# An Individual-Based Model of Chaparral Vegetation Response to Frequent Wildfires

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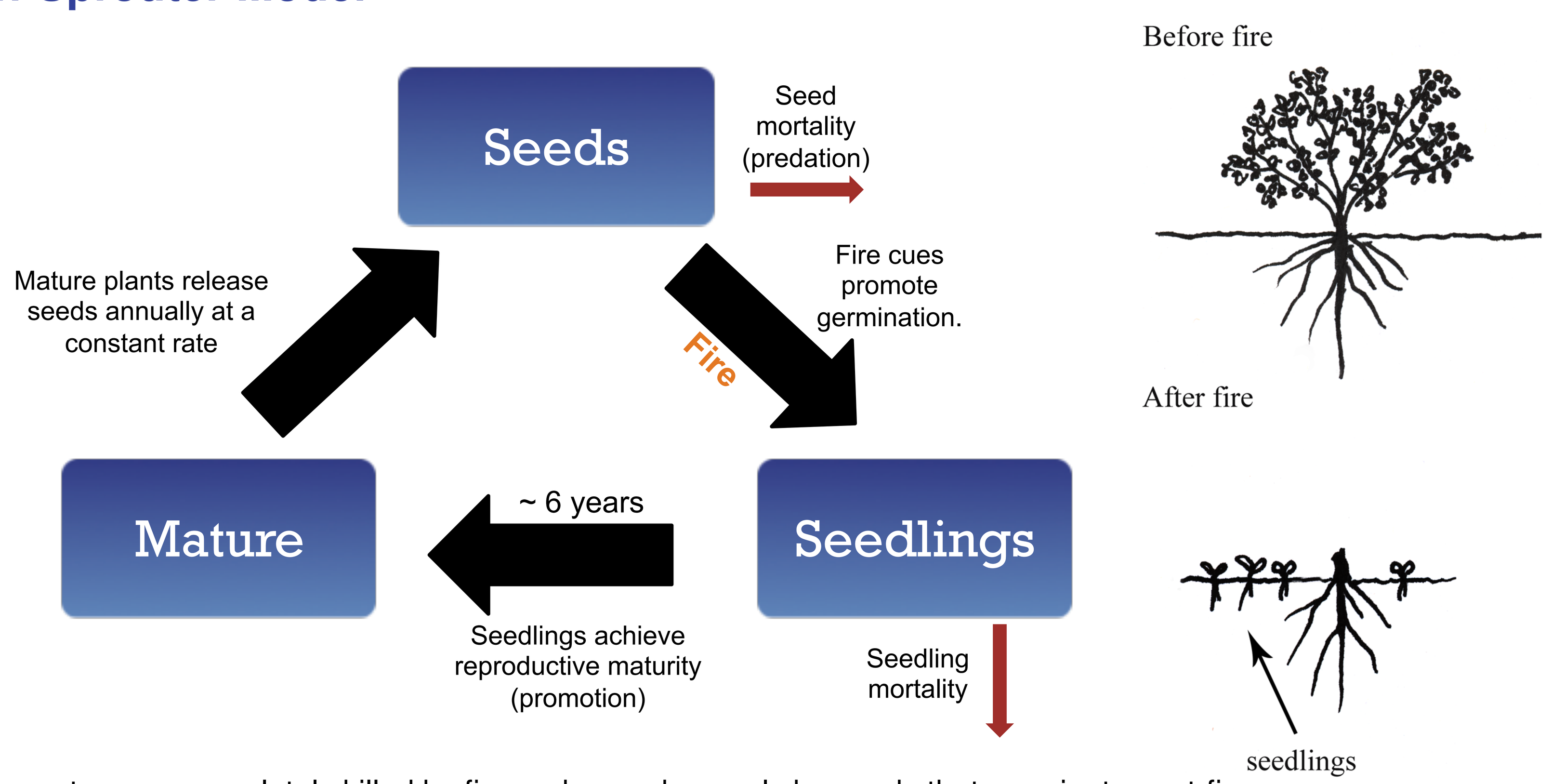
## Pepperdine University Summer Undergraduate Research in Biology

## Introduction


Global climate change continues to impact natural ecosystems around the world. The hot and dry climate of Southern California serves as a likely environment for wildfires, affecting residential communities as well as the Mediterranean-like plant community structure composed primarily of chaparral.[4] Nonsprouting chaparral species (NS) are completely killed by fire and reproduce by seeds that germinate in response to fire cues. Facultative sprouters both resprout after a wildfire and release seeds that germinate post-fire.[1] The average fire return interval (FRI) in the Santa Monica Mountains is 32 years, but in a biological preserve adjacent to Pepperdine University this has recently decreased to 7.5 years. Severe drought conditions coupled with frequent wildfires are threatening the survival of some chaparral species. Short fire return intervals prevent the establishment of a proper seed bank. At the same time, lack of rainfall stunts the growth of resprouts and seedlings. This is concerning because chaparral provide natural vegetative cover and preserve the structure of the steep mountain slopes.[4] Therefore, a model of post-fire recovery of chaparral is pertinent due to the costs of repairing structures, fighting wildfires, and cleaning up rock and mudslides. Our spatial model simulates the growth, competition for space and resources, seedling recruitment, and resprouting behavior of individual shrubs in order to make predictions about the ecological impact of varying levels of rainfall and fire.

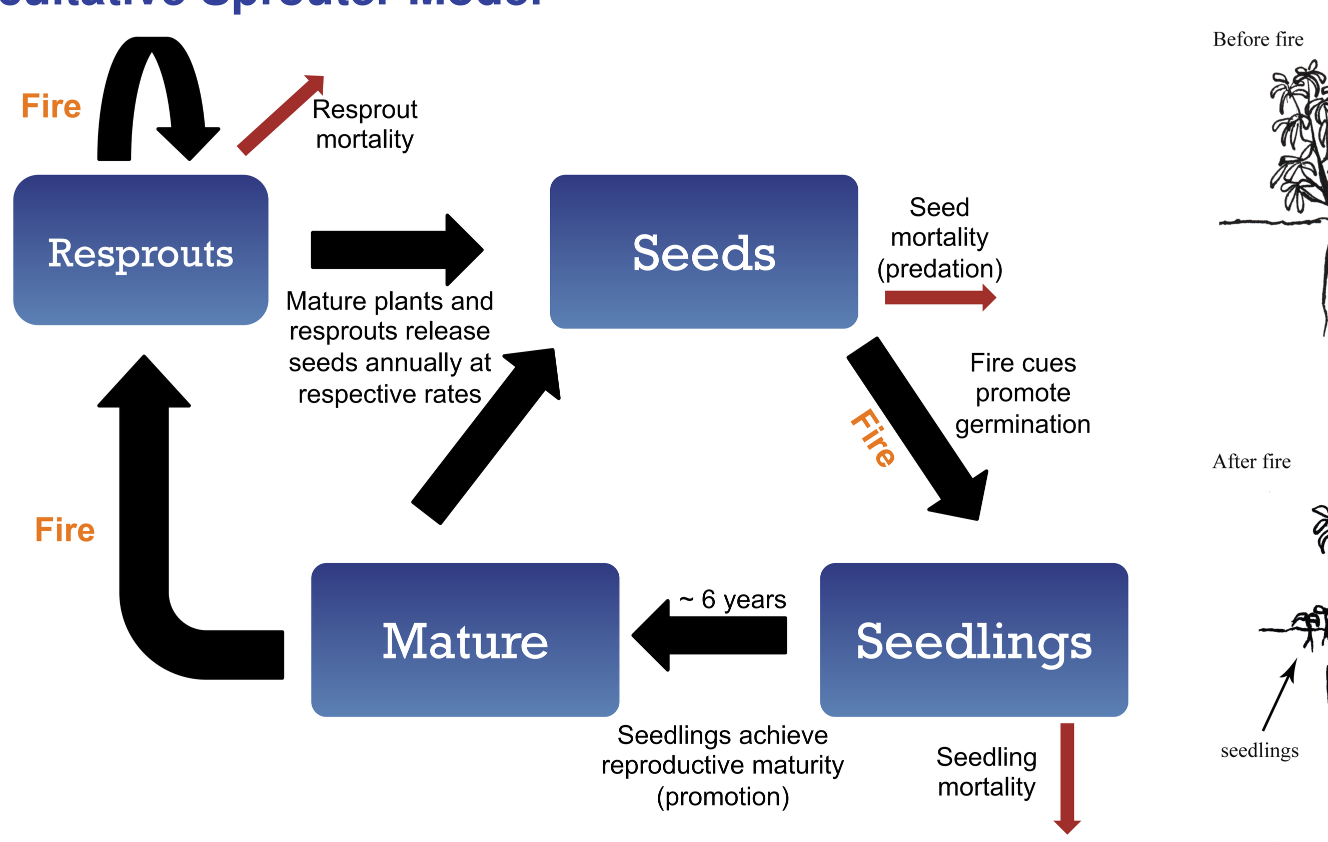
## Life-History Models

### Non-Sprouter Model



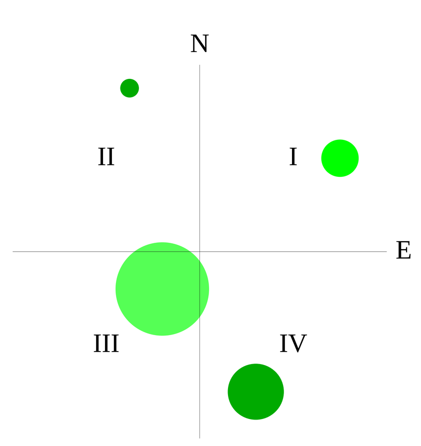

Nonsprouters are completely killed by fire and reproduce only by seeds that germinate post-fire.

### Facultative Sprouter Model




Facultative sprouters both resprout and reproduce by seeds that germinate after fire.

## Data Collection - Point Quarter Sampling

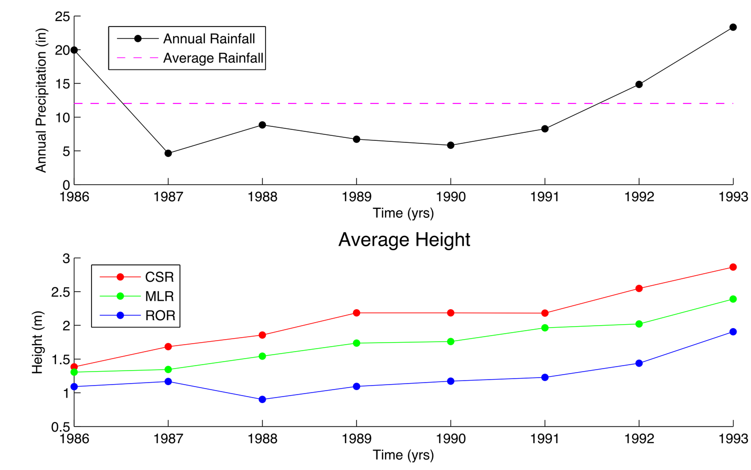



Our study site has been marked and annual data has been collected from 1986-2014.

- 32 rebar poles are arranged in a 4×8 grid and spaced 10m apart.
- At each pole we establish axes along N-S, E-W lines to create 4 quadrants.
- We locate the closest plant of interest and record the distance to the pole, the species, height, crown diameter, and basal diameter.

## Simulation

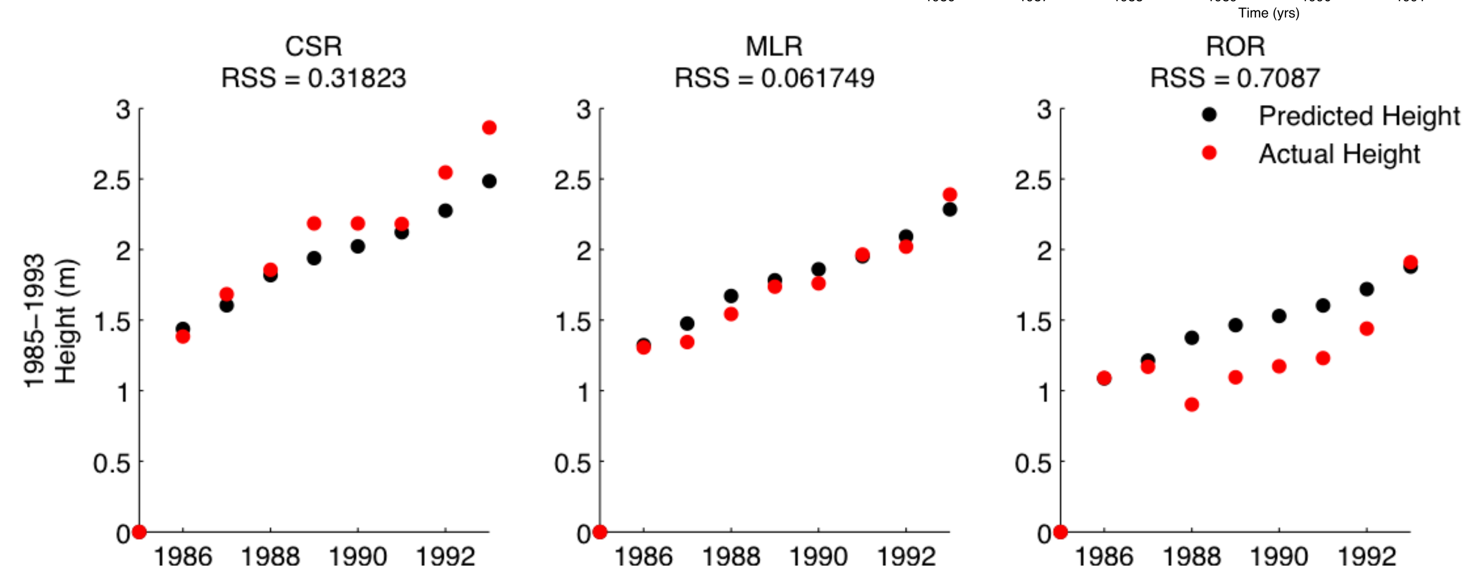
### Growth Models



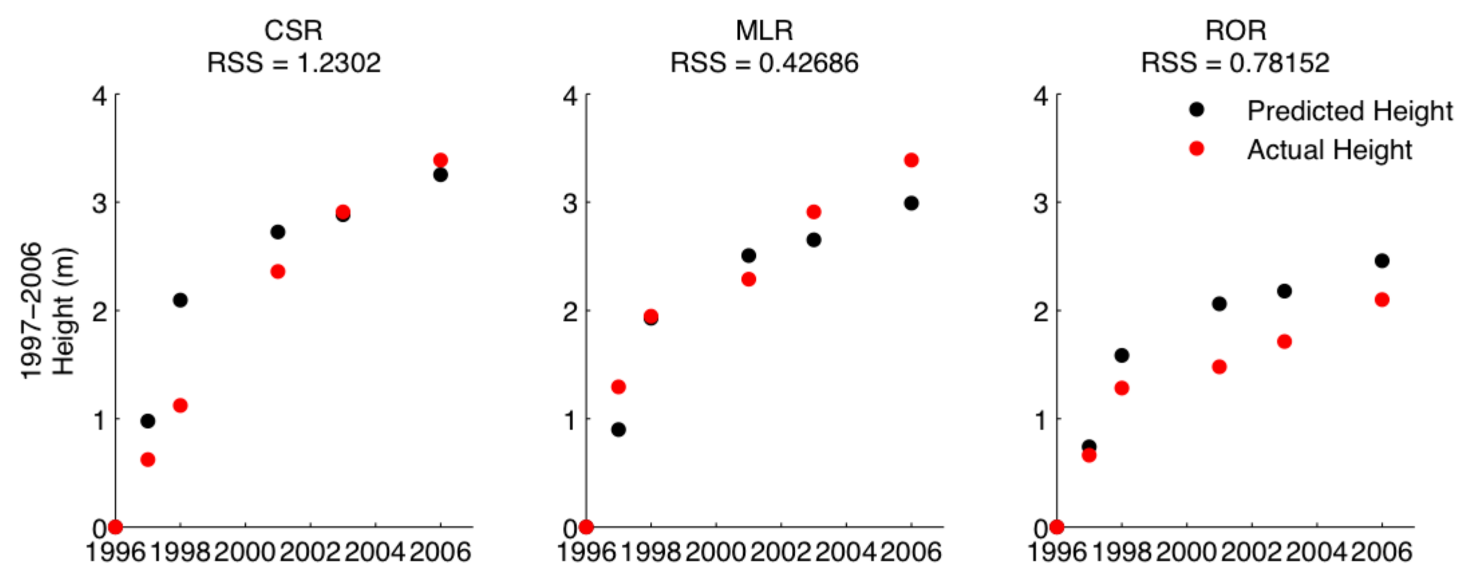

The plots to the right show the effect of low rainfall on seedling and resprout growth. Below is the model of how plant height depends on rainfall $w$ and time $t$ since the previous fire. We estimated the parameters using plant heights from 1985-1993 and then compared the models by projecting the average heights from 1996-2007. The best model for resprout height is for growth to be proportional to rainfall and inversely proportional to time.

$$\Delta h(w,t) = \frac{aw}{t}.$$

The crown growth models are similar.




Simulated heights fit to data from 1985-1993




Simulation checked using data from 1996-2007

Each simulated plant is assigned a growth parameter $a$ drawn from a distribution that corresponds to our data, $a = \bar{a} + s_a Z$, where $Z \sim N(0,1)$. The variance of $a$ is given by

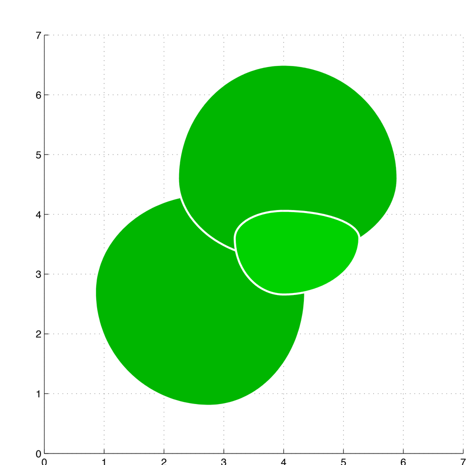
$$s_a^2 = \frac{s_h^2}{\sum(h_i - \bar{h})^2} \quad \text{where} \quad s_h^2 = \frac{\sum \hat{e}_i^2}{n-2}.$$

The numerator is the sum of the squared errors. We estimated these values using height, crown, and seedling data from 1985-1993, validating them using data from 1996-2007.

### Local Competition

Individual plants in our simulation compete with neighboring plants for space and resources. Our model utilizes size-asymmetric competition in which larger individuals have a disproportionately larger effect of competition on smaller plants and are not as affected by the smaller plants in their growth. In our simulation each plant $p$ calculates a competition factor $K_p$ based on the size $V_n = \pi r_n^2 h$ and distance from neighboring plants $d_{np}$.[2] The probability of an individual plant's survival $S_p$ is incorporates the amount of resources available $R$ and the local competition $K_p$.[3]

$$S_p = \frac{R}{1+K_p} \quad \text{where} \quad K_p = \sum_n \frac{c_p}{d_{np}^2}\frac{V_n}{V_p}.$$



Sample plant collision.

### Collisions

Chaparral compete locally with neighboring plants for space as they develop. In crowded areas a plant's growth can be inhibited by limitations of space. Sometimes smaller plants will die if larger plants overtake the space. Initially all crowns are circular, but deform due to "push-back" from other plants.

## References

[1] T. A. Lucas, G. Johns, W. Jiang, and L. Yang. A population model of chaparral vegetation response to frequent wildfires. *Bulletin of Mathematical Biology*, 75(12):2324–2345, 2013.

[2] S. Thomas and J. Weiner. Including competitive asymmetry in measures of local interference in plant pop. *Oecologia*, 80(3):349–355, 1989.

[3] J. Weiner. A neighborhood model of annual-plant interference. *Ecology*, 63(5):1237–1241, 1982.

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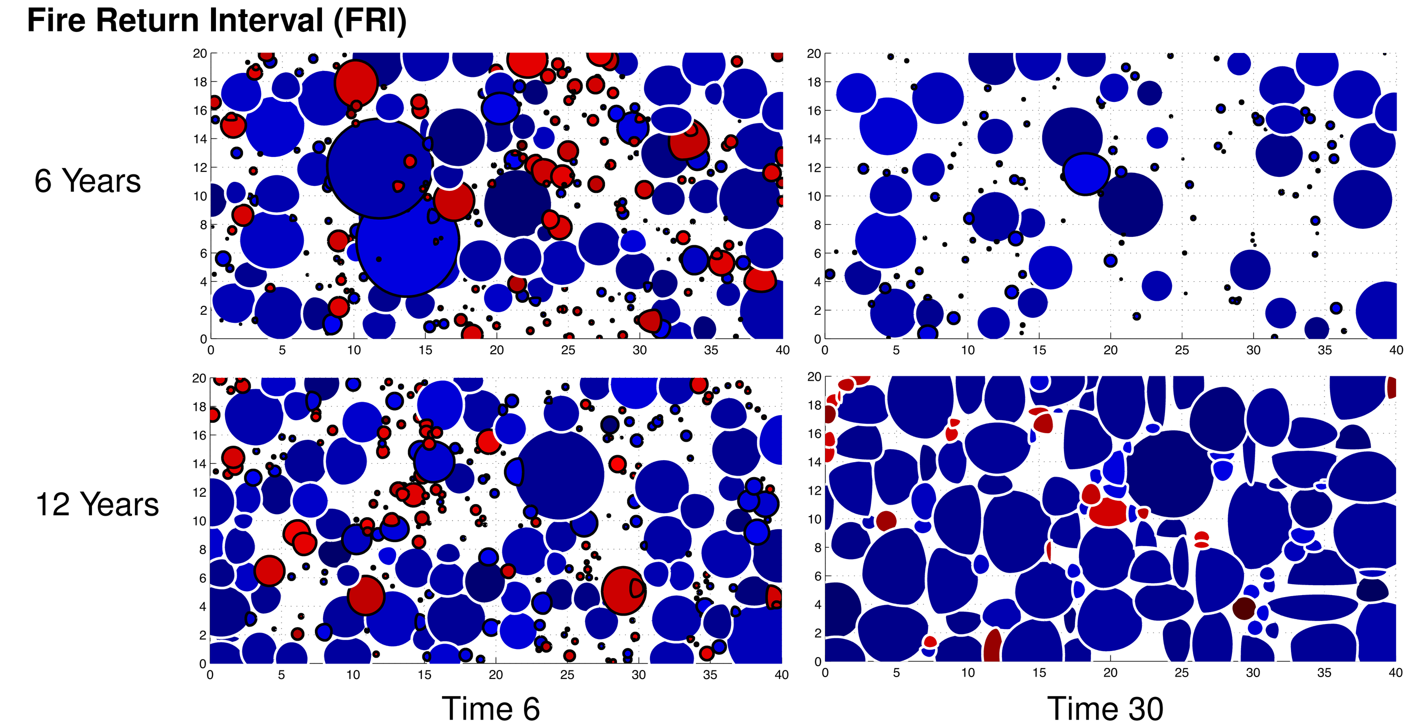
## Results

### *Ceanothus* Simulation

Below are simulations of two *Ceanothus* species with annual rainfall of 12 inches and fire return intervals of 6 and 12 years.

Legend:
*Ceanothus megacarpus (Cm)*
*Ceanothus Spinosus (Cs)*

Fire Return Interval (FRI)

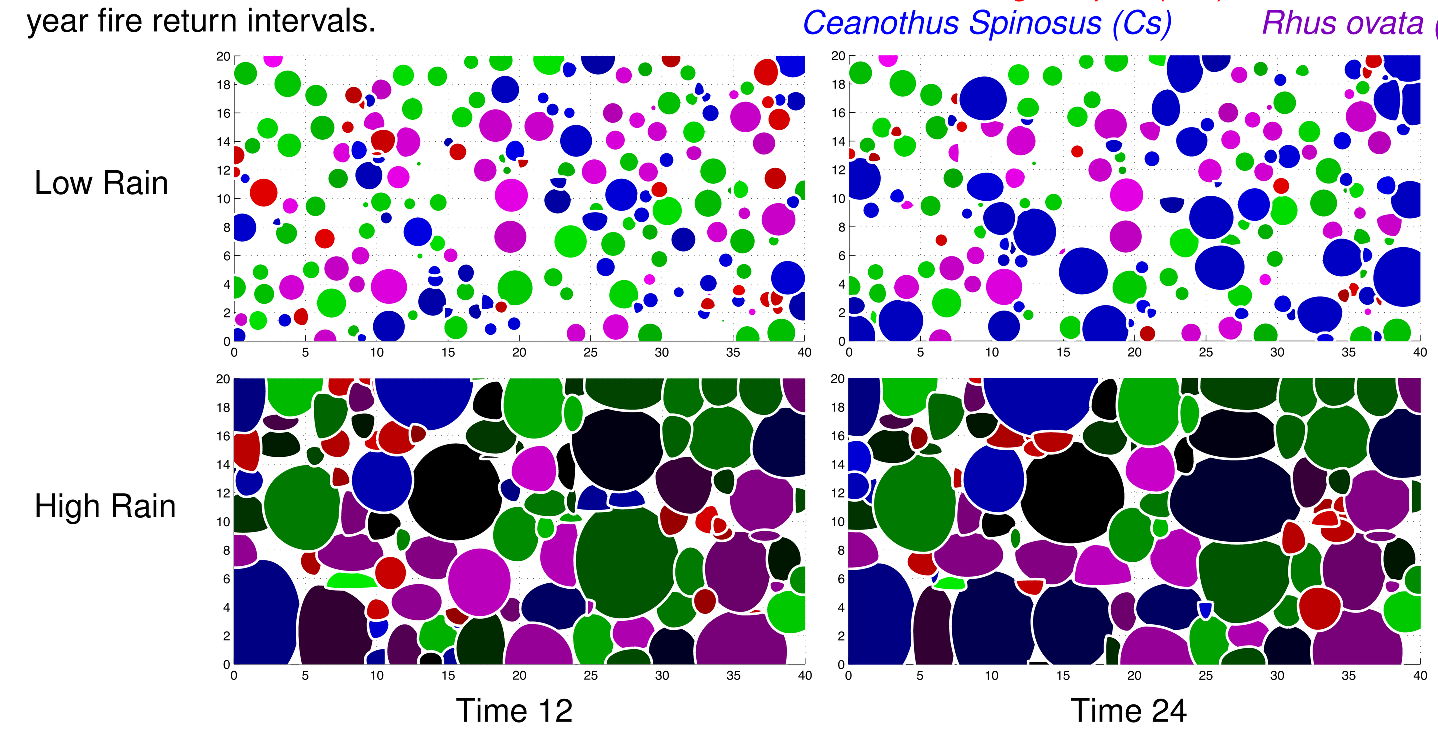



An average fire return interval of 6 years leads to the localized extinction of *Cm* and a fairly sparse landscape. In contrast the *Cm* continue to persist with a twenty year average.

### All Species Simulations

Below are the results of simulations with four species of chaparral with varying rainfall and 12 year fire return intervals.

Legend:
*Ceanothus megacarpus (Cm)*
*Malosma laurina (Ml)*
*Ceanothus Spinosus (Cs)*
*Rhus ovata (Ro)*




Height and crown growth are severely slowed by less rainfall, while plants thrive in heavy rainfall.

### Validation and Prediction

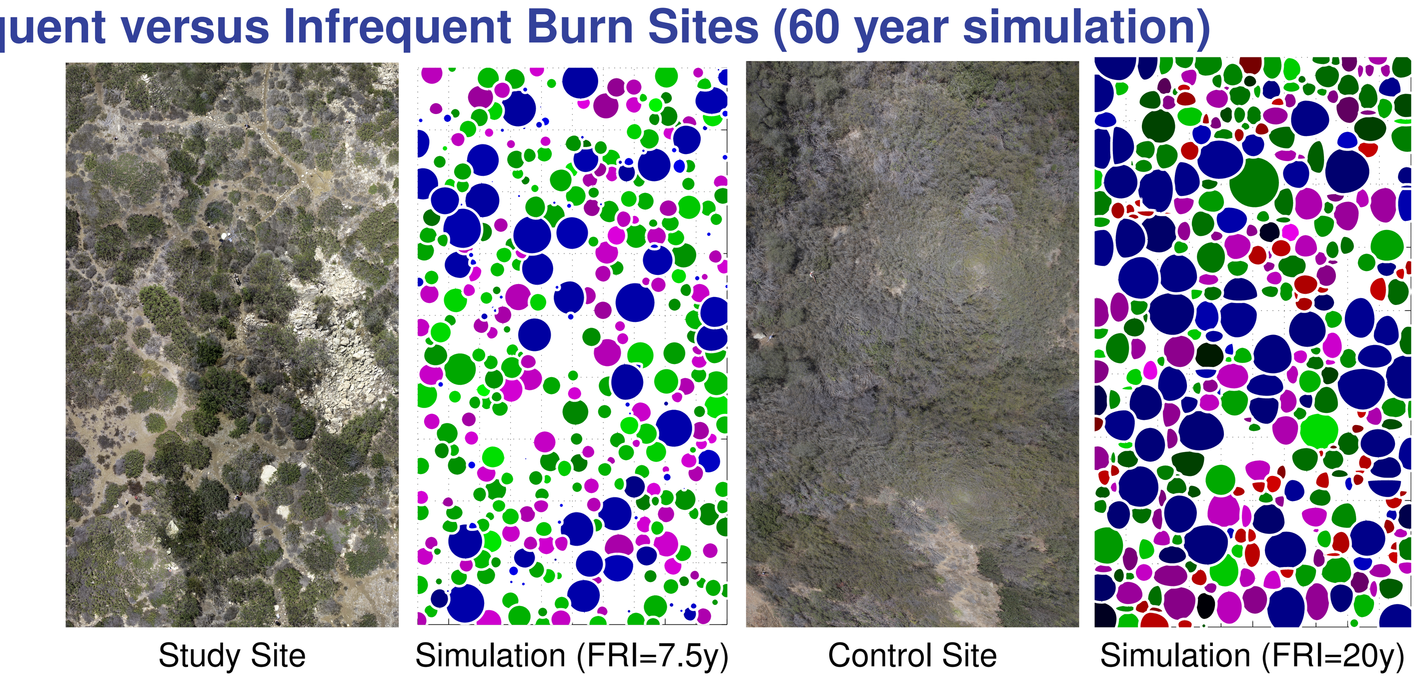
**Simuation Validation 1985-2014**

| | Density | 1985 | Density | 2014 |
|---|---|---|---|---|
| Species | Actual | Simulation | Actual | Simulation |
| Cm | 17.2% | 15.3% | 0.0% | 0.0% |
| Cs | 25.0% | 25.6% | 21.9% | 24.9% |
| Ml | 36.7% | 38.9% | 51.6% | 49.5% |
| Ro | 18.0% | 20.2% | 24.2% | 25.6% |

**60 Year Prediction for Species Densities**

| | 7.5 year FRI | 20 year FRI |
|---|---|---|
| All Species | 67% coverage | 85% coverage |
| Cm | 0.0% | 15.6% |
| Cs | 26.3% | 22.4% |
| Ml | 45.6% | 38.0% |
| Ro | 28.1% | 24.1% |

### Frequent versus Infrequent Burn Sites (60 year simulation)



Study Site Simulation (FRI=7.5y) Control Site Simulation (FRI=20y)

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