Modeling sagebrush ecosystem in the Reynolds Creek Experimental Watershed for different CO2 and fire conditions, with the Ecosystem Demography (EDv2.2) model

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Threats to sagebrush ecosystems

Sagebrush ecosystem in the Western U.S. affected by wildfire frequency, climate change, and invasion from non-native species like Cheatgrass (*Bromus tectorum*) resulting in altered vegetation composition, hydrological function (Schroeder et al., 2004, Connelly et al., 2004; McArthur and Plummer, 1978; Schlaepfer et al., 2014).
Restoration efforts

- **Restoration activities** like reducing flammable vegetation, transplanting sagebrush, seeding native grass (Chambers et al., 2014; McIver and Brunson, 2014)

- **Effectiveness** of these programs are largely unexplored at regional scales
Ecosystem dynamic models

• widely used to estimate terrestrial vegetation composition and biomass over time and space

• efficiency over direct field measurements and their applicability to broader spatial scales (Dietze et al., 2014; Fisher et al., 2017)
General Questions

• Can we **explore the effects of disturbances and restoration** in sagebrush ecosystem at regional scales, using some **dynamic vegetation model**? What would be the associated **uncertainties**?
Ecosystem Demography (EDv2.2) model

- A cohort based dynamic vegetation model where land surface is composed of a series of gridded cells, that experiences meteorological forcing (Medvigy, 2009; Moorcroft et al., 2001)
Specific questions

• parameterizing sagebrush (*Artemisia* spp) shrub PFT in ED model?
• exploring the dynamics of sagebrush ecosystem at basin scale under different climate, vegetation, and fire scenarios?
Fig. Major processes and inputs involved in modeling ecosystem dynamics using ED

- **Ecosystem / Vegetation data**
  - Inventory
  - Remote Sensing/LiDAR

- **Meteorological forcing data**
  - (tmp, ppt, humidity, radiation, wind speed, etc)

- **EC flux tower data**

- **Initial PFT parameters / coefficients**

- **Point based ED simulation**

- **Biomass / carbon outputs**

- **Parameter optimization**

- **Regional ED simulation**

- **Calibration / Validation**

- **Allometric relationship**

- **Up-scaling results**
  - (temporal/spatial)

- **Literature, Parameters from other models eg CLM**
1. Sagebrush PFT parameterization
a. Initial parameterization

- field data (allometric relationships),
- literature,
- PFT parameters in ED/CLM and other land models
b. Sensitivity and optimization

- point scale
- initial vegetation
- 15 years run
- forced with WRF meteorological data
- Calibrated and validated against GPP derived from flux tower data at two locations in Reynold Creek
b. Sensitivity and optimization

parameters selected were mostly related to ecophysiology and biomass allocation
Sensitivity Index was calculated as,

\[ SI = \frac{GPP_{\text{max}} - GPP_{\text{mi}_n}}{GPP_{\text{max}}} \]

Optimization was done with exhaustive search method
c. Validation

• GPP outputs from optimum parameters were compared with GPP from flux tower data

• Nash-Sutcliffe efficiency (NSE) score was used for interpretation (Nash and Sutcliffe, 1970)

\[ NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2} \]

where, \( O_i \) is observation, \( P_i \) is predicted value, \( \bar{O} \) is mean of observation, and \( n \) is number of observations.
# Parameter sensitivity - results

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Initial</th>
<th>Min</th>
<th>Max</th>
<th>SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Leaf Area (SLA) (m²kg⁻¹)</td>
<td>4.5</td>
<td>2</td>
<td>15</td>
<td>0.973*</td>
</tr>
<tr>
<td>$V_{m0}$ (µmolm⁻²s⁻¹)</td>
<td>16.5</td>
<td>4</td>
<td>30</td>
<td>0.962*</td>
</tr>
<tr>
<td>Stomatal Slope</td>
<td>7</td>
<td>2</td>
<td>15</td>
<td>0.951*</td>
</tr>
<tr>
<td>Ratio of fine roots to leaves/ Q-ratio</td>
<td>3.2</td>
<td>0.4</td>
<td>12</td>
<td>0.801*</td>
</tr>
<tr>
<td>Fineroot Turnover rate (a⁻¹)</td>
<td>0.33</td>
<td>0.1</td>
<td>2</td>
<td>0.787*</td>
</tr>
<tr>
<td>Leaf Turnover rate (a⁻¹)</td>
<td>1</td>
<td>0.1</td>
<td>2</td>
<td>0.728</td>
</tr>
<tr>
<td>Growth respiration factor</td>
<td>0.33</td>
<td>0.11</td>
<td>0.66</td>
<td>0.718</td>
</tr>
<tr>
<td>Cuticular conductance (µmolm⁻²s⁻¹)</td>
<td>$10^3$</td>
<td>$10^2$</td>
<td>$10^4$</td>
<td>0.672</td>
</tr>
<tr>
<td>Water Conductance (ms⁻¹kgCroot⁻¹)</td>
<td>$1.9 \times 10^{-5}$</td>
<td>$1.9 \times 10^{-6}$</td>
<td>$1.9 \times 10^{-4}$</td>
<td>0.227</td>
</tr>
<tr>
<td>Seedling mortality</td>
<td>0.95</td>
<td>0.25</td>
<td>0.99</td>
<td>0.007</td>
</tr>
<tr>
<td>Leaf width (m)</td>
<td>0.05</td>
<td>0.01</td>
<td>0.30</td>
<td>0.006</td>
</tr>
<tr>
<td>Storage turnover</td>
<td>0.624</td>
<td>0.50</td>
<td>0.95</td>
<td>0.003</td>
</tr>
</tbody>
</table>
# Optimized parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>LS EC station</th>
<th>WBS EC station</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Best case</td>
<td>Ensemble mean</td>
</tr>
<tr>
<td>$V_{m0}$ ($\mu$mol m$^{-2}$s$^{-1}$)</td>
<td>14.00</td>
<td>18.50</td>
</tr>
<tr>
<td>SLA (m$^2$kg$^{-1}$)</td>
<td>6.00</td>
<td>7.95</td>
</tr>
<tr>
<td>Stomatal slope</td>
<td>10.00</td>
<td>7.60</td>
</tr>
<tr>
<td>Fine root turnover (a$^{-1}$)</td>
<td>0.33</td>
<td>0.22</td>
</tr>
<tr>
<td>Q-ratio</td>
<td>3.20</td>
<td>2.64</td>
</tr>
</tbody>
</table>
Summary

• With optimized parameters, ED predicted daily GPP quite well with some negative bias
• GPP during spring months were not captured well.
• Non-linear relationship between the parameters was not captured.
2. Exploring sagebrush ecosystem dynamics
Study Area

- Covers Reynold Creek Experimental Watershed
- 20 * 40 grid
- 1 Km resolution
Data

Meterological forcing

• Weather Research and Forecasting (WRF) model to subset required forcing data
• 1 km spatial resolution
• 3 hour temporal resolution
• Data from 1988 – 2016 used
Data

• Eddy Covariance tower data from two locations (Fellows et al., 2017)
  • GPP based on observation data
Modeling scenarios

A. Vegetation dynamics
   1. Bare earth (with default CO\textsubscript{2})
   2. Initial vegetation (with default CO\textsubscript{2})
   3. Increased CO\textsubscript{2} (with bare earth)

   Simulated for 20 plus years

B. Disturbance with fire
   Fire introduced after 25 years of bare earth simulation

Bare earth = 0.1 plants / m\textsuperscript{2} for shrub, C3 grass, and conifers
Initial vegetation = 0.25 plants/m\textsuperscript{2} of shrub and C3 grass
Default CO\textsubscript{2} = 370 ppm ambient CO\textsubscript{2}
Increased CO\textsubscript{2} = 740 ppm ambient CO\textsubscript{2}
Results

There are some site specific variations

But, in general, similar PFT competition trends between sites

Shrub (sagebrush) PFT dominating

Increased CO2 – had increasing conifer species but at low magnitude
Comparison of simulated GPP (from final year) with EC tower observation.
GPP (KgC/m²/yr) for C3 grass and Shrub

Bare earth

Increased CO₂

Initial vegetation

Year 1

Year 10

Year 20
Introduction of fire

![Graph showing GPP (KgC/m²/yr) over years for Site I and Site II with different vegetation types before and after fire.](image)
AGB (KgC/m²) for fire and no fire conditions

Year 1

No Fire

Fire

Difference

Year 8

AGB (KgC/m²)
• Can we make some comparisons with actual fire incident at RCEW?
• 2015 Soda Fire
Comparison with information from Landsat data

Model output

Change in NDVI

change in GPP
Summary

• After 20 years we did not see coexistence of C3 grass and shrub
• Conifer could encroach some of the shrublands with increased CO2
• Disturbance from fire is more evident after few years and shows some spatial pattern
Future work

• Compare results from PFT coverage with percent cover maps derived from hyper spectral images.
• Tweak C3 and conifer PFT parameters in ED2 to better model vegetation composition.
• Compare fire related disturbance with some observed data.
Thank You !