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Changes in tree functional composition amplify the response of forest biomass to climate variability

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The response of forest carbon storage to climate change is highly uncertain, contributing substantially to the divergence among global climate model projections. Numerous studies have documented responses of forest ecosystems to climate change and variability, including drought-induced increases in tree mortality rates. However, the sensitivity of forests to climate variability – in terms of both biomass carbon storage and functional components of tree species composition – has yet to be quantified across a large region using systematically sampled data. Here, we combine systematic forest inventories across the eastern USA with a species-level drought-tolerance index, derived from a meta-analysis of published literature, to quantify changes in forest biomass and community-mean-drought-tolerance in one-degree grid cells from the 1980s to 2000s. We show that forest biomass responds to decadal-scale changes in water deficit and that this biomass response is amplified by concurrent changes in community-mean-drought-tolerance. The amplification of the direct effects of water stress on biomass occurs because water stress tends to induce a shift in tree species composition towards more drought-tolerant but lower-biomass species. Multiple plant functional traits are correlated with the above species-level drought-tolerance index, and likely contribute to the decrease in biomass with increasing drought-tolerance. These traits include wood density and P50 (the xylem water potential at which a plant loses 50% of its hydraulic conductivity). Simulations with a trait- and competition-based dynamic global vegetation model suggest that species differences in plant carbon allocation to wood, leaves, and fine roots also likely contribute to the observed decrease in biomass with increasing drought-tolerance, because competition drives plants to over-invest in fine roots when water is limiting. Thus, the most competitive species under dry conditions have greater root allocation but lower total biomass than productivity-maximizing plants. Amplification of the biomass-climate response due to shifts in species functional composition (temporal beta diversity) contrasts with evidence that local (alpha) diversity increases ecosystem stability, including increased resistance to climate extremes. These contrasting effects of alpha and beta diversity highlight the need to better understand how different components of biodiversity, including changes in the functional traits of the dominant plant species, affect ecosystem functioning.