10. Regional Carbon Sequestration and Climate Change: It's All about Water

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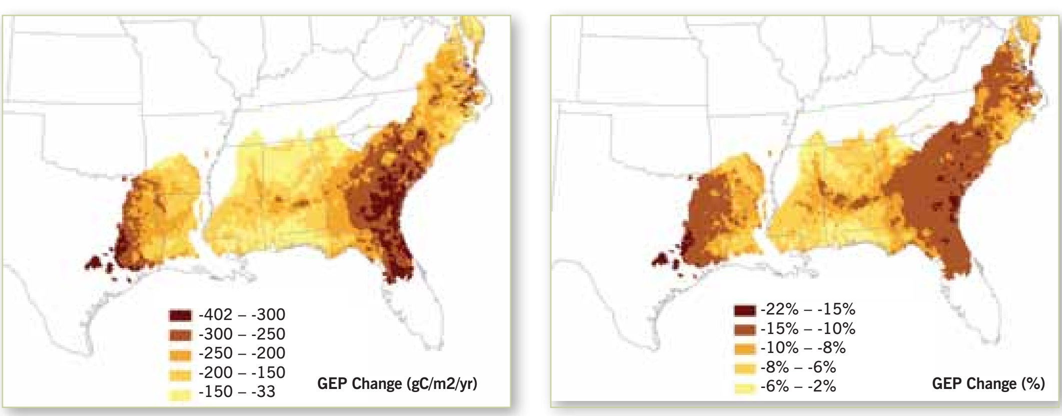
Forests need a lot of water to produce the goods (e.g., timber) and services (e.g., carbon sequestration and climate moderation) that benefit humans. Forests grow naturally in water-rich regions where precipitation is abundant or where groundwater is available, such as riparian areas in arid regions. For example, loblolly pine (*Pinus taeda* L.) forests are found in areas where mean annual precipitation normally exceeds 1,000 mm/yr (40 inches/yr). However, under climate change scenarios, water availability is projected to decrease and become more variable in the future, potentially impacting loblolly pine productivity. Extreme weather events such as heat waves and prolonged droughts are of particular concern for southern forests, which are not as well adapted to extreme soil water stress as their western counterparts.

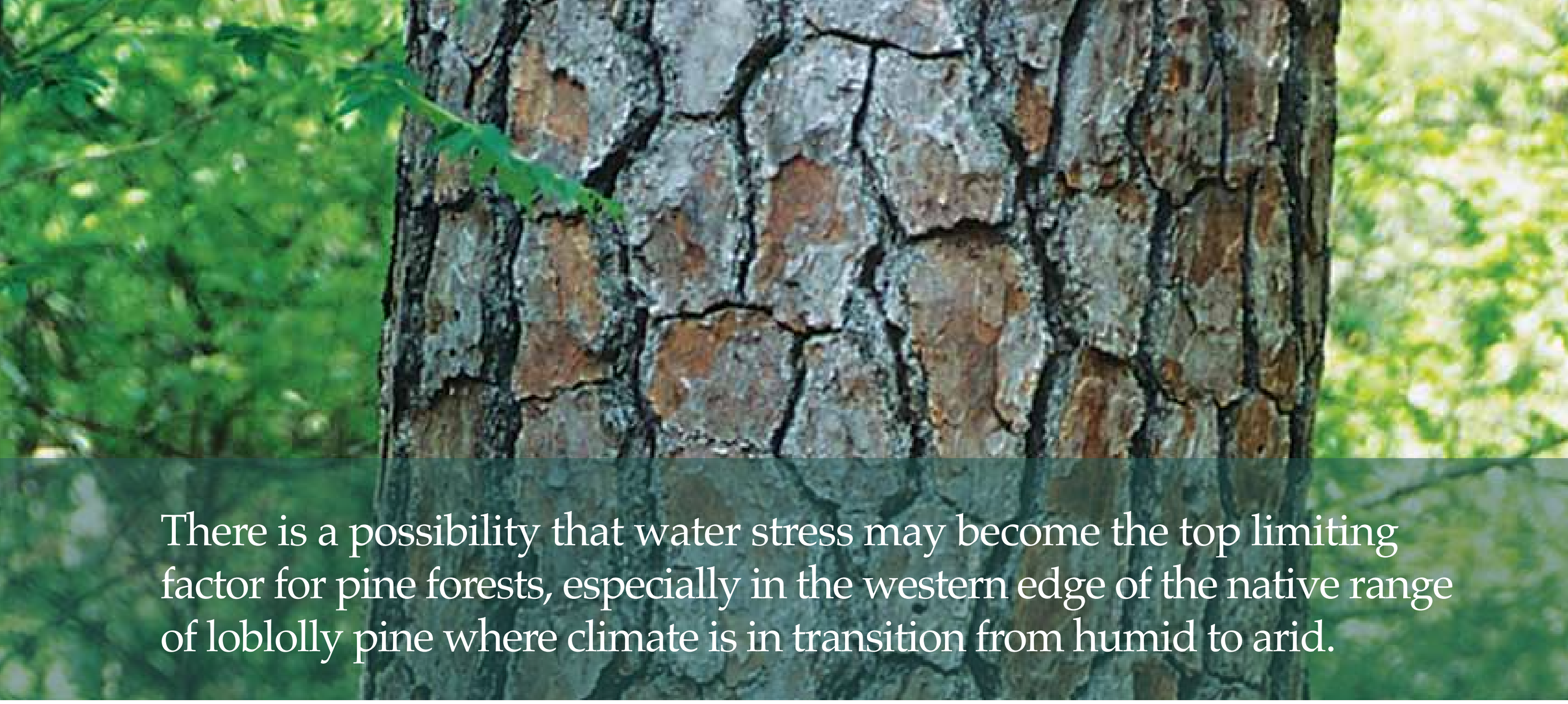
Studies have long documented that southern pine productivity is highly dependent on leaf area, light, and nutrient availability, and southern forests are the most productive in the nation due to plentiful rainfall and abundant sunlight. Water stress in some parts of the South occurs only periodically; therefore, water is a minor environmental control to southern pine productivity. However, projected drought frequency, duration, and severity are on the rise compared to the past decades. Thus, there is a possibility that water stress may become the top limiting factor for pine forests, especially in the western edge of the native range of loblolly pine where climate is in transition from humid to arid.

To understand the sensitivity of forest productivity to droughts, precipitation manipulation experiments and monitoring have been implemented at four Tier III sites across a climatic gradient in the loblolly pine range. These experiments provide a basis for understanding the expected response of these forests to lower precipitation. This research is limited to short-term studies on small sites and may not fully capture the spatial variability of climate, soil, and nutrient conditions across the entire loblolly pine domain. Regional scale models with interlinked carbon and water cycles have the capacity to simulate the sensitivity of forest productivity and water yield to multiple stressors over a large geographic region. Most importantly, a model can predict what will happen in the future to forests under different climate change and forest management scenarios.



(a) (b)

Figure 10.1. WaSSI model simulated drought (30% rainfall reduction year round) impacts on annual gross ecosystem productivity (GEP) of watersheds covered by mid-rotation loblolly pine plantations (age 17) (a) absolute change and (b) relative change compared to historic climate.



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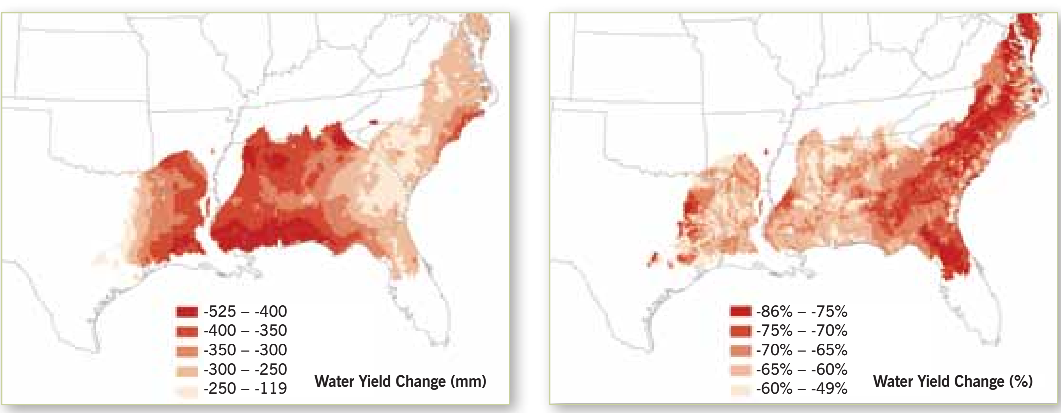
Water-Centric Model : Linking Water and Carbon Cycles

We used the Water Supply Stress Index (WaSSI) model to identify “hot spot” watersheds that are most vulnerable to droughts in the loblolly pine range. At the spatial scale of a watershed, WaSSI simulates monthly evapotranspiration, stream flow, and carbon balances (i.e., gross ecosystem productivity [GEP], ecosystem respiration, and ecosystem net carbon exchange). The basic assumption of the WaSSI model is that water availability is the dominant driver of ecosystem productivity. Forest water use is driven by soil water availability, energy availability, and leaf area. Forest productivity is directly linked to evapotranspiration (ET) through the Water Use Efficiency (WUE) parameter that varies with stand age.

A series of hypothetical climate scenarios have been developed to study how droughts may affect GEP and water yield (Q) across the 9,283 watersheds in the study region. We modeled monthly forest water and carbon balances using 20 years (1990 to 2009) of historic climate data (PRISM database). We examined two levels of hypothetical precipitation reduction (15% and 30% reduction below latest 20 year means) and two stand ages (7 and 17 years) to represent climate impacts on GEP and Q for two stages of forest development.

Findings

Our simulations indicate that when precipitation is reduced by 30%, loblolly pine forest productivity (Figure 10.1) and water yield (Figure 10.2) is dramatically reduced compared to current conditions. The reduction can be as high as 400 g C/m^2/yr or 22% reduction from baseline (Regional mean= 200 ± 145 gC/m^2/yr or 10 ± 7%) and water yield is expected to decrease even more, 320 mm/yr or 65% reduction from baseline on average. Such a reduction is likely to transform many small perennial streams in certain forested watersheds in the drier regions to ephemeral water bodies (i.e., ceasing to flow during certain times of the year). A sensitivity test shows that a moderate reduction (15%) of rainfall may result in only marginal reduction in GEP (3.4± 6%), but still significant reduction in water yield, with regional average of 172 mm/yr or 35% reduction from current baseline. The preliminary results suggest that the effect of the two drought scenarios on the productivity of young stands (7 years old in our simulations) would be similar in magnitude for late-rotation stands (17 years old). Such simulations provide a predictive framework that can readily assimilate data from other PINEMAP research areas, such as transpiration and growth estimates from the Tier III sites.



(a) (b)

Figure 10.2. WaSSI model simulated drought (30% rainfall reduction year round) impacts on annual water yield of watersheds covered by mid-rotation loblolly pine plantations (age 17) (a) absolute change and (b) relative change compared to historic climate.