Objectives:

- Prior studies demonstrate that vegetation is highly active in the urban carbon (C) cycle and that unique growing conditions in urban areas impact biogenic C cycling; however, the influence of urban vegetation on C fluxes remains poorly constrained and is often ignored in many ecosystem models.
- This uncertainty in timing, magnitude, and direction of C fluxes from urban vegetation limits efforts to accurately monitor, report, verify, and mitigate urban anthropogenic C emissions.
- This study attempts to improve estimates of urban biomass and biogenic C fluxes in Massachusetts, where urban areas occupy 1/3 of the state, using existing, nationally available data products.
- The study utilized three 20 km × 30 km (600 km²) focal areas corresponding to communities spanning a gradient from low to high urban development intensity (Petersham, Worcester, and Boston).
- The authors estimated biogenic C fluxes over Massachusetts at hourly time steps and 500 m resolution and built an inventory of anthropogenic CO₂ emissions at 1 km spatial resolution and hourly time steps for 2013.
- Existing land cover products were combined with field estimates of urban vegetation biomass to produce an improved map of urban biomass density, then this map was compared with spatially- and temporally-resolved model estimates of biogenic and anthropogenic C fluxes.
- The Vegetation Photosynthesis and Respiration model (VPRM) was modified to incorporate the altered phenology, higher air temperatures, and ISA in urban ecosystems and was used to estimate biogenic C fluxes (gross ecosystem exchange [GEE] and ecosystem respiration [RE]).

New Science:

- The Boston biomass density was found to be 1/4 of nearby rural forests.
- Model results suggest that, kilogram-for-kilogram, urban vegetation cycles C twice as fast as rural forests.
- Urban vegetation releases (RE) and absorbs (GEE) the equivalent of 11 and 14%, respectively, of anthropogenic emissions in the most urban portions of the state.
- Urban vegetation in Massachusetts fully sequesters anthropogenic emissions from smaller cities in the region, but Boston’s Urban Heat Island (UHI) reduces annual C storage by >20%, such that vegetation offsets only 2% of anthropogenic emissions.
- Asynchrony between temporal patterns of biogenic and anthropogenic C fluxes further constrains the emissions mitigation potential of urban vegetation.
- Where biomass was re-estimated, mean above ground biomass (AGB) was 21.7 (25.8) MgC ha⁻¹, or roughly 25% lower than the National Biomass and Carbon Dataset (NBCD) density of 27.2 (36.5) MgC ha⁻¹ and the areal extent of urban vegetation increased statewide by 62.3%.

Significance:

- The widespread presence of vegetation in and around cities complicates precise characterization of urban CO₂ budgets using atmospheric observations, particularly due to the spatially heterogeneous arrangement of urban vegetation and seasonality of urban biogenic C fluxes.
Regional carbon cycle models that omit urban vegetation may be incomplete, and the inability to accurately account for biogenic C fluxes in cities can impair efforts to accurately monitor, report, verify, and reduce anthropogenic emissions.

The method of estimating AGB in urban areas presented in this study differs fundamentally from that used to produce the NBCD, and the results reveal substantial differences in the spatial patterns of AGB relative to the NBCD.

The study improves estimates of urban biomass and biogenic C fluxes in urban areas, which are often ignored in typical land cover maps and ecosystem models.

The fluxes were compared with new inventories of anthropogenic emissions to produce a comprehensive C budget for the state of Massachusetts.

The significant diurnal and seasonal variation in sources and fluxes of C needs to be resolved at sub-urban scales to accurately attribute sources and sinks, which requires relatively high resolution remote sensing data.

The study methods rely on nationally available data sources coupled with local ground observations and can be readily applied in other cities to improve understanding of the role of vegetation in urban ecosystem C flows across a broad range of biomes and urban forms.
The Better Urban Biomass Map (BU-BioM) provides refined estimates of vegetation biomass in urban ecosystems (A), demonstrating that existing biomass products underrepresent the extent and quantity of vegetation in urban ecosystems (B). Urban biogenic C exchange is strongly influenced by urban factors such as impervious surface area (ISA) (D), which alters spatial patterns of ecosystem respiration (E) and gross ecosystem exchange (F). Carbon fluxes in (E) and (F) are the mean of all noon hours for July 2013 but are reported with annualized units for ease of comparison to Panel C. Purple dots show the center of focal area locations and purple boxes correspond to view extent in Panels D–F.
Spatial patterns of biomass and C fluxes in areas of increasing urban density in Petersham (A), Worcester (B), and Boston (C). Arrows correspond to mean annual C fluxes for 2013 (GEE-green, RE-red, Anthropogenic-black) with arrow direction indicating C movement into (down) or out of (up) the ecosystem. NEE is the difference of GEE and RE. All arrow widths are proportional to Boston’s anthropogenic emissions. Fraction of impervious surface area (ISA), atmospheric CO2 concentration, and mean aboveground biomass (AGB) density from BUBioM are listed for each 20 × 30 km area surrounding an atmospheric monitoring tower (purple dots). Insets (purple boxes) show the location of each focal area within the state. Pie charts illustrate the change in relative contribution of each anthropogenic emissions sector across this gradient of urban intensity.

Cumulative C fluxes (MgC ha$^{-1}$ yr$^{-1}$) for 2013 indicate that MA is a net biogenic C sink and that on an area-basis statewide anthropogenic emissions are of similar magnitude as biogenic fluxes (A1). Both biogenic and anthropogenic fluxes (kgC ha$^{-1}$ h$^{-1}$) follow daily cycles, the amplitude of which varies seasonally (A2, A3). Boston’s biogenic fluxes are dwarfed by anthropogenic C emissions (B1) but follow similar patterns as seen at the state-level (B1, B2). Anthropogenic fluxes in all B panels are plotted on a second y-axis to facilitate comparison with biogenic fluxes.