Soil property recovery on a natural gas pipeline reclamation chronosequence

Caley Gasch, Snehalata Huzurbazar, Peter Stahl
- Our goal: assist in the recovery of degraded ecosystems

- Our basis for assessment: **reference sites**
Like an average parameter, the **degree of variability** of properties is of interest.

- Changes in variance indicate ecological consequences of disturbance, stability, and recovery.
- The variance may help in defining an acceptable range of values for indicating recovery.
Like an average parameter, the **degree of variability** of properties is of interest

- Changes in variance indicate ecological consequences of disturbance, stability, and recovery
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Investigate the recovery of soil properties on reclaimed soils by incorporating both the mean and variance in our assessment of similarity with regard to reference soils
Wamsutter, Wyoming

- Elevation: 2052 m (6731 ft)
- Precipitation: 180 mm (7 in)
- Dominant vegetation:
  - Big sagebrush (*Artemisia tridentata*)
  - Greasewood (*Sarcobatus vermiculatus*)
Bayesian Hierarchical Linear Mixed Model

\[ P_{ijk} \]

- \( i = 1 \) in 12 observations
- \( j = 1 \) in 7 treatments
- \( k = 1 \) in 2 years

Soil Property \((P)\)
- Moisture
- SOC
- TN
- Microbial abundance
- Etc.
Bayesian Hierarchical Linear Mixed Model

*Data Model for the Likelihood*

\[ i = 1 \text{ in } 12 \text{ observations} \]
\[ j = 1 \text{ in } 7 \text{ treatments} \]
\[ k = 1 \text{ in } 2 \text{ years} \]

\[ P_{ijk} \]

\[ P \sim \text{Normal}(\mu, \tau) \]

\[ \tau = (1/\sigma^2) \]
Bayesian Hierarchical Linear Mixed Model

Data Model for the Likelihood

\[ \mu_{jk} = \beta_j + \alpha_{j(k)} \]

Mean value of \( P \) within a treatment

Variability between treatments within years

\( i = 1 \) in 12 observations

\( j = 1 \) in 7 treatments

\( k = 1 \) in 2 years
Bayesian Hierarchical Linear Mixed Model

**Prior Model**

\[ i = 1 \text{ in 12 observations} \]
\[ P_{ijk} \]
\[ j = 1 \text{ in 7 treatments} \]
\[ k = 1 \text{ in 2 years} \]

\[ \beta_j \sim \text{Normal}(\mu_{\beta}, \tau_{\beta}) \]
\[ \alpha_{j(k)} \sim \text{Normal}(0, \tau_{\alpha}) \]
\[ \mu_{\beta} \sim \text{Normal}(0, 0.001) \]
\[ \tau_{jk}, \tau_{\beta}, \tau_{\alpha} \sim \text{Gamma}(0.001, 0.001) \]
Bayesian Hierarchical Linear Mixed Model

*Posterior Distribution*

// Diagram with nodes labeled $\mu_\beta$, $\tau_\beta$, $\tau_\alpha$, $\beta_j$, $\mu_{jk}$, $\tau_{jk}$, $\alpha_{j(k)}$, $\gamma_k$, $\tau_\gamma$

\[
P_{ijk} | \mu_{jk}, \beta_j, \tau_{jk}, \alpha_{j(k)}, \gamma_k, \tau_\alpha, \tau_\gamma \sim \text{Normal}(\mu_{jk}, \tau_{jk})
\]

\[
P_{ijk} | \theta \sim \text{Normal}(\mu_{jk}, \tau_{jk})
\]

\[
\beta_j \sim \text{Normal}(\mu_\beta, \tau_\beta)
\]

\[
\alpha_{j(k)} \sim \text{Normal}(0, \tau_\alpha)
\]

\[
\mu_\beta \sim \text{Normal}(0, 0.001)
\]

\[
\tau_{jk}, \tau_\beta, \tau_\alpha \sim \text{Gamma}(0.001, 0.001)
\]

\[
\Pr(\theta | P_{ijk}) = \int_{\theta} \Pr(P_{ijk} | \theta) \cdot \Pr(\theta) \, d\theta
\]

1 in 12 observations

1 in 7 treatments

1 in 2 years
Bayesian Hierarchical Linear Mixed Model

*Predictive Distribution of Future Observables*

\[
\Pr (P_{ijk} | P_{ijk}) = \int_\theta \Pr (P_{ijk} | \theta) \cdot \Pr (\theta | P_{ijk}) \, d\theta
\]
Probability that the posterior predictive values of a soil property fall within the range of reference site values

<table>
<thead>
<tr>
<th></th>
<th>Moisture</th>
<th>Total N</th>
<th>Organic C</th>
<th>Total Microbial Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2010</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1 year</td>
<td>0.56</td>
<td>1.00</td>
<td>0.98</td>
<td>1.00</td>
</tr>
<tr>
<td>4 years</td>
<td>0.52</td>
<td>1.00</td>
<td>0.97</td>
<td>1.00</td>
</tr>
<tr>
<td>28 years</td>
<td>0.51</td>
<td>1.00</td>
<td>0.95</td>
<td>0.82</td>
</tr>
<tr>
<td>35 years</td>
<td>0.94</td>
<td>1.00</td>
<td>0.97</td>
<td>0.93</td>
</tr>
<tr>
<td>54 years</td>
<td>0.98</td>
<td>0.99</td>
<td>0.93</td>
<td>0.98</td>
</tr>
<tr>
<td><strong>2011</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1 year</td>
<td>0.60</td>
<td>0.99</td>
<td>1.00</td>
<td>0.99</td>
</tr>
<tr>
<td>4 years</td>
<td>0.78</td>
<td>0.99</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>28 years</td>
<td>0.70</td>
<td>1.00</td>
<td>0.99</td>
<td>0.98</td>
</tr>
<tr>
<td>35 years</td>
<td>0.97</td>
<td>1.00</td>
<td>1.00</td>
<td>0.96</td>
</tr>
<tr>
<td>54 years</td>
<td>0.80</td>
<td>0.99</td>
<td>0.96</td>
<td>0.94</td>
</tr>
</tbody>
</table>
$P_{ijk} | \theta \sim Normal(\mu_{jk}, \tau_{jk})$
<table>
<thead>
<tr>
<th></th>
<th>Mean (central tendency)</th>
<th>Variance (spread)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Moisture</strong></td>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td><strong>Total N</strong></td>
<td>=</td>
<td>↓</td>
</tr>
<tr>
<td><strong>Organic C</strong></td>
<td>=</td>
<td>↓</td>
</tr>
<tr>
<td><strong>Microbial abundance</strong></td>
<td>↓</td>
<td>↓</td>
</tr>
</tbody>
</table>
Future work: investigate sources of variability

- Spatial approach (10 cm – 100 m)
- Geostatistical parameter comparison
- Assess degrees of heterogeneity
- Link aboveground-belowground properties
Thank you: Wyoming Reclamation and Restoration Center, Haub School and Environment and Natural Resources, Overland Pass Pipeline Company, ONEOK, Kinder Morgan, El Paso Companies, Bureau of Land Management Rawlins Field Office, Rachana Giri Paudel, Darren Gemoets, Leann Naughton, Kurt Smith
- Soil properties vary in their response to disturbance and reclamation.

- Disturbed soils can differ from reference soils because of a property’s central tendency, or its spread of values.

- Longer recovery time increases the probability that a reclaimed soil property will be similar to a reference soil.

- Variability of a soil property tends to increase with recovery time and is generally high in reference soils.
Bayesian Hierarchical Linear Mixed Model

Posterior Distribution

\[
Pr(\theta | P_{ijk}) = \int_{\theta} Pr(P_{ijk} | \theta) \cdot Pr(\theta) \, d\theta
\]
Moisture

R-squared = 0.73

Total N

R-squared = 0.10

Organic C

R-squared = 0.22

Total microbial abundance

R-squared = 0.35
Table 1. General soil properties for each treatment, years combined. Values are sample mean, with standard error of the mean in parenthesis (n=6).

<table>
<thead>
<tr>
<th></th>
<th>Bulk Density (g cm$^{-3}$)</th>
<th>Gravel (% by wt)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Textual Class$^\S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 year</td>
<td>1.68 (0.09)</td>
<td>1.64 (0.39)</td>
<td>69.71</td>
<td>13.25</td>
<td>17.04</td>
<td>SL</td>
</tr>
<tr>
<td>4 years</td>
<td>1.48 (0.05)</td>
<td>1.44 (0.42)</td>
<td>46.85</td>
<td>14.31</td>
<td>38.84</td>
<td>SC</td>
</tr>
<tr>
<td>28 years</td>
<td>1.50 (0.06)</td>
<td>5.05 (1.08)</td>
<td>69.72</td>
<td>13.25</td>
<td>17.03</td>
<td>SL</td>
</tr>
<tr>
<td>35 years</td>
<td>1.50 (0.08)</td>
<td>2.49 (1.00)</td>
<td>69.58</td>
<td>9.78</td>
<td>20.64</td>
<td>SCL</td>
</tr>
<tr>
<td>54 years</td>
<td>1.61 (0.09)</td>
<td>1.69 (0.44)</td>
<td>66.47</td>
<td>11.39</td>
<td>22.14</td>
<td>SCL</td>
</tr>
<tr>
<td>Undisturbed 1</td>
<td>1.42 (0.06)</td>
<td>0.65 (0.22)</td>
<td>51.81</td>
<td>12.67</td>
<td>35.52</td>
<td>SCL</td>
</tr>
<tr>
<td>Undisturbed 2</td>
<td>1.65 (0.04)</td>
<td>0.61 (0.19)</td>
<td>72.20</td>
<td>9.48</td>
<td>18.32</td>
<td>SL</td>
</tr>
</tbody>
</table>

$^\S$ Textural Class codes: SL = Sandy Loam; SC = Sandy Clay; SCL = Sandy Clay Loam