Soil property recovery on a natural gas pipeline reclamation chronosequence

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Wyoming Reclamation and Restoration Center

University of Wyoming • Ecosystem Science & Management •

PIE program in ecology

University of Wyoming New Thinking

- Our goal: assist in the recovery of degraded ecosystems

- Our basis for assessment: **reference sites**

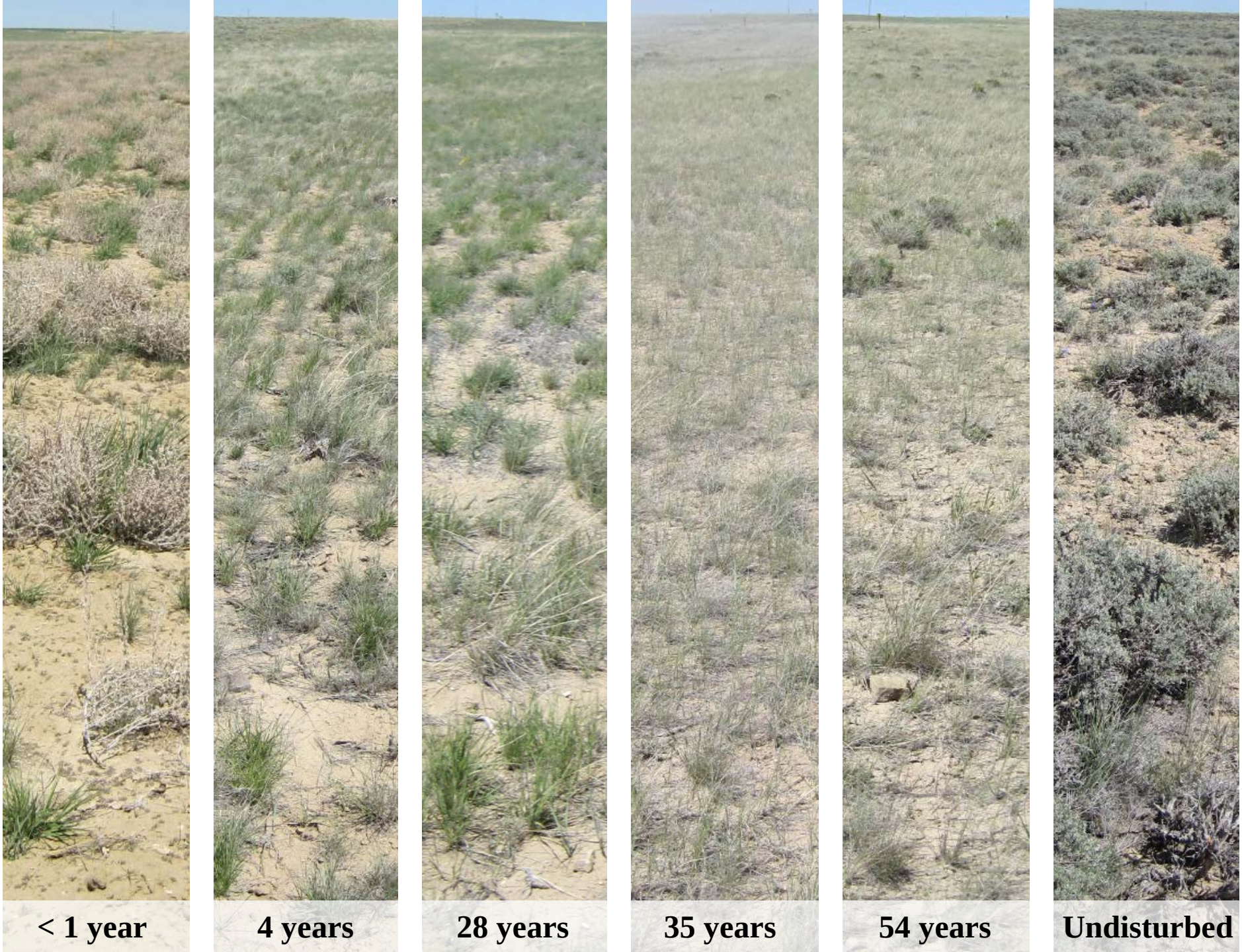
- Like an average parameter, the **degree of variability** of properties is of interest
  - Changes in variance indicate ecological consequences of disturbance, stability, and recovery
  - The variance may help in defining an acceptable range of values for indicating recovery

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

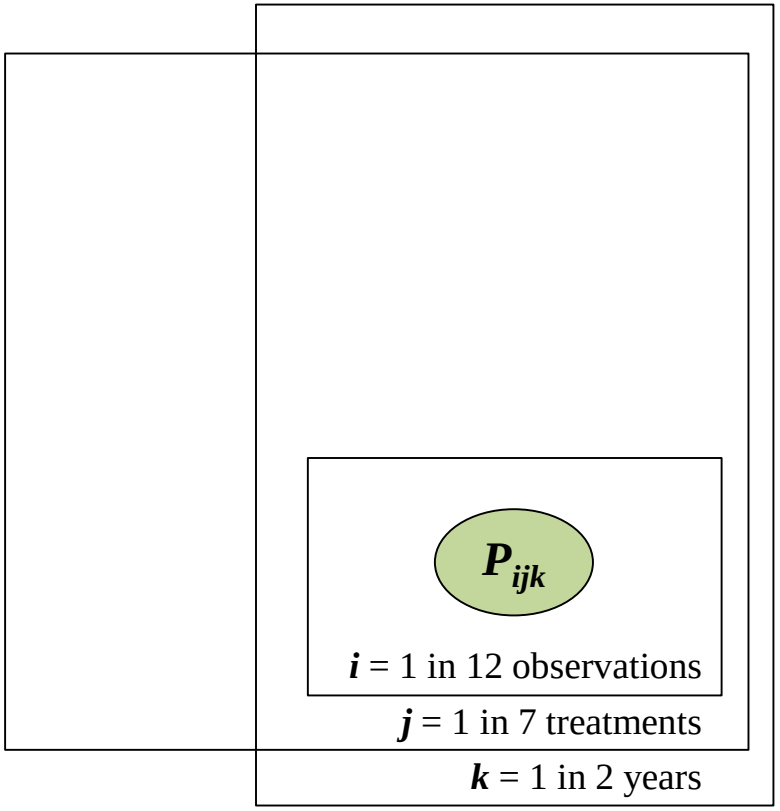
Investigate the recovery of soil properties on reclaimed soils by incorporating both the mean and variance in our assessment of similarity with regard to reference soils

Wamsutter, Wyoming

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


< 1 year
4 years
28 years
35 years
54 years
Undisturbed

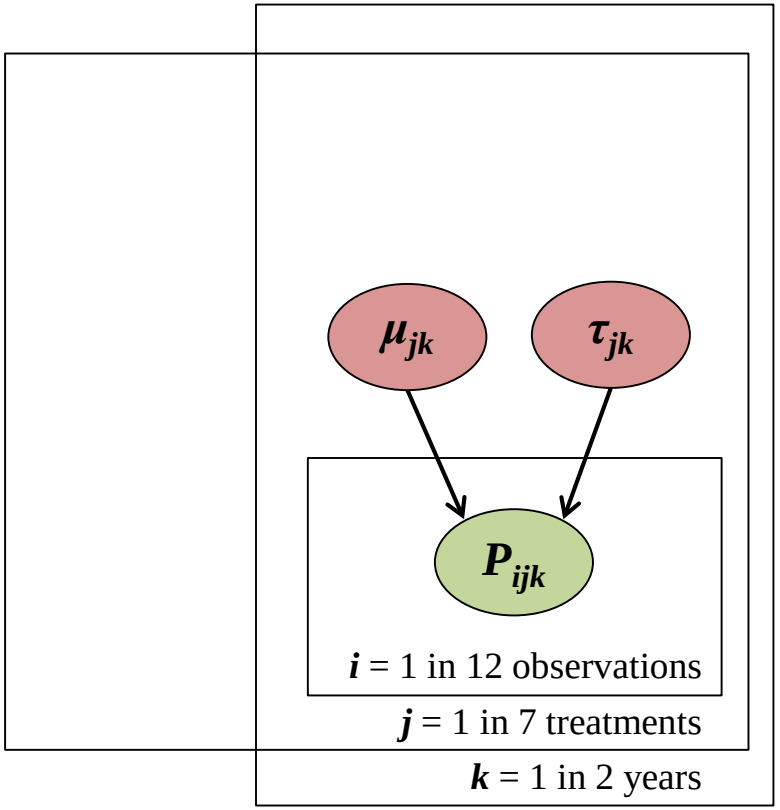
Bayesian Hierarchical Linear Mixed Model

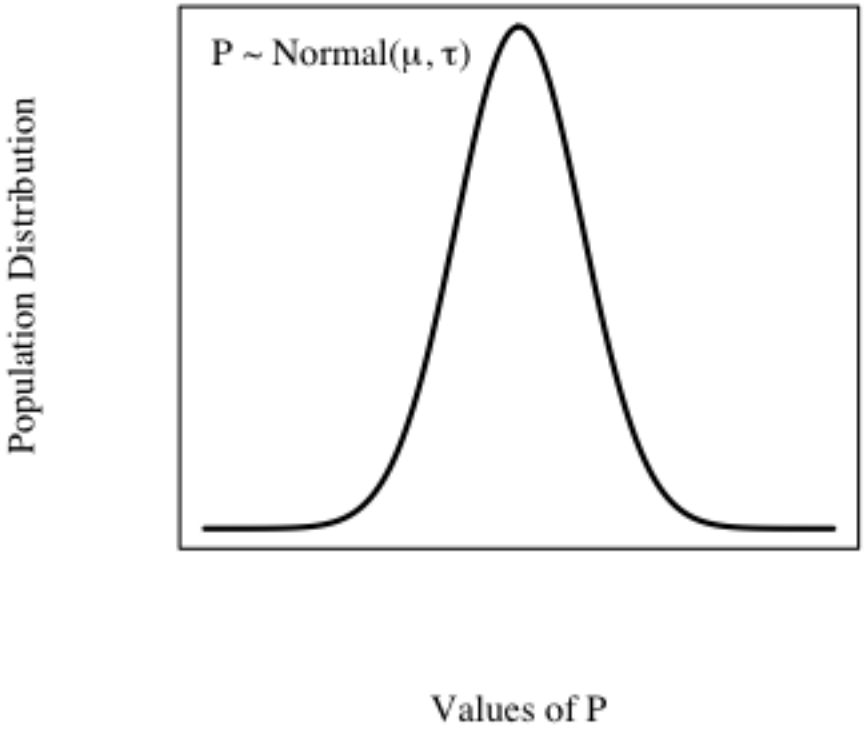


Soil Property (***P***)
Moisture
SOC
TN
Microbial abundance
Etc.

Bayesian Hierarchical Linear Mixed Model

Data Model for the Likelihood

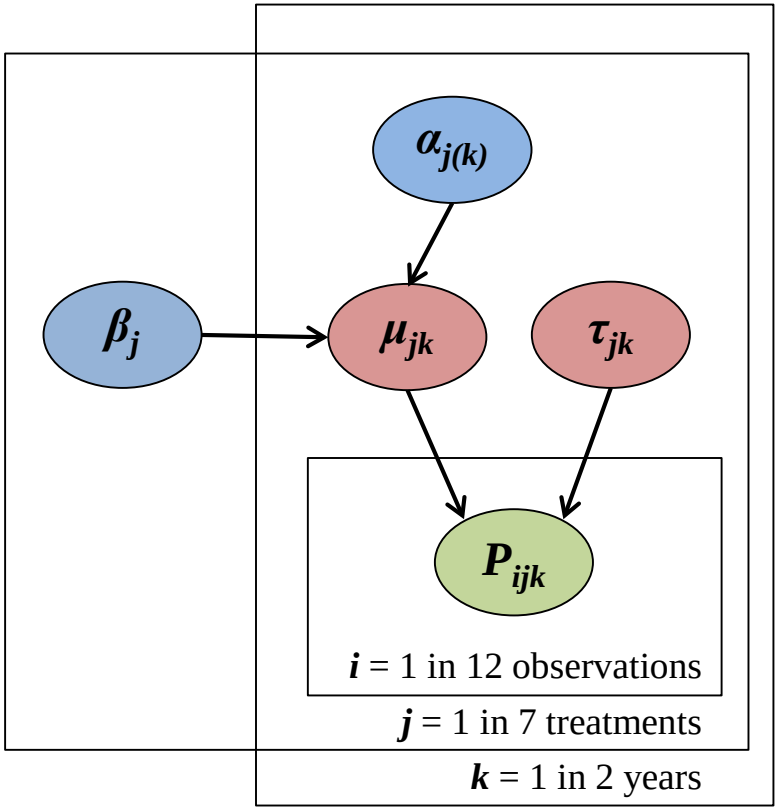




$\tau = (1/\sigma^2)$

Bayesian Hierarchical Linear Mixed Model

Data Model for the Likelihood



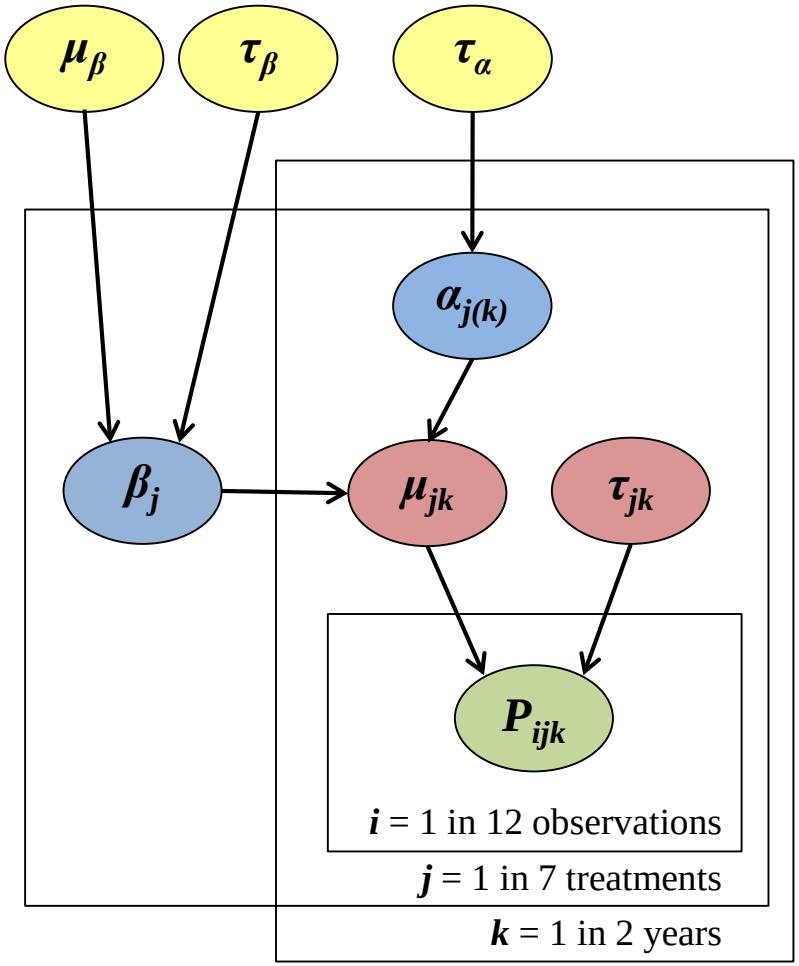
Mean value of P within a treatment

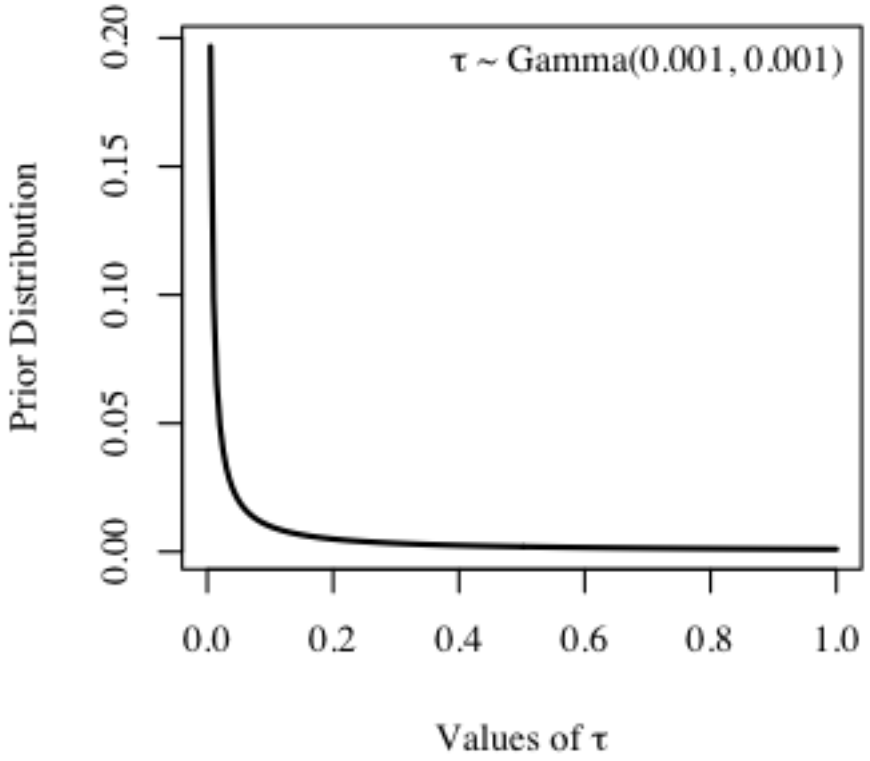
$$\mu_{jk} = \beta_j + \alpha_{j(k)}$$

Variability between treatments within years

Bayesian Hierarchical Linear Mixed Model

Prior Model

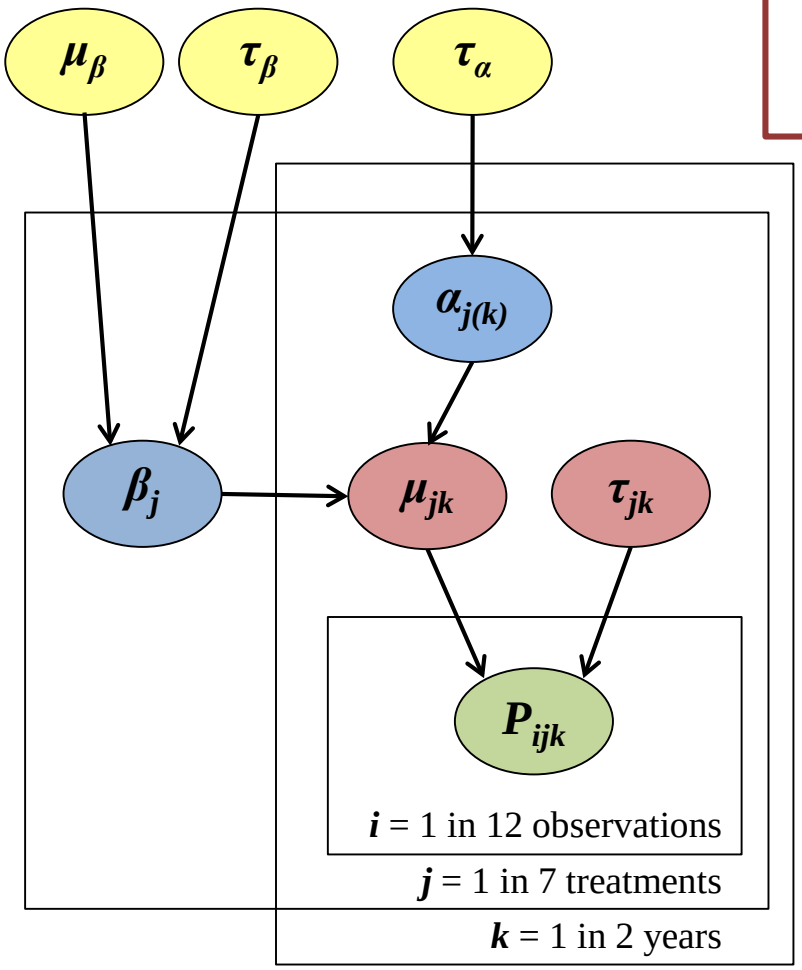




$$\beta_j \sim Normal\left(\mu_\beta, \tau_\beta\right)$$
$$\alpha_{j(k)} \sim Normal\left(0, \tau_\alpha\right)$$
$$\mu_\beta \sim Normal\left(0, 0.001\right)$$
$$\tau_{jk}, \tau_\beta, \tau_\alpha \sim Gamma(0.001, 0.001)$$

Bayesian Hierarchical Linear Mixed Model

Posterior Distribution



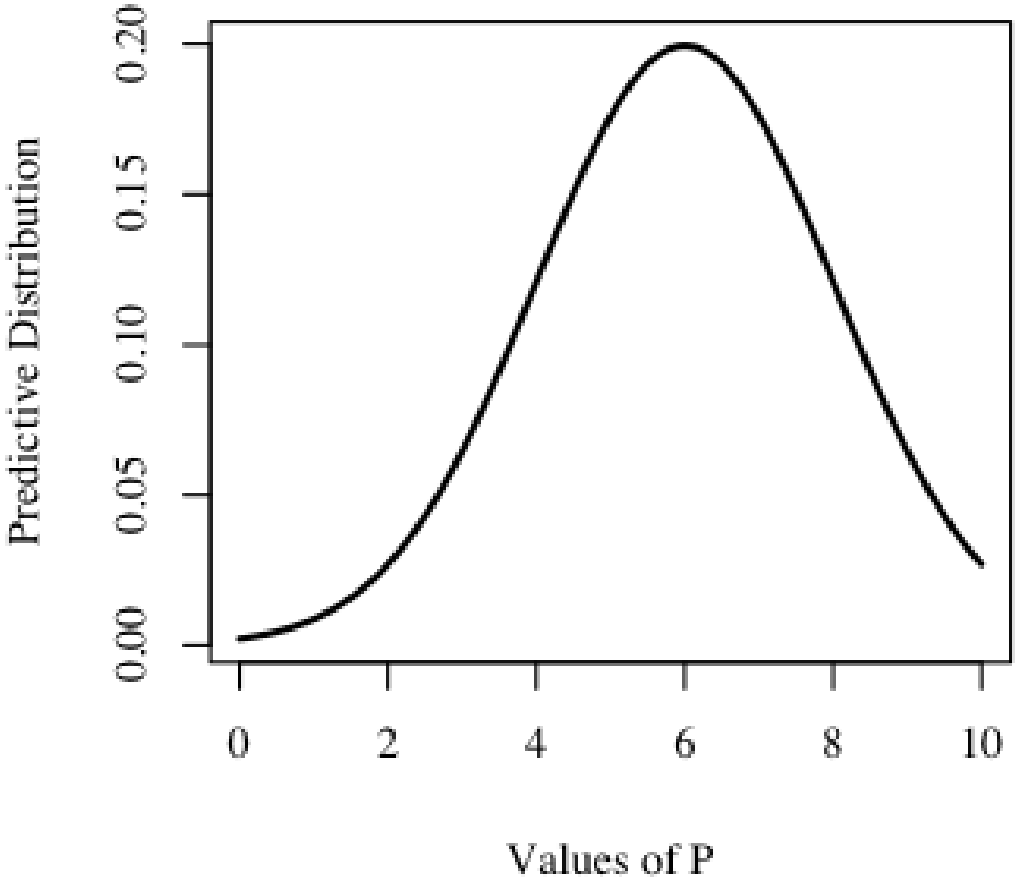
$$P_{ijk} | \mu_{jk}, \beta_j, \tau_{jk}, \alpha_{j(k)}, \gamma_k, \tau_\alpha, \tau_\gamma \sim Normal(\mu_{jk}, \tau_{jk})$$
$$P_{ijk} | \theta \sim Normal(\mu_{jk}, \tau_{jk})$$

$$\beta_j \sim Normal\ (\mu_\beta, \tau_\beta)$$
$$\alpha_{j(k)} \sim Normal\ (0, \tau_\alpha)$$
$$\mu_\beta \sim Normal\ (0, 0.001)$$
$$\tau_{jk}, \tau_\beta, \tau_\alpha \sim Gamma(0.001, 0.001)$$

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

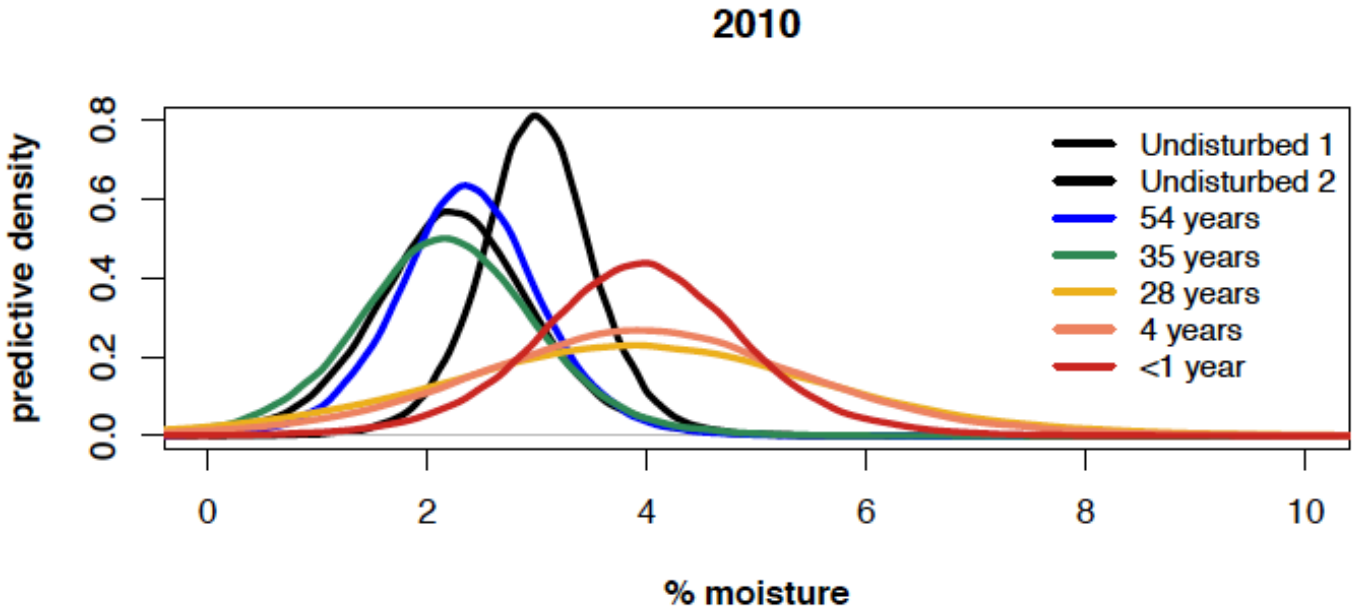
Bayesian Hierarchical Linear Mixed Model

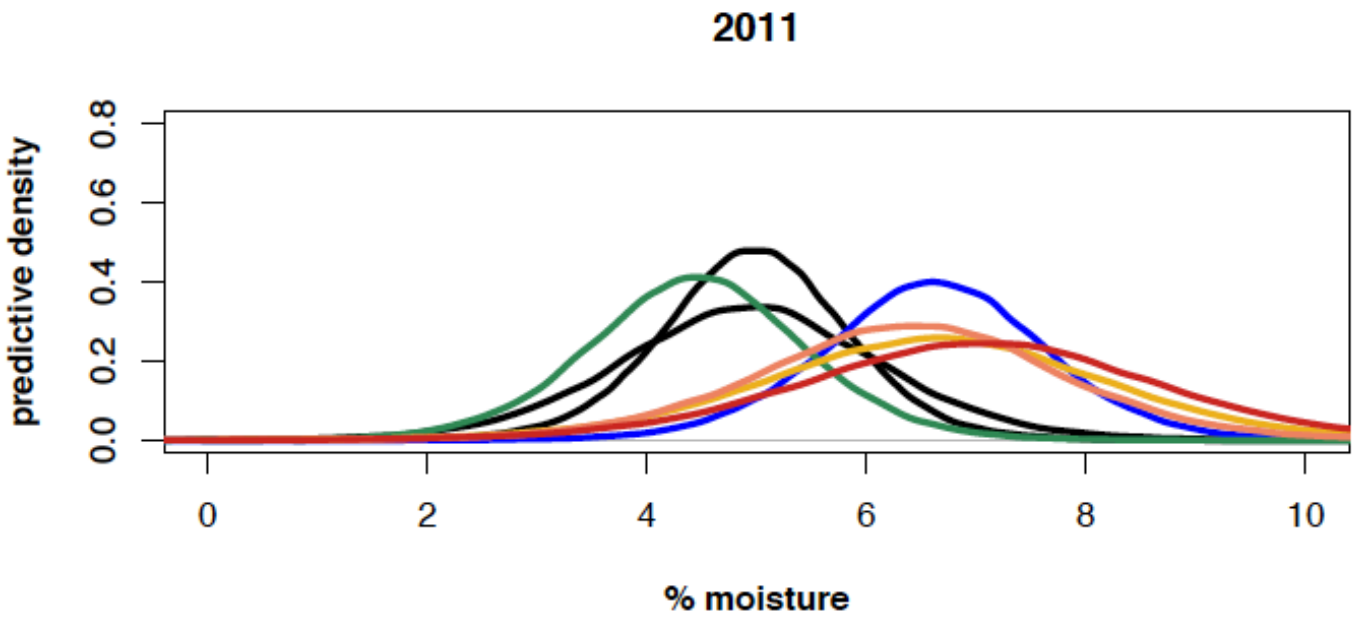
Predictive Distribution of Future Observables

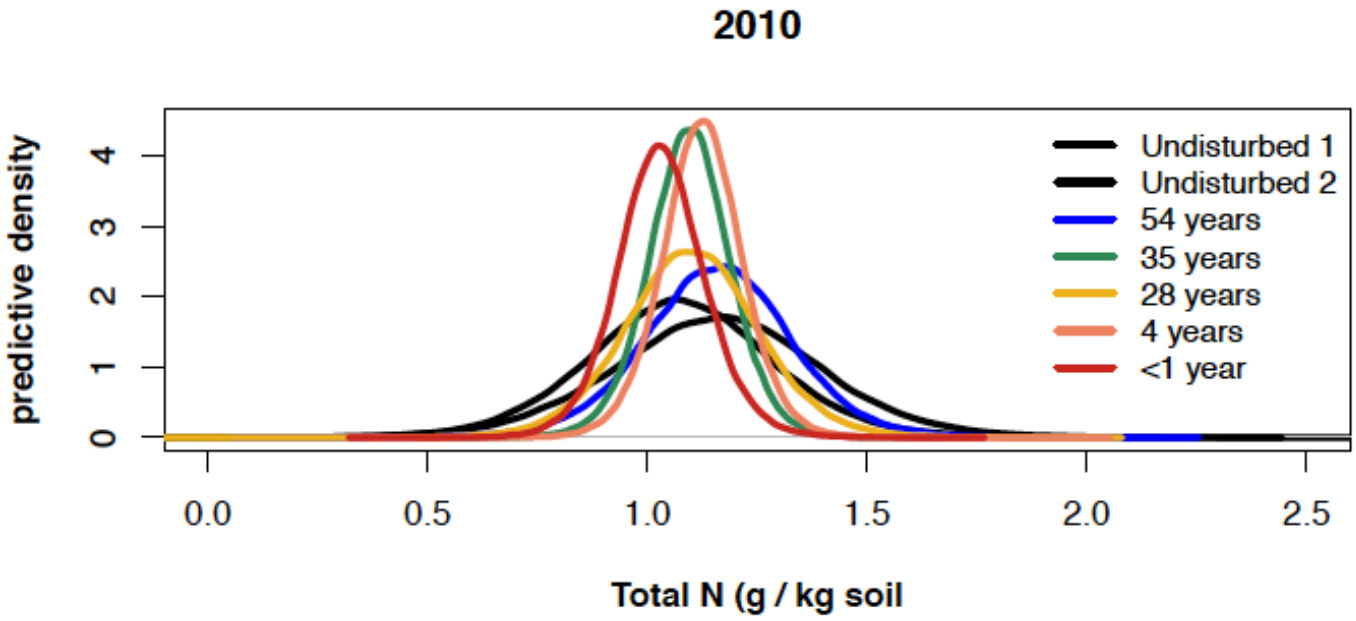


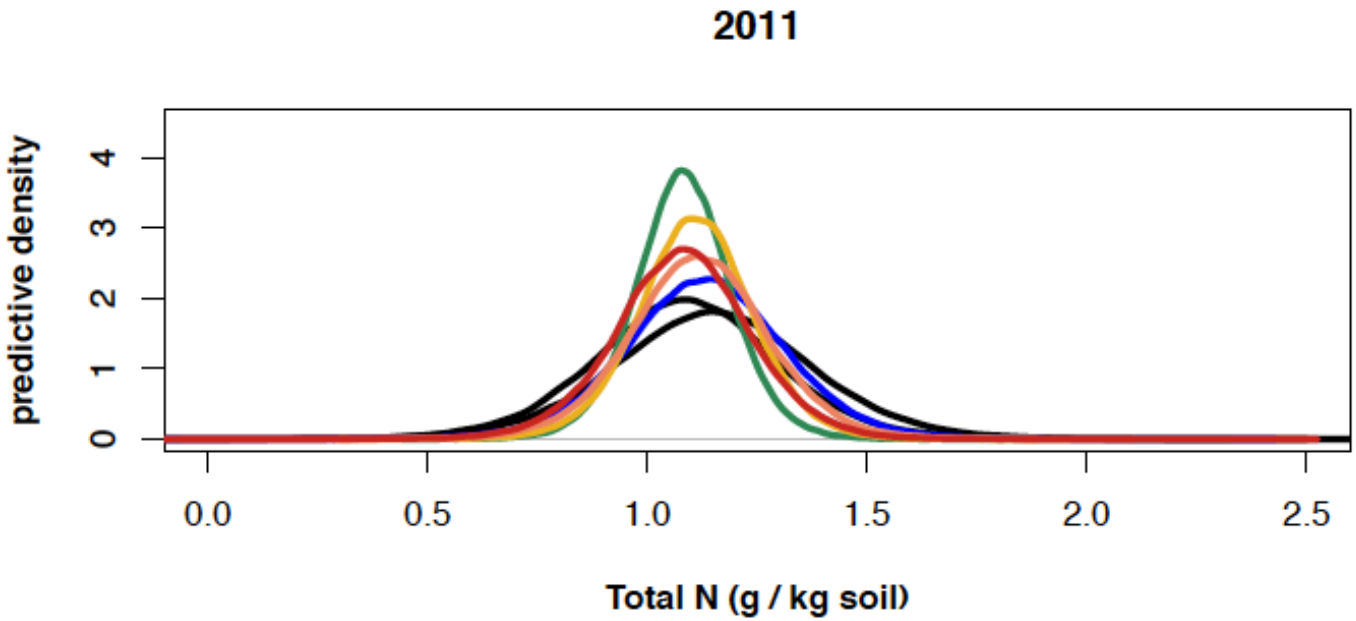
$$\Pr\left(\widetilde{P_{ijk}}|P_{ijk}\right) = \int_{\theta} \Pr\left(\widetilde{P_{ijk}}|\theta\right) \cdot \Pr\left(\theta\middle|P_{ijk}\right) d\theta$$

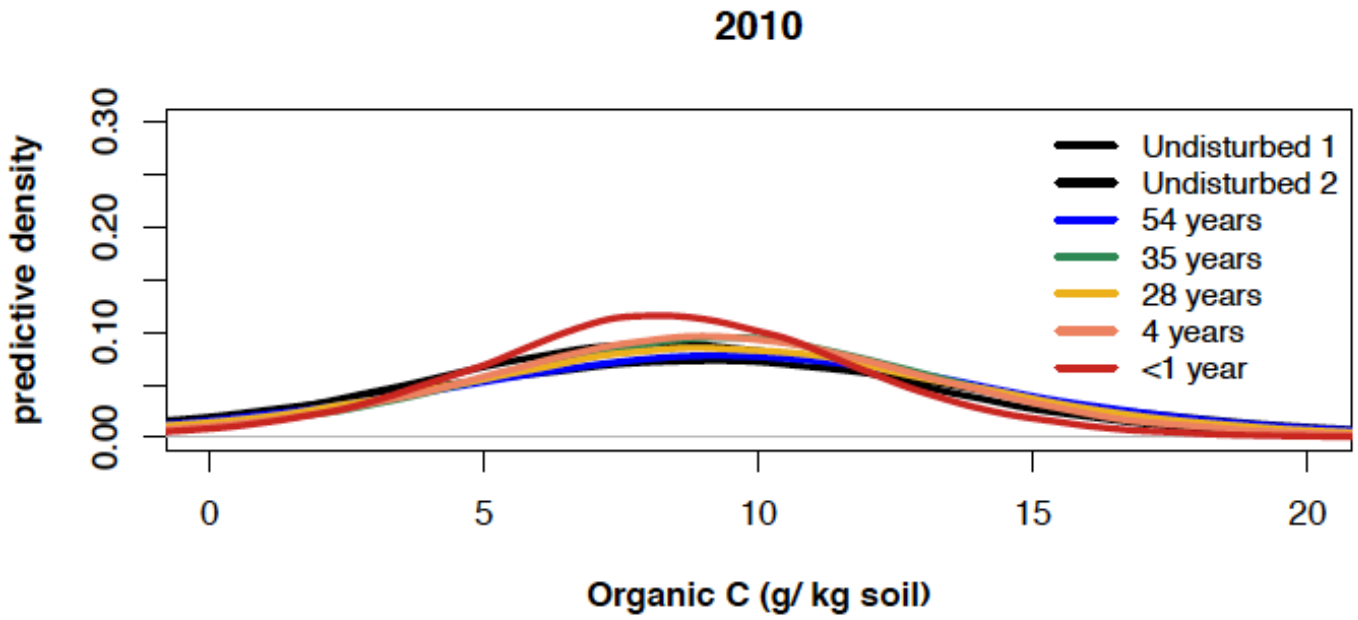
Huzurbazar et al. *In Press* SSSAJ

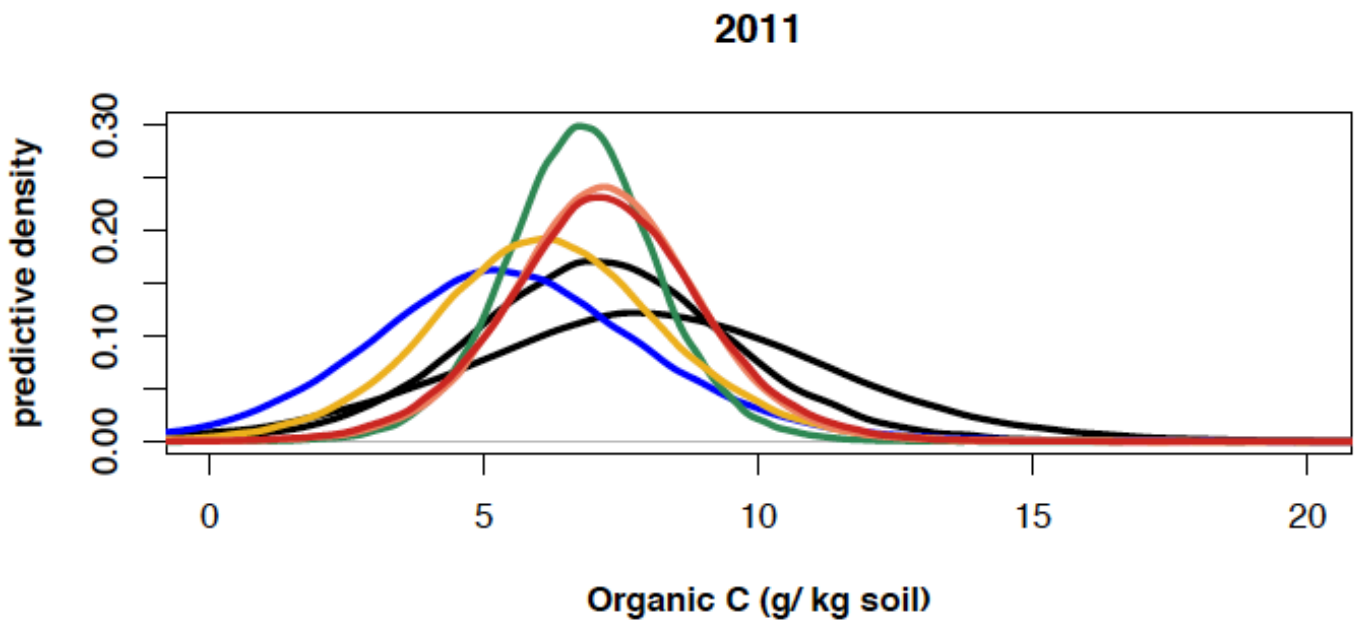

2010
predictive density
0.0
0.2
0.4
0.6
0.8
0
2
4
6
8
10
% moisture
Undisturbed 1
Undisturbed 2
54 years
35 years
28 years
4 years
<1 year

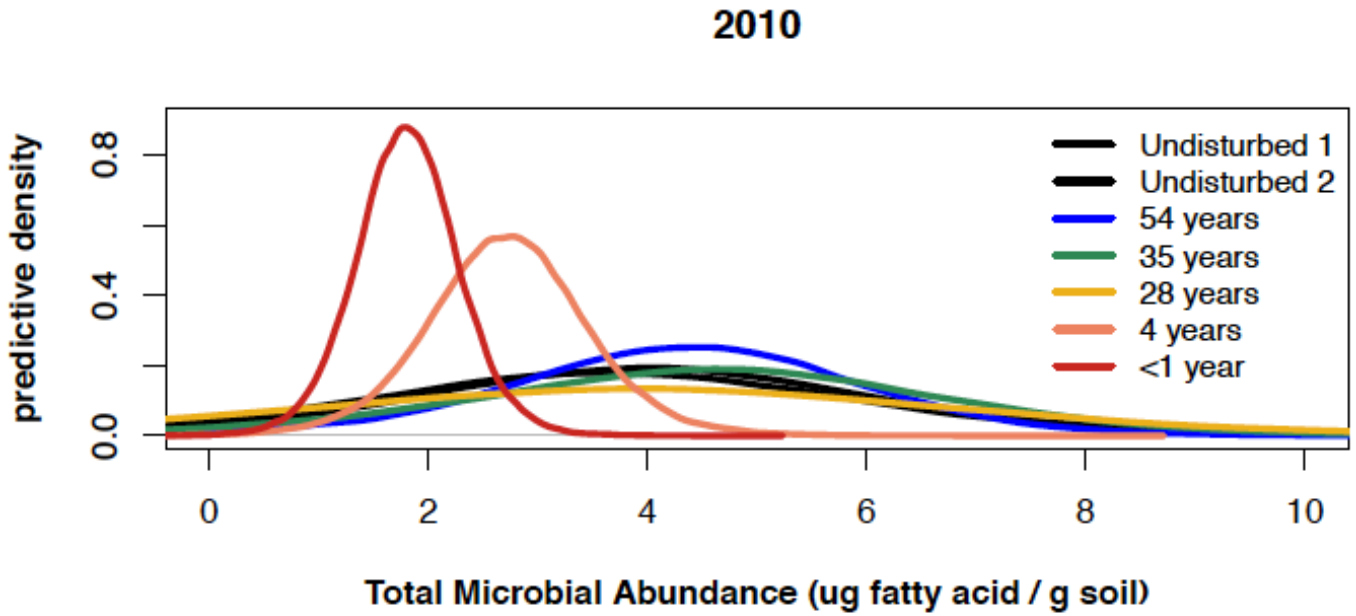

2011
predictive density
0.0
0.2
0.4
0.6
0.8
0
2
4
6
8
10
% moisture

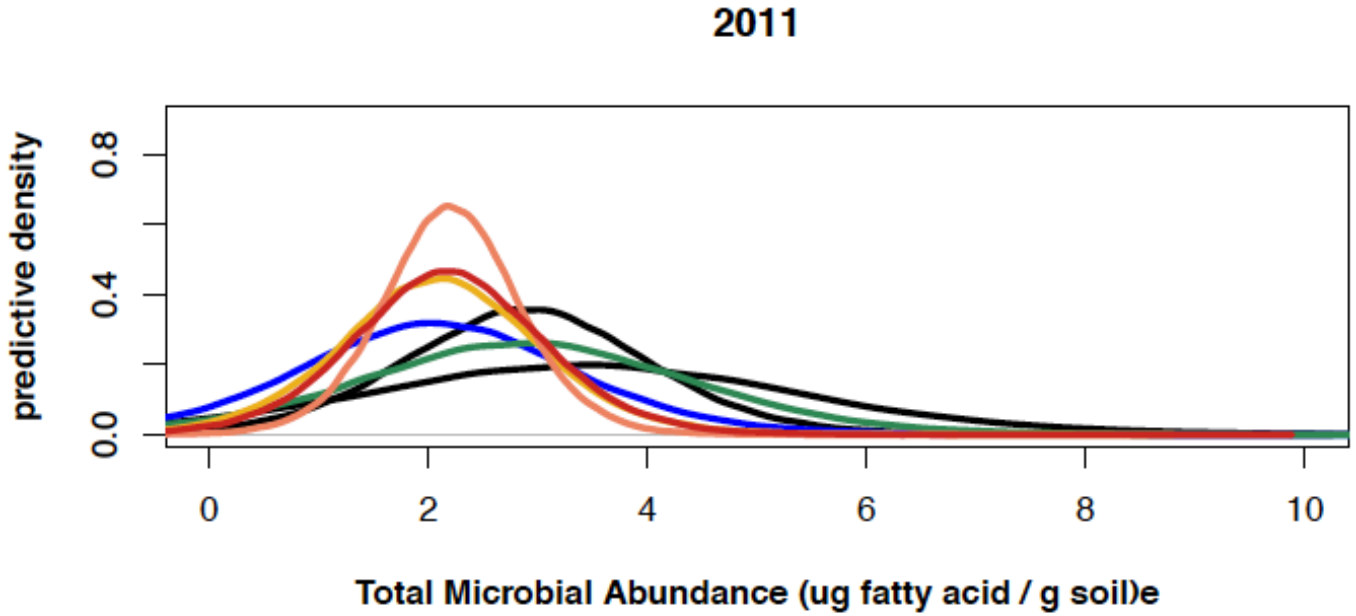

2010
predictive density
0
1
2
3
4
0.0
0.5
1.0
1.5
2.0
2.5
Total N (g / kg soil
Undisturbed 1
Undisturbed 2
54 years
35 years
28 years
4 years
<1 year

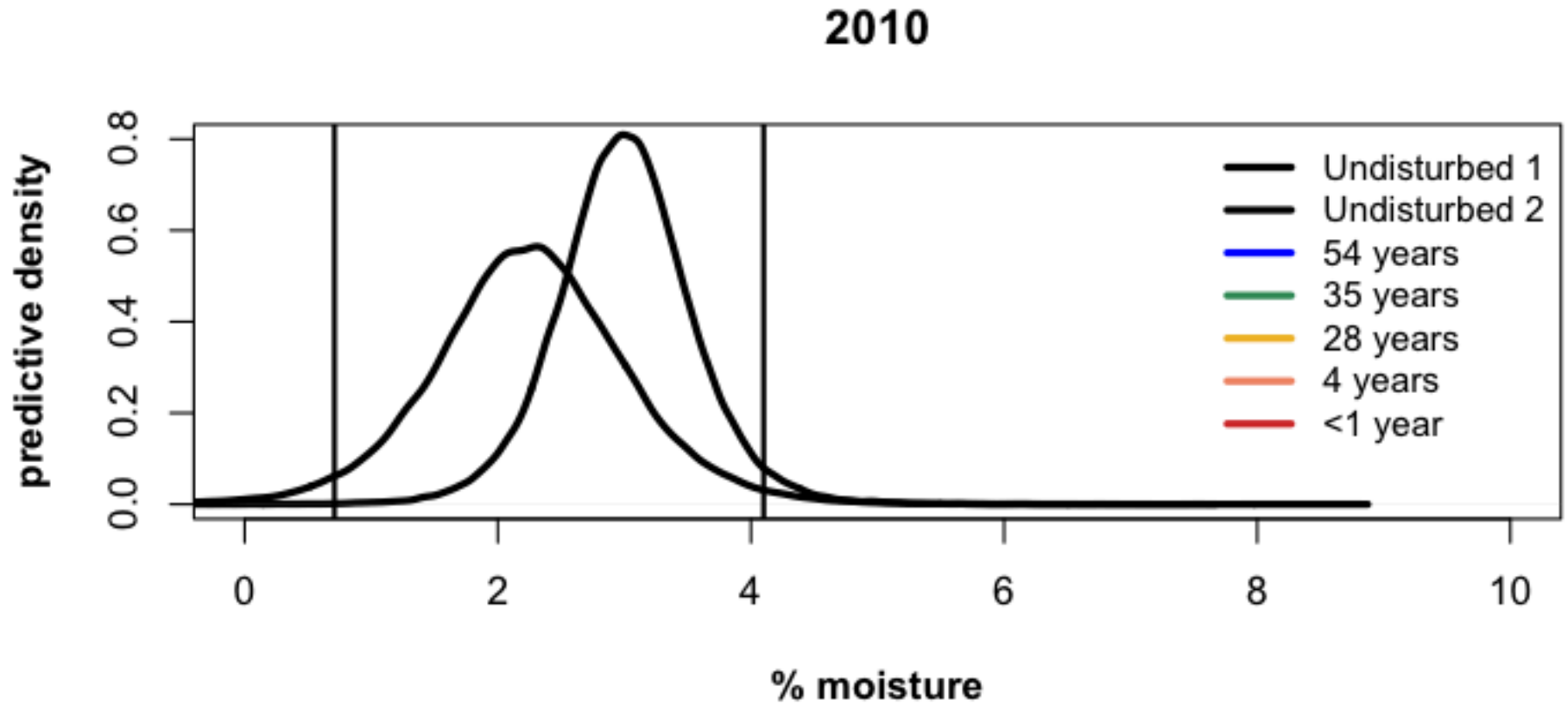

2011
predictive density
0
1
2
3
4
0.0
0.5
1.0
1.5
2.0
2.5
Total N (g / kg soil)

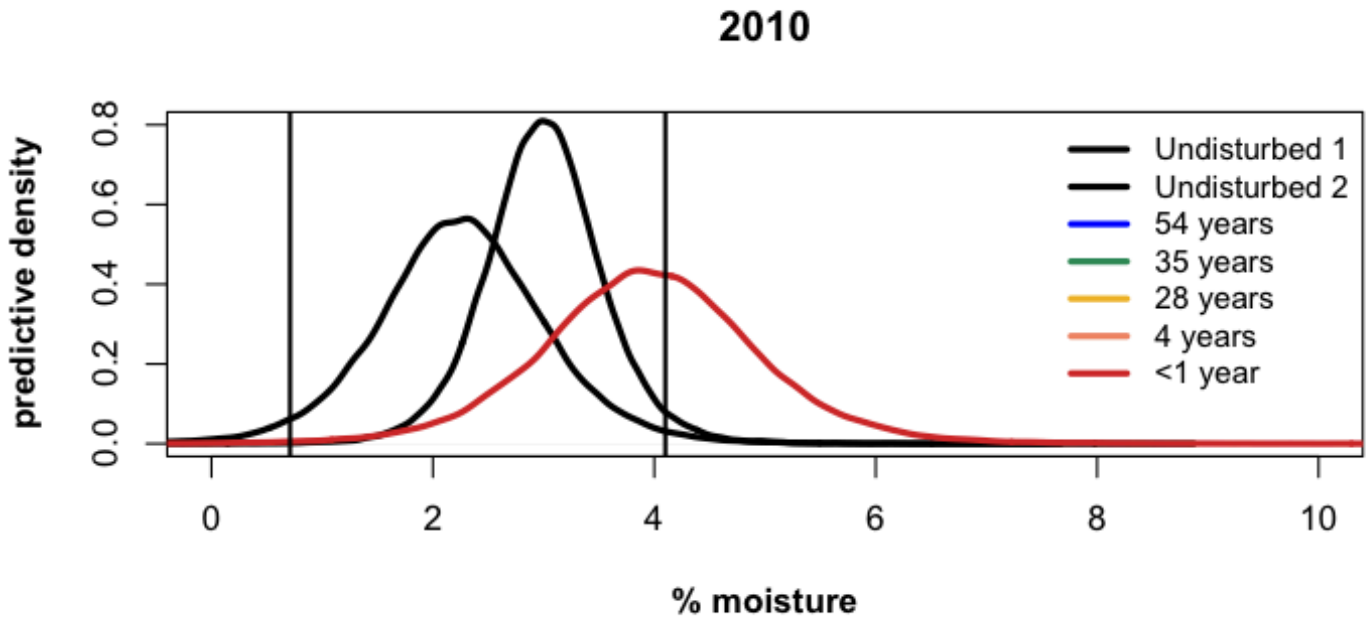

2010
predictive density
0.00
0.10
0.20
0.30
0
5
10
15
20
Organic C (g/ kg soil)
Undisturbed 1
Undisturbed 2
54 years
35 years
28 years
4 years
<1 year

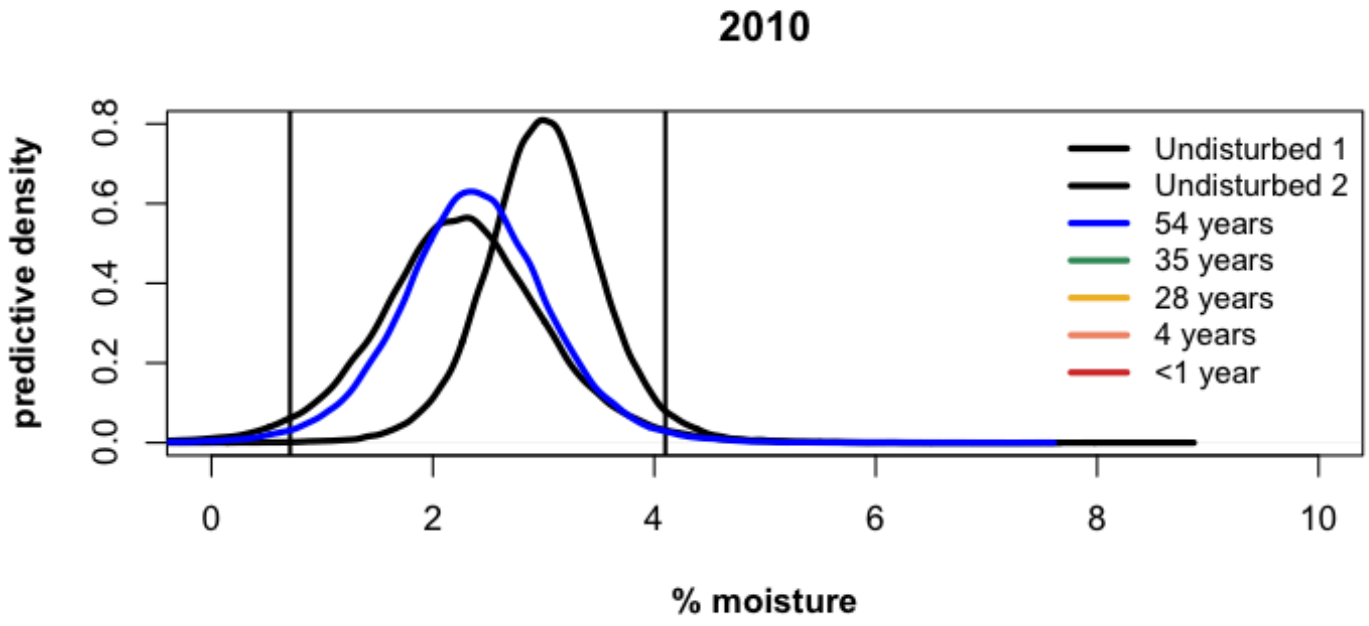

2011
predictive density
0.00
0.10
0.20
0.30
0
5
10
15
20
Organic C (g/ kg soil)


2010
predictive density
0.0
0.4
0.8
0
2
4
6
8
10
Undisturbed 1
Undisturbed 2
54 years
35 years
28 years
4 years
<1 year
Total Microbial Abundance (ug fatty acid / g soil)


2011
predictive density
0.0
0.4
0.8
0
2
4
6
8
10
Total Microbial Abundance (ug fatty acid / g soil)e

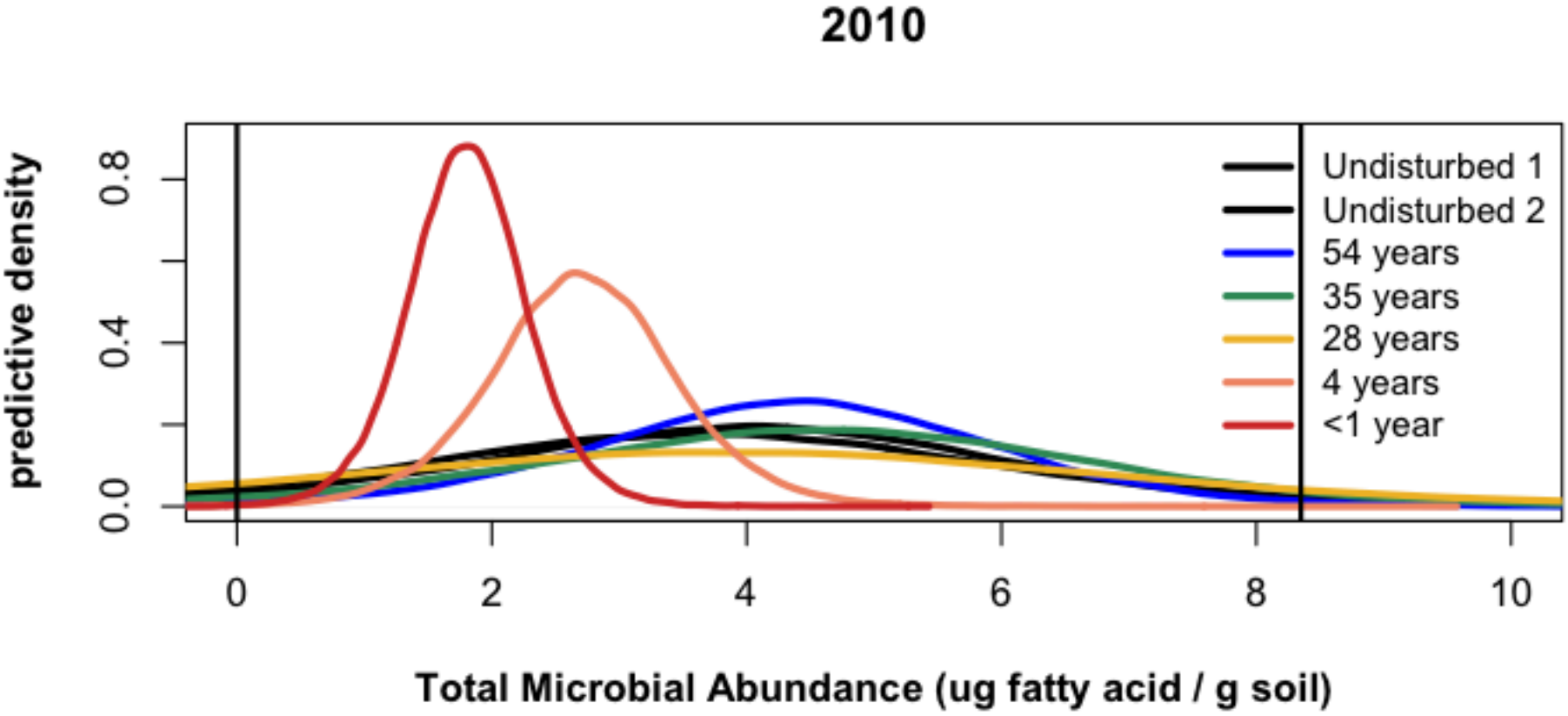

2010
predictive density
0.0
0.2
0.4
0.6
0.8
0
2
4
6
8
10
% moisture
Undisturbed 1
Undisturbed 2
54 years
35 years
28 years
4 years
<1 year


2010
predictive density
0.0
0.2
0.4
0.6
0.8
0
2
4
6
8
10
% moisture
Undisturbed 1
Undisturbed 2
54 years
35 years
28 years
4 years
<1 year

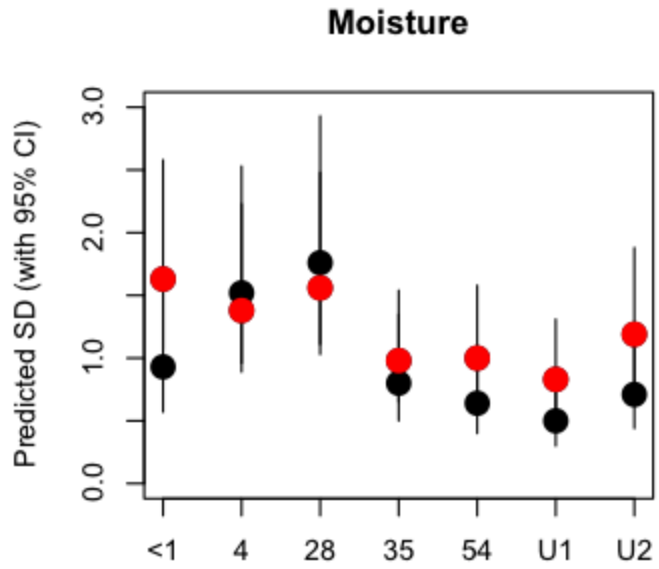

2010
predictive density
0.0
0.2
0.4
0.6
0.8
0
2
4
6
8
10
% moisture
Undisturbed 1
Undisturbed 2
54 years
35 years
28 years
4 years
<1 year

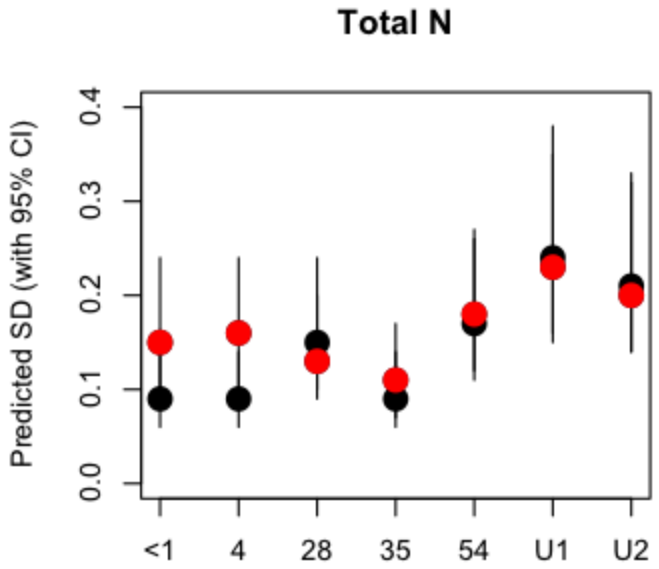
Probability that the posterior predictive values of a soil property fall within the range of reference site values

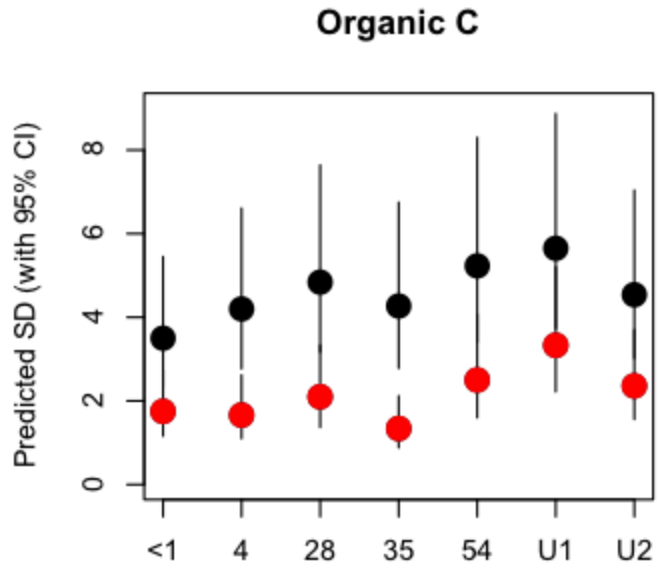
	Moisture	Total N	Organic C	Total Microbial Abundance
		--------*2010*--------		
< 1 year	0.56	1.00	0.98	1.00
4 years	0.52	1.00	0.97	1.00
28 years	0.51	1.00	0.95	0.82
35 years	0.94	1.00	0.97	0.93
54 years	0.98	0.99	0.93	0.98
		--------*2011*--------		
< 1 year	0.60	0.99	1.00	0.99
4 years	0.78	0.99	1.00	1.00
28 years	0.70	1.00	0.99	0.98
35 years	0.97	1.00	1.00	0.96
54 years	0.80	0.99	0.96	0.94

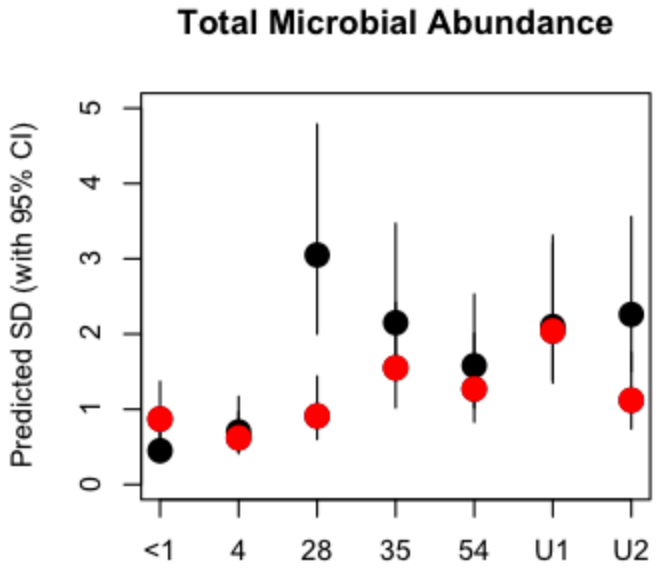


$$P_{ijk} | \theta \sim Normal(\mu_{jk}, \tau_{jk})$$


Moisture
Predicted SD (with 95% CI)
0.0
1.0
2.0
3.0
<1
4
28
35
54
U1
U2

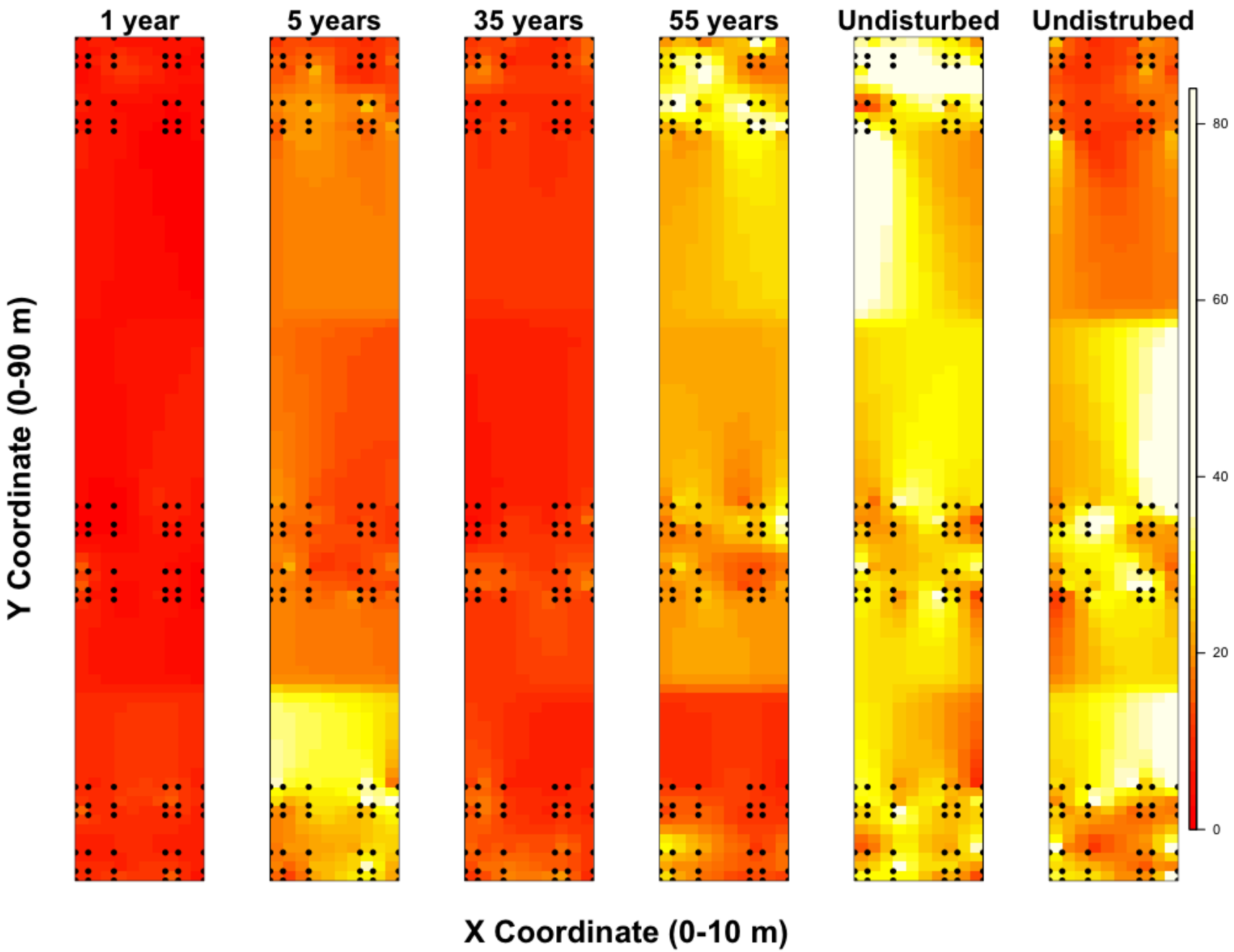

Total N
Predicted SD (with 95% CI)
0.0
0.1
0.2
0.3
0.4
<1
4
28
35
54
U1
U2

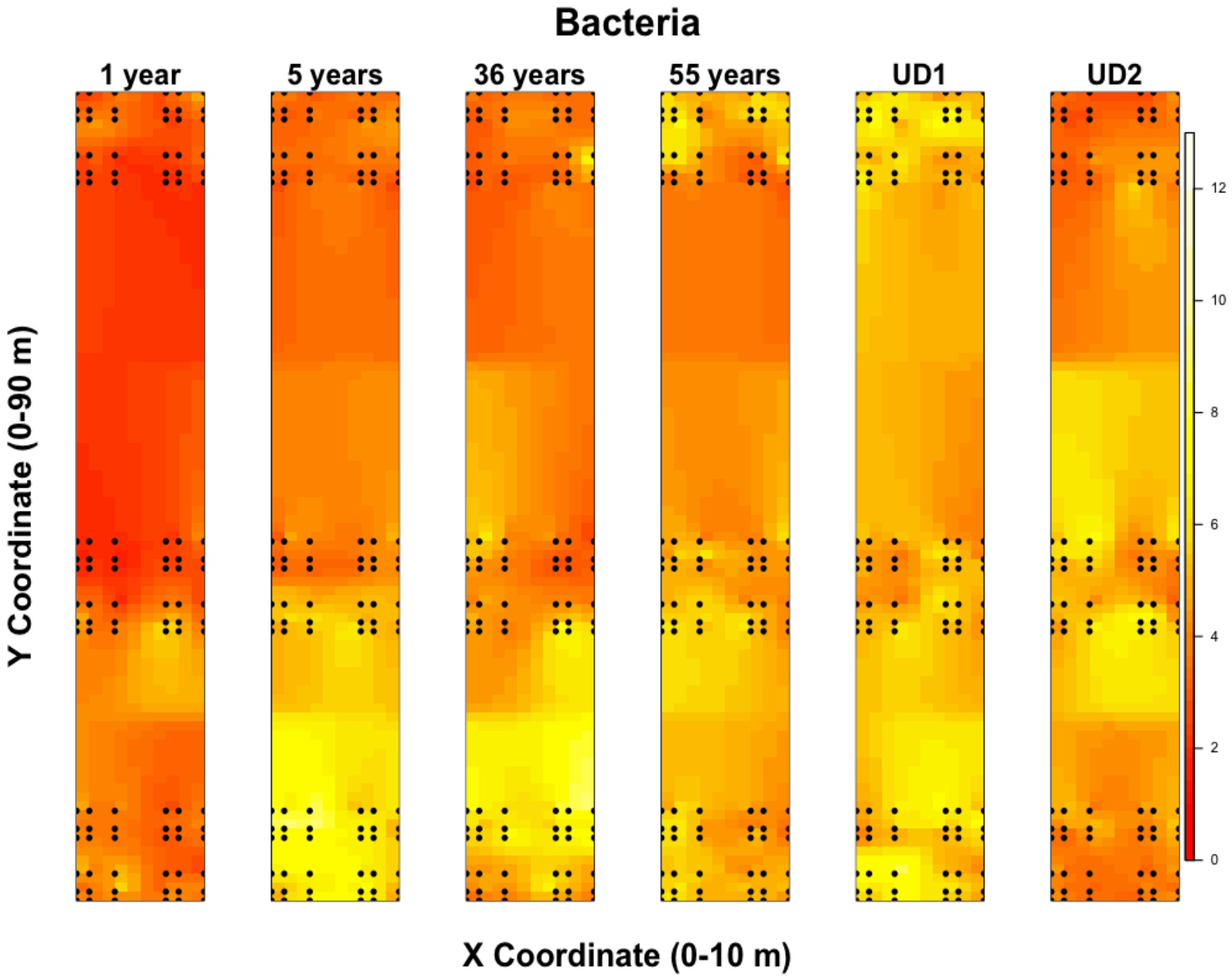

Organic C
Predicted SD (with 95% CI)
0
2
4
6
8
<1
4
28
35
54
U1
U2


Total Microbial Abundance
Predicted SD (with 95% CI)
0
1
2
3
4
5
<1
4
28
35
54
U1
U2

	Mean (central tendency)	**Variance (spread)**
Moisture	↑	↑
Total N	=	↓
Organic C	=	↓
Microbial abundance	↓	↓

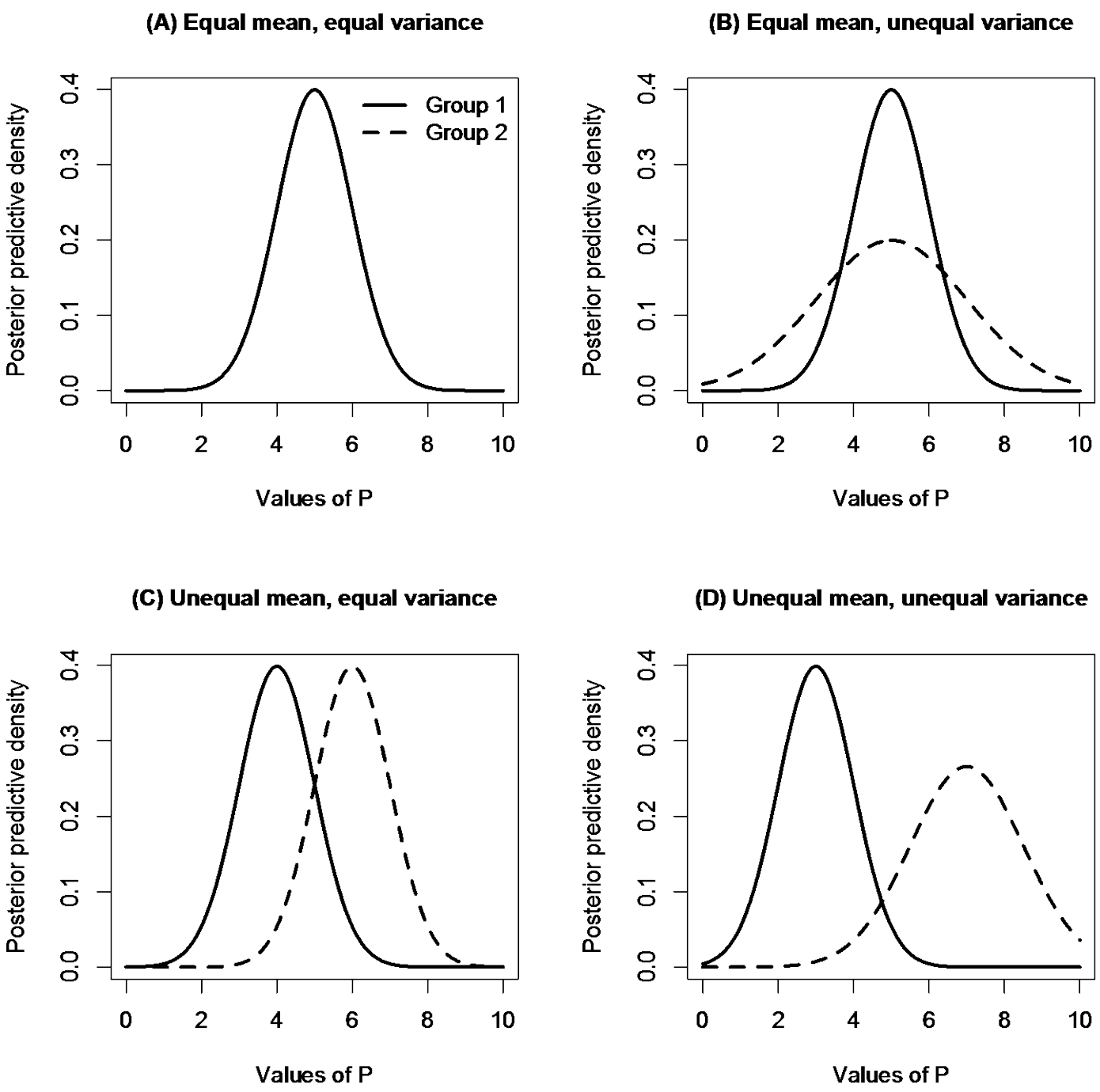
- Future work: investigate sources of **variability**
  - Spatial approach (10 cm – 100 m)
  - Geostatistical parameter comparison
  - Assess degrees of heterogeneity
  - Link aboveground-belowground properties


Total Vegetation Cover
1 year
5 years
35 years
55 years
Undisturbed
Undistrubed
Y Coordinate (0-90 m)
X Coordinate (0-10 m)
80
60
40
20
0


Bacteria
1 year
5 years
36 years
55 years
UD1
UD2
Y Coordinate (0-90 m)
X Coordinate (0-10 m)
12
10
8
6
4
2
0

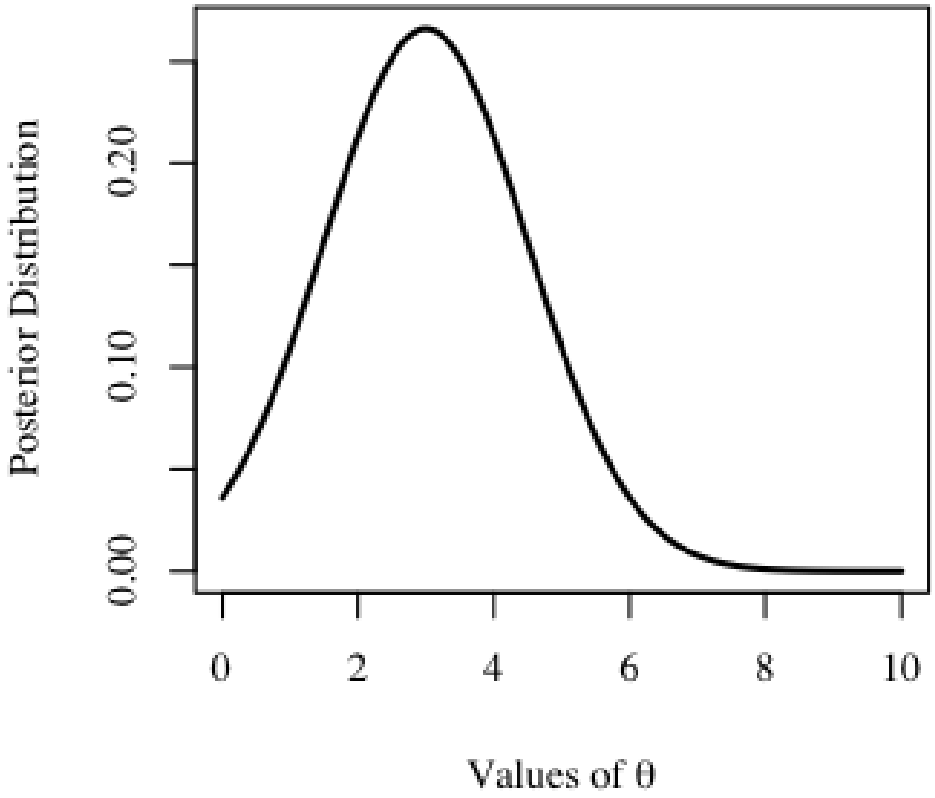
Thank you: Wyoming Reclamation and Restoration Center, Haub School and Environment and Natural Resources, Overland Pass Pipeline Company, ONEOK, Kinder Morgan, El Paso Companies, Bureau of Land Management Rawlins Field Office, Rachana Giri Paudel, Darren Gemoets, Leann Naughton, Kurt Smith

- 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

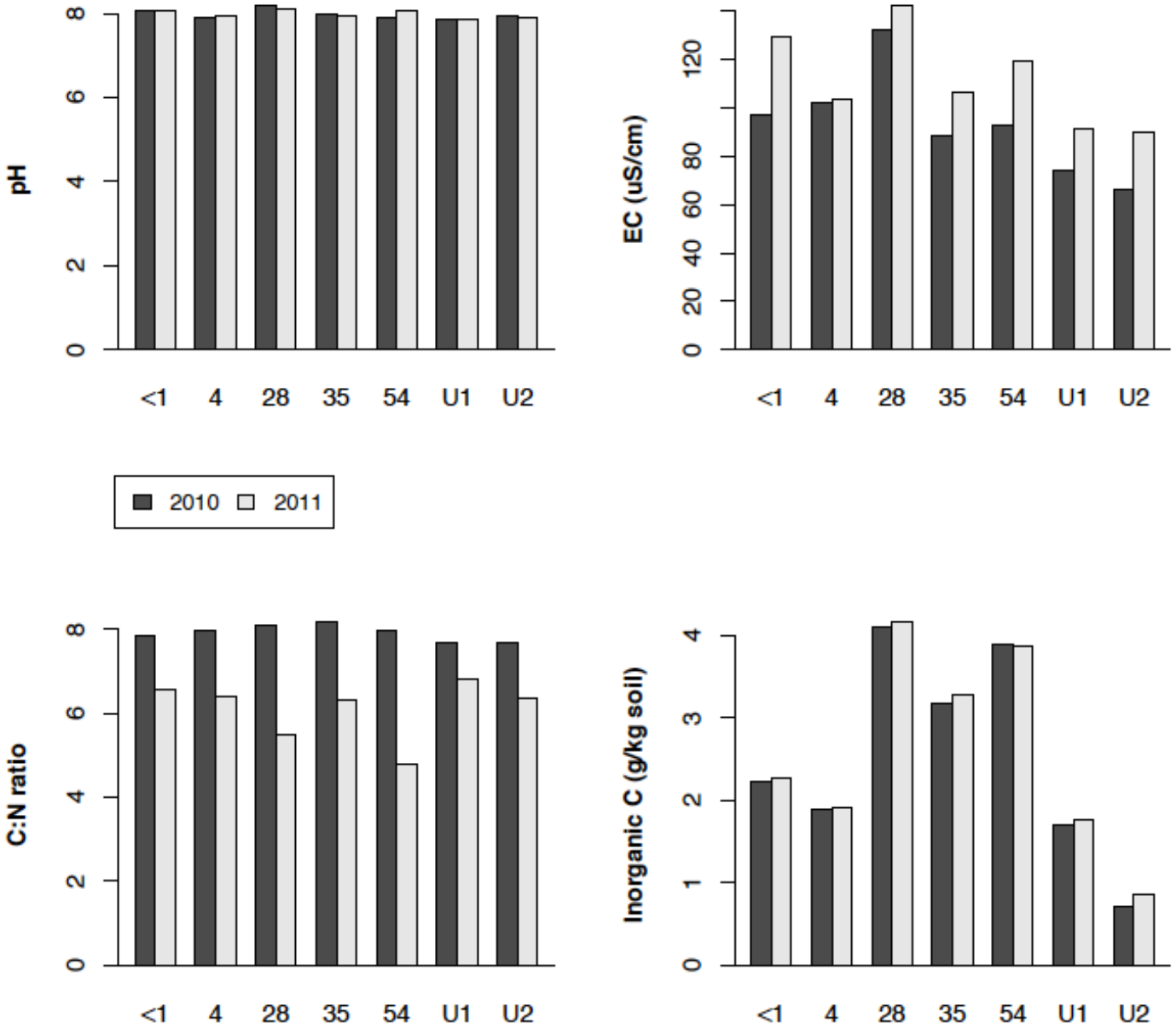

(A) Equal mean, equal variance
(B) Equal mean, unequal variance
(C) Unequal mean, equal variance
(D) Unequal mean, unequal variance
Group 1
Group 2
Posterior predictive density
Values of P
0.0
0.1
0.2
0.3
0.4
0
2
4
6
8
10

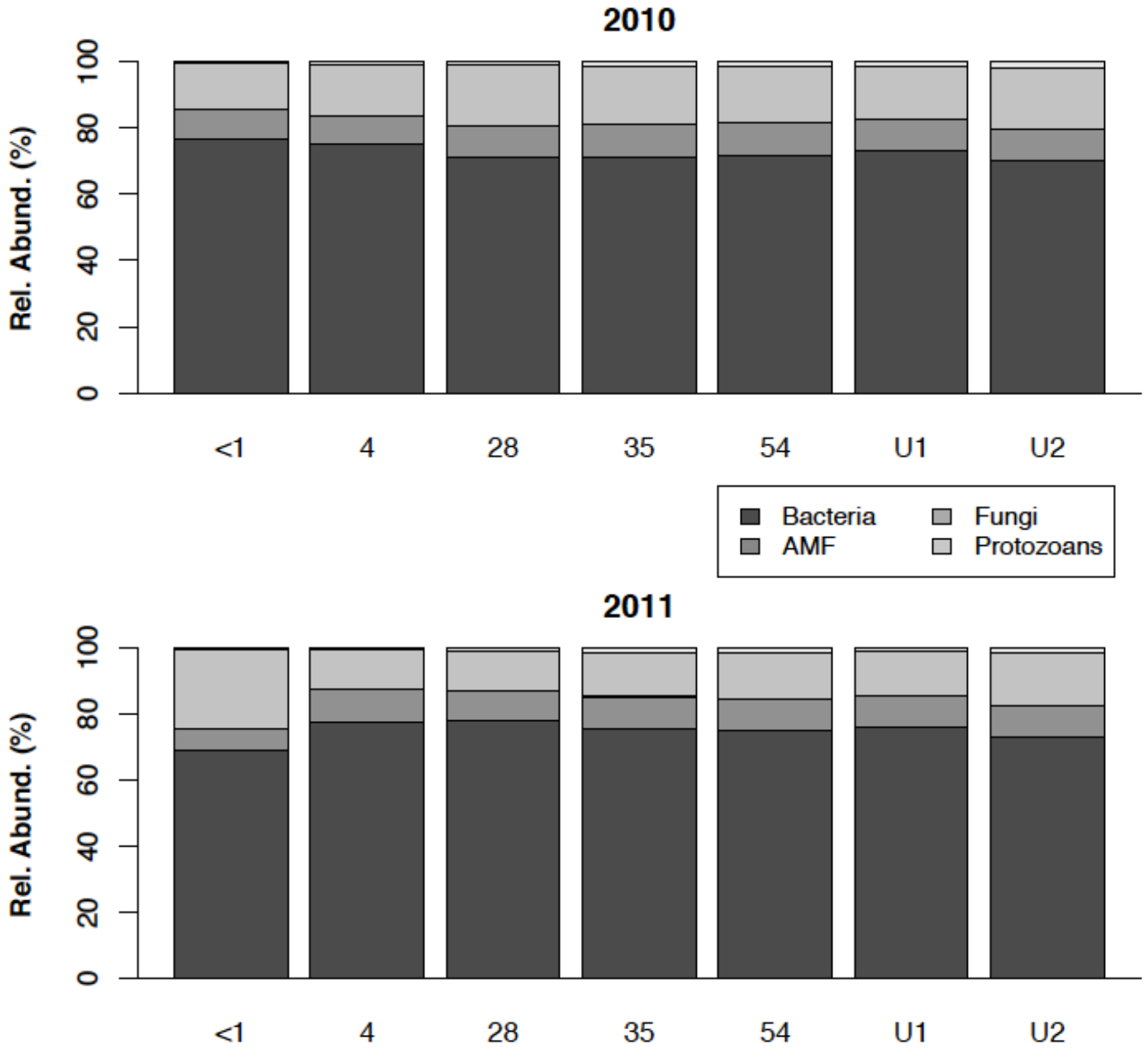
Bayesian Hierarchical Linear Mixed Model

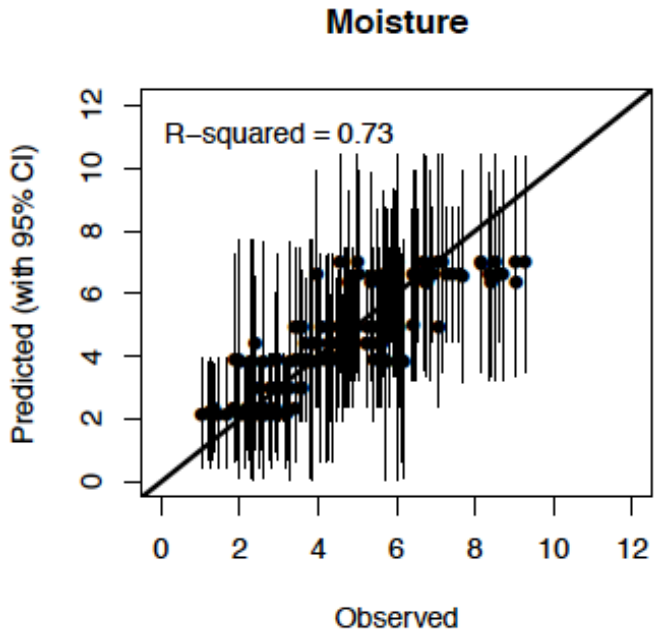
Posterior Distribution

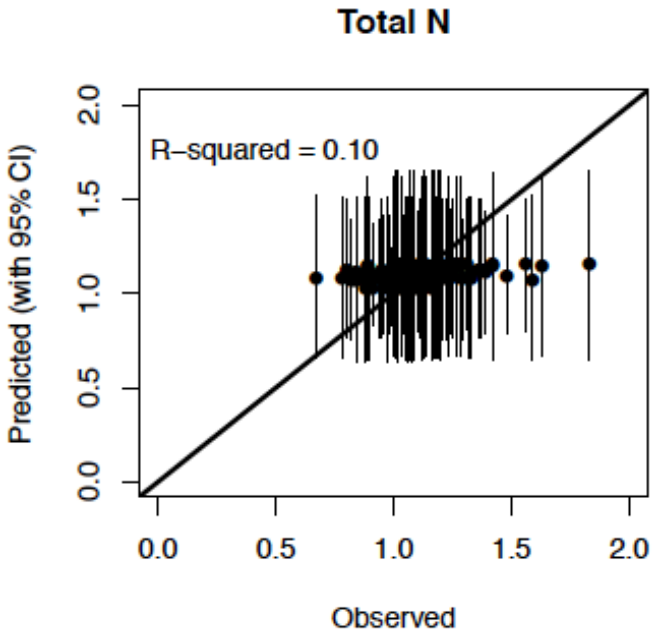


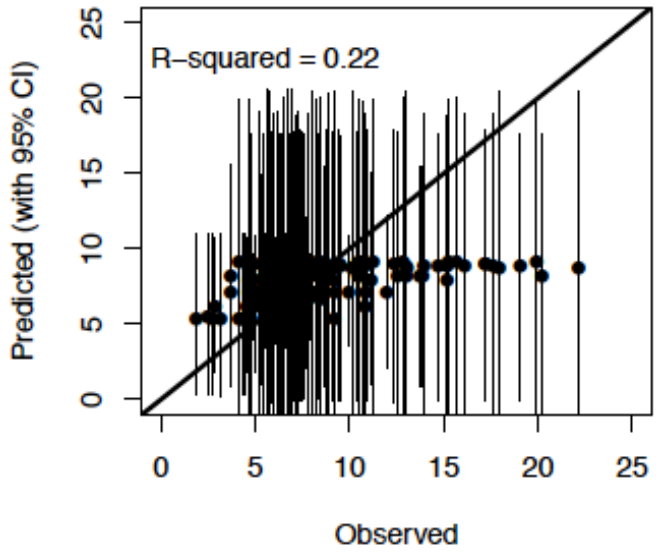
$$\Pr(\theta|P_{ijk}) = \int_{\theta} \Pr(P_{ijk}|\theta) \cdot \Pr(\theta)\, d\theta$$


pH
0
2
4
6
8
<1
4
28
35
54
U1
U2
EC (uS/cm)
0
20
40
60
80
120
2010
2011
C:N ratio
Inorganic C (g/kg soil)
0
1
2
3
4


2010
Rel. Abund. (%)
0
20
40
60
80
100
<1
4
28
35
54
U1
U2
Bacteria
AMF
Fungi
Protozoans
2011
Rel. Abund. (%)
0
20
40
60
80
100
<1
4
28
35
54
U1
U2


Moisture
R–squared = 0.73
Predicted (with 95% CI)
Observed
0
2
4
6
8
10
12


Total N
R–squared = 0.10
Predicted (with 95% CI)
Observed
0.0
0.5
1.0
1.5
2.0


Organic C
R–squared = 0.22
Predicted (with 95% CI)
Observed
0
5
10
15
20
25

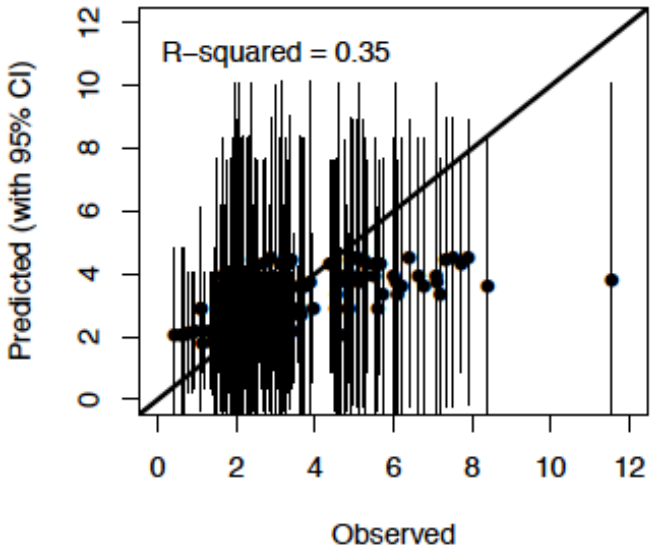
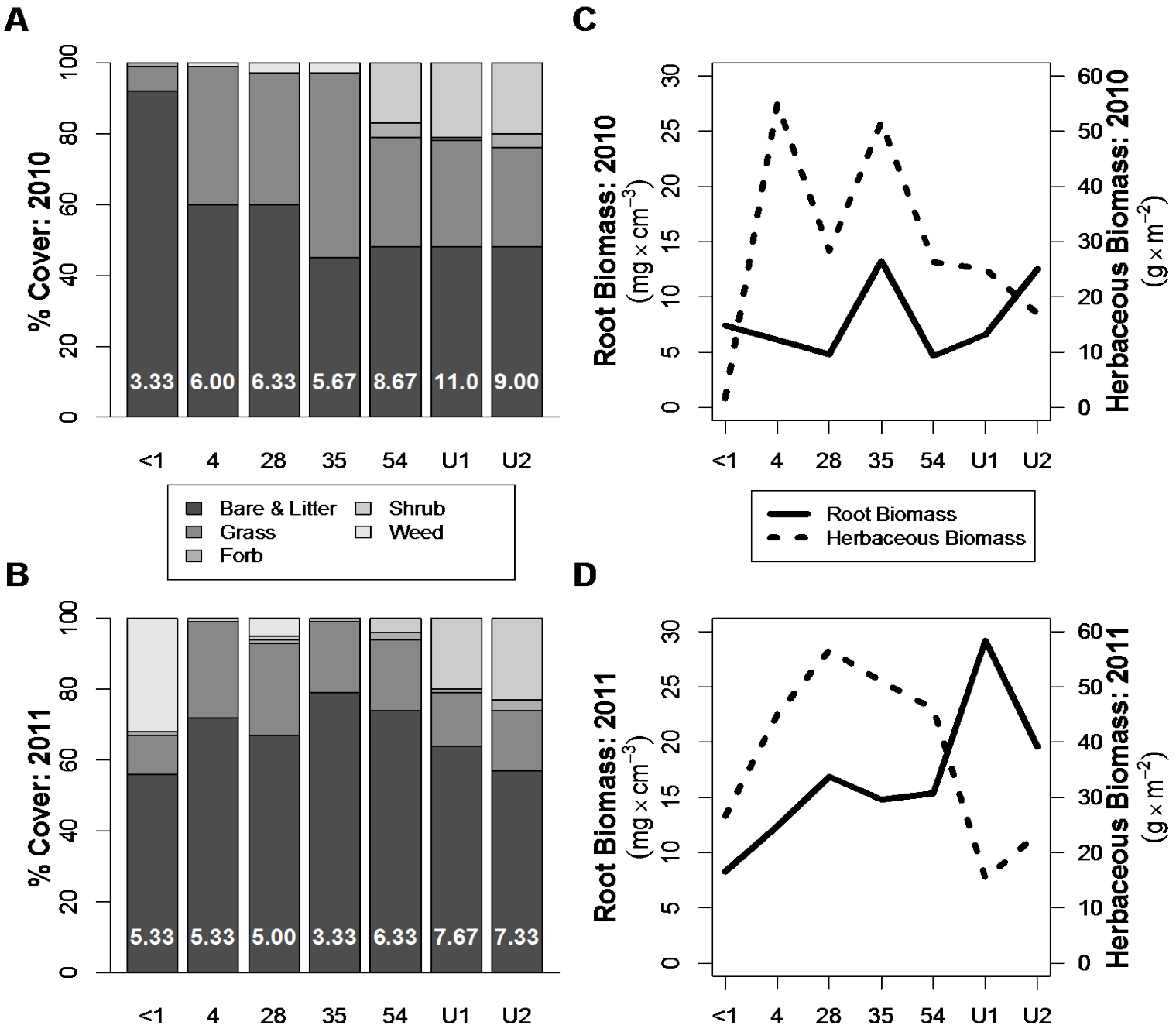

Total microbial abundance
R–squared = 0.35
Predicted (with 95% CI)
Observed
0
2
4
6
8
10
12

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

	Bulk Density ($g * cm^{-3}$)	Gravel (% by wt)	Sand (%)	Silt (%)	Clay (%)	Textual Class[§]
< 1 year	1.68 *(0.09)*	1.64 *(0.39)*	69.71 *(2.46)*	13.25 *(1.03)*	17.04 *(1.56)*	SL
4 years	1.48 *(0.05)*	1.44 *(0.42)*	46.85 *(3.44)*	14.31 *(0.81)*	38.84 *(3.66)*	SC
28 years	1.50 *(0.06)*	5.05 *(1.08)*	69.72 *(2.92)*	13.25 *(0.91)*	17.03 *(2.11)*	SL
35 years	1.50 *(0.08)*	2.49 *(1.00)*	69.58 *(1.96)*	9.78 *(1.04)*	20.64 *(1.05)*	SCL
54 years	1.61 *(0.09)*	1.69 *(0.44)*	66.47 *(2.79)*	11.39 *(1.44)*	22.14 *(1.50)*	SCL
Undisturbed 1	1.42 *(0.06)*	0.65 *(0.22)*	51.81 *(3.89)*	12.67 *(0.95)*	35.52 *(4.02)*	SCL
Undisturbed 2	1.65 *(0.04)*	0.61 *(0.19)*	72.20 *(0.71)*	9.48 *(0.64)*	18.32 *(0.43)*	SL

[§] Textural Class codes: SL = Sandy Loam; SC = Sandy Clay; SCL = Sandy Clay Loam


A
% Cover: 2010
0
20
40
60
80
100
3.33
6.00
6.33
5.67
8.67
11.0
9.00
<1
4
28
35
54
U1
U2
Bare & Litter
Grass
Forb
Shrub
Weed
B
% Cover: 2011
5.33
5.33
5.00
3.33
6.33
7.67
7.33
C
Root Biomass: 2010
(mg × cm−3)
0
5
10
15
20
25
30
Herbaceous Biomass: 2010
(g × m−2)
0
10
20
30
40
50
60
Root Biomass
Herbaceous Biomass
D
Root Biomass: 2011
Herbaceous Biomass: 2011