Estimating urban tree recovery after drought using an eco-hydrologic model parameterized by remote sensing data

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Abstract

Urban trees provide several ecosystem services including stormwater filtering and reducing the urban heat island, but these services depend on tree health and may change in response to climate extremes such as drought. Quantifying how tree health and ecosystem services change over time is challenging due to lack of data and the spatial heterogeneity of urban layouts. Remote sensing can capture the spatial distribution of tree canopies at fine resolutions but is limited to singular moments in time. To use this data to make predictions of how vegetation will change with climate, we combined LAI data produced from hyperspectral imagery and waveform lidar with a distributed eco-hydrologic model. The model, Regional Hydro-Ecologic Simulation System (RHESSys), simulates water, carbon, and energy fluxes, which depend on several vegetation parameters that affect how plants respond to water stress. It was initialized with maps of LAI and carbon data to capture pre-drought conditions. The model was then used to simulate evapotranspiration and net primary production (NPP), as proxies of tree resilience to water stress. Simulations estimated plant responses both prior to, during, and following a drought (2012-2016) for Santa Barbara, a medium sized urban area in semi-arid southern California. The simulations were run at 3 spatial scales: a single patch with one species of tree, an urban park with a stand of mixed vegetation, and a small hillslope with a mix of vegetation and impervious area. By running the model at different spatial levels, we were able to explore the various pathways through which water contributes to vegetation drought vulnerability and post-drought vegetation recovery. All three spatial levels were ran with and without irrigation. Irrigation rates were derived from long- term Santa Barbara water use data sets and were assumed to be constant throughout the simulation period. The single patch scale and urban park scale have only direct precipitation or irrigation as local water inputs. At the hillslope scale, both upslope lateral groundwater subsidy and additional runoff from impervious area contribute to tree water availability.

Research Questions

How does drought affect different urban tree types and their ecosystem services?
How resilient is Santa Barbara's urban forest to the most recent drought (2012-2016)?

Study site: Santa Barbara, CA

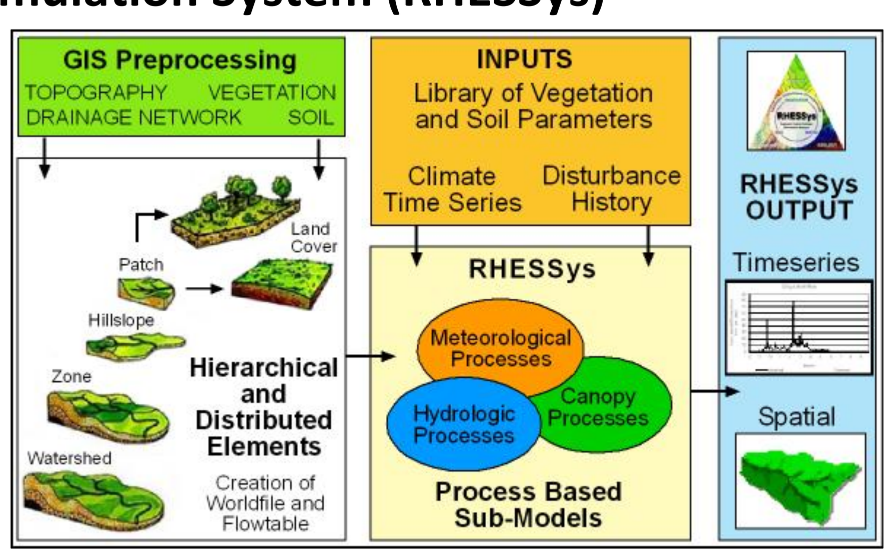
- Mediterranean climate
- Mean annual precipitation: 482mm
- Mean temperature: 42ºF to 77ºF
- Main vegetation types: urban forest is composed of a mix coastal live oak (*Quercus agrifolia*), eucalyptus trees (*Eucalyptus globulus*), native California sycamore (*Platanus racemosa*), along with several 'drought tolerant' nonnative species.

Methods

To capture ecohydrologic fluxes throughout the drought, RHESSys, a hydro-ecological model is combined with remote sensing data of tree carbon, height and LAI.

Regional Hydro-Ecological Simulation System (RHESSys)

- Simulates carbon, water, and nutrients
- Input maps include vegetation, impervious cover, and other environmental factors like elevation, slope, etc.
- Target driven spin-up allows carbon stores in trees and soils to be initialized from remote sensing data



Remote sensing data from 2010 (Alonzo et al. 2016):
- Carbon per area
- LAI
- height

→ Initialize vegetation carbon and nitrogen stores through RHESSys target driven spin up

→ Vegetation parameters:
- Stomatal conductance
- Height to stem coefficient
- C:N allocation

→ Run RHESSys from 2010 (pre-drought) to 2018 (post-drought)

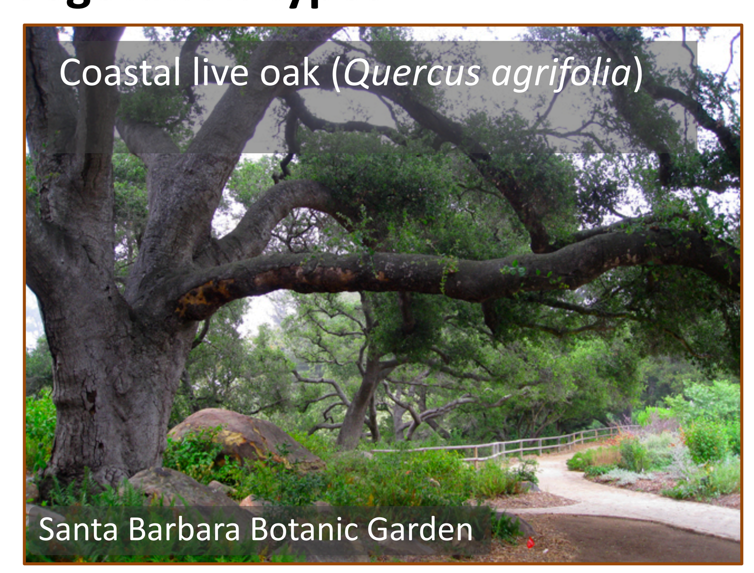
→ Output: spatial-temporal simulation
- Gross photosynthesis
- LAI
- evapotranspiration

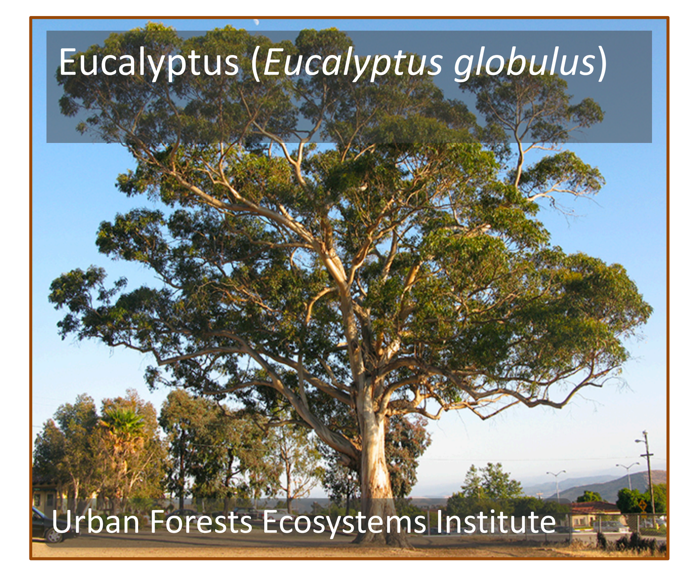
→ Compare against remote sensing vegetation indices from 2017

Patch Level simulations

- A patch is the smallest unit in the model - it represents a single vegetation type for a 10m grid space.
- Patch simulations were used to parameterize different vegetation type and to compare model estimates with remote sensing heights and carbon stores.
- Estimates of LAI, height, and carbon stores are derived from hyperspectral imagery and waveform lidar data and mapped over downtown Santa Barbara (Alonzo et al. 2016)

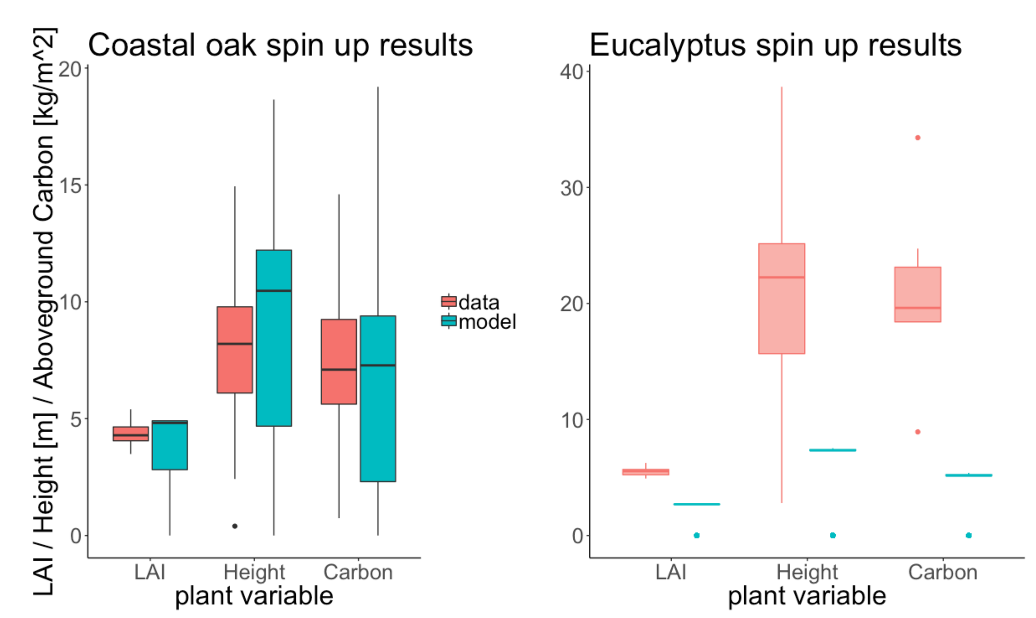
Vegetation types

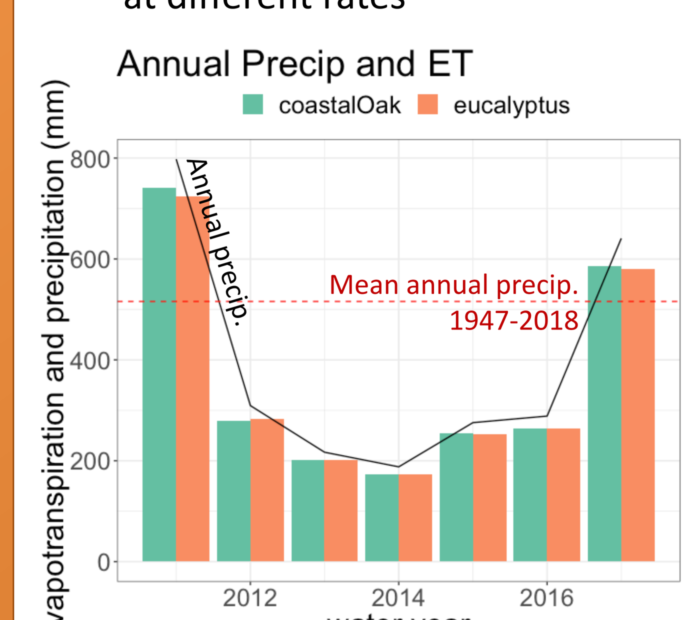


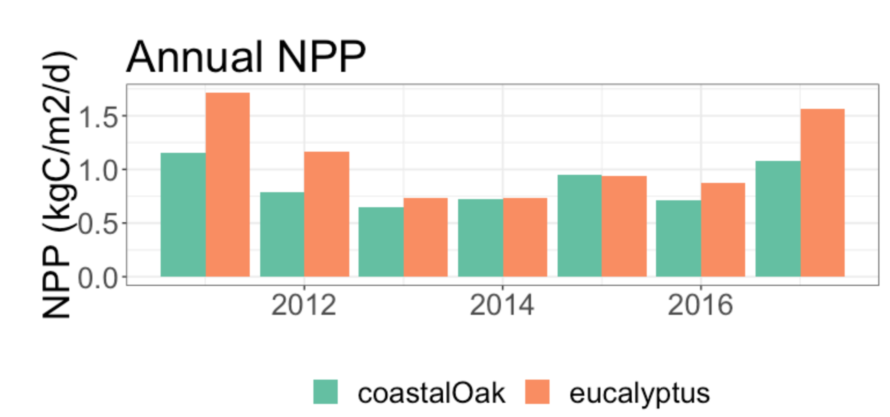


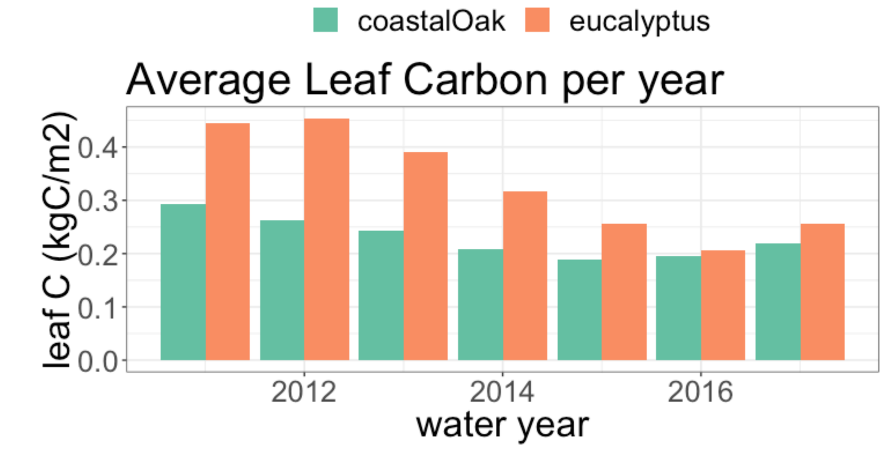
Preliminary Spin up Results

- The spun-up model captures the range in oak LAI and carbon, but overestimates height
- It underestimates eucalyptus for all variables
- Both veg types water use was driven by the amount of precipitation
- Both veg types experience a decrease in carbon intake at beginning of drought, with a recovery at end, but at different rates



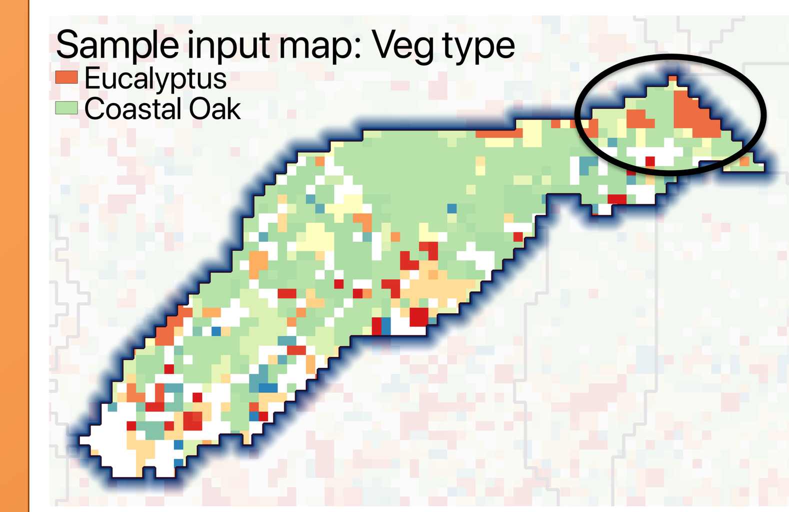


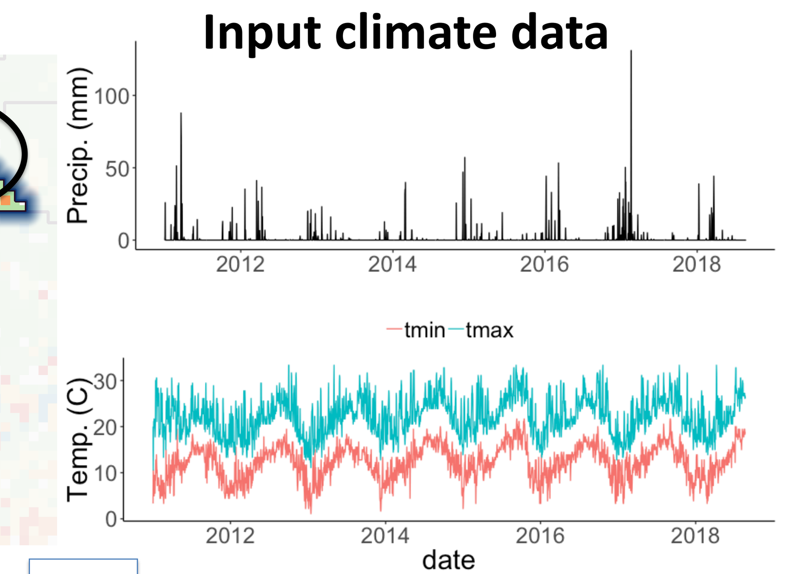




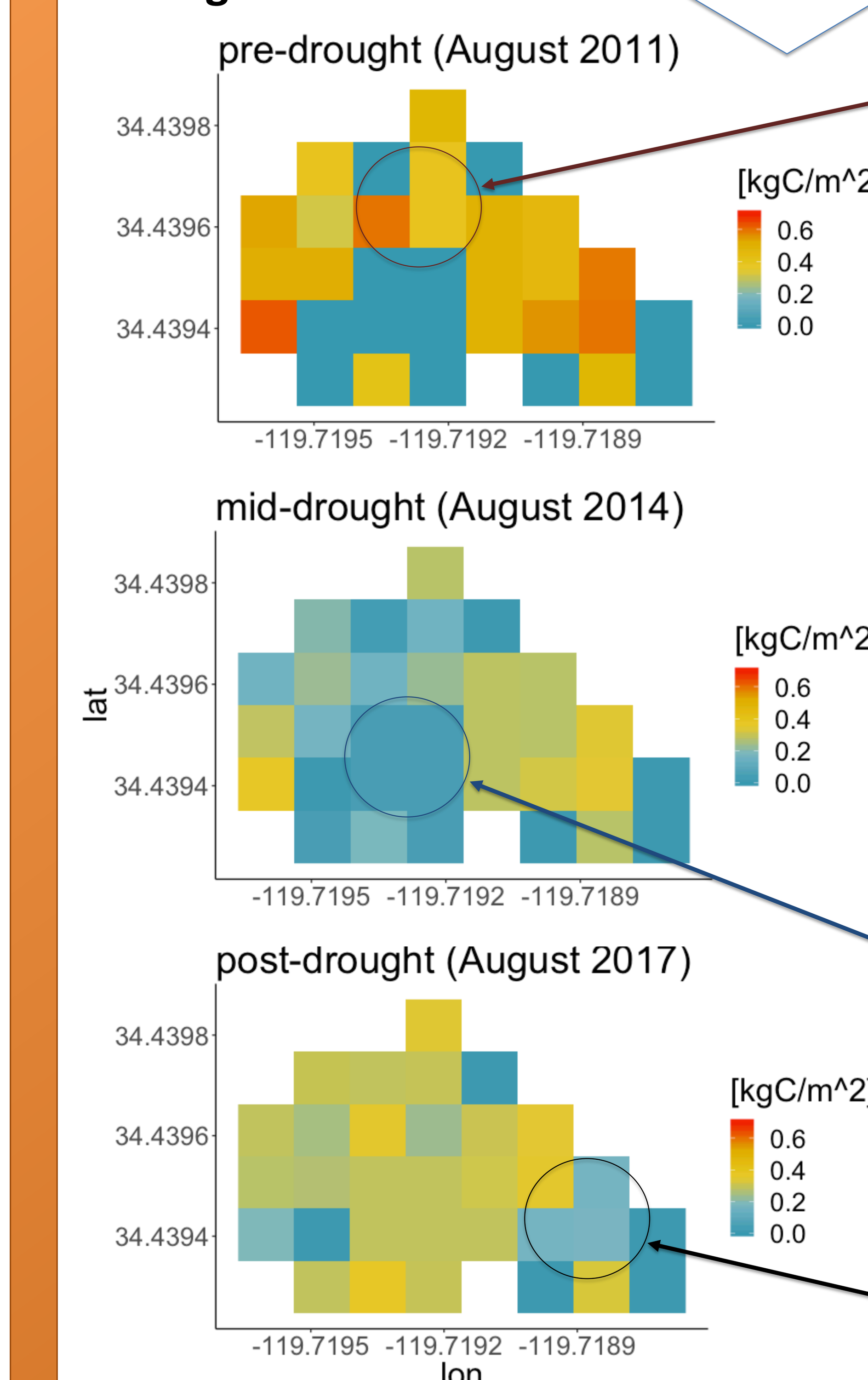
Hillslope Level

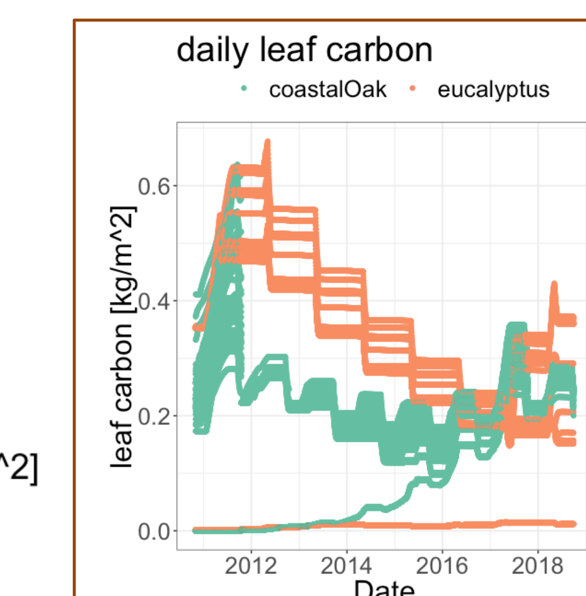
Using the same vegetation parameters from the patch spin up, we estimate stand scales drought responses for oak and eucalyptus trees. The selected area is located within a small hillslope in the Mission creek watershed. Tree are in a forested riparian area near downtown Santa Barbara.





Average Leaf Carbon





Spatio-temporal model outputs allow us to explore patterns in greater detail

Next Steps:

- Vegetation parameters sensitivity analysis for a more robust parameter selection
- Run model for other tree species and analyzes responses by categories:
  - native v. nonnative
  - drought tolerance index
  - deciduous and evergreen
- Include impervious area and irrigation as an additional factors
- Compare against 2017 remote sensing data of 'greenness' indices (Miller et al.)
- Re-run for possible future climate scenarios – longer, and more frequent drought

References

1. Alonzo, M., McFadden, J. P., Nowak, D. J. & Roberts, D. A. Mapping urban forest structure and function using hyperspectral imagery and lidar data. *Urban Forestry & Urban Greening* **17**, 135–147 (2016).
2. Miller et al. Quantifying changes in condition of urban tree species and turfgrass during a multi-year drought using airborne imaging spectroscopy. *In Review* (Poster B11N-2356)

Acknowledgements

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