Benchmarking and parameter sensitivity of a vegetation demographic model in a mixed conifer forest of the Sierra Nevada Mountains, California

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Abstract

Western U.S. conifer forests harbor diverse ecological strategies that enable species to persist across a wide range of hydroclimate conditions, along with wildfire and eruptive insect outbreaks. Assessing climate influences on future forest composition and carbon sequestration requires vegetation process models that have sufficient ecological resolution to simulate this range of ecological variability. Here we present progress towards incorporating multiple shade and drought tolerance strategies in a vegetation demographic model parameterized for Western U.S. forests. We used the Functionally Assembled Terrestrial Ecosystem Simulator (FATES) to simulate a mixed conifer forest dominated by ponderosa pine and incense cedar in the Sierra Nevada Mountains of California. FATES resolves plant growth and respiration at the level of cohorts, defined by size and plant functional type. Incense cedar is shade and drought tolerant, while ponderosa pine is shade intolerant and the canopy dominant. We synthesized literature values of plant traits that correspond to important physiological and allometric parameters in FATES and conducted a sensitivity analysis within the observed parameter ranges with respect to carbon and water fluxes. Model output was benchmarked against carbon flux, water flux, and leaf area index measurements from the Critical Zone Observatory/AmeriFlux CZ2 site during 2010-2012. Specific leaf area, Vcmax, rooting distribution, and allometric equations had the most influence on simulated carbon and water fluxes. Final simulated average annual gross primary production (GPP) over 2010-2012 (1156 +- 79.2 gC/m2/yr) was 3.8% lower than observed GPP (1202 +-138.2 gC/m2/yr). Simulated evapotranspiration (ET, 373 +- 25 mm/yr) was 62% lower than measured ET (993 +-158 mm/yr). Simulated leaf area index (LAI, 1.2) was within the range of measured LAI (0.5-1.5). Preliminary analysis indicates underestimation of ET is likely due to an overestimation of soil water drainage. Our final parameter set allows pine and cedar coexistence to emerge from a bare ground initialization, and additional sensitivity testing of parameters important for coexistence are in progress. Clearly, observationally constrained parameters are critical for simulating ecosystem dynamics in Western U.S. forests.

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A Component of the California Ecosystem Futures Project

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The Need: Understand and plan for forest responses to novel future climate conditions and disturbance regimes

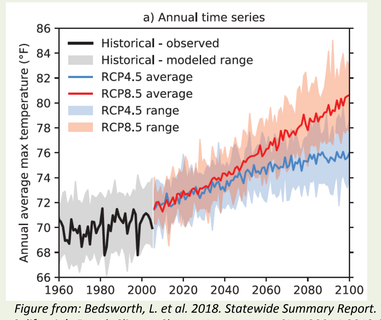
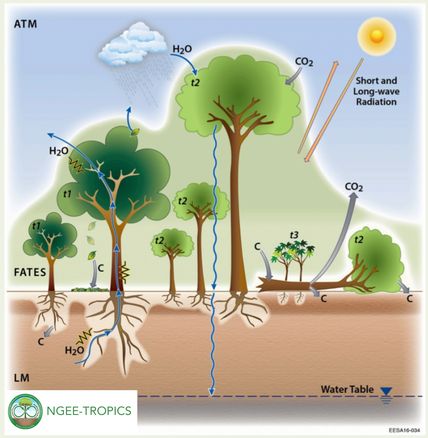


Figure from: Bedsworth, L. et al. 2018. Statewide Summary Report. California's Fourth Climate Change Assessment. : SUMCCCA4-2018-013.

Will novel climate conditions, CO_2 levels, and disturbance regimes lead to novel ecosystems?

Photo Credit: Keri Greer, In: Evans et al. 2011. Comprehensive fuels treatment practices guide for mixed conifer forests: California, central and southern Rockies, and the Southwest. Forest Guild.

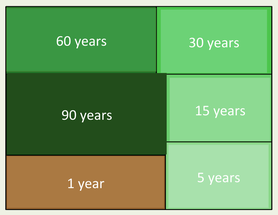
The Framework: The Functionally Assembled Terrestrial Ecosystem Simulator (FATES)

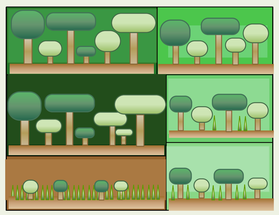


- Explicit physiology drives carbon and water balance, demography, and forest structure
- Effects of elevated CO_2 incorporated
- Flexible plant functional type definitions
- Heterogeneity in light availability
- Physical environment and competition determine plant coexistence
- Plant type distribution is emergent
- Ignitions, weather, and vegetation types interact to determine fire occurrence, intensity, area burned, and plant mortality
- Option for explicit hydrodynamics modulated by plant traits

Vegetation structure in FATES

Each time since disturbance tile contains cohorts of identical plants defined by functional type and size



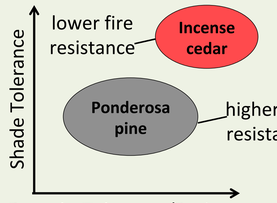


To date, FATES has been exercised in the tropics, the eastern US, the arctic, and the boreal forest, but not in western US forests.

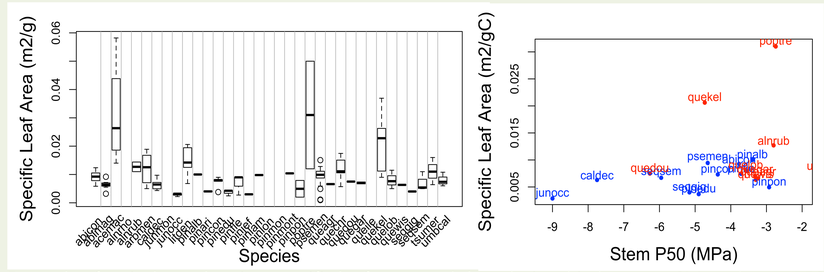
Bringing FATES to California: An iterative process of parameterization and benchmarking

Plant Functional Type definition

- Compiled observations of 16 plant traits for 33 tree species



Example of two PFT definitions

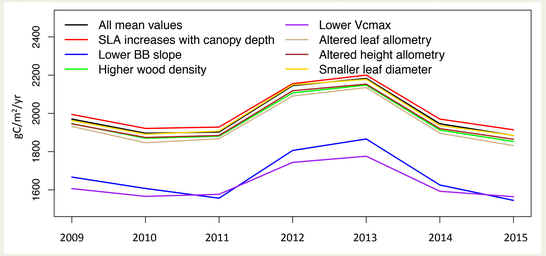


Example of trait data, showing specific leaf area, and the relationship between SLA and stem P50

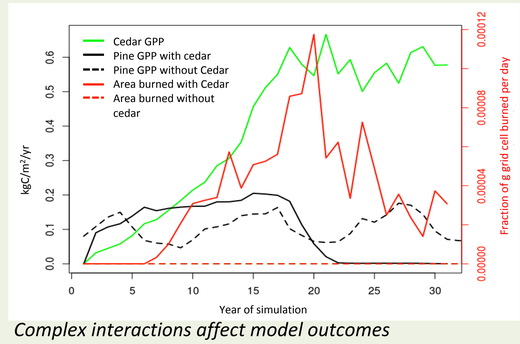
- Defined PFTs by shade tolerance, drought tolerance, and fire resistance
- Refined through sensitivity analysis and benchmarking

Parameter Sensitivity Analysis:

- One-by-one parameters perturbations inadequate to disentangle the interactions among plant traits, climate, competition, and fire



Multiple parameters affect annual GPP in simulations with initialized stands and one PFT

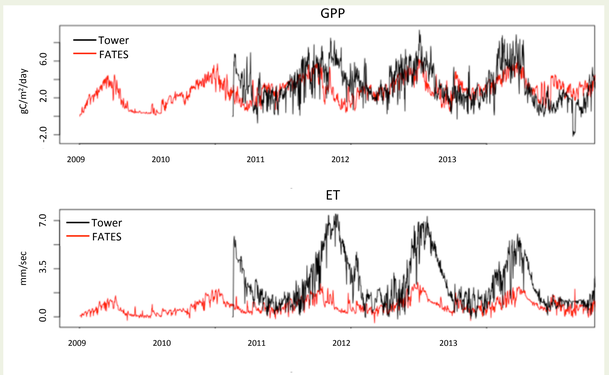


Complex interactions affect model outcomes

- Currently running 5,000 member ensemble varying 50 parameters that affect mortality, recruitment, allometry, physiology, fire, and patch dynamics

Initial Benchmarking

- Seasonal GPP simulated well
- ET underestimation likely due to incorrect rooting distribution, or lack of simulated tree diversity and understory vegetation
- Will expand to include multiple PFTs and additional towers spanning an elevational and forest type gradient
- Iteratively refine trait parameters within the range of trait observations



Comparison of Southern Sierra CZ2 tower data and fluxes simulated with one pine PFT starting from initialized stand conditions

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