High-resolution forest carbon modeling for climate mitigation planning over the 11-state RGGI+ region, USA

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Abstract

Climate mitigation planning requires accurate information on forest carbon dynamics. Forest carbon monitoring and modeling systems need to step beyond the traditional Monitoring, Reporting, and Verification (MRV) framework of current forest cover and carbon stock. They should be able to project potential future carbon stocks with high accuracy and high spatial resolution over large policy-relevant spatial domains. Previous efforts have demonstrated the possibility and value of combining a process-based ecosystem model (Ecosystem Demography, ED), high-resolution (1-meter) lidar and NAIP data, field inventory data, and meteorology and soil properties in a prototype carbon monitoring and modeling system developed for the state of Maryland. Here we present recent work on expanding the Maryland prototype to a 10x larger domain, namely the Regional Greenhouse Gas Initiative (RGGI+) domain consisting of the states of Maryland, Delaware, Pennsylvania, New York, New Jersey, Rhode Island, Connecticut, Massachusetts, Vermont, New Hampshire, and Maine. The system expansion includes an updated version of the ED ecosystem model, improved initialization strategy, and expanded Cal/val approach. High-resolution wall-to-wall maps of current aboveground carbon, carbon sequestration potential, carbon sequestration potential gap, and time to reach sequestration potential are provided at 90m resolution across the RGGI+ domain. Total forest aboveground carbon sequestration potential gap is estimated to be over 2,300 Tg C for the RGGI+ region, about 1.5 times of contemporary aboveground carbon stock. States and counties exhibit variations in carbon sequestration potential gap, implying different policy planning for future afforestation/reforestation and forest conservation activities. Here we present the details of this new carbon monitoring and modeling system as well as regional results, including evaluations of our estimates against USFS Forest Inventory and Analysis (FIA) data, multiple wall-to-wall AGB maps, and state-wide and county-wide future carbon sequestration potential over time.

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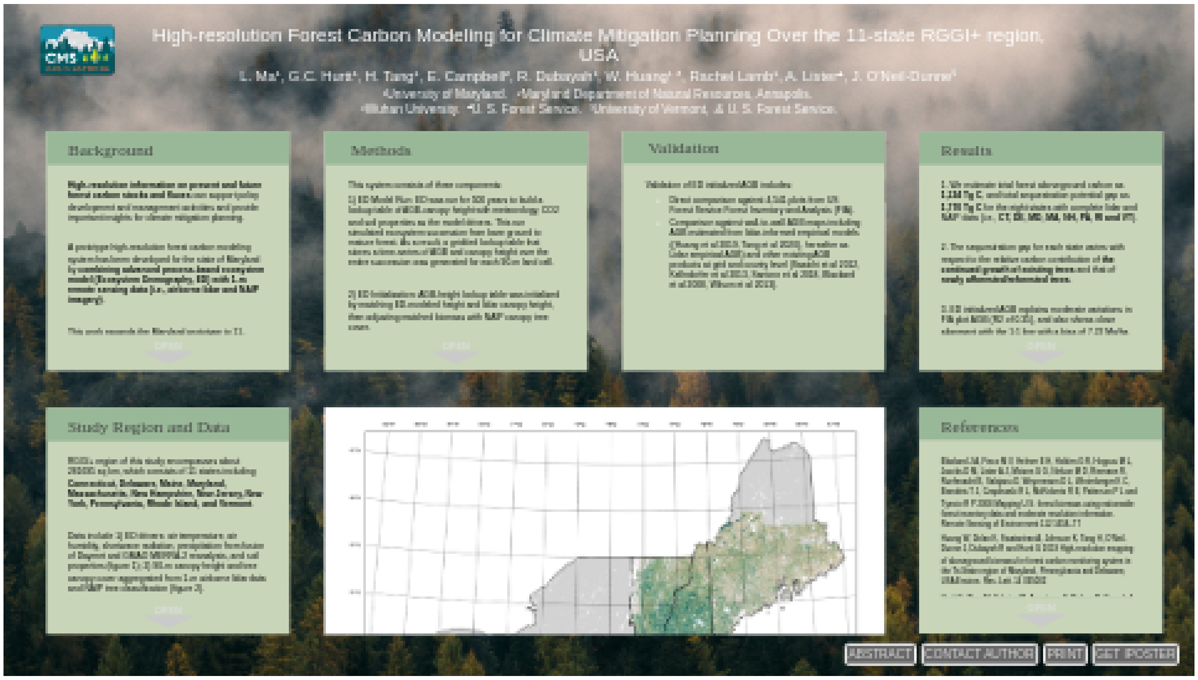

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BACKGROUND

High-resolution information on present and future forest carbon stocks and fluxes can support policy development and management activities and provide important insights for climate mitigation planning.

A prototype high-resolution forest carbon modeling system has been developed for the state of Maryland by **combining advanced process-based ecosystem model (Ecosystem Demography, ED) with 1-m remote sensing data (i.e., airborne lidar and NAIP imagery)**.

This work expands the Maryland prototype to 11-states in the Regional Greenhouse Gas Initiative (RGGI+) region, providing **90-m estimates of current aboveground biomass, carbon sequestration potential and time required to reach the potential**.

METHODS

This system consists of three components:

1) ED Model Run: ED was run for 500 years to build a lookup table of AGB-canopy height with meteorology, CO2 and soil properties as the model drivers. This run simulated ecosystem succession from bare ground to mature forest. As a result, a gridded lookup table that stores a time-series of AGB and canopy height over the entire succession was generated for each 90-m land cell.

2) ED Initialization: AGB-height lookup table was initialized by matching ED-modeled height and lidar canopy height, then adjusting matched biomass with NAIP canopy tree cover.

3) ED Projection: carbon sequestration potential is defined as 95% of maximum AGB from ED run, and sequestration gap is defined by differencing present AGB and carbon sequestration potential. Future sequestration comes from both continued growth of existing trees, as identified by the NAIP canopy cover map (hereafter referred as continued growth), and newly reforested or afforested trees. Land cover of non-forested wetland, inland water, and impervious surface was excluded from the analysis.

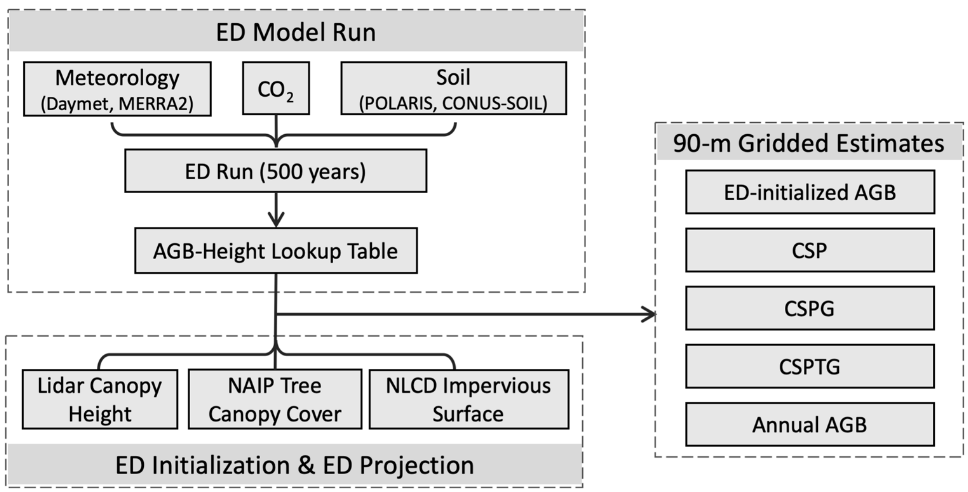

Figure 3. Illustration of ED initialization and projection workflow (a) and the indexing of ED- modelled AGB-Height lookup table with lidar canopy height in (b)

VALIDATION

Validation of ED initialized AGB includes:

- Direct comparison against 4,541 plots from US Forest Service Forest Inventory and Analysis (FIA).
- Comparison against wall-to-wall AGB maps including AGB estimated from lidar-informed empirical models ((Huang et al 2019, Tang et al 2020), hereafter as Lidar empirical AGB) and other existing AGB products at grid and county level (Saatchi et al 2012, Kellndorfer et al 2013, Santoro et al 2018, Blackard et al 2008, Wilson et al 2013).

RESULTS

1. We estimate total forest aboveground carbon as **1,134 Tg C**, and total sequestration potential gap as **1,770 Tg C** for the eight states with complete lidar and NAIP data (i.e., **CT, DE, MD, MA, NH, PA, RI and VT**).

2. The sequestration gap for each state varies with respect to the relative carbon contribution of **the continued growth of existing trees** and that of **newly afforested/reforested trees**.

3. ED initialized AGB explains moderate variations in FIA plot AGB (R2 of 0.35), and also shows close alignment with the 1:1 line with a bias of 7.22 Mg/ha and RMSE of 61.87 Mg/ha.

4. New weighting-based initialization approach proposed in this study improves correlation between ED initialized AGB and FIA plot AGB, especially for tall forests.

STUDY REGION AND DATA

RGGI+ region of this study encompasses about 281695 sq km, which consists of 11 states including **Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont**.

Data include 1) ED drivers: air temperature, air humidity, shortwave radiation, precipitation from fusion of Daymet and GMAO MERRA-2 reanalysis, and soil properties (figure 1); 2) 90-m canopy height and tree canopy cover aggregrated from 1-m airborne lidar data and NAIP tree classification (figure 2).

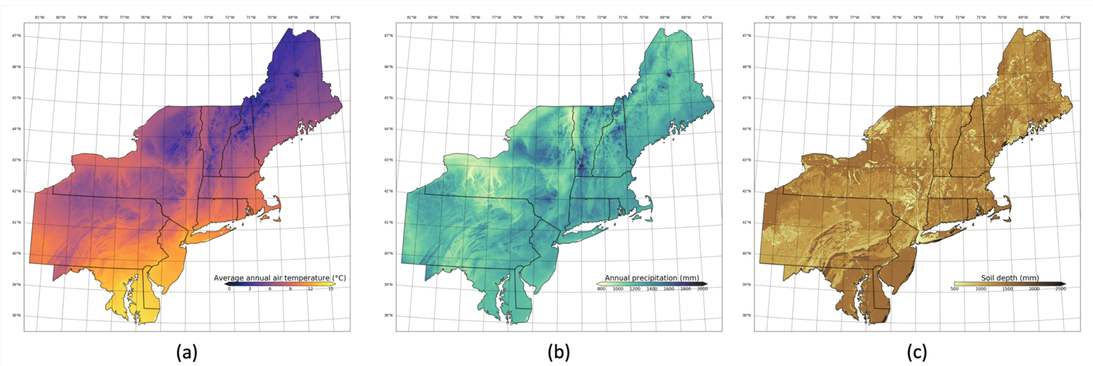

Figure 1. Examples of ED input drivers of average annual air temperature (a) and annual precipitation (b) from Daymet and soil depth from CONUS-PSU (c).

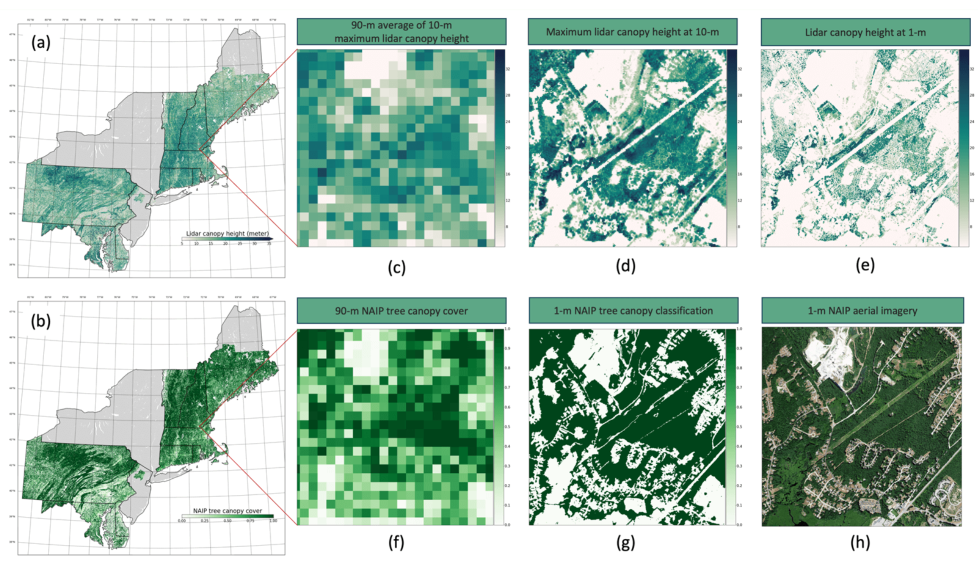

Figure 2. 90-m lidar canopy height (a) and NAIP tree canopy cover (b) over the RGGI region. Using a sample region in New Hampshire, (c)-(h) illustrate the process of 90-m lidar canopy height and NAIP tree canopy cover generation, where (e) and (h) are lidar canopy height and NAIP aerial imagery at 1-m resolution; (d) utilizes (e) to identify the maximum lidar canopy height over 10-m land cells; (g) is NAIP tree canopy classification of (h) at 1-m. (c) and (f) are derived by averaging (d) and (g) respectively to 90-m resolution.

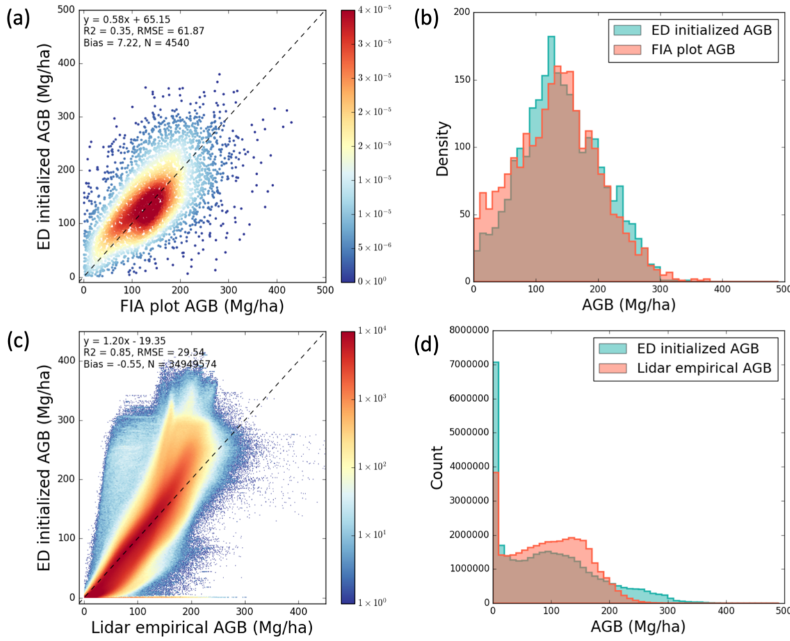

Figure 4. Density scatter plots and histograms comparing ED initialized AGB to FIA plot AGB in (a) and (b), and to lidar empirical AGB in (c) and (d) for all 90-m land cells. For (a) and (b), the corresponding ED initialized AGB is obtained by averaging original 90-m ED initialized AGB over overlapping land cells within the bounded circle area of four FIA subplots (about 40-m in radius).

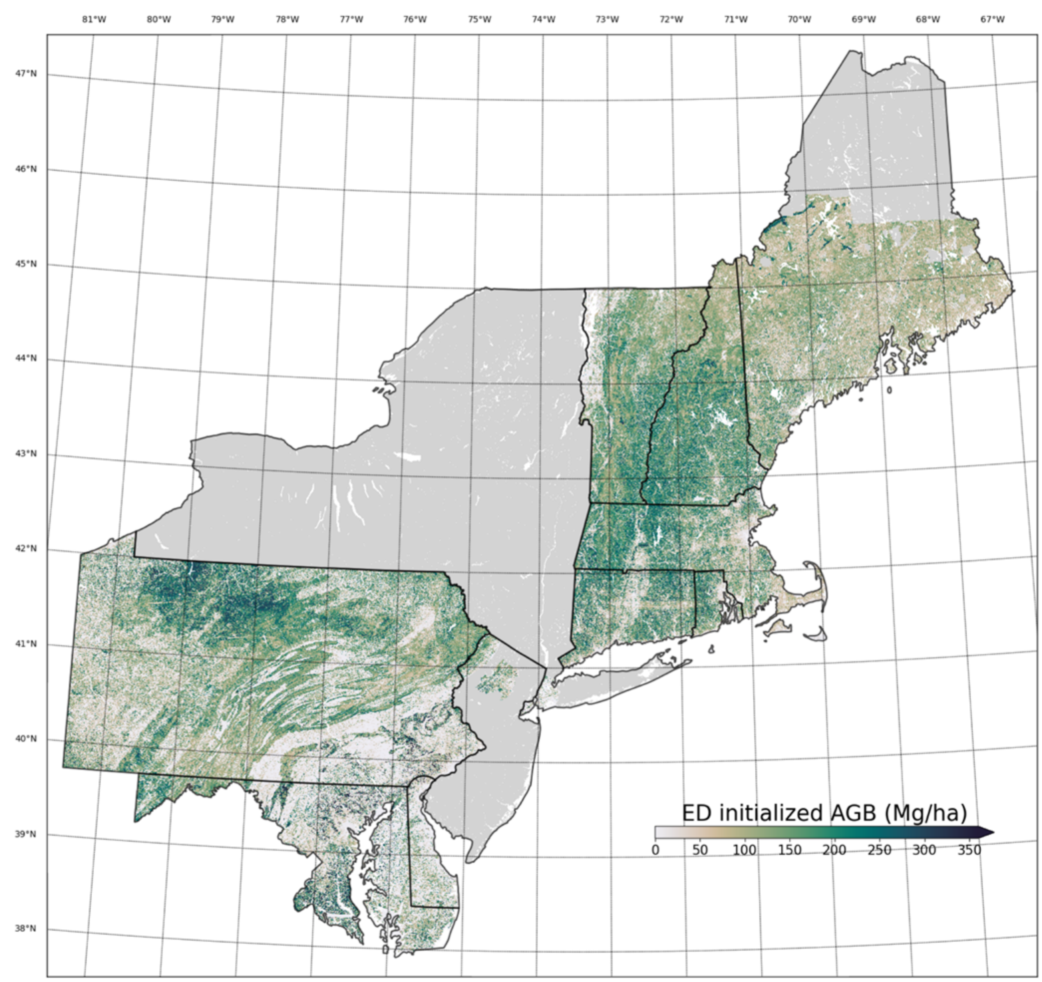

Figure 5. 90-m map of ED initialized AGB

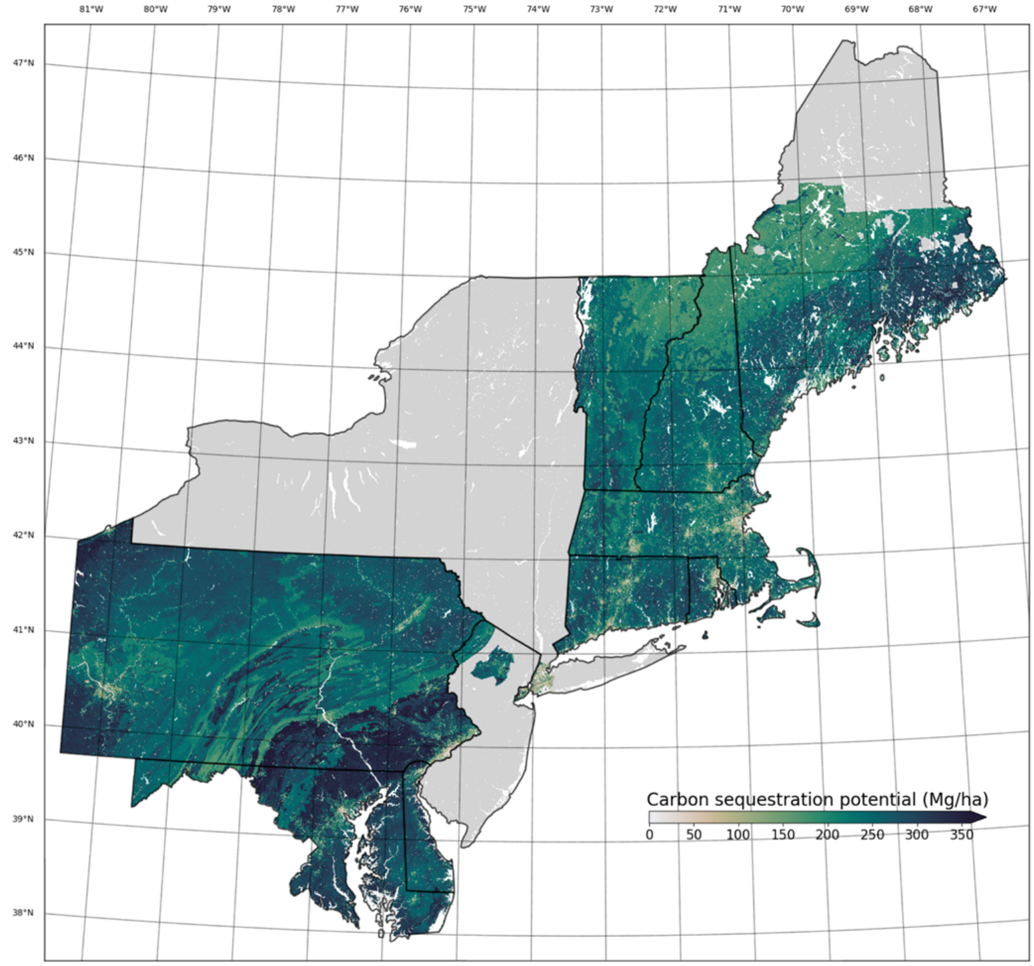

Figure 6. 90-m map of ED projected carbon sequestration potential (CSP).

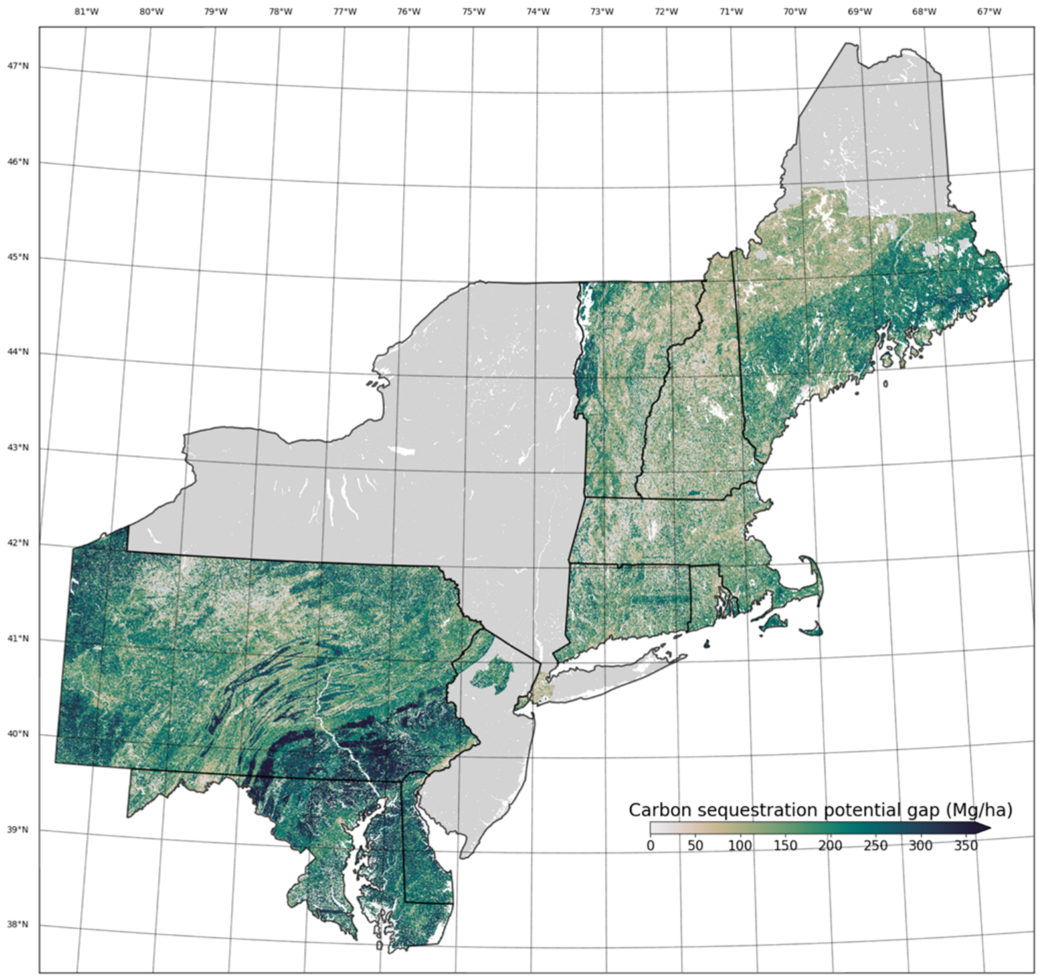

Figure 7. 90-m map of ED projected carbon sequestration potential gap (CSPG).

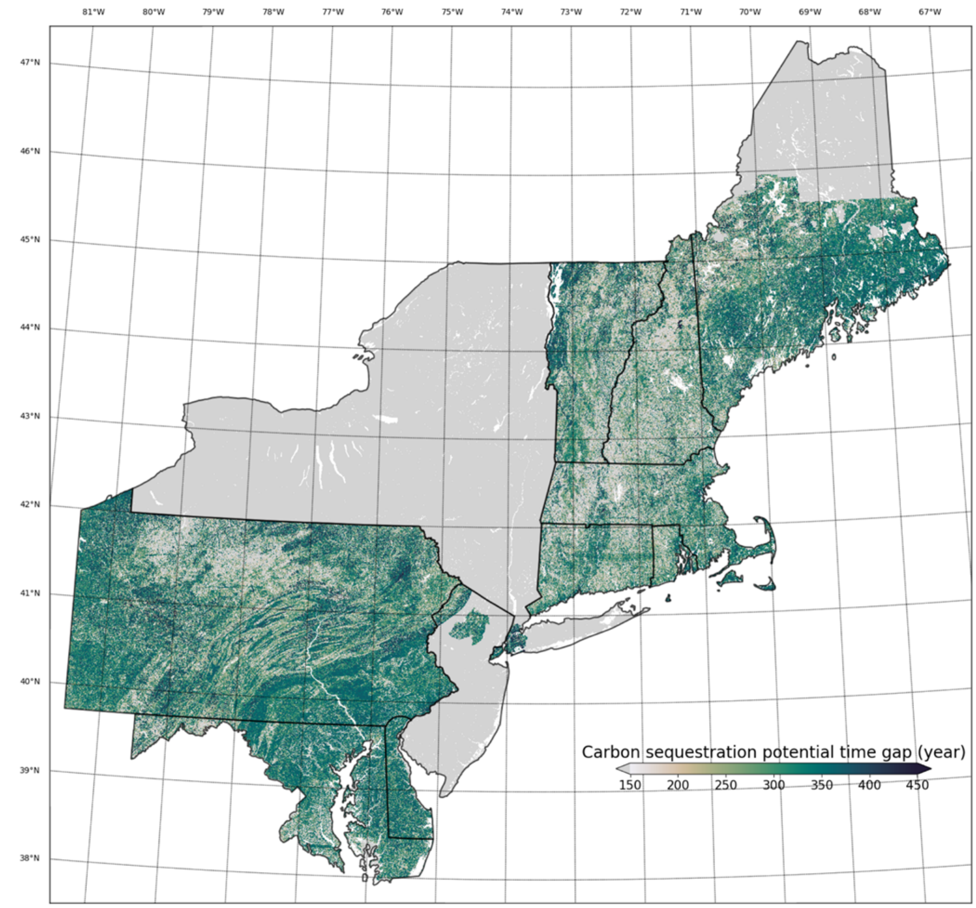

Figure 8. 90-m map of ED projected carbon sequestration potential time gap (CSPTG).

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ABSTRACT

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