cover

Neighborhood-scale assessment to support community-based planning and decision-making