Sample Size Analyses for Soil Moisture and Root Biomass in Knuthsen Meadow, Carmen Valley, Sierra Nevada Mountains, California
July 22-26, 2002

Anne Senter extracting soil core from Knuthsen Meadow

Abstract

In the effort to determine if hydrologic restoration in Knuthsen Meadow affects root abundance and soil moisture, we gathered preliminary data to determine the optimal experimental design and sample size necessary to detect a 25% increase in root biomass and soil moisture following restoration. We found high variability in root biomass, with upstream meadow reaches having substantially greater variability than downstream meadow reaches. As a result, we recommend studying the effect of meadow restoration on root biomass separately in different meadow reaches. For examination of the effects of reach and restoration (between year effects) on soil moisture, a two-factor mixed model analysis with $n = 8$ would provide power greater than 80% for all hypotheses.

Introduction

The hydroperiod of Carmen Valley, California has been shortened by head cutting of the stream channel initiated by the construction of a rail line early in the 1900's. The deepened stream channel that resulted from head cutting lead to more rapid drainage of the meadow after the annual snowmelt, and to the conversion of Carmen Valley from a series of wet meadows to drier meadows and sagebrush. Hydrologic restoration was completed in the Knuthsen Meadows section of Carmen Valley in late summer, 2001. A twelve-foot deep head-cut stream channel was eradicated and replaced by a series of ponds and earthen plugs that were designed to send overflow, winter-melt water directly onto the meadow in spring and early summer, and to provide a series of perennial catchment ponds throughout the meadow. In the effort to design a monitoring program to determine if, over time, the restoration will increase soil moisture and the biomass of plant roots, we gathered data on the abundance of plants roots and soil moisture by extracting soil cores within various plant communities.

Field Methods

We anticipated that the effects of the restoration in re-hydrating the meadow might display a spatial and temporal pattern in which regions of the meadow further downstream or away from the ponds might re-hydrate to a lesser extent and more slowly than up stream regions. In light of such potential spatial and temporal patterns of re-hydration, we collected preliminary data using two sampling methods. We divided the meadow into four reaches. In the upper wettest reach, Reach 1, the predominant plants were hydrophilic sedges, grasses, and willows, with a few patches of sage on higher ground. In the middle reach, Reach 2, the willows thinned out, grasses became drier, and sage more abundant. Grasses were also dry in the lower reach, Reach 3, with sage, willows, and conifers present. Reach 4 was driest and lowest in elevation, and was not sampled in this analysis.

Anticipating that increased soil moisture and root biomass might first be detected in the spillways from the constructed ponds, we first adapted a method from the Eastern Sierra Nevada Riparian Field Guide (1999). At each of two ponds within Reach 1, we dug two soil samples using a spade shovel, sampling randomly in the middle of the main outflow channel of each pond between one and ten meters from its edge. We also sampled at each pond five meters upstream from the initial site, parallel to the pond shore. From each sample we took a small volume of soil from the greatest depth to estimate soil moisture levels. We estimated percent moisture content gravimetrically by weighing, drying overnight at 60^{o} C, and weighing again.

The following day we collected four soil cores by randomly selecting two sample sites along established monitoring-well transect lines within Reaches 1 and 3. While the samples were all extracted within 50 meters of the new pond and plug hydro-system, Reach 3 was much drier than Reach 1. Samples were weighed before the separation of roots from soil. We used a crude method of sifting the samples through a mesh screen, which allowed most of the dirt to be removed from the roots and not too many roots to be lost. The roots were weighed, dried overnight at 60^{o} C, and weighed again.

Mike Kunz supplying the muscle to obtain a soil core

Sample Size Analyses

Soil Moisture –We used the paired observations on soil moisture from the two spillways to calculate the sample size necessary to detect a difference in soil moisture of 25% with

$\alpha = 0.05$, and $\beta = 0.2$. We also treated these observations as independent and calculated the necessary sample size under the same conditions. These sample size analyses were conducted using the program PS (Dupont and Plummer 1997). Finally, we conjectured that a sampling program might involve a broader program of monitoring soil moisture throughout the meadow in which a fixed set of sampling stations would be established. We examined the sample size necessary to detect differences in soil moisture between different upstream and downstream meadow reaches, between years, and an interaction between year and reach. The conjectured patterns of mean soil moisture are presented in Table 1. These means are based on our observed mean percent soil moisture of 13% in Reach 1, and the conjecture that soil moisture decreases by 25% between each reach within each year. We conjecture that the effects of the restoration as percentage increase in soil moisture between years will be greater in the upper reaches of the meadow than in the lower reaches. This conjecture is based on the observation that current levels of soil moisture are higher in the upper reaches. We hypothesized that the effects of the restoration would be to increase the soil moisture between years by 50% for Reach 1, 35% for Reach 2, 25% for Reach 3, and 15% for Reach 4. Sample size analyses were conducted for this pattern of means, assuming that the correlations within reaches, but between years, would either be $r = 0.2$ or $r = 0.4$ (Table 2). The sample size analysis for this two-factor within-subjects experimental design was conducted using the program PASS (Hintze 2001).

Table 1. Conjectured pattern of means for two-factor within-subjects sample size analysis.

	Reach 1	Reach 2	Reach 3	Reach 4
Year 1	13	9.5	7.3125	5.484
Year 2	19.5	12.925	9.1406	6.3066

Table 2. Variance-Covariance matrix for sample size analysis. Standard deviations on main diagonal and alternative correlations on off diagonal.

0.3187	0.2 (0.4)
0.2 (0.4)	3.187

Biomass of Plant Roots – Because our estimates of variability in root biomass differed by 60 fold, we conducted separate sample size analyses, one for the site along well transect at Reach 1, and one for the site along well transect at Reach 3. Analyses were conducted using the program PS (Dupont and Plummer 1997).

Results

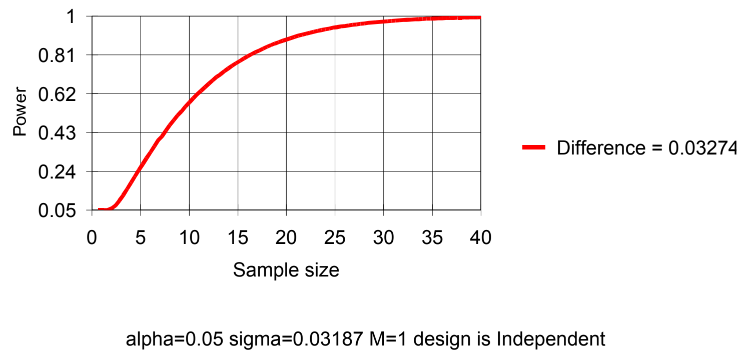
Soil Moisture – The observed values of soil moisture are reported in Table 3. Assuming that our estimates of variability in soil moisture are independent, Figure 1 illustrates that the sample size necessary to detect a 25% increase in soil moisture with Power = 80% is approximately $n = 15$ samples per year. Based on the paired observations that we collected, the sample size necessary to detect a 25% increase in soil moisture in spillways would have been greater than 300 samples.

Table 3. Soil Moisture data collected from Knuthsen Meadow, July 23-24, 2002.

Soil Moisture Analysis

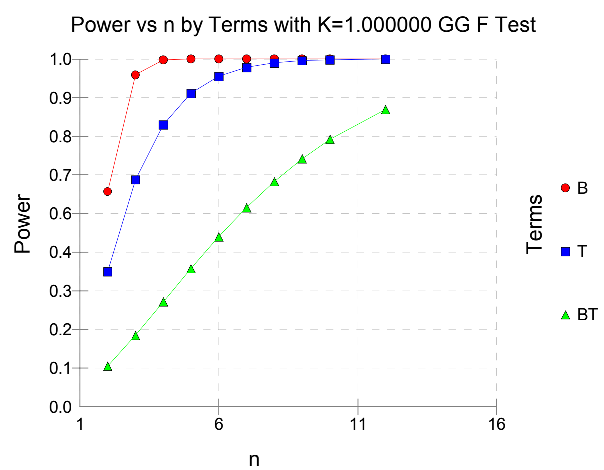
	Core Depth	Initial Wet Wt.	Final Dry Wt.	Moisture Content	% Moisture
	(inches)	(grams)	(grams)	(grams)	
Spillway 1	12.5	22.1	19.1	3.0	13.6
Above spill 1	9.5	28.0	23.5	4.5	16.1
Spillway 2	15.0	33.2	28.5	4.7	14.2
Above spill 2	12.0	25.6	23.4	2.2	8.6

Figure 1. Sample size analysis based on preliminary data for soil moisture. Calculations assume that observations are independent and that we wish to detect an increase in soil moisture of 25%.



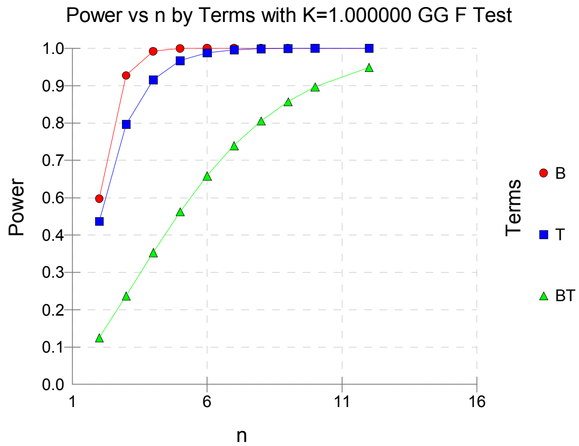
Examination of the two-factor within-subjects sample size analysis indicates that Power > 80% can be achieved with a sample size of $n = 6$ per reach relative to tests for differences between reaches and differences between years when the assumed correlation within subjects is 0.2. However, the power for the test of an interaction between reach and year is only 50% with $n = 6$ (Figure 2).

Figure 2. Sample size analysis for two-factor within-subjects design with $r = 0.2$. B – reach effect, T – effect of year, BT – interaction between reach and year.



However, if the actual correlation within sample sites between years is $r = 0.4$, then a sample size of $n = 6$ would yield a power of 65% for the test of the interaction of reach and year. Increasing sample size to $n = 8$ per reach would yield a power of 80% if $r = 0.4$ (Figure 3).

Figure 3. Sample size analysis for two-factor within-subjects design with $r = 0.4$. B – reach effect, T – effect of year, BT – Interaction between reach and year.



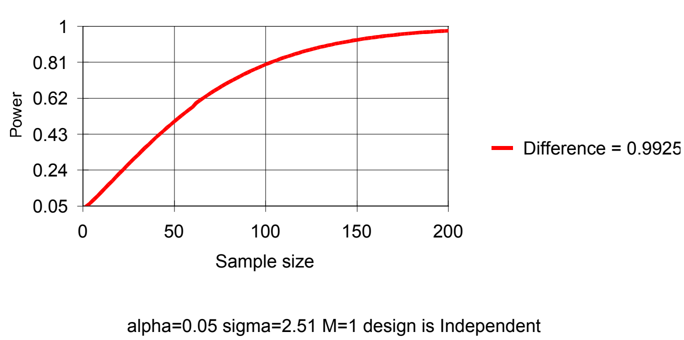
Biomass of Plant Roots - Our plant root biomass analysis yielded the data shown in Table 4. The estimated mean (standard deviation) of percent root biomass based on wet roots is 0.55% (0.04) for sites downstream in the meadow and 3.97% (2.51) for sites upstream in the meadow.

Table 4. Data on Biomass of Plant Roots Collected from Knuthsen Meadows, July 23-24, 2002

Location	Distance from pond (meters)	Core Weight (gms)	Root Wet Weight (gms)	Root Dry Weight (gms)	% Roots (Wet Weight)
Reach 1	19.75	337.10	7.40	5.50	2.20
Reach 1	37.64	297.30	17.10	13.90	5.75
Reach 3	18.50	343.40	1.80	1.70	0.52
Reach 3	24.46	328.20	1.90	1.70	0.58

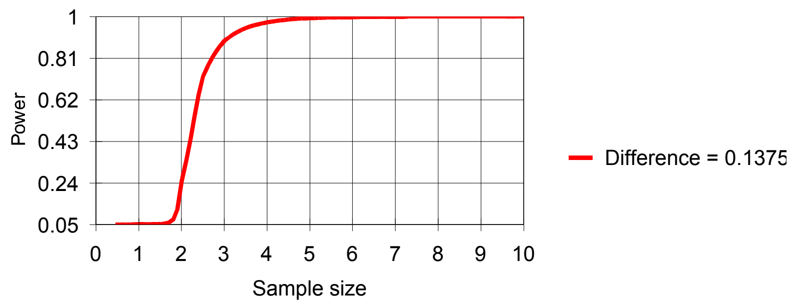
Because the variability in root biomass is so much greater for upstream sites in the meadow, the sample sizes necessary to detect a 25% increase in root biomass will be much greater than for downstream sites in the meadow. A sample size of $n = 100$ cores would be necessary to have 80% power to detect a 25% increase in root biomass (Figure 4).

Figure 4. Sample size analysis for root biomass using upstream sites in the meadow.



However, a sample size of $n = 3$ is all that is necessary to detect a 25% increase in root biomass at sites downstream in the meadow (Figure 5).

Figure 5. Sample size analysis for root biomass using downstream sites in the meadow.



alpha=0.05 sigma=0.04 M=1 design is Independent

Discussion

Sampling with a spade was an unsatisfactory method of obtaining a standardized soil sample to a constant depth. Furthermore, maintaining the stratification of the sample was very difficult since the spaded soil was often relatively dry and would crumble. Therefore, we recommend against attempting estimating rooting depth, root biomass, or soil moisture using a spade sample. The standard 6-inch corer provided a repeatable means of sampling to estimate rooting depth, root biomass, and soil moisture content. Our preliminary estimates were obtained with crude facilities for sieving, drying, and weighing samples. Presumably, variation caused by our sample acquisition and sample processing techniques could be reduced with more controlled procedures.

An analysis of the optimal sampling design to monitor the effects of meadow restoration on patterns of soil moisture and plant root biomass should be based on more information about the existing spatial patterns within the meadow and a more informed view of how those patterns might be expected to change after the restoration. We conjectured that increases in soil moisture might be seen initially in the spillways from the ponds. However, our estimate of soil moisture content was lower in one spillway than in adjacent pond-side habitat. We did detect a strong up-stream-downstream gradient in soil moisture and root biomass, with higher soil moisture and root biomass in the upstream reaches.

In any event, our sample size analyses suggest that if we use sites further down-meadow that sample sizes of fewer than n = 10 samples per reach would be sufficient to detect a 25% increase in soil moisture and root biomass between years. While we have no information on the expected time course to re-hydrate the meadow, year-to-year variability in rain and snow could delay this process. Therefore, it may be necessary to monitor soil moisture or root biomass for several years to detect effects due to the restoration of at least as great as a 25% increase in soil moisture and root biomass.

Literature Cited

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