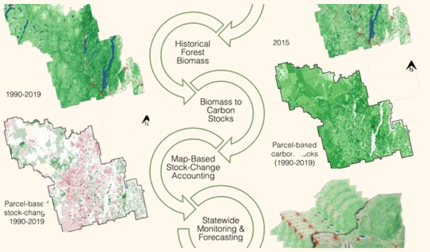
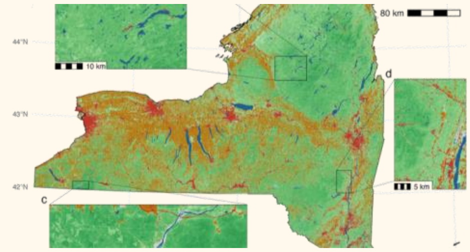
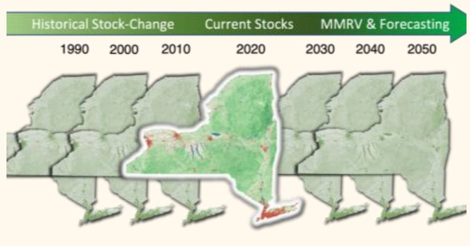
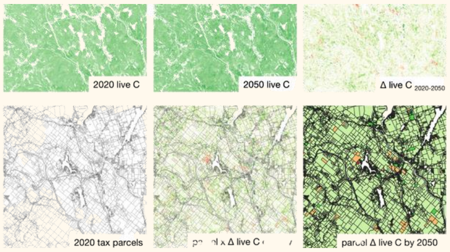
NEW YORK FOREST CARBON ASSESSMENT

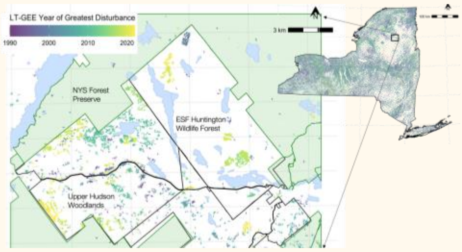
SUMMARY REPORT

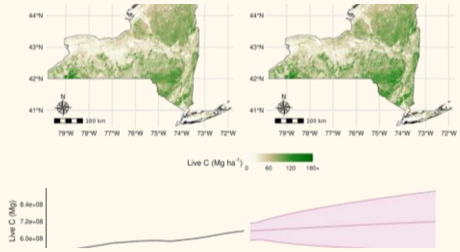












CLIMATE & APPLIED FOREST RESEARCH INSTITUTE

JUNE 2023

ESF
State University of New York College of Environmental Science and Forestry

CAFRI
Climate & Applied Forest Research Institute

NEW YORK STATE
Department of Environmental Conservation

SYNOPSIS

New York's forests will play an essential role in attaining the 2050 goal of 'net-zero' greenhouse gas emissions, by offsetting hard-to-decarbonize sectors while providing many other social and environmental co-benefits. Based on federal reporting, the climate benefits provided by New York forests have decreased since 1990, resulting in a statewide carbon sink that is now roughly half the size needed by 2050. However, state-level numbers cannot shed light on where, why, or how New York's forest C sink has been changing, or what lands are ideal for reforestation, conservation or improved management, or how existing and emerging threats could affect land use practices and outcomes. Because most of New York's forest land is privately owned in small non-industrial parcels, better data and tools are needed to design effective programs, engage with landowners, monitor and verify benefits, and support forest-based solutions across New York's complex and changing landscape.

The New York Forest Carbon Assessment developed a leading-edge system for mapping carbon stocks over time, estimating stock-changes at variable spatial and temporal scales, and translating stock-change maps into IPCC-based carbon accounting. Map-based estimates of trends in carbon stocks provide estimates of net sequestration and emissions using an accounting workflow that also incorporates past and projected future land use change. The ability to geographically summarize and analyze these map products for any area of interest within NYS, such as by individual parcels or administrative units, undergirds a statewide forest carbon assessment with versatile end-uses and decision-support applications.

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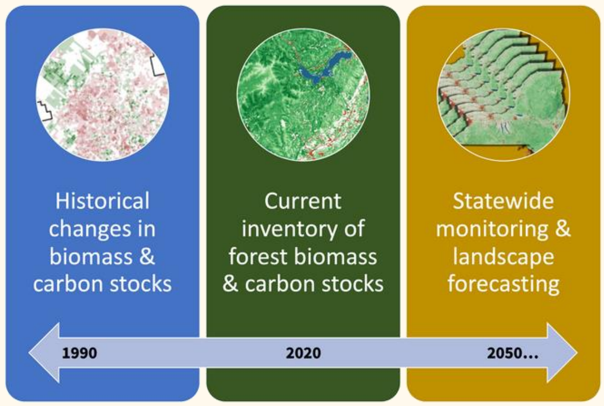
CLIMATE & APPLIED FOREST RESEARCH INSTITUTE @ SUNY ESF

June 2023

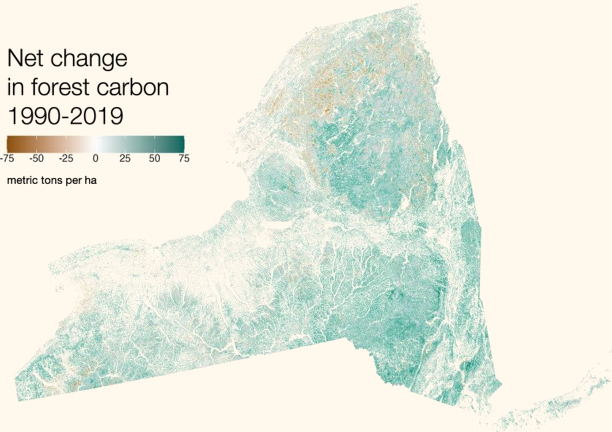
EXECUTIVE SUMMARY

Achieving New York's net zero emissions by 2050 goal will require substantial and sustainable growth of the statewide forest carbon sink – the amount of greenhouse gas sequestered annually by all natural and working forest lands – to offset future emissions from hard-to-decarbonize sectors and reduce climate risk. For regulatory and voluntary programs to achieve this goal across New York's complex and changing landscape, better data and tools were needed that operate at the scales where planning, decision-making, and action occur: parcels, administrative units, municipalities, etc.



Statewide annual 30-meter resolution maps & data

In the New York Forest Carbon Assessment, we developed a map-based carbon accounting system that produced fine-grained 'wall-to-wall' estimates of past, present, and future climate benefits, based on publicly available data and open-source tools. Statewide monitoring and forecasting capabilities were built into the system, which generated carbon accounting estimates (consistent with IPCC and EPA reporting) at the scale of individual forest parcels. This report outlines the system's development, demonstrates its outputs, and highlights some applications to public and private-sector decision-making under New York's Climate Act.



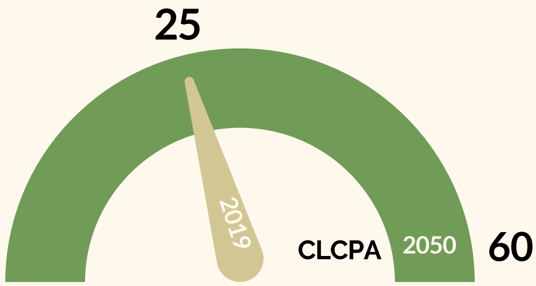
Deliverables include statewide maps and data products representing historical, present-day, and potential future carbon stocks, which provided a basis for parcel-level, landscape-scale accounting and monitoring of climate benefits. A cost-efficient carbon monitoring system was built to provide annual statewide map updates in near real-time (within a calendar year) via freely available satellite imagery. A reference level estimate of statewide forest carbon benefits from 1990-2050 was produced under a 'business-as-usual' (BAU) scenario.

KEY OUTCOMES

- **Forest biomass and carbon accounting estimates for every forested parcel in NYS from 1990 to 2019, with carbon benefits forecasted to 2050.**
- **A cost-efficient, ready-to-deploy statewide forest carbon monitoring system to support voluntary programs and regulatory compliance.**
- **Monitoring capabilities for the NY Connects project ($60M) funded by US Dept. of Agriculture to invest in forest-based climate solutions.**
- **A versatile basis for decision-support needs related to CLCPA and other state and local government policy, planning, and regulatory priorities.**
- **Data sharing with state and local governments and private-sector partners, including forest landowners and land trust organizations.**

AT A GLANCE: NEW YORK FORESTS & CLIMATE

New York needs to grow and sustain a much larger forest carbon sink

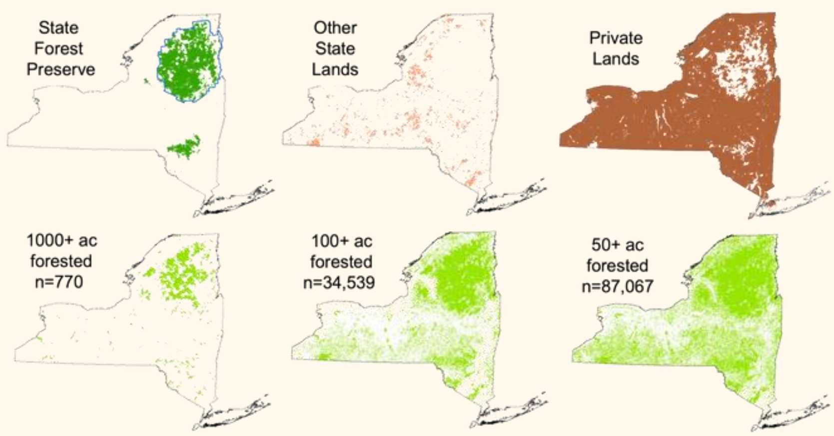


New York's Forest Carbon Sink
(million metric tons CO2 eq removals per year)

Based on reporting by the US Forest Service, New York's forests have sequestered **24-26 million metric tons (MMT)** carbon dioxide equivalent (CO2 eq) annually over the last decade, i.e., the GHG emissions offset by forests each year. In addition, statewide carbon sequestration rates have been decreasing since 1990, due primarily to conversion of forest lands to non-forest uses. Overall, this shrinking NYS forest carbon sink stands in contrast with the CLCPA mandate for net-zero emissions by 2050, which counts on forests to offset up to **60 MMT** CO2 eq annually from New York's hard-to-decarbonize sectors.

Most of New York forest land is privately owned in small unmanaged parcels

Nearly three in four (74%) of New York's 19 million acres of forested land are privately owned, mostly in small parcels 10-150 acres in size. Landowners typically intend to conserve their forest and its values long-term, but relatively few have management plans. Small parcel sizes, changing markets, ecological degradation and other factors limit the commercial viability of these forest parcels, making them more vulnerable to growing pressures for development, leading to forest loss.



New York's climate goals require effective forest-based climate solutions

Reforestation
Establish more forested land through passive and active measures

Avoided Forest Conversion
Prevent conversion of existing forest lands to other land use types

Natural Forest Management
Enhance carbon benefits on working forest lands and help forests adapt to changing environment

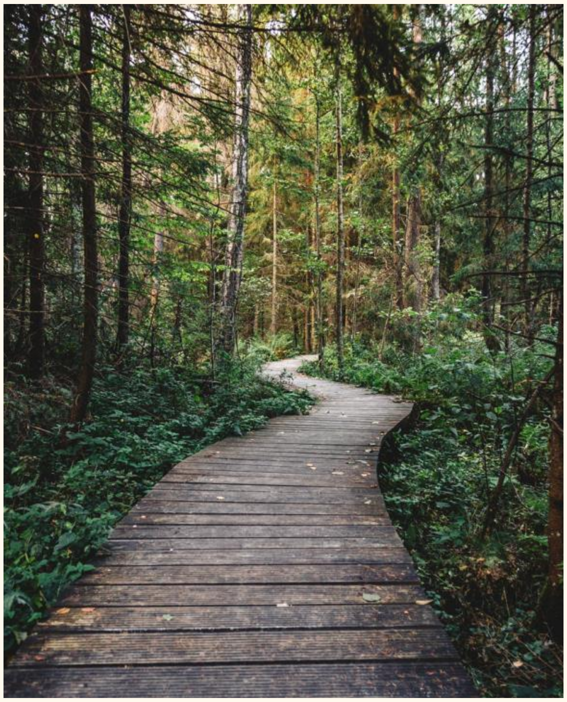
Forest-based climate solutions are practices that seek to sustainably increase carbon sequestration and storage by natural and working lands, in balance with other forest benefits and values. Together these practices will undergird a strategy to sustain, expand, and adaptively manage our forest land base to play its essential role in reducing climate risk while supporting community well-being. Given New York's complex and changing forest landscape, an effective strategy requires finding the best 'fit' between specific practices and local conditions and targeting efforts to maximize outcomes. To this end, better data and tools are needed at the relevant scales where planning, decision-making and action take place.

RATIONALE & PURPOSE

The Forest Inventory & Analysis (FIA) program of the US Forest Service reports state-level estimates of annual forest carbon (C) stocks and changes to the US EPA's Greenhouse Gas Inventory program. For New York State (NYS), these estimates of carbon sequestration and emissions are based on a statewide network of roughly 5,500 inventory plots remeasured every 7 years.

Although FIA is the most advanced national forest inventory program in the world, it was never designed to provide 'small area estimates' based on its extensive plot network. Estimating carbon benefits at state levels is valuable; however, both public and private-sector initiatives to advance forest-based climate solutions must engage with individual landowners to secure easements, offsets, and other incentive-based agreements. Likewise, verifying compliance with current and future regulations, as well as voluntary programs, must take place on the basis of individual landowners. New York faces a major challenge and opportunity to engage a large population of forest landowners, who predominantly own small parcels of forest land, in working towards the 2050 net zero emissions goal required by the state's 2019 Climate Act (CLCPA).

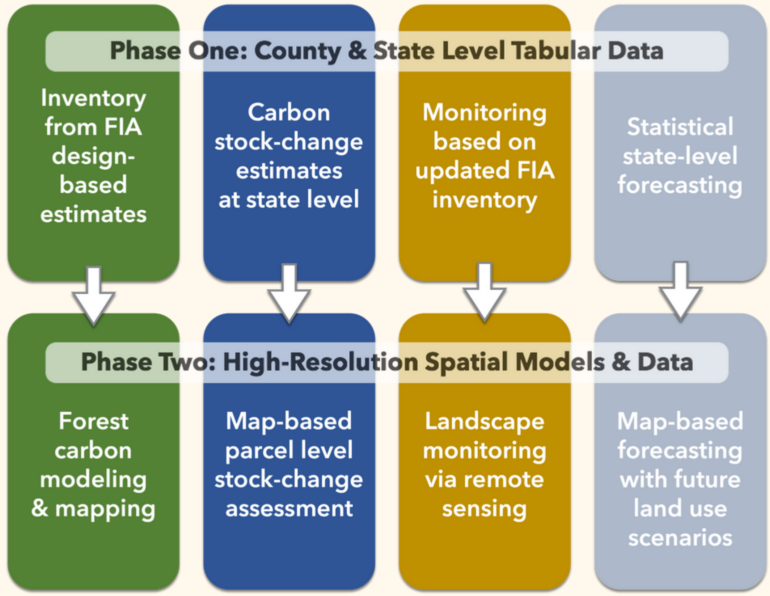
Build a map-based carbon accounting system for New York's natural and working forest lands, to support policy, regulatory, and stewardship decision-making that advances practical and sustainable forest-based climate solutions.



Forests will be essential for offsetting emissions from hard-to-decarbonize sectors and NYS will need to **roughly double the size of its current forest carbon sink by 2050** to meet this need. State-level FIA accounting clearly defines the scope of New York's challenge – doubling the size of a forest C sink that has been shrinking since 1990 – but offers few insights on how, why, and where the statewide forest C sink has been changing. It therefore provides little actionable information at relevant scales needed to design and implement forest-based solutions across New York's complex and changing forest landscape.

OBJECTIVES

The goal of the New York Forest Carbon Assessment was to translate the US Forest Service FIA program's data and methods for stock-change forest carbon accounting for EPA (Phase One) into a map-based approach that integrated remote sensing and machine learning to produce fine-grained geographic information at scales needed for planning and decision-making (Phase Two). Working in partnership with FIA, NYSDEC, NYS landowners, and carbon science experts, we built map-based inventory, stock-change, monitoring and forecasting capabilities, and integrated these tools and outputs using a carbon accounting framework based on IPCC and US EPA guidelines.

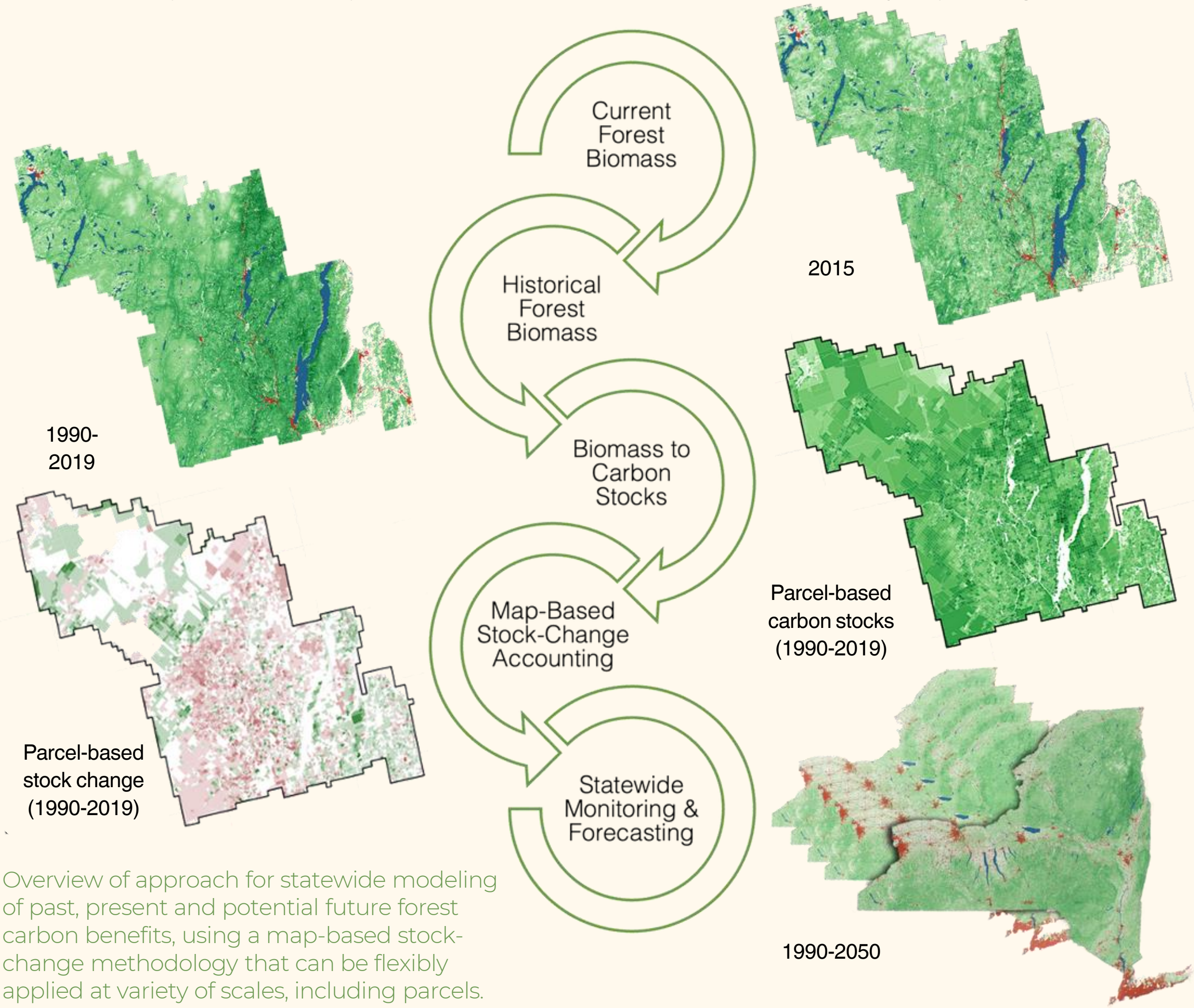


This project fundamentally relied on and sought to build upon the robust foundation provided by the US Forest Service FIA program's data and expertise. Collaboration with FIA staff was essential for a careful 'translation' of FIA methods and outputs into geospatial models and products. Our work was intended as an extension of, not a substitute for, FIA program activities.

- **MODEL AND MAP FOREST BIOMASS AND CARBON STOCKS USING FIELD INVENTORY, REMOTE SENSING AND MACHINE LEARNING**
- **APPLY STATEWIDE MODELING FRAMEWORK TO MAP HISTORICAL CARBON STOCKS AND STOCK-CHANGES SINCE 1990**
- **CONTINUOUSLY TRACK CARBON STOCKS AND LAND USE-LAND COVER CHANGE FOR MONITORING/REPORTING/VERIFICATION**
- **FORECAST CARBON STOCK CHANGES TO 2050 WITH SCENARIOS INCORPORATING PROJECTED LAND USE-LAND COVER**
- **COMPILE MAP DATA INTO IPCC-COMPLIANT GHG ACCOUNTING OUTPUTS**
- **DEMONSTRATE APPLICATIONS OF MAPS, DATA, AND MODELING TOOLS IN DECISION-SUPPORT CONTEXTS**

APPROACH

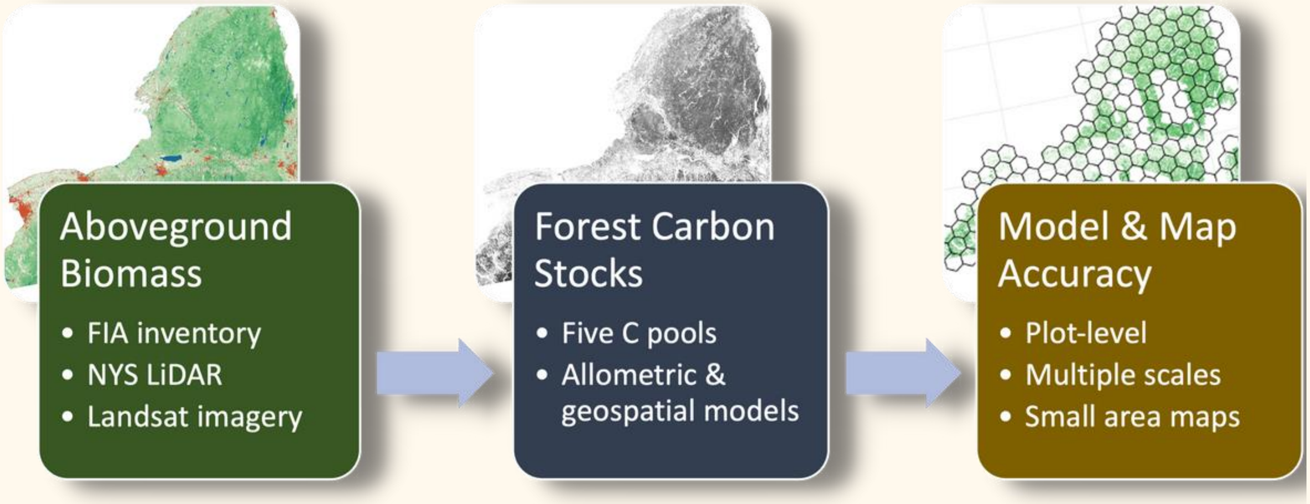
This project developed an integrated system for mapping biomass and carbon stocks over time, estimating stock changes at fine spatial and temporal scales, and translating stock-change maps into carbon accounting outputs based on IPCC guidelines. Models based on field inventory (FIA) and remote sensing data, including airborne LIDAR and Landsat imagery, were used to generate maps of aboveground biomass at fine-grained spatial (30 m) and temporal (yearly) resolution. First, statewide biomass maps were produced for recent past (1990-2019) and converted to estimates of forest carbon pools. Next, the same models will be used to produce annual monitoring update maps (2020, 2021, …) as Landsat imagery is released. Last, forecasting was done by training statistical models on historical map series, generating annual future carbon maps (2020-2050) and incorporating projected future land use-land cover (LULC) scenarios. All map products undergo rigorous testing against field inventory to estimate accuracy and uncertainty at multiple scales. Historical, monitoring and forecasting maps were compiled for stock-change analysis and passed to an accounting workflow that produces outputs consistent with IPCC GHG inventory reporting standards.



Overview of approach for statewide modeling of past, present and potential future forest carbon benefits, using a map-based stock-change methodology that can be flexibly applied at variety of scales, including parcels.

MAPPING FOREST BIOMASS & CARBON STOCKS

We developed a two-stage modeling approach to map aboveground biomass (AGB) as the basis to estimate and map carbon (C) stocks on forested lands across NYS. First, we trained machine learning models to predict AGB based on field inventory (FIA), airborne LIDAR (multiple sources via the NYSGPO repository) and satellite imagery (Landsat). We then combined these models into an ensemble for statewide mapping that relies primarily on Landsat imagery as input data. Use of Landsat allowed us to model historical AGB at a 30m resolution on a yearly basis back to 1990. Historical mapping at regular intervals provided the basis for map-based estimation of net additions (emissions) and removals (sequestration) using an IPCC stock-change methodology.



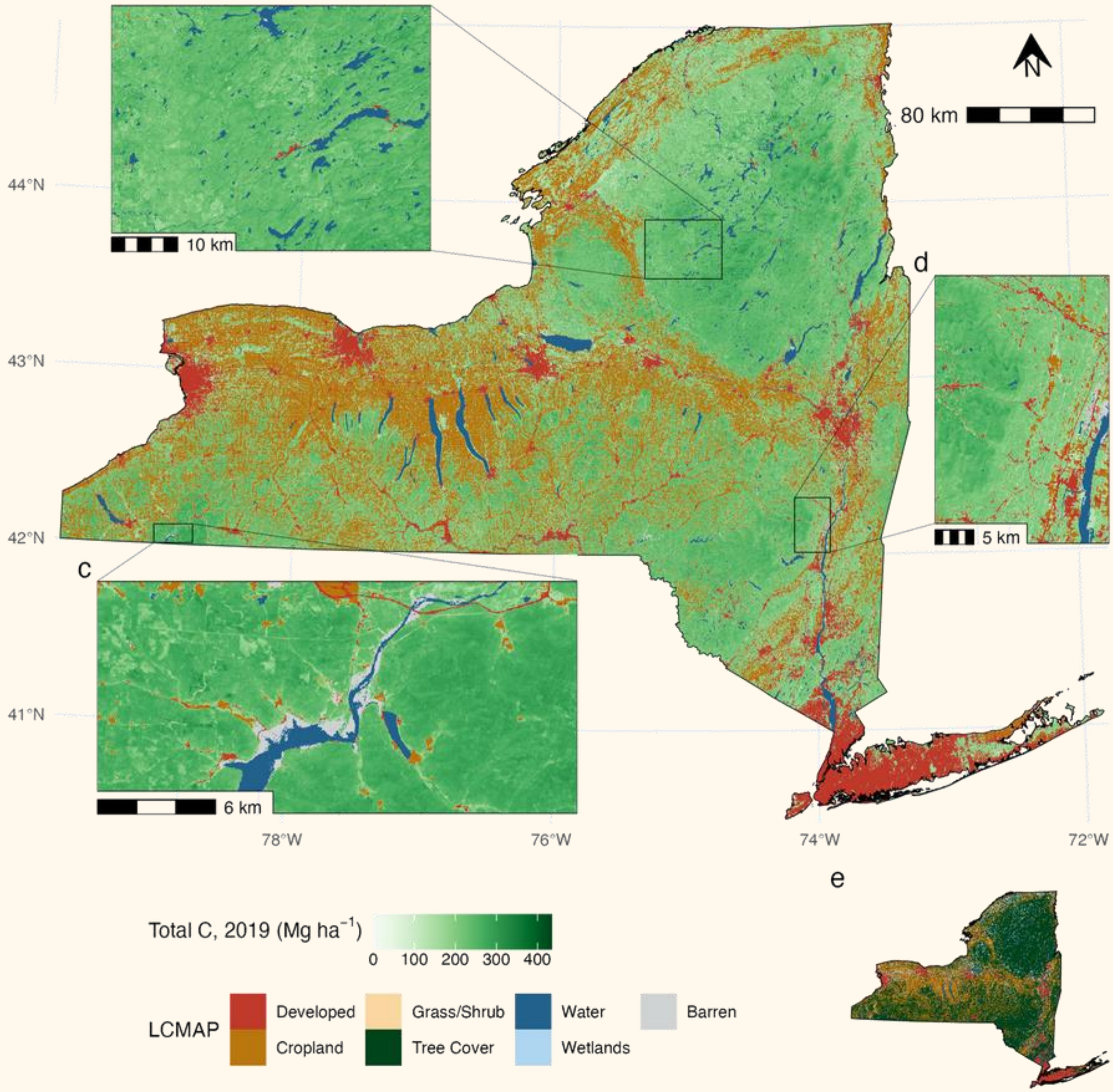
Conversion of AGB estimates to forest carbon (C) stocks was done on a pool-by-pool basis (above-ground and below-ground biomass, soil, litter, dead-wood) using relationships derived from FIA plot measurements across NYS, in combination with geospatial data representing local landform, soil types, land use and climate. By training separate models for each C pool, we can continue to improve them as new data and knowledge become available in the future.

Biomass-to-carbon conversions were implemented on AGB maps to estimate C pools on a pixel-by-pixel basis, yielding a set of five C stock maps for every AGB map. Carbon stock mapping was limited to pixels that fit our working definition of 'forest land' based on land cover classification as tree cover, wetlands and shrubs. Biomass estimates are provisionally available for other non-forest cover types, including agricultural and developed lands across NYS, but there was insufficient data to make reliable predictions about the C stocks in those areas.

Overall, we have higher confidence in estimates of live C stocks (in biomass) and lower confidence in the soil, litter, and dead-wood C estimates, because the latter group of C pools are more complex and difficult to model with available data. Our relative levels of confidence in these outputs are reflected in how these data are used in mapping, in stock-change analysis, and in our carbon accounting workflow. Model and map accuracy were rigorously evaluated by comparing AGB and forest C pool predictions with field inventory measurements across multiple spatial scales. Uncertainty estimates are provided with all map/data products.

CURRENT FOREST CARBON STOCKS

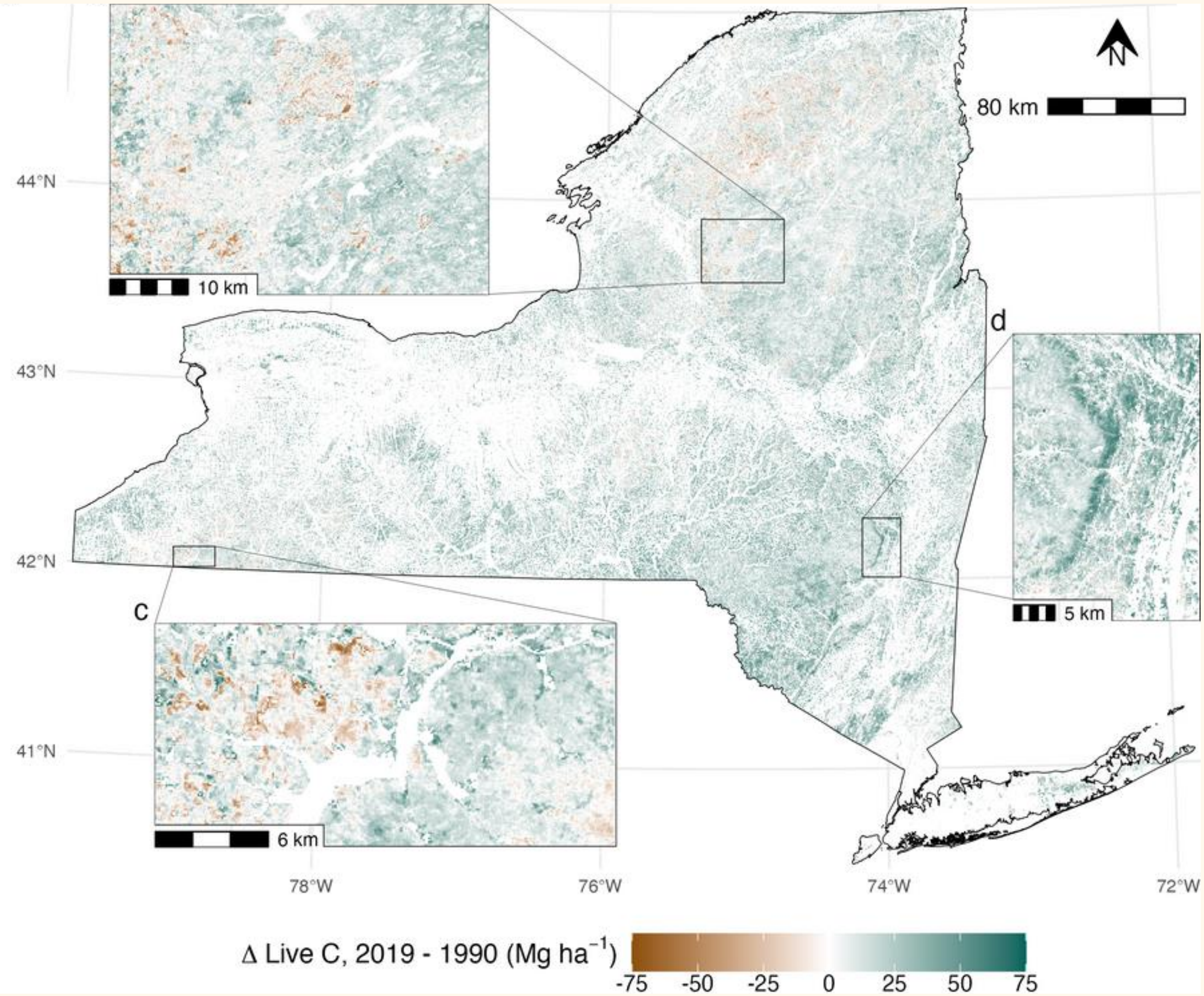
Using our modeling framework based on field inventory and remote sensing, we produced statewide, high-resolution maps of forest carbon stocks each year from 1990 to 2019. Each annual map provides a snapshot of carbon stored in the forest landscape. These maps are 'stacked' chronologically to provide inputs for stock-change analysis and map-based carbon accounting. Annual land cover maps from the LCMAP project were incorporated to focus carbon stock estimates on lands where forests currently exist or could be most readily established in the future, by excluding current agricultural (orange) and developed (red) lands.



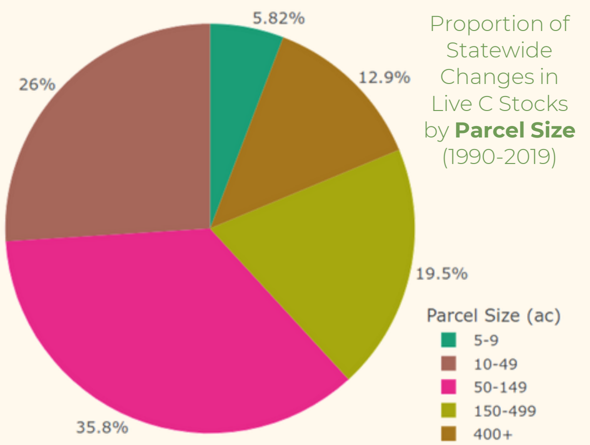
Maps of 2019 total forest carbon stocks including land use-land cover types (LCMAP; www.usgs.gov/special-topics/lcmap) across NYS, with inset 'zooms' for three areas of interest. Component maps of the five forest C pools (above-ground live, below-ground live, soils, litter and dead-wood) in metric tons per hectare were aggregated into total C stocks for all areas classified in 2019 as tree cover, wetlands and grass/shrub. Because the LCMAP land use-land cover products and our C pool maps align 1:1 pixel-for-pixel, the C stock and stock-change maps can be summarized by various cover type(s) and transition type(s).

HISTORICAL CHANGES IN CARBON STOCKS

We mapped carbon sinks and sources across New York, based on net changes in forest biomass and carbon stocks over the last three decades (1990-2019). These maps represent live C stock-changes on the land, but do not incorporate the carbon storage and substitution benefits of harvested wood products (HWP) that determine their overall climate impacts. We have begun to integrate HWP life-cycle analysis methods and data into our map-based accounting system, in order to provide fair and accurate carbon accounting for working forests at the parcel level.



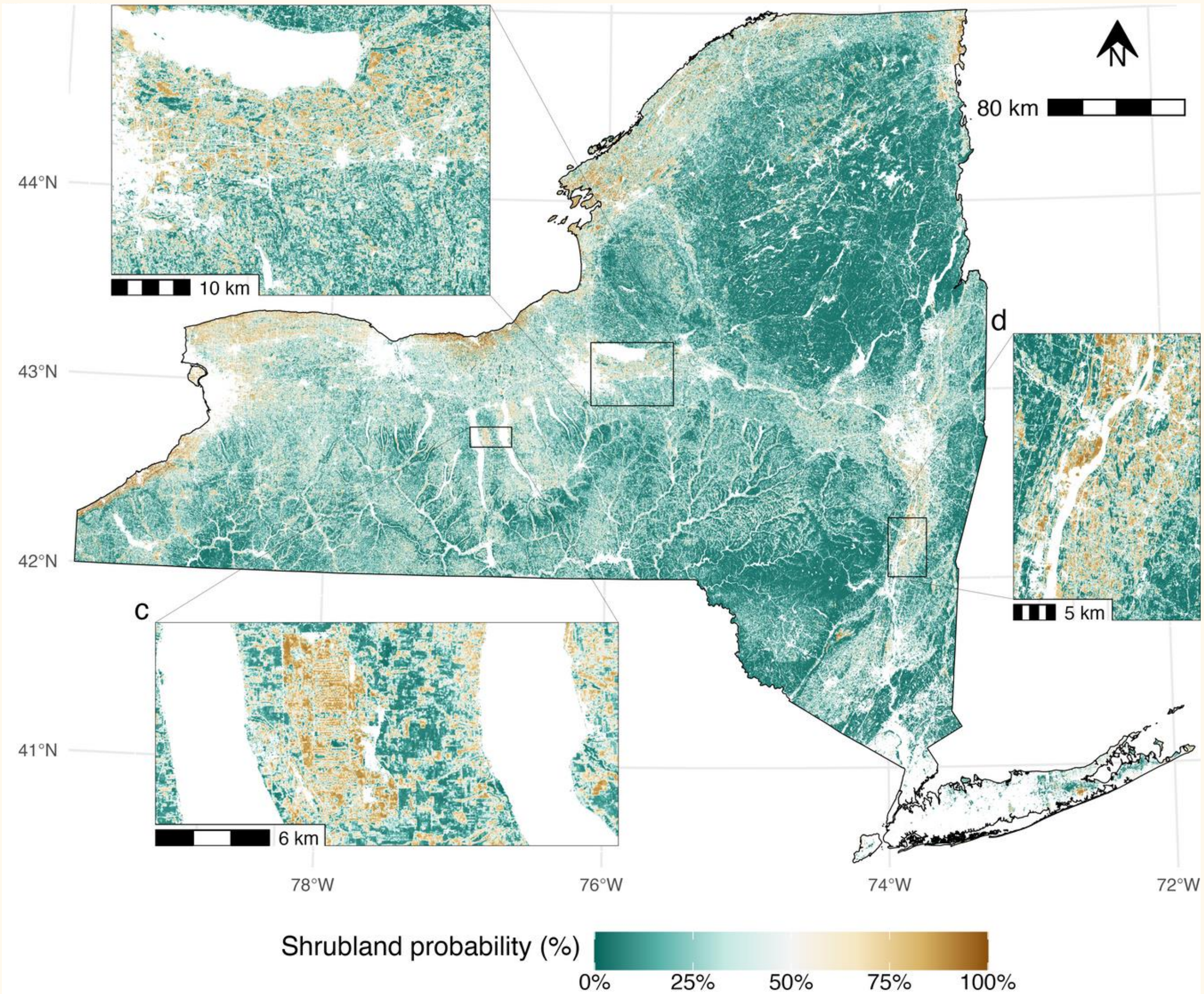
Maps above show estimated net changes in forest live C stocks from 1990 to 2019, in metric tons C per hectare. Gains in live C stocks (blue-green) indicate rates of net total sequestration (CO2 removals) during this 30-yr period. Some areas with losses of live C (brown) represent managed forests that were recently harvested, but where not enough time has passed for live biomass and carbon stocks to recover to pre-harvest levels. Other areas represent permanent C loss to land use conversions resulting in deforestation. Our monitoring system can be used to determine whether or not forest regrowth is occurring, using tools currently being developed. When detected, land use change is handled at a later stage in our carbon accounting workflow.

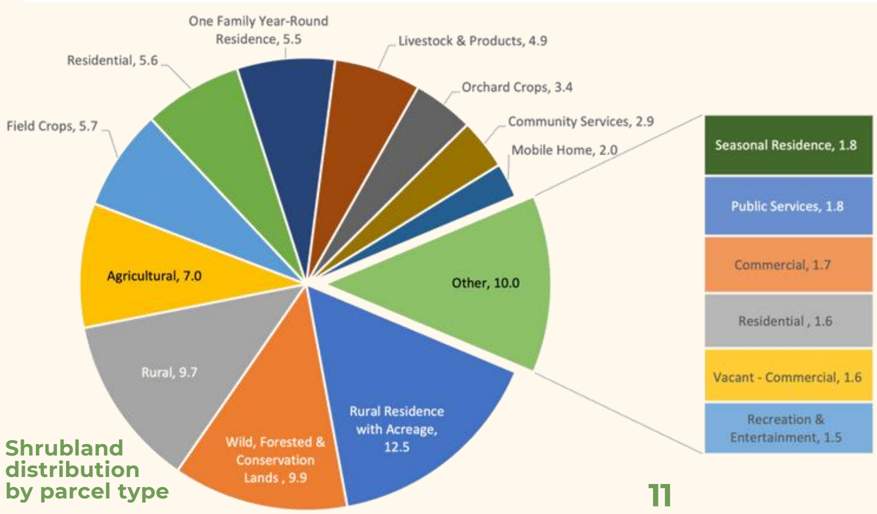


Proportion of Statewide Changes in Live C Stocks by **Parcel Size** (1990-2019)

MARGINAL & TRANSITIONAL LANDS

Although most of New York's forests have regrown in the last 150 years, there are areas where forests have been very slow or unable to develop in old pastures, croplands and industrial sites. These marginal and transitional lands contain a mixture of woody plants and grasses but are often dominated by invasive shrubs that prevent natural forest development. As a result, these lands provide limited carbon benefits and have become a focal point for a variety of climate solutions such as reforestation, bioenergy crops, and solar/wind farms. Despite the potential opportunities these lands offer, little was known about their extent or location across NYS, so we developed models and maps of these 'shrublands' as part of our statewide assessment.



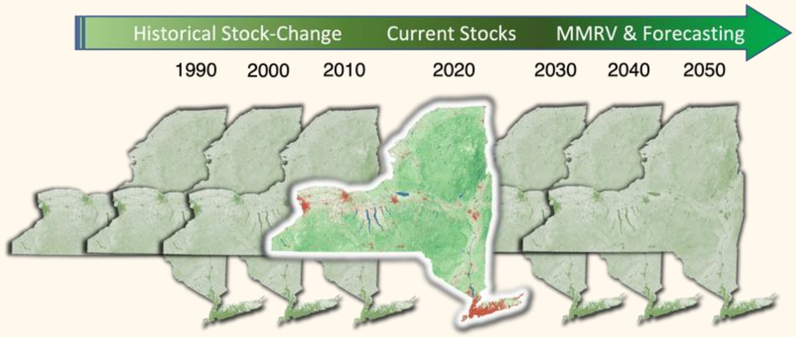


Shrubland distribution by parcel type

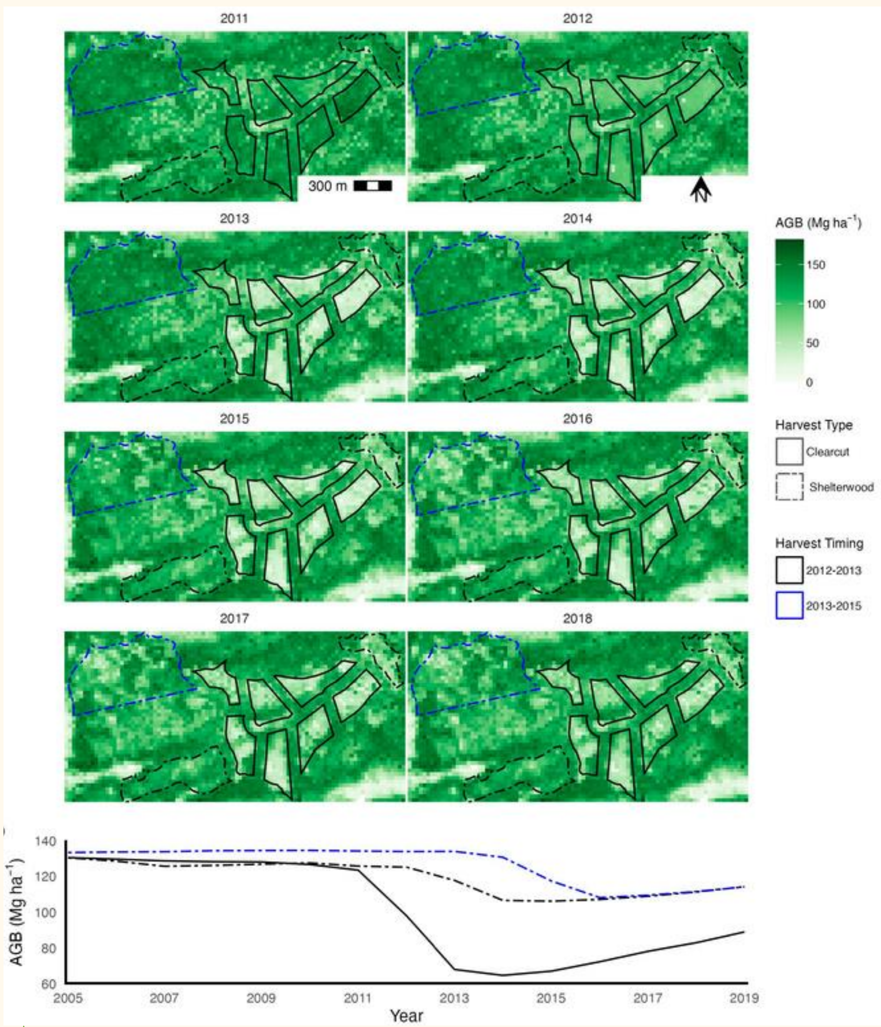
Marginal and transitional lands, or 'shrublands', cover at least 1.4 million acres of NYS. These lands are mostly distributed among rural residential (25%), agricultural (23%), vacant (21%) and conservation (14%) parcel types. Recent LIDAR data releases will allow us to improve these maps, which can support decision-making on how these lands can best provide climate solutions.

MEASUREMENT, MONITORING, REPORTING & VERIFICATION (MMRV)

Our modeling framework for forest carbon mapping and stock-change analysis, when applied prospectively instead of retrospectively, provides the basis for a carbon monitoring system for NYS. In short, the same models for historical mapping are applied to new Landsat imagery released each year, providing a flexible and cost-efficient platform for near real-time measurement, monitoring, reporting and verification (MMRV) at 30m annual resolution statewide.



Open-source data and computing tools

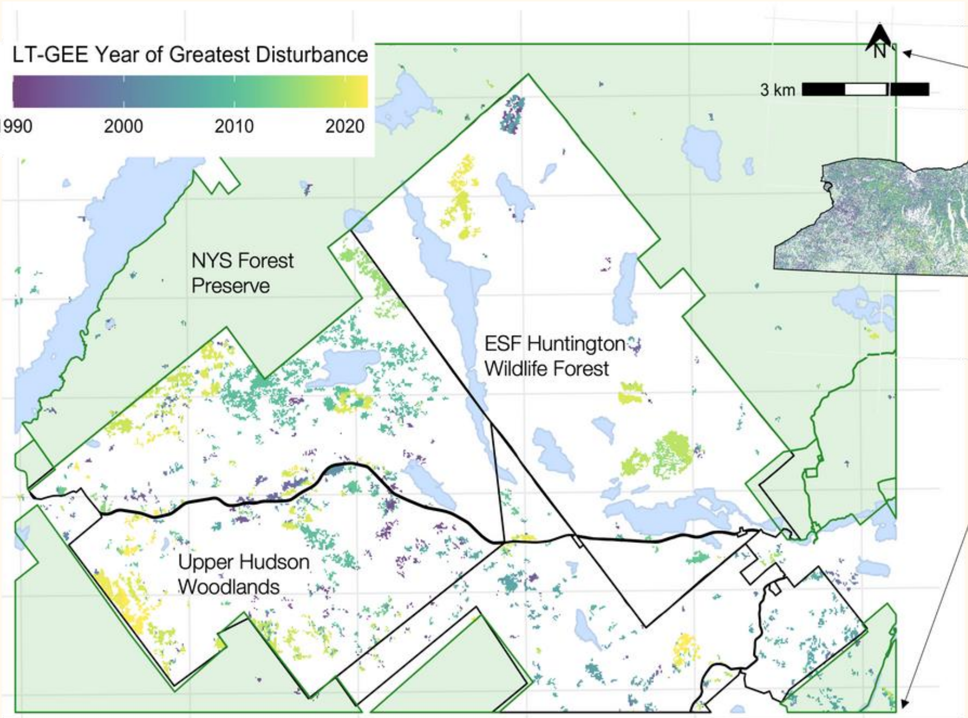


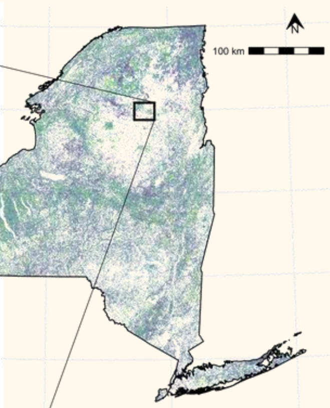
Example of stand-level monitoring outputs for a managed forest, showing pre-harvest (2011), during harvest (2012-2015) and early regrowth after harvest (2016-2018), in units of aboveground biomass (AGB; metric tons per hectare). Harvest maps and records were provided by the landowner.

New York's forest carbon monitoring system tracks forest C stocks and stock-changes annually statewide, from parcel to landscape scales. It can also be used to distinguish stock-changes resulting from land use practices, such as forest management, from land cover conversions, such as deforestation. The system operates with open-source computing tools and freely available public-sector data from long-standing federal programs including NASA Landsat and the US Forest Service FIA program. Its MMRV capabilities will first be deployed for the $60M NY Connects project funded by USDA (see p.23). Future upgrades will explore newer remote sensing data sources, such as space-borne LiDAR and very high-resolution satellite imagery.

FOREST CHANGE DETECTION

Understanding landscape change is fundamental to emissions inventory and forest carbon accounting. We built on existing tools and open data repositories to develop the capacity to efficiently and accurately detect changes in forest biomass and cover across NYS. Several forest change detection tools are available that rely on long-term satellite imagery such as Landsat. We tested these tools' performance against recent harvest records (provided by industrial forest landowners) to identify the best option for our modeling and monitoring work, which needed a consistent and reliable basis for change detection. We found that Landtrendr on Google Earth Engine* (LT-GEE) was the best tool for detecting partial harvests and smaller-scale disturbances that are most common in New York's forests. Meanwhile, the LT-GEE platform offered many practical advantages including access to decades of satellite imagery collections and processing tools at no cost.





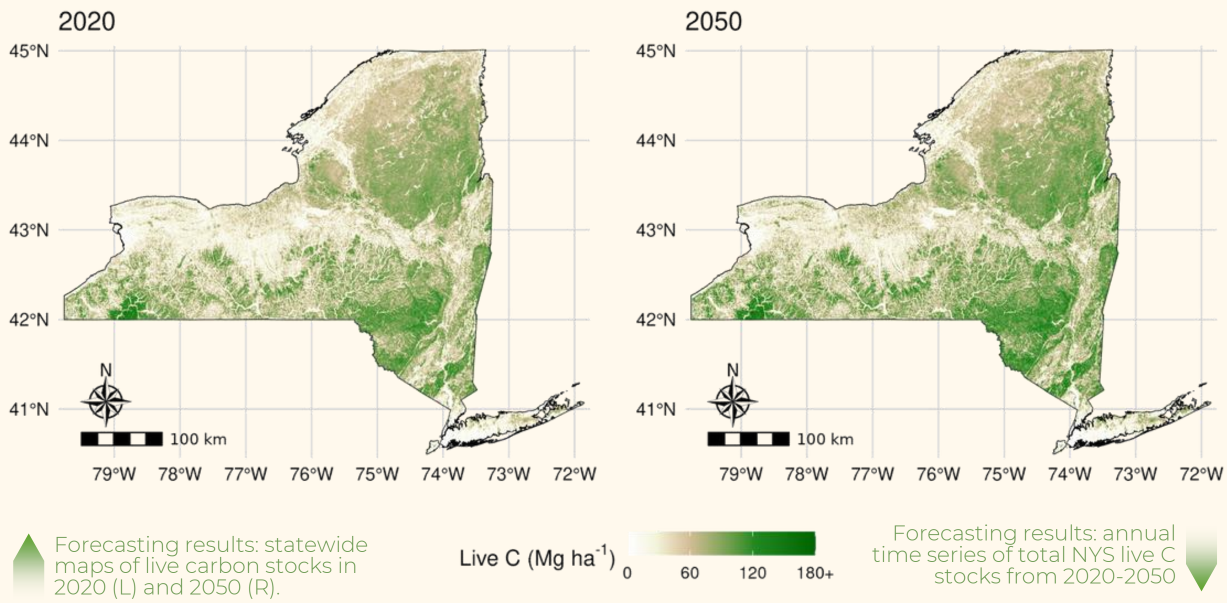
Patterns of forest disturbance, 1990-2022, for a portion of the central Adirondack Park. Map is based on open-source NY-tuned LT-GEE tool developed by this project.

Although LT-GEE was the best option for change detection 'off the shelf', the tool was originally developed for western US forests with very different species and disturbance patterns, including forest management practices. Our testing found that LT-GEE still had significant room for improvement when applied to New York's natural and working forest landscapes. To improve LT-GEE performance for applications in and across NYS, we 'tuned' the LT-GEE algorithm using extensive management records from landowner partners, aerial imagery, and field work. This tuning effort produced a more accurate tool that is, in many ways, central to our modeling and monitoring framework. Our 'NYS' tuned version of LT-GEE and its outputs will be freely available on Google Earth Engine to support forest health monitoring and resource protection by both public authorities and private citizens.

*LT-GEE Guide; eMapR Lab, Oregon State University; https://emapr.github.io/LT-GEE/

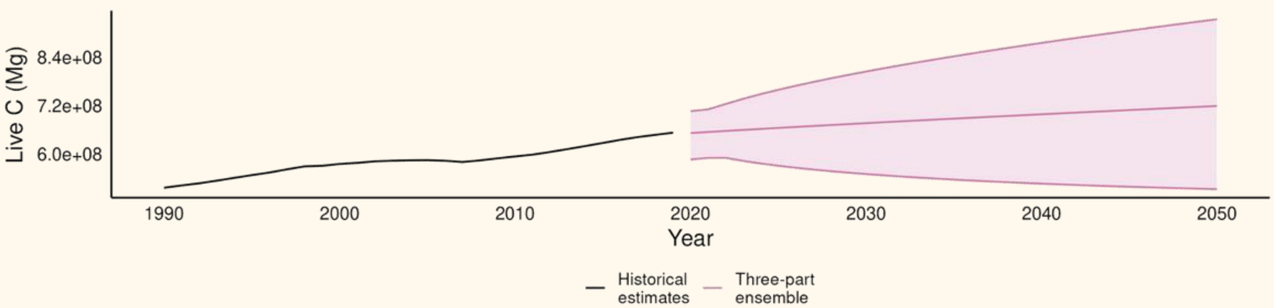
FORECASTING

To understand how forest carbon benefits could change in the future across NYS, we used time-series forecasting models to advance our statewide maps forward in time to 2050. Models were trained on our historical map series of 1990 to 2019 and used to generate a similar series of 30 m annual statewide forecast maps from 2020 to 2050. Using these outputs, we estimated a baseline projection of future C stock changes under a ‘business as usual’ (BAU) scenario, in which recent trends were essentially carried forward in time on persistent forest lands. Current land use patterns (2019) were initially held constant in the forecasting process, but future projections of land use change were incorporated later via map-based carbon accounting.



Forecasting results: statewide maps of live carbon stocks in 2020 (L) and 2050 (R).

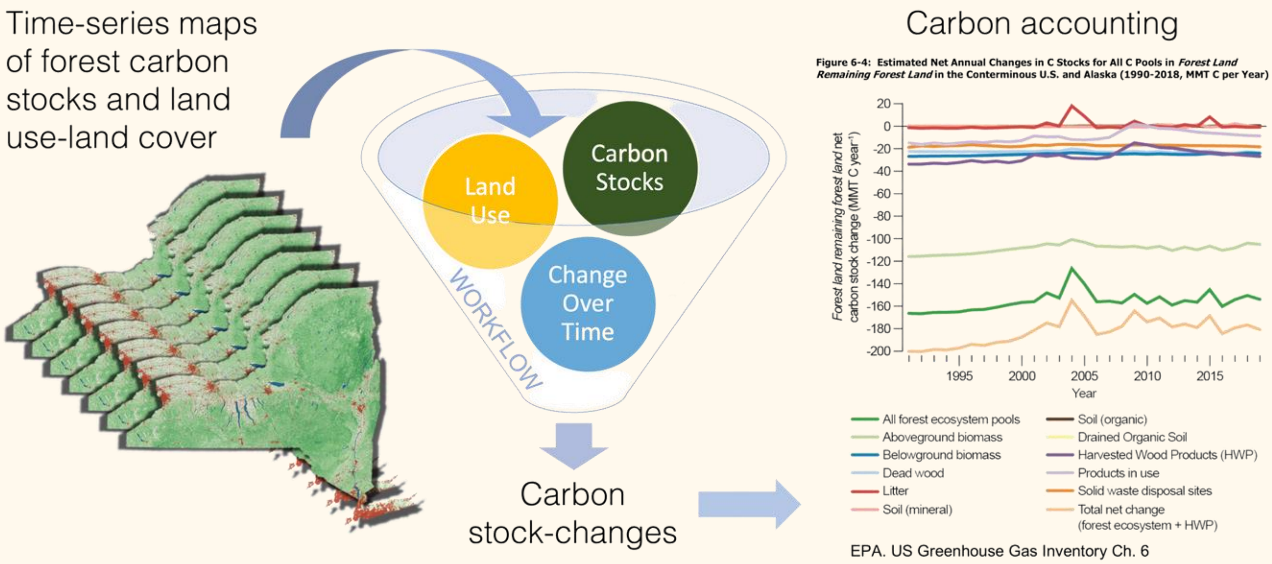
Forecasting results: annual time series of total NYS live C stocks from 2020-2050



Predicting the future is difficult. These forecasts involve assumptions (e.g., recent trends = future trends), have ample uncertainty, and are best interpreted as a benchmark for evaluating future scenarios and training improved forecast models. We know our forecasting models poorly represent forest regrowth in areas that were very recently harvested or disturbed (after 2015). This can result in either a gross underestimation of future C stocks, if the parcel is a working forest, or a reasonably accurate prediction if the land is converted to non-forest. The problem is that we cannot know which outcome has taken place until we have enough annual monitoring updates (based on satellite imagery) to verify either recovery or permanent loss of forest cover. For these reasons, statewide forecasting of carbon benefits required consideration of how future gains and losses in forest land area could impact the emissions bottom-line. The following pages describe how this was achieved using land use-land cover forecasts (to 2050) and the carbon accounting workflow to produce a reference level under a 'business as usual' scenario.

MAP-BASED CARBON ACCOUNTING

We built a novel computational workflow to convert our statewide map/data products into estimates of CO2 additions and removals, consistent with an IPCC stock-change methodology. The workflow involves a series of data post-processing steps that generate tabular summaries which are comparable side-by-side with US Forest Service FIA's state-level reporting of annual net carbon additions/removals to EPA. The workflow operates with all of our primary map datasets, providing a consistent basis to derive carbon accounting information from historical assessment, annual monitoring, and scenario forecasting outputs, for any geographic area and time period of interest within NYS.



Currently, the workflow's default configuration for *forest land remaining forest* uses our annual map time-series to estimate net sequestration (removals) by 'live' forest C pools, while holding the other C pools (including soil) constant over time, based on historical map averages. In other words, the soil, litter and deadwood C pool estimates were spatially resolved to 30 m statewide but temporally averaged over a thirty-year period.

Meanwhile, where *forest land gains and losses* have occurred, the workflow incorporates either US Forest Service FIA or IPCC estimates of C stock-changes related to various forest/non-forest transitions, along with our carbon maps, to account for net removals and additions associated with land use change. Combining these outputs in our workflow yields a time-series of net annual CO2 equivalent removals / additions (i.e., size of carbon sinks and sources) that can be estimated for any geographic area within NYS (preferably 10 acres and larger) and time period from 1990 onward. Such estimates were compiled to provide the statewide reference level (next page) from 1990 to 2050, using models to forecast forest C stocks and land use change under a 'business as usual' scenario.

Our default workflow reflects relative confidence levels in the different input data sources and models used, as well as uncertainty and knowledge gaps in key areas, such as soil carbon dynamics. This configuration can be adjusted to explore and implement future revisions to accounting protocols, reference data sources, land use definitions, etc.

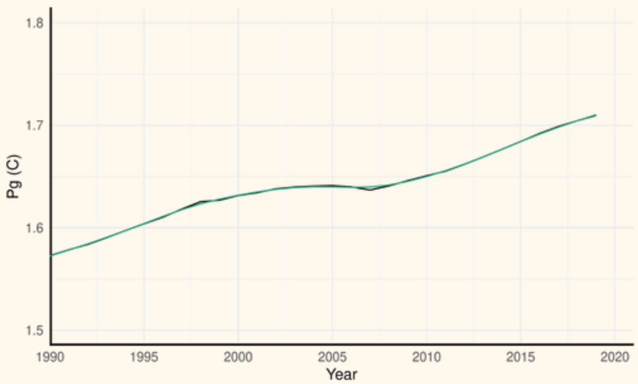
STATEWIDE REFERENCE LEVEL

A statewide carbon reference level serves as a baseline estimate of the future size of the NYS forest carbon sink under a 'business as usual' (BAU) scenario. In essence, the BAU scenario and forecasting models assume that future trends and patterns will reflect the recent past. Historical trends and patterns include both changes on persistent forest lands (growth, mortality, removals) and forest land conversions (deforestation, reforestation) over the last 30 years. This information was used to train two types of forecasting models (carbon stocks, land use) for the next 30 years. To forecast carbon stocks on persistent forest lands, we trained models on our historical map series (1990-2019) to produce annual 30m forecast maps from 2020 to 2050. To forecast land use changes, scientists at Harvard Forest trained models from their New England Landscape Futures Project* on recent land use patterns to produce maps of future NYS land use to 2050, also using a BAU scenario.

These forecast maps were compiled and analyzed together in our accounting workflow to estimate future forest-sector carbon stock-changes and, in turn, a map-based projection of the NYS forest carbon sink by 2050, under a BAU scenario. The reference levels below summarize these maps for the entire state; however, carbon reference levels can be estimated for any geographic area of interest below the state level, including parcels, administrative units, municipalities, etc. Parcel-scale reference levels provide a common benchmark to estimate the additionality of climate benefits realized from voluntary and compulsory programs, and to assess the increased climate risk associated with deforestation, insect outbreaks, extreme weather and other factors that impact forests.

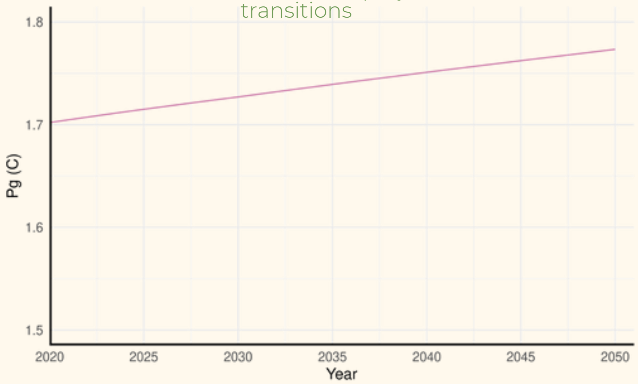
Historical & Forecasted Statewide Carbon Benefits

Historical NYS Forest Carbon Stocks
1990-2019; all forest lands & LULC transitions

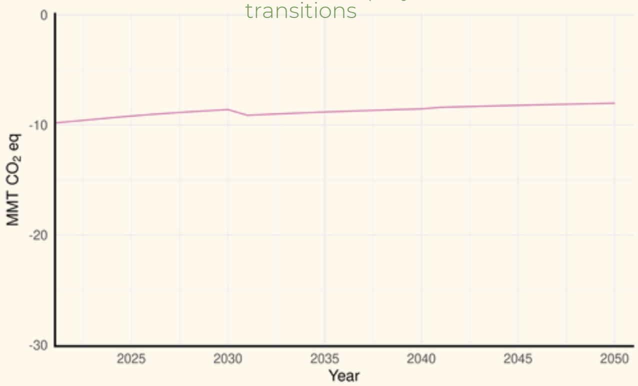


Historical NYS Net Ecosystem Exchange
1990-2019; all forest lands & LULC transitions

Forecasted NYS Forest Carbon Stocks
2020-2050; all forest lands & projected LULC transitions



Forecasted NYS Net Ecosystem Exchange
2020-2050; all forest lands & projected LULC transitions

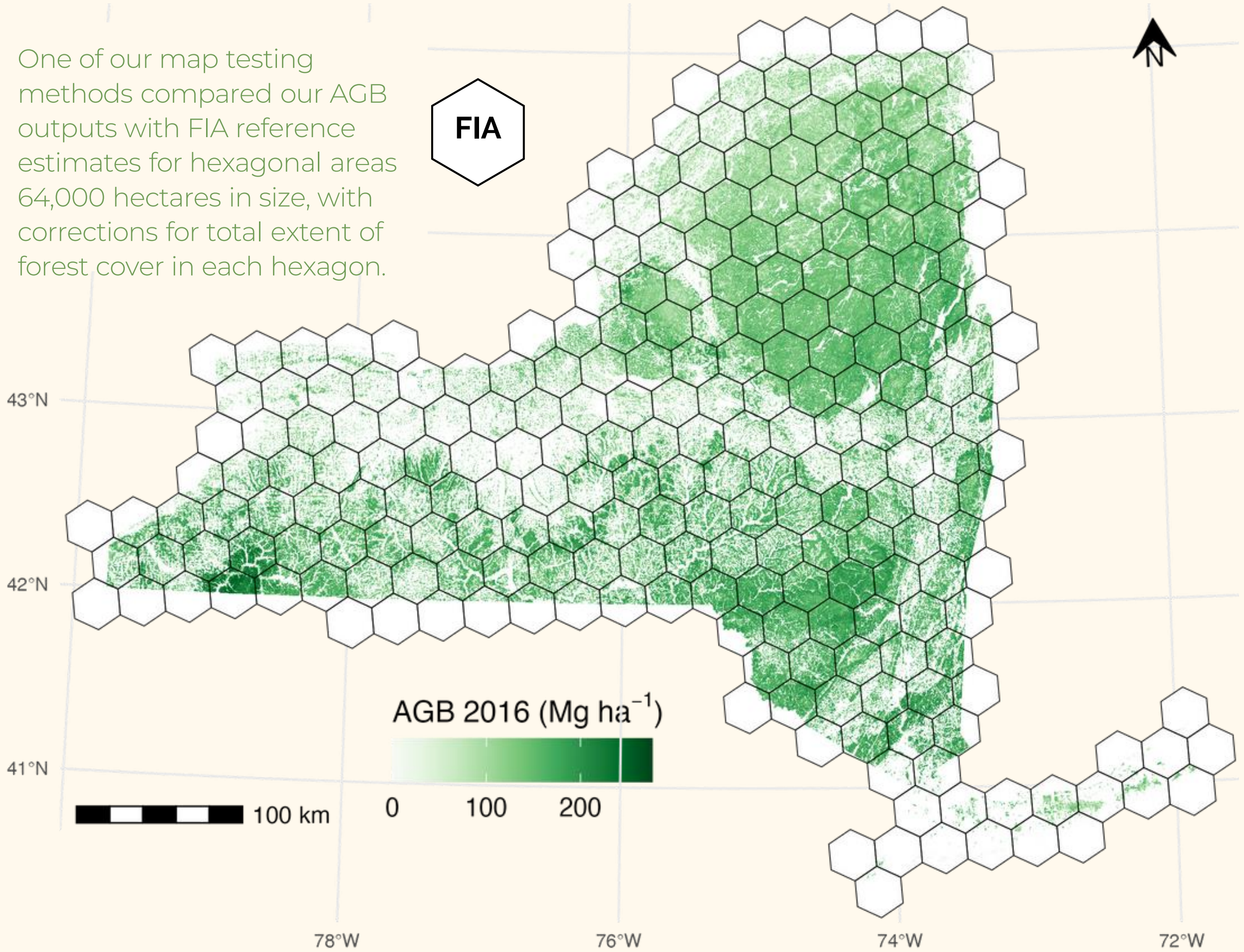


*https://harvardforest.fas.harvard.edu/other-tags/future-scenarios; also see https://newenglandlandscapes.org/

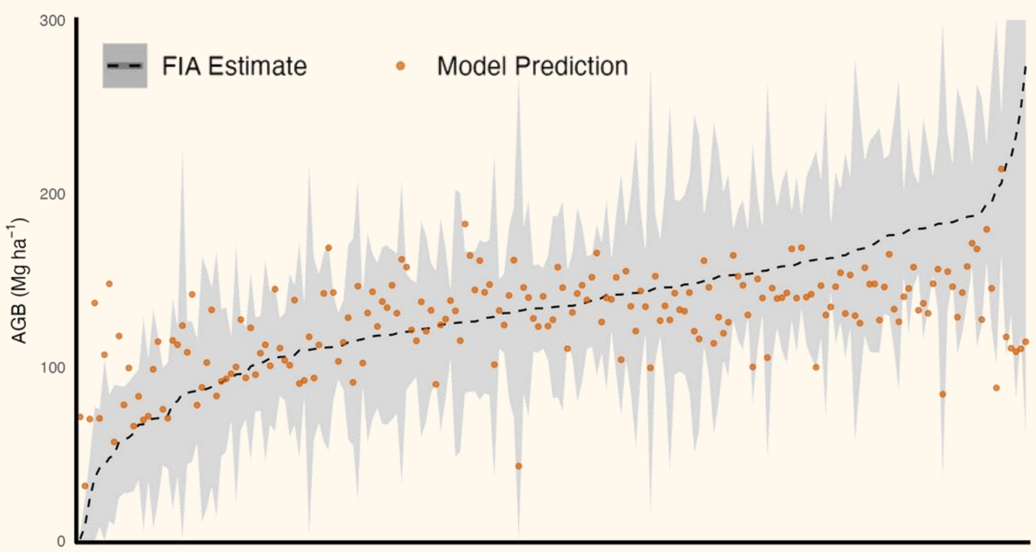
ASSESSING MAP ACCURACY

To provide reliable data and decision-support, maps must be 'ground-referenced' to assess how well they represent real-world conditions. We tested our map products and their underlying models in several ways, relying mainly on FIA plot-level and design-based estimates as reference data, to understand how well our outputs agree with FIA reporting across scales. Map accuracy results both guide our ongoing work to improve models and tools and inform our relative confidence levels in different map outputs and products.

One of our map testing methods compared our AGB outputs with FIA reference estimates for hexagonal areas 64,000 hectares in size, with corrections for total extent of forest cover in each hexagon.

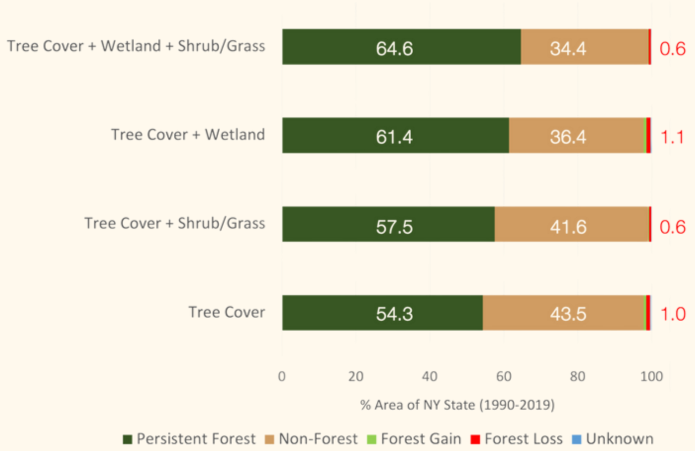


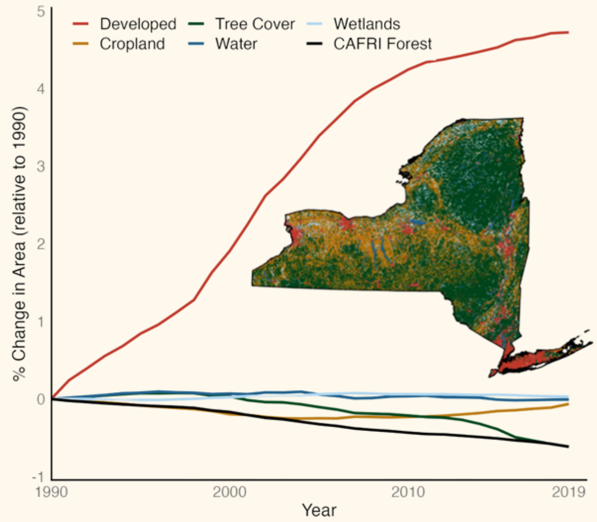
Our AGB maps **agree with 89%** of the FIA program's 'small-area' map estimates for all of NYS. We then combined our AGB maps with FIA models to map forest C stocks and stock-changes for carbon accounting.



LAND USE & LAND COVER CHANGE

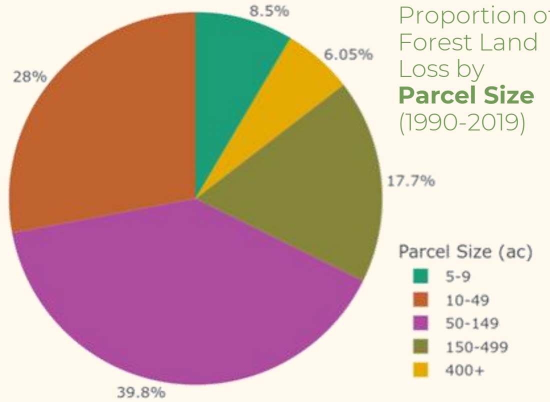
Land use and land cover play a critical role in achieving carbon neutrality through natural climate solutions. State-level reporting by FIA suggests that New York's shrinking forest carbon sink (since 1990) has not been caused by trees growing slower, being over-harvested, or damaged by insect pests, but mainly because conversion of forest land (deforestation) has outpaced establishment of new forests by about a 3-to-1 margin. Even if gains and losses in forest land were equal, this would result in a net loss of climate benefits in the near term, because new forests take time to develop and effectively sequester carbon, while deforested areas lose their carbon stocks more rapidly.



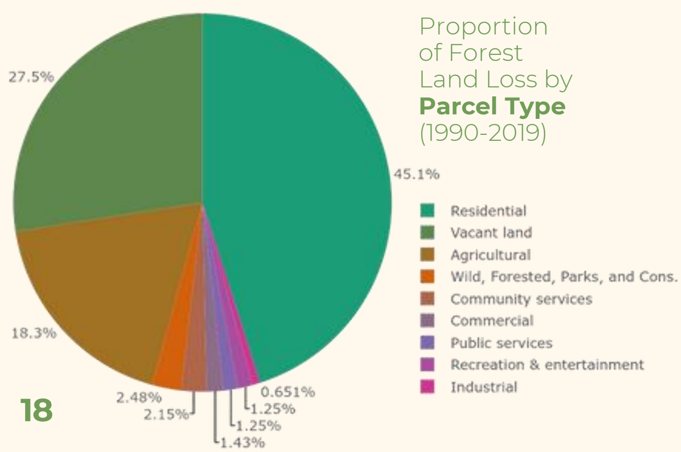


New York forest and land cover status and trends: 1990-2019; (left) forest cover as a percentage of statewide land area, depending on the cover type(s) included in our 'Forest Land' definition; (right) annual percentage changes in cover types over 1990-2019. Land cover data based on LCMAP product.

For these reasons, **avoiding forest loss** is arguably New York's first and most critical strategy to sustainably expand its forest carbon sink. Using maps of past, present and projected future carbon stocks and land use, we can estimate the 'carbon debt' resulting from deforestation anywhere within NYS. Our analysis found that most forest loss since 1990 has occurred on residential and vacant parcels between 10-150 acres in size, which are broadly representative of most privately owned forest lands across NYS and currently provide the majority of statewide forest climate benefits. These 'family forest owners' face both economic challenges in maintaining forest land as forested and increasing development pressures to convert forest lands to non-forest uses. Our map-based framework can help decision-makers focus conservation investments on the forest lands that provide the greatest climate benefits (and co-benefits) and that likely will be most vulnerable to future development.



Proportion of Forest Land Loss by **Parcel Size** (1990-2019)

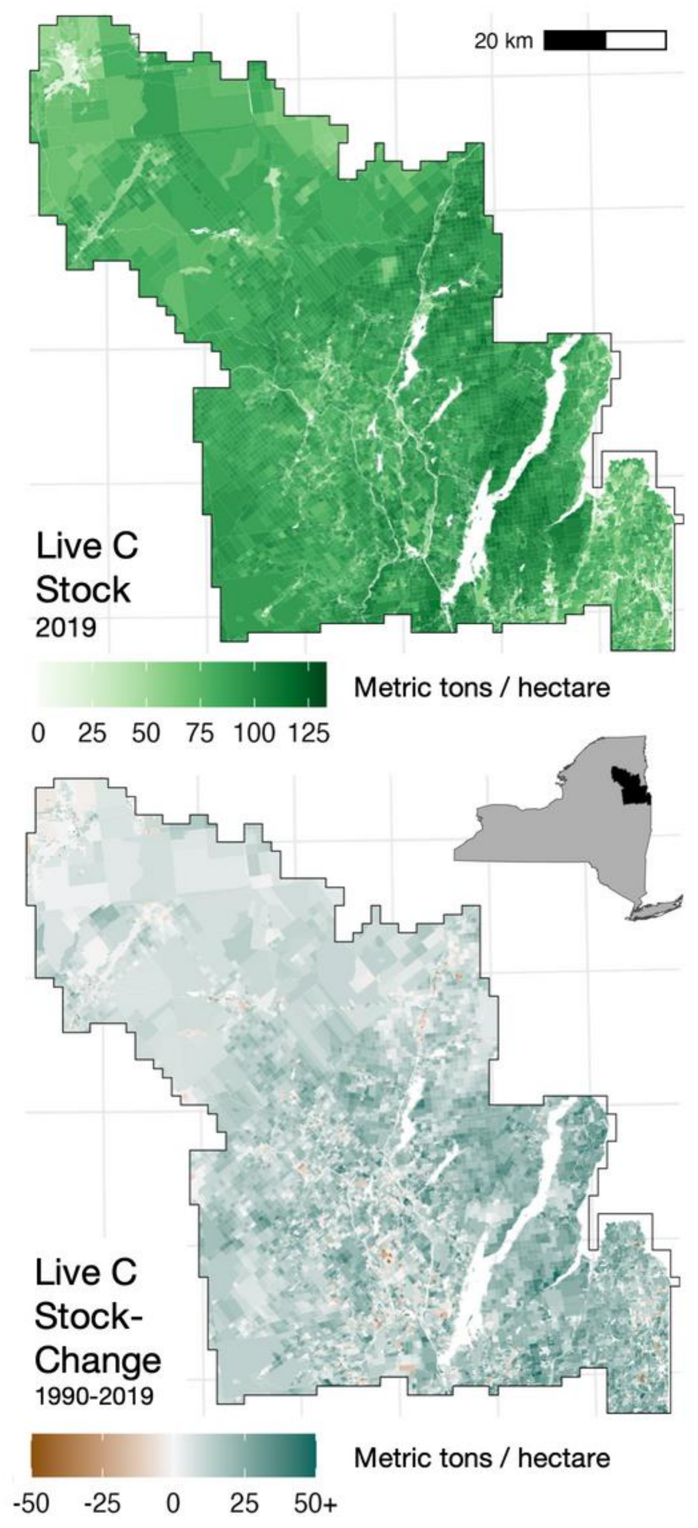


Proportion of Forest Land Loss by **Parcel Type** (1990-2019)

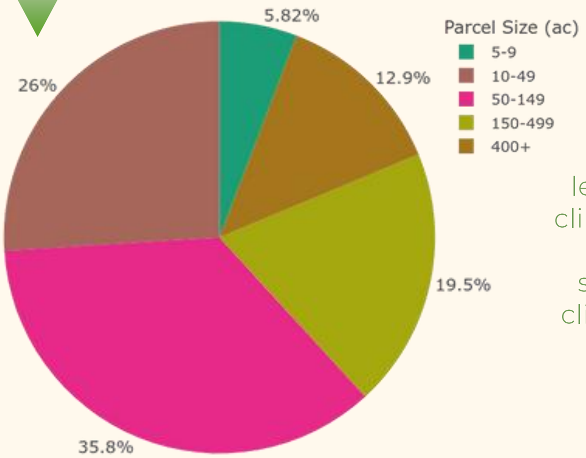
PARCEL-SCALE ASSESSMENT & MONITORING

Parcel-based summaries of our maps provide essential data for carbon accounting, monitoring and forecasting at the scale of individual properties, where forest stewardship decisions are made and where landowner compliance with regulations and voluntary programs are enforced. Although our map outputs can be summarized for any area in NYS, we have the most confidence in estimates for parcels 10 acres and larger, based on extensive testing of model and map accuracy.

Statewide parcel-level data have versatile applications: 'top-down' by public-sector authorities and NGOs to design and implement landowner-facing programs for climate solutions; and 'bottom-up' to support stewardship by private landowners, who mostly lack basic inventory or carbon estimates for smaller parcels (10-150 acres), which contribute over 60% of statewide forest sequestration benefits (based on our estimates).



Proportion of Statewide Forest C Sequestration (1990-2019) by Parcel Size



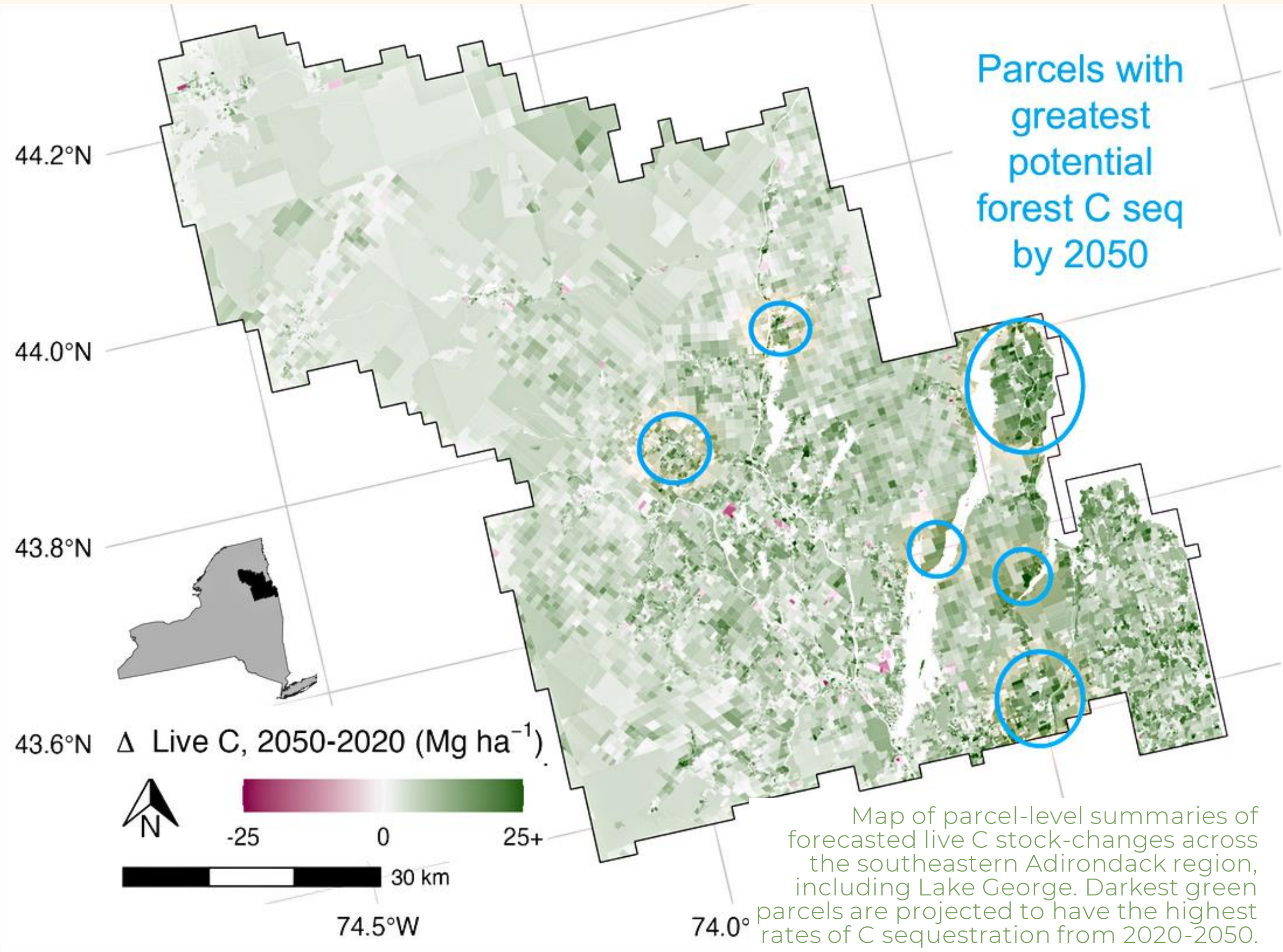
Combining our statewide carbon and land use maps with tax parcel boundaries (compiled by NYSGPO) provides a rapid, high-level assessment of recent and potential future climate benefits for every forested parcel in NYS. Annual monitoring updates can likewise be summarized with updated tax records to track climate benefits in tandem with any changes in parcel boundaries, ownership type and use codes that may occur over time.

MAP & DATA PRODUCTS

PRODUCT	COVERAGE	RESOLUTION	AVAILABILITY
Aboveground biomass (AGB)	NYS 1990-2019	30m, annual	May 2023
Forest carbon pools · Live C (AGC+BGC) · Soil, Litter, Dead Wood	NYS 1990-2019	30m, annual	May 2023
Stock change metrics · Aboveground biomass (AGB) · Live C (AGC+BGC)	NYS 1990-2019	30m, variable	May 2023
Annual monitoring updates · New AGB and C maps · Updated C stock-change	NYS 2020, 2021, 2022...	30m, annual	Aug 2023
Forecast maps · AGB and Live C · Carbon Stock-Change · NYS Reference Level	NYS 2020-2050	30m, annual	May 2023
Shrubland probability	NYS 2019	30m, single year	May 2023
Canopy height models	LIDAR-specific	1m, variable year	Varies by region

All map and data products from the NY Forest Carbon Assessment are managed in CAFRI's secure data infrastructure, which we use to efficiently and flexibly access, analyze, and visualize project outputs for various applications and end-users. Data sharing is a high priority that must be balanced with respect for landowner privacy as well as non-disclosure of confidential data sources provided by public and private-sector partners. Private individuals and organizations requesting data may be required to sign a data use agreement with CAFRI. We consult with end-users to help them understand data product strengths and limitations for their intended uses and to define specifics of their request in terms of geographic area, target variables, etc. After data delivery, we follow up with end-users to address questions and technical issues, offer new or updated products, and review public-facing documents including the data provided. CAFRI is currently able to provide data and consulting services at no cost to end-users, thanks to ongoing programmatic support from the NYS Environmental Protection Fund.

Effectively Engaging Forest Landowners in Climate Solutions



Map of parcel-level summaries of forecasted live C stock-changes across the southeastern Adirondack region, including Lake George. Darkest green parcels are projected to have the highest rates of C sequestration from 2020-2050.

To maximize the climate benefits of policies and programs that advance forest-based solutions across NYS, our map-based assessment provides a versatile basis to identify and prioritize the parcels and landowners that are best suited for different strategies and practices, based on their recent, current and projected future carbon stocks and land use changes, among other criteria. Decision-support applications using parcel-level maps and data could include:

- targeting forest parcels with the greatest potential for future carbon sequestration (as shown above) for stewardship initiatives that seek to sustain and enhance forest productivity;
- prioritizing the most carbon-dense forest parcels for easement, fee acquisition, or other measures to avoid future deforestation due to development;
- locating parcels with marginal and transitional land and assessing their relative suitability for land use practices, including reforestation, bioenergy crops, solar/wind energy, etc.
- evaluating the potential parcel-level outcomes of policy and regulatory scenarios.

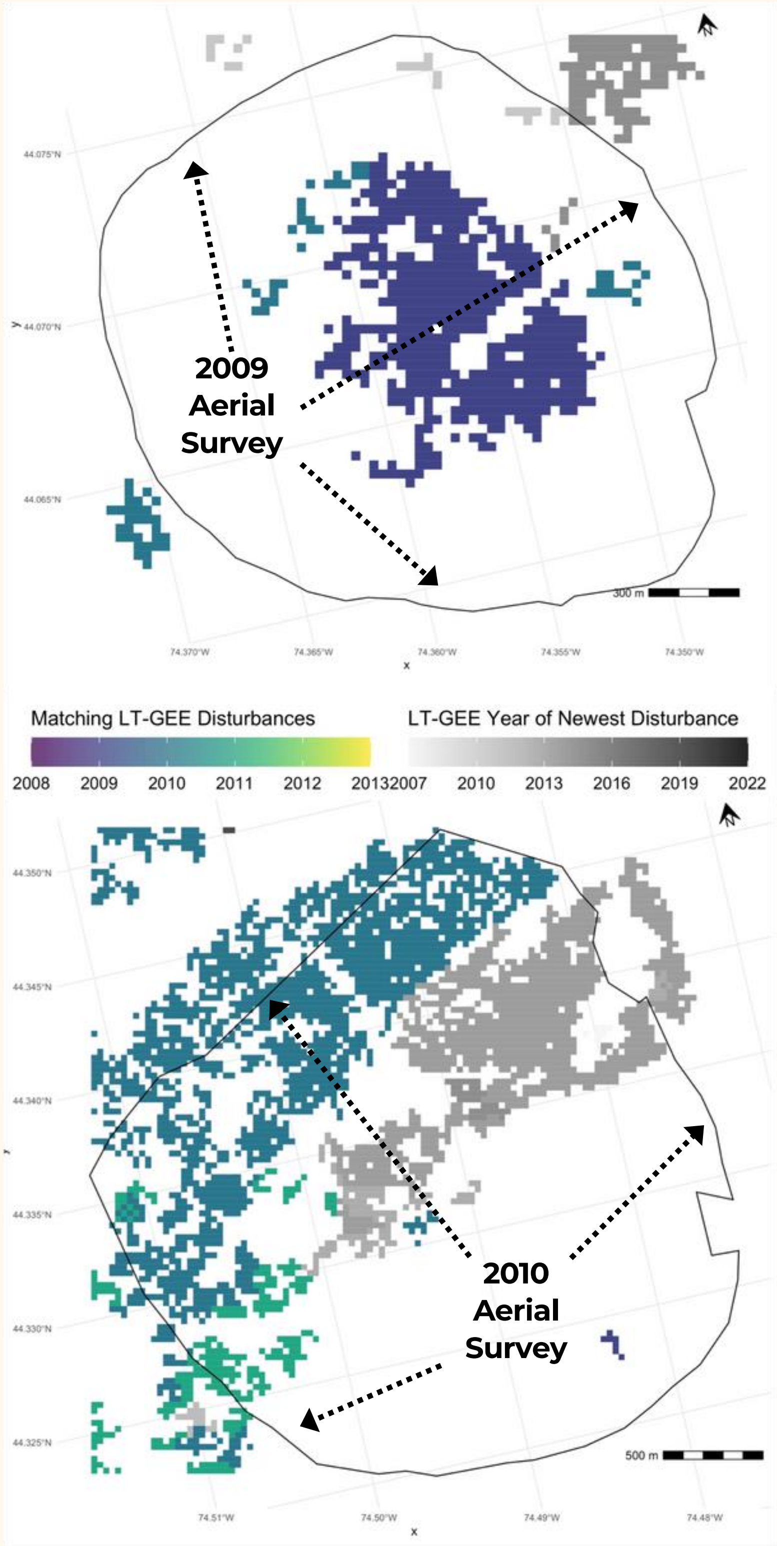
Maps can support more effective engagement with landowners, who can also use parcel-level monitoring data provided by CAFRI for ongoing stewardship purposes. After landowners engage with such programs, we can monitor parcel-level changes to verify climate benefits and ensure compliance, allowing field audits to focus mainly on potentially non-compliant parcels.

Fostering a Healthy & Resilient Forest Landscape

New York's forests continue to face mounting stressors, including pests and pathogens, invasive species, over-browsing by deer, legacies of past land use, and climate change itself, among others. Altogether, these factors will test the resilience of New York's forest landscapes and their benefits, including climate regulation. Stewardship actions will be needed in many cases to restore and sustain productive forests.

This project built capabilities for remote detection of forest change, which sets the stage for modeling the causes of recent and ongoing forest change. Our tuning of the LT-GEE toolkit was initially focused on detecting forest management using landowner harvest records. The same approach, using reference maps from DEC forest health surveys, shows promise for LT-GEE based tools that can reliably classify disturbances as harvest vs. non-harvest, and provide broad-scale monitoring to support managers and landowners in ongoing forest stewardship and protection efforts.

To this end, settings and outputs of our NY-tuned LT-GEE tool will made freely available online. Other next steps include mapping emerald ash borer (EAB) mortality and its impacts on the statewide C sink; and an 'early warning system' for monitoring hemlock wooly adelgid (HWA) mortality in the Forest Preserve of the Adirondack Park.



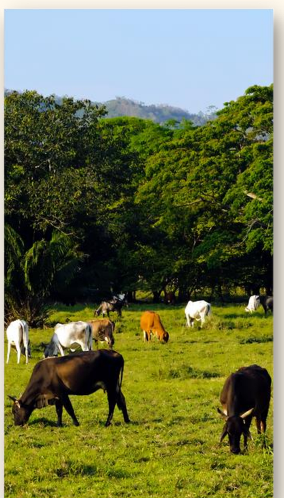
Initial results from testing the LT-GEE change detection tool for forest health monitoring purposes, using DEC forest health aerial survey maps (black lines) as reference data. Colored pixels show where LT-GEE correctly detected the disturbance recorded by the survey (same timing); grayscale pixels show forest disturbances that were detected by LT-GEE in other years (different timing).

Informing a 'Solar Scorecard' for Renewable Energy Siting

Rapid expansion of solar energy across NYS is a key strategy to achieve net-zero emissions by 2050. An estimated 56 square miles (35,840 acres) of land will be needed* to build the 6000 MW of solar production capacity that is mandated by CLCPA. Many factors determine a site's suitability for solar and in some cases the lowest-cost options involve forested lands. Clearing forests for solar farms removes existing C stocks and future sequestration potential, creating an initial 'carbon debt' that is 2-4 times greater than that on non-forested land*, while also reducing or negating other forest co-benefits. As NYS does not prohibit solar installations on forests or farmlands, NYSERDA is developing a 'Solar Scorecard' tool to help decision-makers minimize trade-offs among these essential land uses. Our statewide map/data products can feed directly into this tool to support local-scale assessment and planning.

*Ali et al. 2022. The Environmental Life Cycle Assessment of Electricity Production in New York State from Distributed Solar Photovoltaic Systems. *Energies* 15(19): https://doi.org/10.3390/en15197278

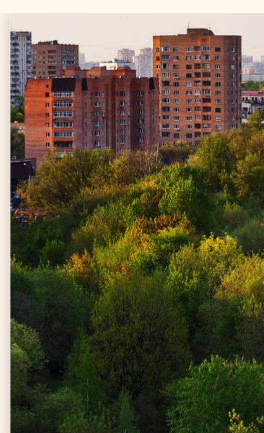
Verifying the Benefits of Climate-Smart Farms & Forests



Our statewide carbon monitoring system will provide essential MMRV capabilities for **NY Connects**, a new $60M initiative funded by USDA* to implement 'climate-smart' farming and forestry practices across NYS. The USDA required proposals have a reliable basis for MMRV (measurement, monitoring, reporting and verification of climate benefits), which we directly leveraged from the NY Forest Carbon Assessment project. Building on DEC's RegenerateNY program, **NY Connects** will engage forest landowners to implement a range of proven stewardship practices that restore, enhance and sustain more diverse and productive forests. Parcel-based assessment and monitoring will support the data-driven design, implementation and verification of forest-based climate solutions.

*NY Connects will invest over $40M in New York's farmers and forest landowners via a partnership of NYS DEC, NYS Agriculture & Markets, Cornell University, SUNY ESF, Syracuse University and others, with funding from USDA's Climate Smart Commodities program.

Building Capacity for Urban & Community-Based Forestry



Our forest biomass and carbon maps are 'wall-to-wall' for the entire 300+ square miles of land in NYS, including urban, exurban and other developed areas where tree cover is patchy and fragmented, and model training data is limited, making prediction more difficult. Maps for these areas may be less reliable, which is why we 'masked' them out from current versions of statewide products. However, 'unmasked' maps appear to represent tree cover and green spaces accurately at neighborhood scales (see page A-7), providing a starting point for local stewardship, community engagement, and participation in state and federal programs. To this end, CAFRI seeks partnerships with local governments and community organizations.

GLOSSARY

Aboveground biomass (AGB) is the dry weight of all vegetation growing above the ground, commonly in units of metric tons per hectare (Mg/ha). AGB is typically estimated or modeled as the first step in estimating or modeling forest C stocks, especially for remote-sensing and mapping applications.

Business-as-usual (BAU) scenario, in which a forecast is based on current conditions and/or recent trends being carried forward into the future. BAU scenarios provide a baseline or benchmark for evaluating the potential impacts of policy and regulatory changes.

Carbon (C) stored in forests consists of five pools or stocks: aboveground carbon (AGC), belowground carbon (BGC), dead wood (DW), litter (LI) and soil (SL). The 'live C' stock combines AGC and BGC, which represents the C stocks in vegetation. The 'dead organic C' pool combines DW and LI. In temperate forests, soil C pools are typically the largest and may exceed all other pools combined but are also the least reliably measured and scientifically understood.

Carbon dioxide (CO2) is the predominant form of C exchanged between land and atmosphere; most GHG inventory results are given in units of CO2 equivalent with respect to the atmospheric pool of CO2, i.e., additions (emissions) and removals (sequestration).

Carbon accounting or **greenhouse gas (GHG) inventory** is the process of quantifying the net amount of GHG added to (emissions) or removed from (sequestration) the atmosphere for a given entity or geographic area over a defined period of time.

Forest Inventory & Analysis (FIA) is the US Forest Service program that operates the National Forest Inventory and provides state-level reporting of forest-sector GHG emissions and removals to EPA using a stock-change methodology.

Landtrendr on Google Earth Engine (LT-GEE) is a landscape change detection toolkit based on temporal segmentation of long-term satellite imagery collections, such as Landsat and Sentinel-II, available on the GEE platform (see https://emapr.github.io/LT-GEE/).

Harvested wood products (HWP) reduce standing carbon stocks in managed forests and can provide varying degrees of carbon storage and substitution benefits, depending on multiple factors, including source forest conditions, product type and longevity, and disposal methods.

Land Use-Land Cover (LULC) is a classification of the landscape into discrete categories such as cropland, developed, tree cover, wetland, barren, grassland, etc. LULC transitions refer to changes among types over time, such as conversion of forest to commercial development. **LCMAP** is a LULC map product used in this assessment that provides CONUS-wide coverage at a 30m annual resolution (from 1990-) using a classification scheme that aligns closely with LULC categories defined by the IPCC.

Measurement, Monitoring, Reporting and Verification (MMRV) is a multi-step process to account for changes in GHG emissions resulting from programs and activities intended to mitigate climate change. MMRV seeks to prove that an activity has avoided or removed GHG emissions, in order to underwrite results-based payments to those providing climate benefits.

Pixel is the smallest estimable unit of an image or raster map, most commonly rendered as a uniform grid of equal-sized squares, for which a single value can be estimated or assigned. The spatial resolution of an image or raster map is typically reported as the nominal pixel size, e.g., a 30m map pixel represents an area 30 by 30 meters (900 m2) square on the ground.

Stock-Change Approach is a carbon accounting method in which C stocks are measured or estimated at multiple points in time and then differenced to estimate net stock-changes. Increasing carbon stocks indicate a net C sink (removals > additions), while decreasing carbon stocks indicate a net C source (additions > removals) for the given entity or geographic area.

Acronyms

AFOLU – Agriculture, Forests and Other Land Uses sector (as defined by IPCC); **AGB** – aboveground biomass; **BAU** – business as usual scenario; **C** – carbon; **CO2** – carbon dioxide; **CO2eq** – carbon dioxide equivalent; **CLCPA** – Climate Leadership & Community Protection Act of 2019; **EPA** – US Environmental Protection Agency; **FIA** – Forest Inventory & Analysis Program, US Forest Service; **GHG** – greenhouse gases (carbon dioxide, methane, nitrous oxide); **HWP** – harvested wood products; **IPCC** – Intergovernmental Panel on Climate Change; **LCMAP** – Land Change Monitoring, Assessment and Projection (usgs.gov/special-topics/lcmap); **LIDAR**: light distance and ranging (also known as laser altimetry or airborne laser scanning); **LT-GEE** – Landtrendr on Google Earth Engine (https://emapr.github.io/LT-GEE); **LULC** – land use-land cover; **MMRV** – measurement, monitoring, reporting and verification; **MMT** – million metric tons; **NGO** – non-governmental organization; **NYS** – New York State; **NYSDEC** – NYS Department of Environmental Conservation; **NYSERDA** - NYS Energy Research & Development Authority; **NYSGPO** – NYS GIS Program Office.

Units: acres (ac), hectares (ha), metric tons per hectare (Mg/ha), million metric tons (MMT), petagrams (Pg), megawatts (MW),.

ACKNOWLEDGMENTS

This project was funded primarily by the NYS Department of Environmental Conservation through appropriations from the NYS Environmental Protection Fund. Additional support was provided by the Forest Ecosystem Monitoring Cooperative and SUNY ESF via the Pathways to Net Zero Carbon Initiative funded by the SUNY Discovery Challenge. This work was made possible by several state and federal agency partners, including the US Forest Service Forest Inventory & Analysis program (inventory plot locations), the NYS GIS Program Office (NYS LIDAR repository), and the NYS Office of Information Technology Services (statewide tax parcel database). Technical advisors included John Battles (UC Berkeley), Michelle Brown (The Nature Conservancy - NY), William Keeton (UVM) and David Saah (UC San Francisco & Spatial Informatics Group). The project also relied on multiple open-source or freely accessible data assets and computing tools, including Google Earth Engine, Landtrendr, Landsat Collection 2 (NASA/USGS), PostgreSQL and Project R.

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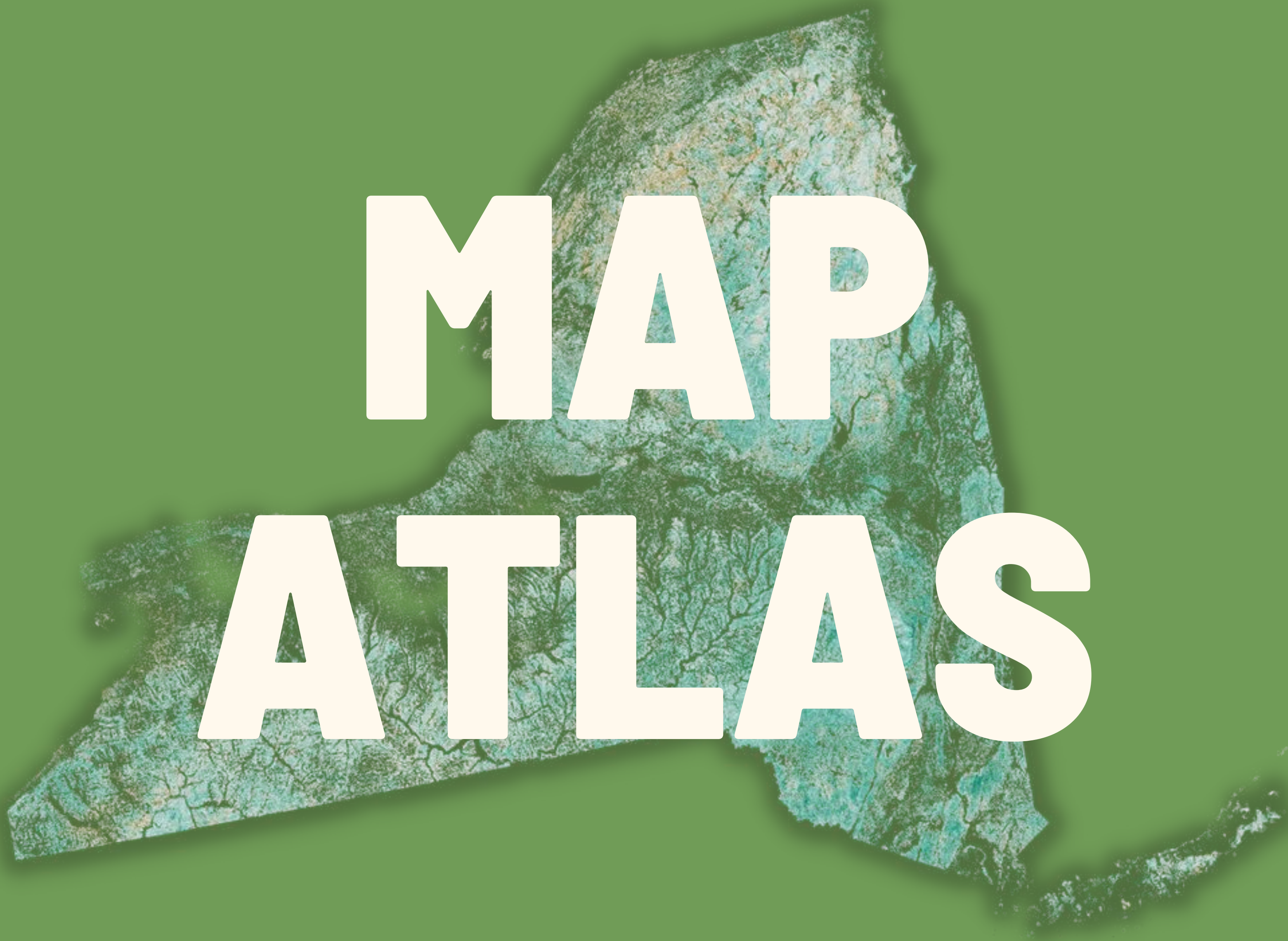
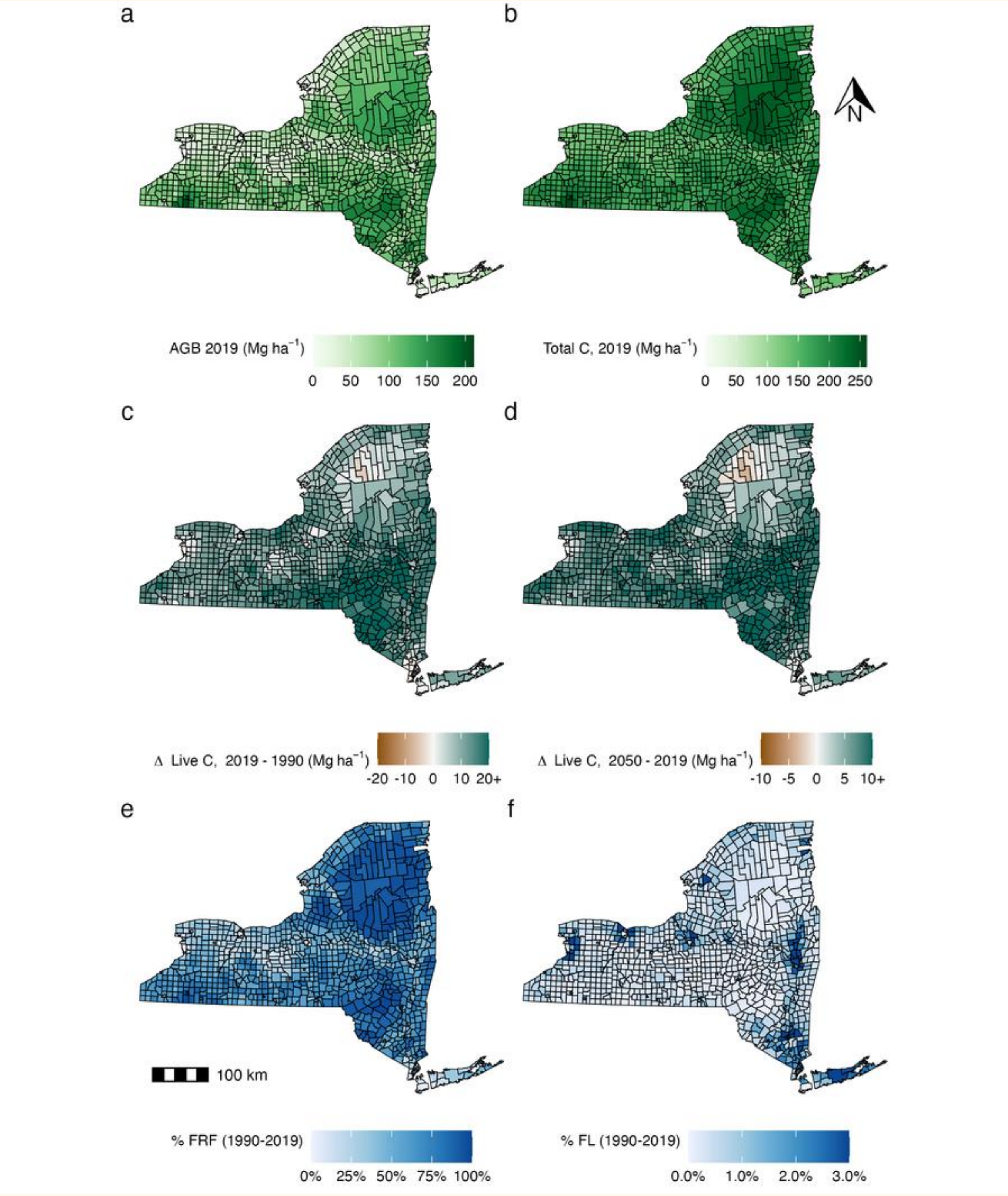
NYS DEC: Suzanne Hagell, Jeffrey Mapes, Molly Hassett, Bryan Ellis and Robert Davies
F&W Forestry / Timberlink: Wayne Tripp and Steven Logan
Lyme Adirondack Forest Company: Eric Ross

MAP ATLAS

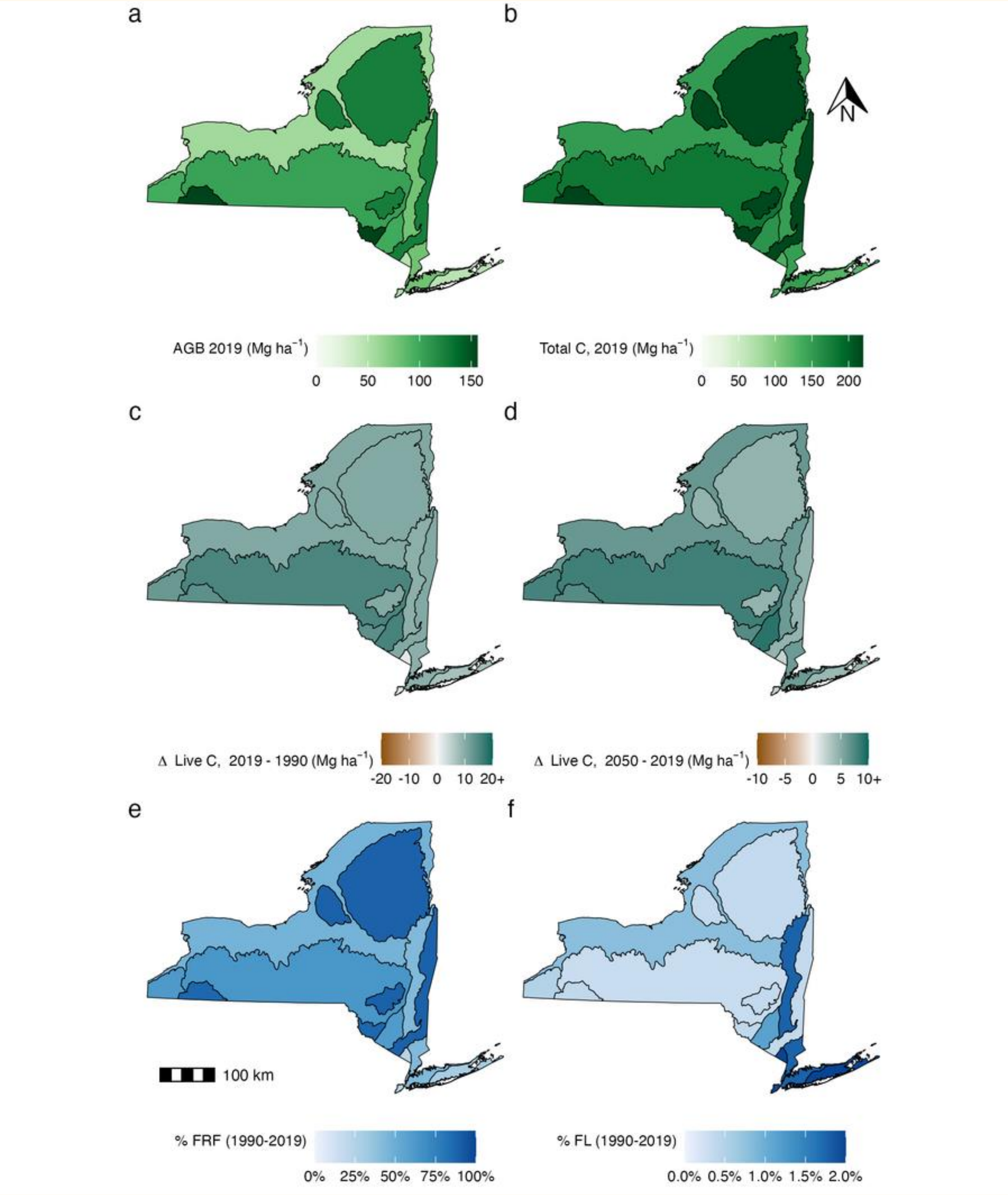


TOWNS & CITIES



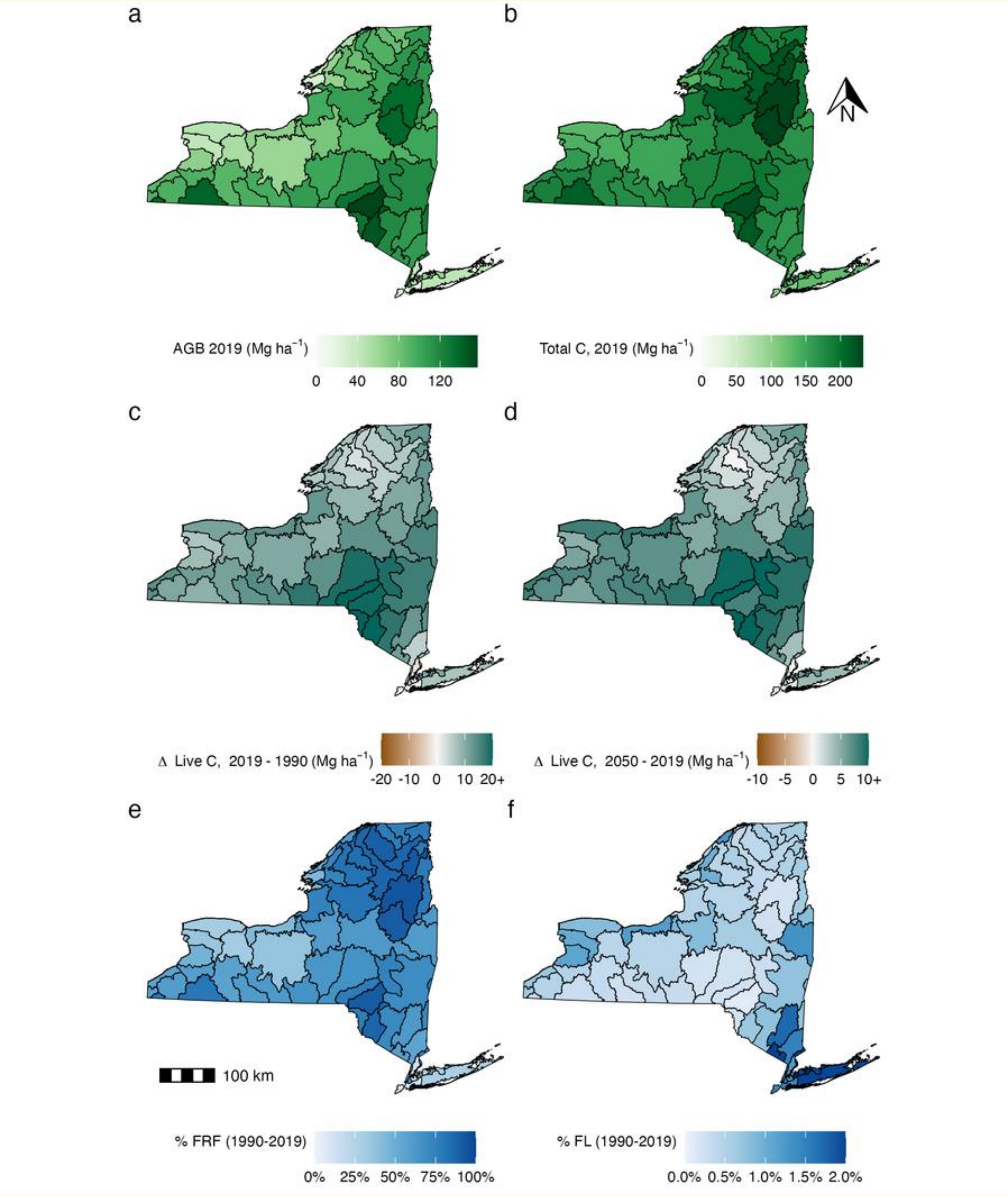
Forest carbon and land use maps for NYS towns and cities: a) 2019 aboveground biomass (all vegetated lands), b) 2019 total forest C stocks (forests only), c) recent changes in live forest C stocks 1990-2019, d) projected live C stock change by 2050, e) forest remaining forest 1990-2019 (percent by area), f) forest loss 1990-2019 (percent by area). Positive stock-changes (maps c, d) represent net C sequestration (removals).

ECOREGIONS



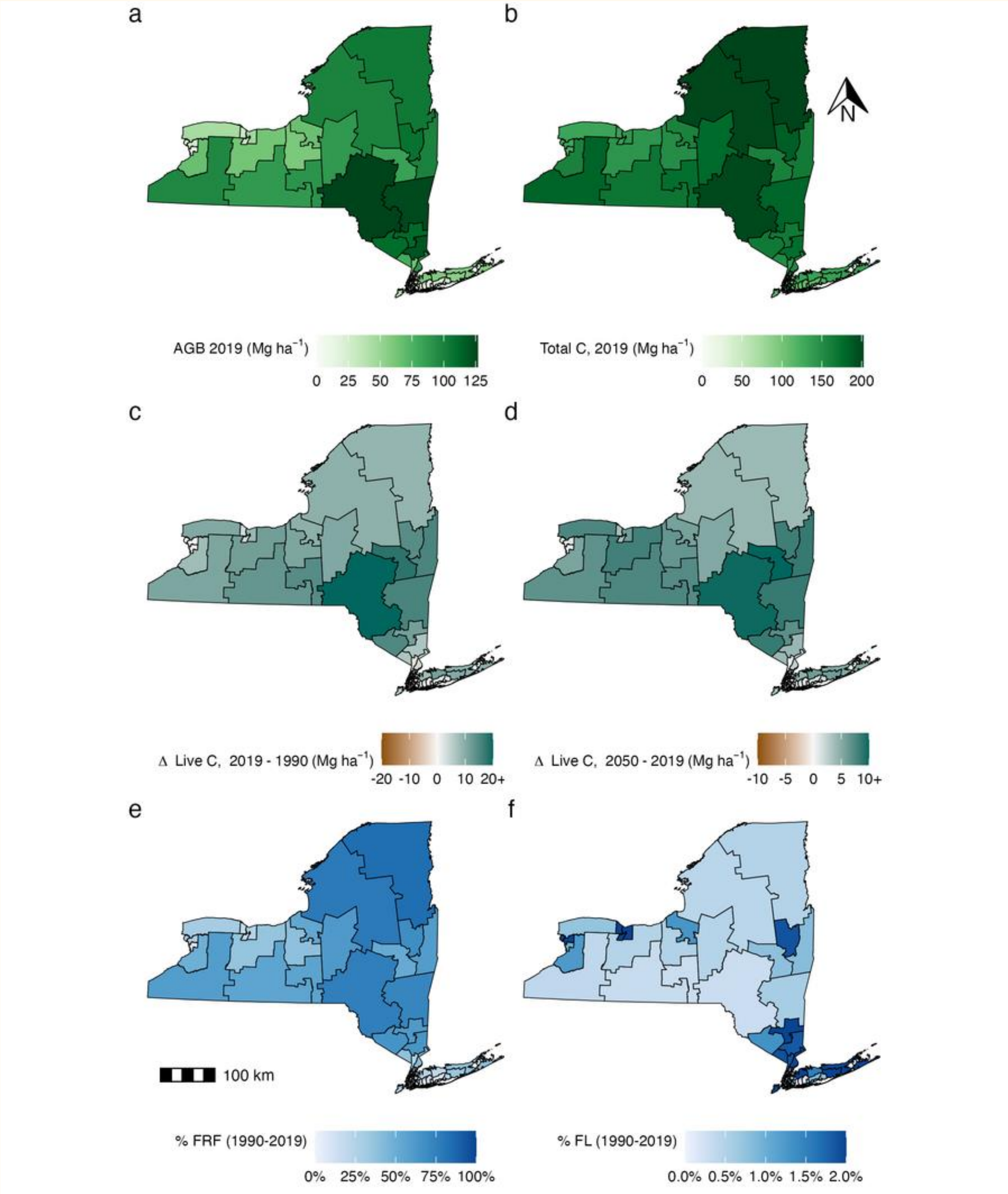
Forest carbon and land use maps for EPA Level I ecoregions: a) 2019 aboveground biomass (all vegetated lands), b) 2019 total forest C stocks (forests only), c) recent changes in live forest C stocks 1990-2019, d) projected live C stock change by 2050, e) forest remaining forest 1990-2019 (percent by area), f) forest loss 1990-2019 (percent by area). Positive stock-changes (maps c, d) represent net C sequestration (removals).

MAJOR WATERSHEDS



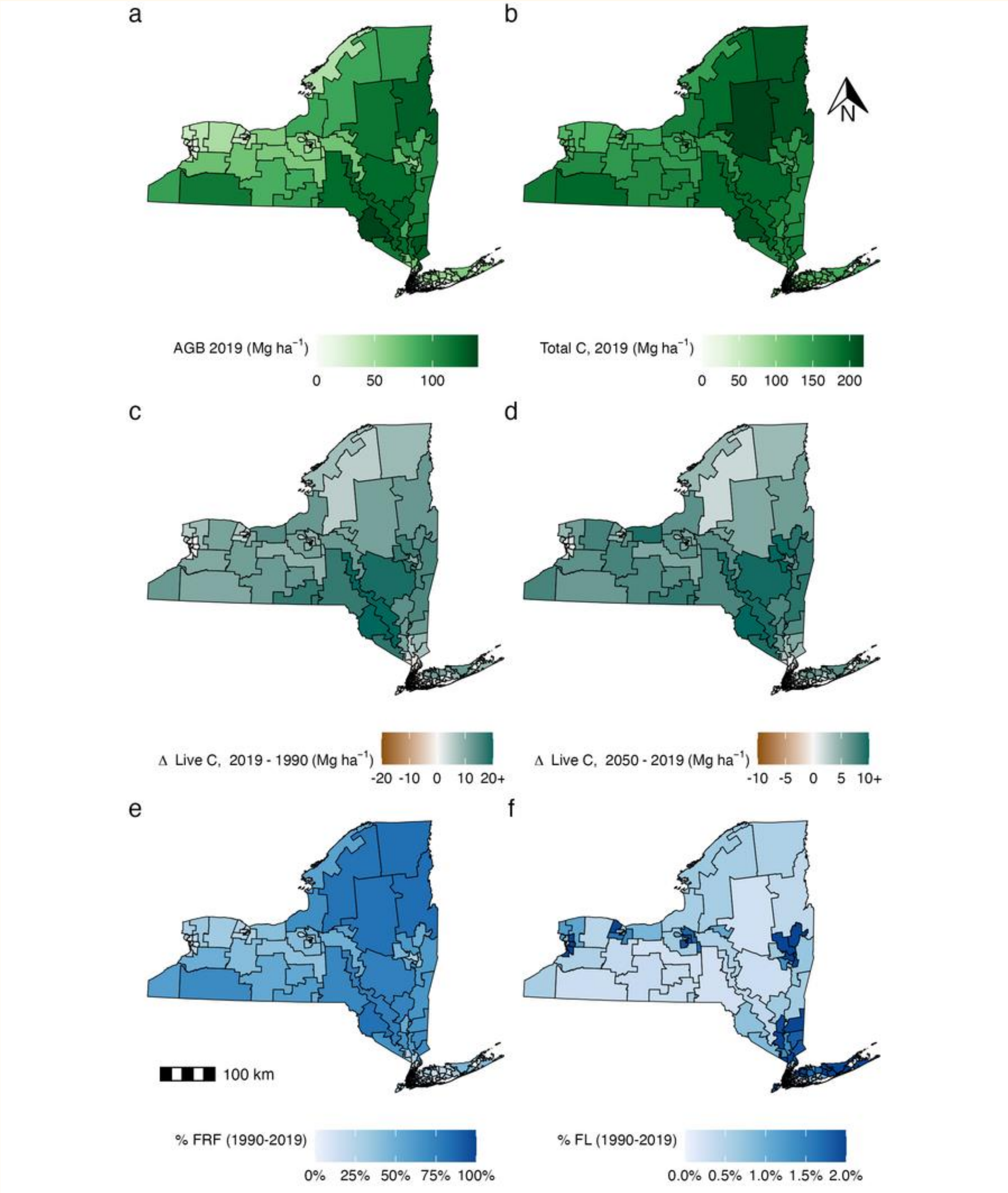
Forest carbon and land use maps for major (C NYS watersheds: a) 2019 aboveground biomass (all vegetated lands), b) 2019 total forest C stocks (forests only), c) recent changes in live forest C stocks 1990-2019, d) projected live C stock change by 2050, e) forest remaining forest 1990-2019 (percent by area), f) forest loss 1990-2019 (percent by area). Positive stock-changes (maps c, d) represent net C sequestration (removals). Watersheds are 8-digit HUC.

NYS SENATE DISTRICTS



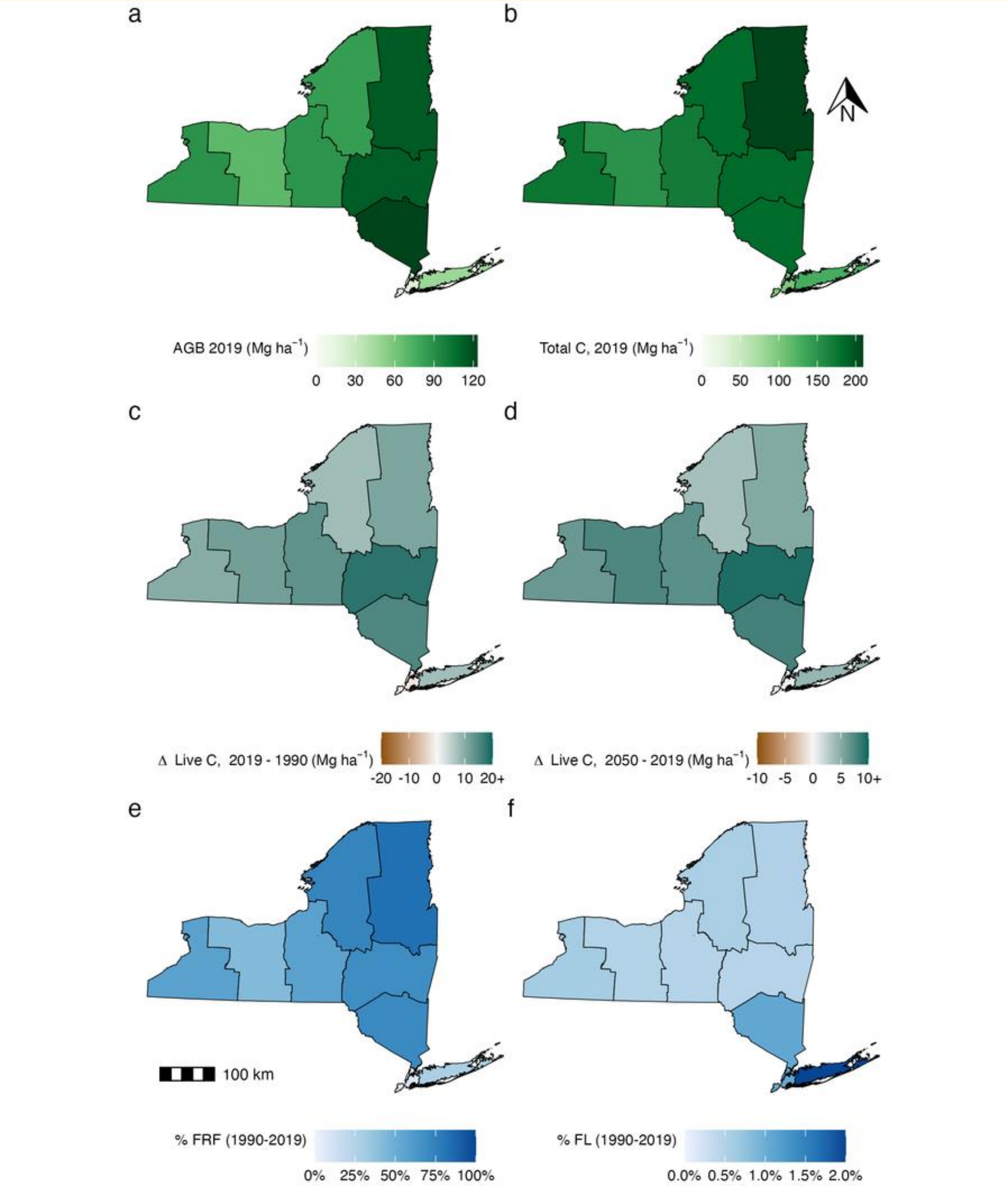
Forest carbon and land use maps for NYS Senate districts: a) 2019 aboveground biomass (all vegetated lands), b) 2019 total forest C stocks (forests only), c) recent changes in live forest C stocks 1990-2019, d) projected live C stock change by 2050, e) forest remaining forest 1990-2019 (percent by area), f) forest loss 1990-2019 (percent by area). Positive stock-changes (maps c, d) represent net C sequestration (removals).

NYS ASSEMBLY DISTRICTS

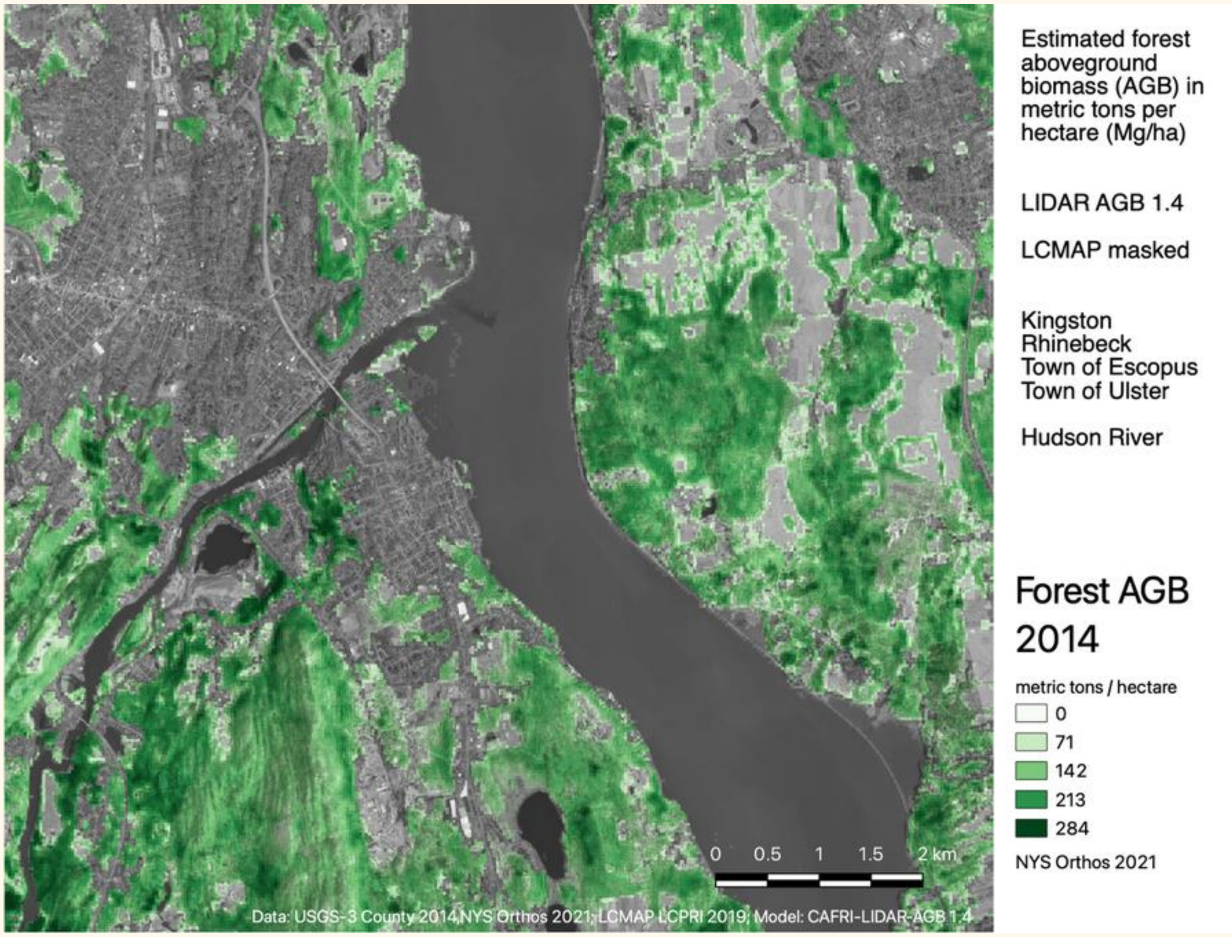


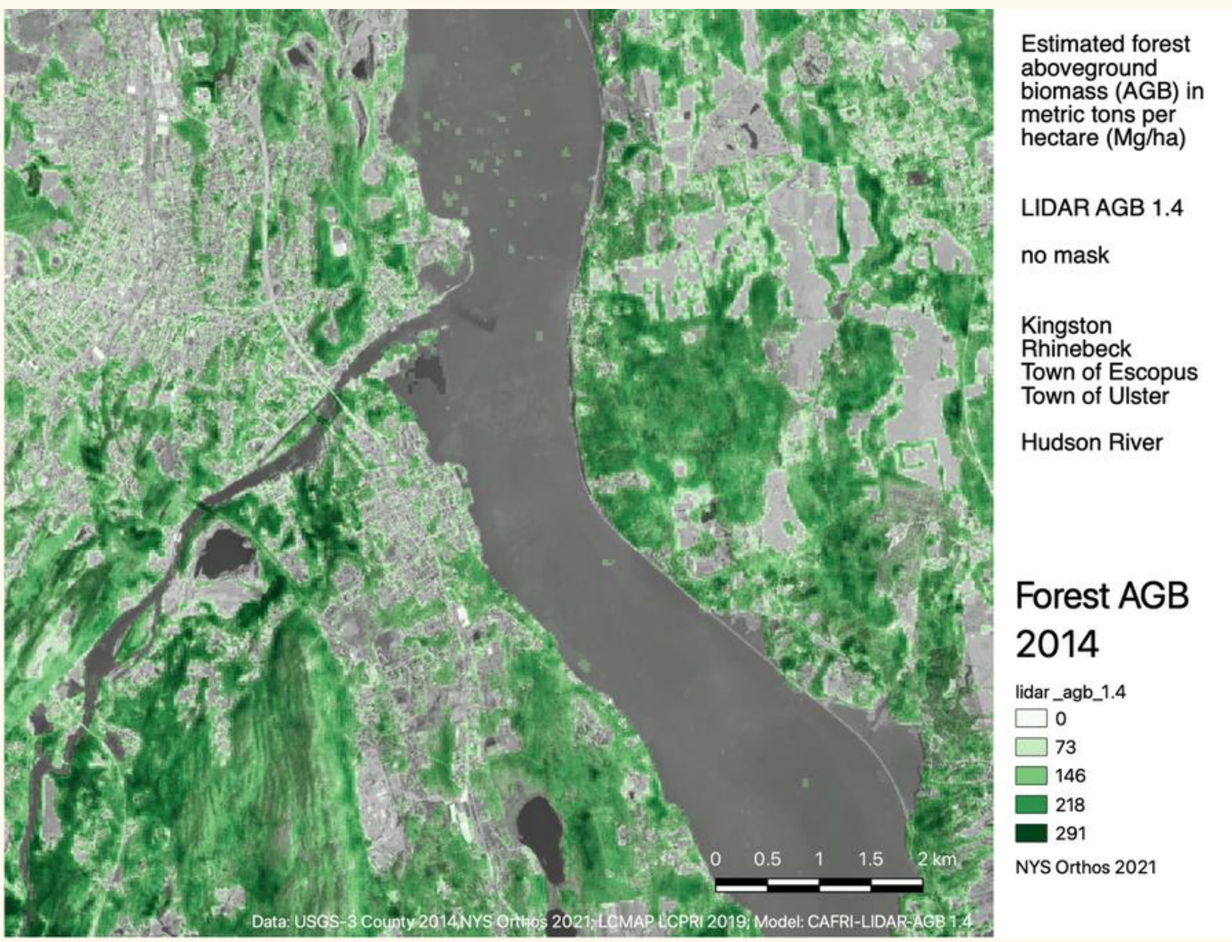
Forest carbon and land use maps for NYS Assembly districts: a) 2019 aboveground biomass (all vegetated lands), b) 2019 total forest C stocks (forests only), c) recent changes in live forest C stocks 1990-2019, d) projected live C stock change by 2050, e) forest remaining forest 1990-2019 (percent by area), f) forest loss 1990-2019 (percent by area). Positive stock-changes (maps c, d) represent net C sequestration (removals).

NYS DEC REGIONS



Forest carbon and land use maps for NYS DEC regions: a) 2019 aboveground biomass (all vegetated lands), b) 2019 total forest C stocks (forests only), c) recent changes in live forest C stocks 1990-2019, d) projected live C stock change by 2050, e) forest remaining forest 1990-2019 (percent by area), f) forest loss 1990-2019 (percent by area). Positive stock-changes (maps c, d) represent net C sequestration (removals).


Estimated forest aboveground biomass (AGB) in metric tons per hectare (Mg/ha)
LIDAR AGB 1.4
LCMAP masked
Kingston
Rhinebeck
Town of Escopus
Town of Ulster
Hudson River
Forest AGB 2014
metric tons / hectare
0
71
142
213
284
NYS Orthos 2021
0 0.5 1 1.5 2 km
Data: USGS-3 County 2014,NYS Orthos 2021; LCMAP LCPRI 2019; Model: CAFRI-LIDAR-AGB 1.4


Estimated forest aboveground biomass (AGB) in metric tons per hectare (Mg/ha)
LIDAR AGB 1.4
no mask
Kingston
Rhinebeck
Town of Escopus
Town of Ulster
Hudson River
Forest AGB 2014
lidar _agb_1.4
0
73
146
218
291
NYS Orthos 2021
0 0.5 1 1.5 2 km
Data: USGS-3 County 2014,NYS Orthos 2021; LCMAP LCPRI 2019; Model: CAFRI-LIDAR-AGB 1.4