4. Regional Soil Respiration: Measurement, Validation, and Modeling

Brian Strahm[1, 8] • Robert Brown[2, 9] • Sabine Grunwald[3, 10] • Eric Jokela[3, 11] • Dan Markewitz[3, 8]
Kristin McElligott[4, 8] • Wen Lin[4, 12] • Asko Noormets[5, 12] • Wade Ross[4, 10] • John Seiler[3, 8] • Ben Templeton[7, 13]
Bob Teskey[3, 9] • Jason Vogel[6, 14] • Rod Will[3, 15] • Jianyan Yang[4, 9]

[1] *Assistant Professor* • [2] *M.S. Student* • [3] *Professor* • [4] *Ph.D. Student* • [5] *Research Assistant Professor* • [6] *Assistant Professor* • [7] *Inspector* • [8] *Department of Forest Resources and Environmental Conservation, Virginia Tech* • [9] *Warnell School of Forestry and Natural Resources, University of Georgia* • [10] *Department of Soil and Water Science, University of Florida* [11] *School of Forest Resources and Conservation, University of Florida* • [12] *Department of Forestry and Environmental Resources, North Carolina State University* [13] *Virginia Dpeartment of Agriculture and Consumer Services, Office of Plant Industry Services* • [14] *Department of Ecosystem Science and Management, Texas A&M University* [15] *Department of Natural Resource Ecology and Management, Oklahoma State University*

{CO₂}

Increasing carbon sequestration in forests requires an improved understanding of the factors that affect soil carbon inputs and outputs. Clarifying the regional patterns of total, plant-based, and microbial soil respiration versus climate and soil factors will guide the development of management scenarios aimed at optimizing both forest productivity and carbon sequestration.

Managing forests for both timber production and carbon sequestration requires an improved understanding of the factors that affect carbon sequestration in soil. While there are robust models predicting aboveground loblolly pine productivity across climate and soil gradients in the southeastern United States, our understanding of the mechanisms governing belowground carbon sequestration is much more limited. Carbon sequestration in soil depends on the balance between soil carbon inputs and losses. Inputs of aboveground and belowground litter can be measured or estimated allometrically. Measuring the carbon losses from respiration of decomposer microorganisms (heterotrophic respiration, R_H) is more resource intensive and must be inferred from total soil CO_2 efflux (soil respiration, R_S) observations. After gross primary productivity (GPP, an ecosystem-level measure of photosynthesis), R_S is the largest carbon flux in forests (Figure 4.1). Partitioning R_S into its plant-derived (autotrophic, R_A) and decomposer derived (heterotrophic) components remains an area of active PINEMAP research, especially the search to understand how these fluxes vary with soil type, climate, and seasonality. The primary goals of the PINEMAP regional soil respiration group are to provide a region-wide model for R_S, partition R_S into heterotrophic and autotrophic components, understand how partitioning varies over space and time, and incorporate this information into ecosystem-level models to better quantify the carbon sequestration capacity of loblolly pine forests under variable climate and management scenarios.

One of the great strengths of the PINEMAP research approach is its ability to integrate and leverage existing data sets to address PINEMAP-specific questions or challenges. Development of a region-wide model for R_S is a prime example. Even at the large scope and scale of PINEMAP, developing this information anew would be inefficient and time consuming. PINEMAP scientists have combined years of historic research from more than 150 study plots in 11 states spanning the natural range of loblolly pine in order to derive a region-wide model of R_S (Figure 4.2; Templeton et al. 2015). Five different environmental variables (soil temperature, soil bulk density, soil nitrogen concentration, latitude, and soil moisture) accounted for 56% of the variability in R_S. A single-variable model based on soil temperature alone (which accounted for 45% of R_S variability) was also developed to ease the computational burden of integration into regional ecosystem carbon flux modeling efforts.

A challenge in developing a region-wide model of R_S is describing both how this carbon flux changes across different forest stands (space) and how it changes throughout the year at any particular place (time). For example, the model shown in Figure 4.2 has a high degree of spatial coverage but potentially low predictive power at finer time intervals. Incorporating additional data sets and research sites (i.e., Duke FACE and two regional AmeriFlux sites) has enabled PINEMAP scientists to evaluate the robustness of this region-wide model across daily, seasonal, and annual time scales. Efforts to date have shown that the existing region-wide model accounts for about

Photo by John Seiler.

One of the great strengths of the PINEMAP research approach is its ability to integrate and leverage existing data sets to address PINEMAP-specific questions or challenges.

60% of the variability in instantaneous flux measurements, an improvement over the original range-wide model. Further model refinement is underway using both the existing range-wide data set and the new data collected by PINEMAP scientists. This new model will improve our predictive power, better capture interannual variability in R_S, and provide a more accurate annual estimate of this important ecosystem carbon flux.

Improved prediction of R_S is an important step toward estimating forest carbon sequestration. Many existing models (e.g., 3-PG) require both accuracy in predicting R_S and accurate partitioning of R_S into R_H and R_A. Previous PINEMAP work has reported near uniform partitioning of R_S ($R_H/R_S = 0.84$) across the Tier III manipulative experiments, irrespective of drought, fertilization, or time of year. Further exploration is underway across the Tier II sampling network and is already providing a more nuanced view of the dynamic components of R_S. Preliminary results suggest that the degree of site occupancy by both trees and understory vegetation changes the relative size

of autotrophic and heterotrophic soil respiration components. So, forest management, and the degree of control of competing vegetation in particular, is expected to be an important driver of the net carbon balance of forest ecosystems.

PINEMAP scientists are working to parameterize process-based models of belowground carbon and nitrogen fluxes to extend the empirical observations being made at the Tier II and Tier III sites. DayCent (a daily time-step version of the CENTURY biogeochemical model) is being parameterized using observations from the Florida and Georgia Tier III sites, incorporating loblolly pine-specific phenology and leveraging existing weather and soils data. Ultimately, DayCent will be calibrated and validated across all four Tier III sites and scaled up across the region. This approach will help improve seasonal estimates of productivity and will provide the added advantage of facilitating the modeling of other important soil-atmosphere gas fluxes, like nitrous oxide, to more fully understand the role of forest management in mitigating climate change.
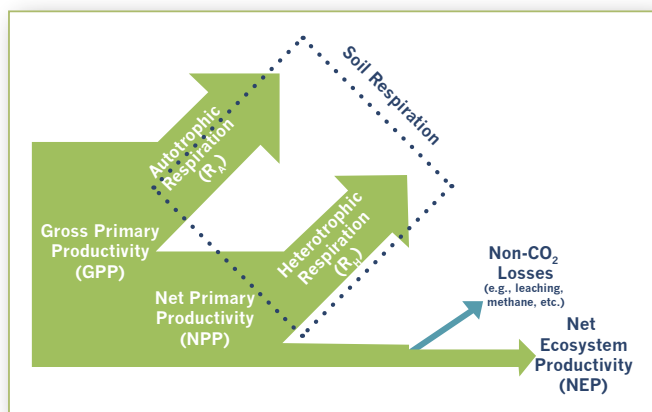

Figure 4.1. Carbon flow in forest ecosystems leading to net ecosystem productivity (NEP), or carbon sequestration.
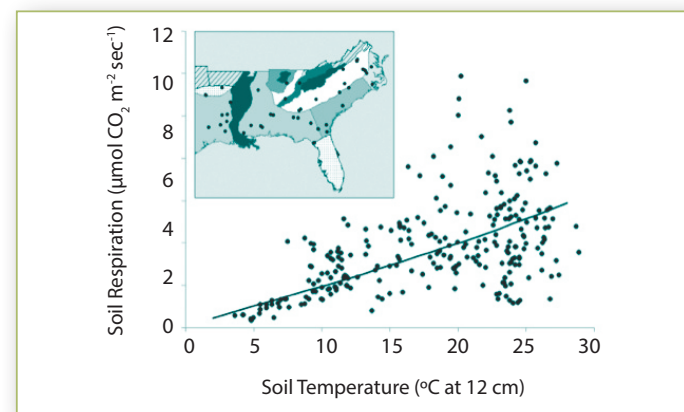

Figure 4.2. Region-wide model of soil respiration as a function of a single environmental variable, soil temperature derived from the sites depicted in the inset.