U.S. Department of the Interior

National Park Service

Inventory and Monitoring Program

Northern Colorado Plateau Network
Integrated Upland Monitoring

Dinosaur National Monument

Variance and Power-for-trend Assessment of 2009-2011 Pilot Data

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April 2012

Abstract

Power analysis provides an a priori understanding of the ability and confidence to estimate the condition (i.e., status) of a resource and detect trends in that resource over time. This report describes the power analysis conducted by the Northern Colorado Plateau Network to identify an "affordable" sample size that optimizes tradeoffs between trend and status estimation and overall operational reality for its integrated upland monitoring protocol at Dinosaur National Monument (NM). Forty plots were monitored at Dinosaur NM for three consecutive years. Key response measurements for (1) detecting shifts in vegetation and (2) understanding the susceptibility of soil to wind and water erosion were used in this analysis. For each key response in sagebrush and pinyon-juniper vegetation types, we estimated the variance using linear mixed-effects models. We also examined power and precision of standard error of status for four alternative revisit designs and five sample sizes, as well as for the ability to detect different amounts of annual trend. The recommended revisit design for Dinosaur NM samples big sagebrush (*Artemisia tridentata*) and pinyon-juniper (*Pinus edulis* and *Juniperus osteosperma*) plots for one or two years in a row and rests plots for 3-4 years. A total of 36 plots are sampled each year, with twelve plots sampled in each of the priority vegetation types (high elevation big sagebrush, low elevation big sagebrush, and pinyon-juniper). Graphs of power for trend are presented in Appendix A.

Acknowledgements

Many thanks to Billy Schweiger, quantitative ecologist for the Rocky Mountain Network, and Amy Symstad, U. S. Geological Survey Ecologist working with the Northern Great Plains Network, for sharing drafts of their variance and power-for-trend assessments and allowing me to adapt their work for the Northern Colorado Plateau Network. I also would like to thank Dusty Perkins and Joel Brumm for their thoughtful reviews.

1 Introduction

The Northern Colorado Plateau Inventory and Monitoring Network (NCPN) implemented upland monitoring at Dinosaur NM during the 2009 field season. Upland monitoring was initiated as a three-year pilot study to estimate the variance for responses used to monitor vital signs. The power analysis described in this report used variance from the pilot study to evaluate the appropriateness of proposed split-panel revisit designs for detecting a trend and estimating the precision (or standard error) of status for long-term monitoring.

Power analysis provides an *a priori* understanding of the ability and confidence with which one can estimate the condition (i.e., status) of an extensive and variable resource and detect trends in that resource over time (Gerrodette 1987). Statistical power is the ability to detect an effect, given that the effect actually exists (i.e., the probability of *not* making a Type-II error of failing to detect a real trend). This report describes the power analysis conducted by the NCPN to identify an 'affordable' sample size that optimizes tradeoffs between trend and status estimation and overall operational reality by allocating the sample size into alternative revisit designs and determining the maximum number of vegetation types that this sample can be divided.

2 Survey design

2.1 Sampling frame

Survey designs use explicitly mapped areas as the sampling frame. For Dinosaur NM, we focused on soil map units in the Dinosaur National Monument Soil Survey (USDA NRCS 2007) that contained big sagebrush and pinyon-juniper (PJ) ecological sites. Ecological sites provide an effective way to stratify upland ecosystems by taking into consideration soil geomorphology, landform, and climate, in addition to vegetation characteristics. All big sagebrush ecological sites were included (rather than 2 or 3 specific site types) because additional work remains to remedy differences between the ecological sites used in Utah and the old range sites used in Colorado, and it is expected that some similar ecological/range sites from each state may be combined in the future. Although pinyon-juniper is currently not differentiated by ecological sites in the Dinosaur NM Soil Survey, it is well associated with specific soil map units.

A sampling frame was created using the soil map to predict the location of target vegetation types. Changes were made to specific polygons based on field assessments. The sampling frame delineated accessible big sagebrush (hereafter referred to as "sagebrush") and pinyon-juniper vegetation types in Dinosaur NM (Figure 2-1; Table 2-1). Sagebrush was sampled throughout the entire area of the monument and was additionally divided into grazed and ungrazed areas using the 2009 allotments, and high and low elevations that approximately delineated the ranges of Wyoming and mountain big sagebrush in the Uinta Basin. The pinyon-juniper sampling frame was limited to the southern central portion of the monument based on our assessment of affordable effort and priorities of management questions.

2.2 Site Selection

A membership design specifies how sites in a survey design are chosen across space (McDonald 2003). For Dinosaur NM, Reversed Randomized Quadrat-Recursive Raster (RRQRR) (Theobald et al. 2007) was used to select a spatially-balanced random sample that was then stratified by target vegetation type. In probability-based surveys, such as RRQRR, the site-selection process allows unbiased estimation of both status and, with repeated visits, trend (Larsen et al. 1995).

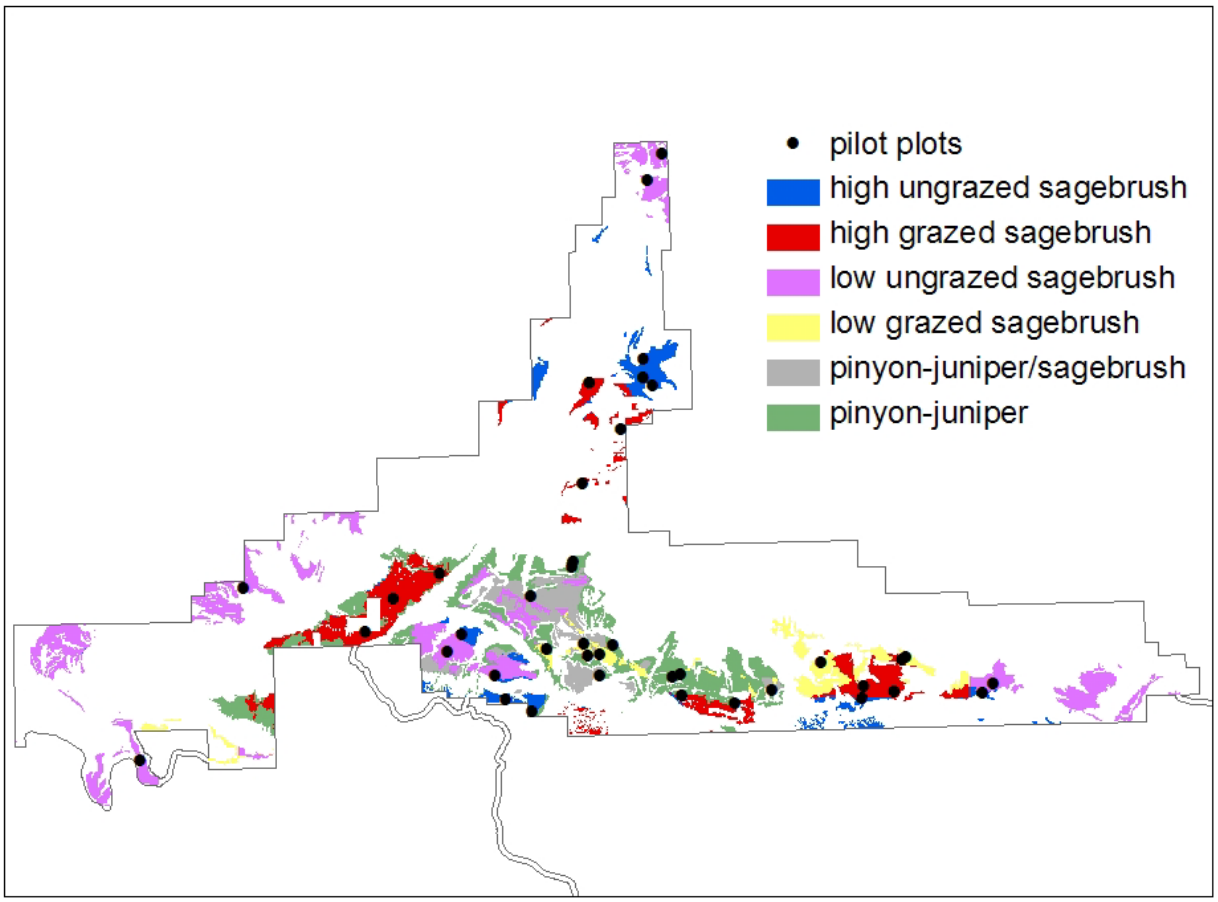

Figure 2-1. Sampling frame and location of pilot monitoring plots in Dinosaur National Monument.

Table 2-1. Area (ha) of each vegetation type included in the sampling frame for upland monitoring at Dinosaur National Monument.

Vegetation type	Elevation	Grazing	Area (ha)*
Mountain big sagebrush	High	Grazed	3328
		Ungrazed	1680
Wyoming big sagebrush	Low	Grazed	2111
		Ungrazed	5917
		Total big sagebrush	13035
		Total pinyon-juniper	6082
		Pinyon-juniper/sagebrush**	(1812)
Total sampling frame			17306

Numbers are approximate.

* Based on the accessible area within a 6 km hiking distance.

** The PJ/sagebrush area has already been included in the estimated areas for all of the sagebrush types and PJ.

2.3 Pilot study

Using the ordered lists of points produced by RRQRR, forty plots were established for Dinosaur NM pilot monitoring: 32 sagebrush and 8 pinyon-juniper plots. Sagebrush was further stratified by elevation and grazing so that there were 8 high elevation ungrazed, 8 high elevation grazed, 8 low elevation ungrazed, and 8 low elevation grazed plots. Thirty-five plots (32 sagebrush and 3 PJ) were established in 2009 and sampled for 3 consecutive years. The remaining 5 pinyon-juniper plots were established in 2010, and sampled for 2 consecutive years. Plots were sampled in September/October in 2009 and in June/July in 2010 and 2011. A broad sampling window was used to capture potential variation during the growing season. In addition, field-crew members visited different plots each year, when possible, to include the maximum amount of variation between observers. Plots were sampled according to the Integrated Upland Monitoring Protocol for Park Units in the Northern Colorado Plateau Network (Witwicki et al. draft).

Although 2-3 years of pilot data from 40 plots is a limited data set, it provides a starting point for creating a defensible long-term sampling design. Variance and power-for-trend assessments will be performed every 5-7 years in order to analyze the operational sampling design, ensure that monitoring goals are being met, and make changes to the design as needed.

2.4 Response variables

Response variables examined in this analysis were those with potentially important thresholds in the target vegetation types. Although threshold values have not been defined for the ecological sites used in this survey design, it is well understood, through conceptual models, that biological soil crusts (BSCs) are a critical component of many sagebrush systems, responsible for holding the soil in place and preventing erosion by wind or water. In addition, the cover of major plant functional groups can in many cases define ecological states.

Important response measurements for detecting shifts in vegetation include percent cover of (1) trees, (2) shrubs, and (3) perennial grasses. Shrub and perennial grass cover were analyzed for all

3 vegetation types, while tree cover was only considered important for pinyon-juniper. Key response measurements for understanding the susceptibility of soil to wind and water erosion include (4) BSC cover, (5) basal gap size, (6) canopy gap size, and (7) soil stability. All four of these measures were analyzed for sagebrush, and BSC cover and soil stability were included for pinyon-juniper.

2.5 Linear models and variance components

Using the seven response variables described above, we developed linear models to estimate variance following Larsen et al. (1995, 2001) and Urquhart and Kincaid (1999). Residual plots, histograms, and normal QQ (quantile quantile) plots were reviewed for each response to determine the need for data transformation. Natural-log transformation was used to improve model assumptions of normality and constant variance for all responses. Variance components in the model are shown in Table 2-2.

Analyses were performed in SAS 9.2 using Proc Mixed models. Year and site covariates were treated as random effects (Urquhart et al. 1998). To account for our unbalanced design (e.g., different numbers of revisit years for some plots), the restricted maximum likelihood (REML) approach was used to estimate variance and the Kenward-Roger method was used to calculate degrees of freedom (Spilke et al. 2005).

Because the sample size was relatively small, data from all sagebrush sites were combined for this analysis (see Table 2-3). This should provide a conservative estimate of power and standard error of status since we would expect variance within each elevation zone to be smaller than the variance for all sagebrush plots combined. For the two pinyon-juniper responses that had a year variance of 0 (see Table 2-3), year variance was substituted from the same response in sagebrush in order to give a more realistic estimate. It is more likely that SAS produced a year variance of 0 due to the unbalanced design and low sample size than actually having a year variance of 0. Thus, it is more conservative to use year variance from a similar response than to use the 0 generated by SAS. Variances were also examined after data were detrended, however, this altered the variances little and increased the number of responses with year variances of 0. Therefore, the original model was used to estimate variance.

Annual precipitation data from the Dinosaur NM Coop weather stations were examined to see if estimated variances from the 2009-2011 pilot study needed to be further inflated to be comparable with historic variability in annual precipitation. Variance of annual precipitation is typically calculated for (1) the three years of the pilot study (2009-2011), and (2) the history of the weather station (1966-2011 and 1915-2011). Unfortunately, annual precipitation data was not available at either weather station in 2009, thus, we were not able to make this comparison. However, variance of yearly precipitation for the history of a weather station is usually many times higher than the variance for the years of the pilot study, and this should be taken into consideration when selecting a revisit design.

Table 2-2. Variance components used in power analysis.

Component	Description
σ^2_{Site}	Variation among sites that is consistent across years (e.g., variation in vegetation cover or soil stability due to soil component)
σ^2_{Year}	Variation among years that affects all sites in the population (e.g., region-wide climatic variation)
$\sigma^2_{Residual}$	Variation specific to a site during a particular year, including measurement error (e.g., erosion occurs at a single site due to heavy cattle trampling of BSCs).

2.6 Affordable sample size

The NCPN has determined that the affordable annual sample size for upland monitoring is 36-48 plots per park for all large parks in the network (Black Canyon of the Gunnison National Park (NP)/Curecanti National Recreation Area, Canyonlands NP, Capitol Reef NP, Dinosaur NM, and Zion NP), 18-24 plots per park for medium-size parks (Arch and Bryce Canyon NPs) and 3-8 plots for our smaller parks (Cedar Breaks and Timpanogos NMs). This is based on an estimate of six field-crew members monitoring uplands full-time for 13 pay periods.

We estimated that the total annual sample size for Dinosaur NM is approximately 36 plots, since there is more travel time needed to get to remote areas of the park that were included in the sampling design. We used an affordable sampling size of 12 plots per year per vegetation type for the purpose of evaluating alternative split panel designs (see Figure 3-1). One of the designs was used to evaluate the effect of using different sample sizes (see Figure 3-2).

Table 2-3. Site, year, and residual variance estimates for responses in sagebrush and pinyon-juniper pilot plots at Dinosaur NM.

Vegetation type	Response	Variance		
		site	year	residual
Sagebrush	Shrub cover	0.99690	0.00233	0.03309
	Perennial grass cover	0.58680	0.01247	0.05702
	BSC cover	0.30780	0.00568	0.05214
	Basal gap size	0.40960	0.00353	0.02794
	Canopy gap size	0.21370	0.00606	0.01238
	Soil stability	0.01721	0.00110	0.00707
Pinyon-juniper	Tree cover	0.02691	0.01597	0.00332
	Shrub cover	0.54990	0	0.09544
	Perennial grass cover	0.70070	0.04700	0.10150
	BSC cover	0.04690	0	0.02142
	Soil stability	0.02458	0.00102	0.00216

3 Panel Designs

A serious concern of sampling semiarid upland vegetation and soils is that sites may become fatigued if sampled too often. The most likely scenario of site fatigue at Dinosaur NM is increased soil loss caused by repeated trampling of BSCs in sagebrush monitoring plots. Our goal is to disturb plots as little as possible and to avoid monitoring the effects of our presence at plots as much as possible. As such, designs that revisit the same sites each year were not considered at semiarid sites for upland monitoring. Instead, we investigated split-panel designs that rest plots for 3 to 7 years between revisits.

In order to understand year-to-year variation of shrub and perennial grass cover, we needed a design that sampled some sites two years in a row. A preliminary analysis determined that split-panel designs, like those in Figure 3-1, provided better precision of status and higher power to detect trend in early years by allocating more plots to panels that were visited for only 1 consecutive year (e.g., panels 6 through 10 in Design 1) than to panels where plots were visited for two consecutive years (e.g., panels 1 through 5 in Design 1). Therefore, all four designs analyzed in this power analysis are structured in this way. Design 1 was used to examine the effect of different sample sizes (Figure 3-2) and annual trends.

As per MacDonald (2003), the numerical notation of a panel design indicates the number of consecutive years of sampling followed by the number of consecutive years of rest for plots in each type of panel. For example, Design 1, notated as (2-3),(1-4), calls for 2 consecutive years of sampling followed by 3 consecutive years of rest for plots in panels 1–5, and 1 year of sampling followed by 4 years of rest for plots in panels 6–10.

Design 1 (2-3),(1-4) 45 unique plots, 12 plots per vegetation type per year

Panel↓/Year→	1	2	3	4	5	6	7	8	9	10
1	3	3				3	3			
2		3	3				3	3		
3			3	3				3	3	
4				3	3				3	3
5	3				3	3				3
6	6					6				
7		6					6			
8			6					6		
9				6					6	
10					6					6

Design 2 (2-5),(1-6) 63 unique plots, 12 plots per vegetation type per year

Panel↓/Year→	1	2	3	4	5	6	7	8	9	10
1	3	3						3	3	
2		3	3						3	3
3			3	3						3
4				3	3					
5					3	3				
6						3	3			
7	3						3	3		
8	6							6		
9		6							6	
10			6							6
11				6						
12					6					
13						6				
14							6			

Design 3 (2-7),(1-8) 81 unique plots, 12 plots per vegetation type per year

Panel↓/Year→	1	2	3	4	5	6	7	8	9	10
1	3	3								3
2		3	3							
3			3	3						
4				3	3					
5					3	3				
6						3	3			
7							3	3		
8								3	3	
9	3								3	3
10	6									6
11		6								
12			6							
13				6						
14					6					
15						6				
16							6			
17								6		
18									6	

Design 4 (2-7),(1-2) 45 unique plots, 12 plots per vegetation type per year

Panel↓/Year→	1	2	3	4	5	6	7	8	9	10
1	3	3								3
2		3	3							
3			3	3						
4				3	3					
5					3	3				
6						3	3			
7							3	3		
8								3	3	
9	3								3	3
10	6			6			6			6
11		6			6			6		
12			6			6			6	

Figure 3-1. Split-panel designs tested in power analysis.

Design 1a (2-3),(1-4) 30 unique plots, 8 plots per vegetation type per year

Panel↓/Year→	1	2	3	4	5	6	7	8	9	10
1	2	2				2	2			
2		2	2				2	2		
3			2	2				2	2	
4				2	2				2	2
5	2				2	2				2
6	4					4				
7		4					4			
8			4					4		
9				4					4	
10					4					4

Design 1b (2-3),(1-4) 45 unique plots, 12 plots per vegetation type per year

Panel↓/Year→	1	2	3	4	5	6	7	8	9	10
1	3	3				3	3			
2		3	3				3	3		
3			3	3				3	3	
4				3	3				3	3
5	3				3	3				3
6	6					6				
7		6					6			
8			6					6		
9				6					6	
10					6					6

Design 1c (2-3),(1-4) 70 unique plots, 18 plots per vegetation type per year

Panel↓/Year→	1	2	3	4	5	6	7	8	9	10
1	4	4				4	4			
2		4	4				4	4		
3			4	4				4	4	
4				4	4				4	4
5	4				4	4				4
6	10					10				
7		10					10			
8			10					10		
9				10					10	
10					10					10

Design 1d (2-3),(1-4) 90 unique plots, 24 plots per vegetation type per year

Panel↓/Year→	1	2	3	4	5	6	7	8	9	10
1	6	6				6	6			
2		6	6				6	6		
3			6	6				6	6	
4				6	6				6	6
5	6				6	6				6
6	12					12				
7		12					12			
8			12					12		
9				12					12	
10					12					12

Figure 3-2. Variations of Design 1 used to analyze sample sizes of 8, 12, 18, 24, and 32 plots per vegetation type per year.

Design 1e (2-3),(1-4) 120 unique plots, 32 plots per vegetation type per year

Panel↓/Year→	1	2	3	4	5	6	7	8	9	10
1	8	8				8	8			
2		8	8				8	8		
3			8	8				8	8	
4				8	8				8	8
5	8				8	8				8
6	16					16				
7		16					16			
8			16					16		
9				16					16	
10					16					16

Figure 3-2. Cont.'d

4 Analysis

4.1 Minimum Detectable Difference

The minimum detectable difference (MDD) is the annual rate of change in trend that a design can detect. For log-transformed responses, such as those described here, this equates to a proportional change or annual percent increase or decrease. A 5% annual decrease equates to a 39% total decrease over 10 years, or a decrease in perennial grass cover from 27.1% in 2009 to 16.4% in 2019. The annual rate is equivalent to the slope of the regression line in a linear model.

The minimum detectable difference for a trend should be ecologically relevant and can be determined using thresholds of ecological sites, if known. Because no threshold values have been determined for target ecological sites in Dinosaur NM, we attempted to determine ecologically meaningful annual increases or decreases for each response variable based on the pilot plot means and extremes, change over a 10-year period, and professional judgment (Table 4-1). Cover of BSC and vegetation types required at least 5% change per year for meaningful ecological changes to occur. Changes in all other soil-related variables were meaningful at a 2-5% annual rate of change.

Table 4-1. Summary of proposed minimum detectable differences (MDD) for each response in each vegetation type.

Vegetation type	Response	MDD (annual trend)	Mean (min – max)		Possible range
			Current status*	After 10 years**	
Sagebrush	Shrub cover	5-10% decrease	14.4% (0-37.3%)	8.7% (0-22.6%)	0-100%
	Perennial grass cover	5-10% decrease	27.1% (0-76.3%)	16.4% (0-46.3%)	0-100%
	BSC cover	5-10% decrease	29.3% (2.7-70.3%)	17.8 (1.6-42.6%)	0-100%
	Basal gap size	2-5% increase	106 cm (29-490 cm)	129 cm (35-598 cm)	0-5000 cm
	Canopy gap size	2-5% increase	74 cm (26-363 cm)	90 cm (32-443 cm)	0-5000 cm
	Soil stability	2-5% decrease	4.6 (2.4-5.8)	3.8 (2.0-4.7)	1-6
Pinyon-juniper	Tree cover	5-10% decrease	24.8% (14.0-34.3%)	15.0% (8.5-20.8%)	0-100%
	Shrub cover	10% decrease	3.4% (0-12.3%)	1.3% (0-4.5%)	0-100%
	Perennial grass cover	10% decrease	6.7% (0-18.0%)	2.5% (0-6.6%)	0-100%
	BSC cover	5-10% decrease	34.8% (16.7-48.3%)	21.1 (10.1-29.3%)	0-100%
	Soil stability	2-5% decrease	4.6 (3.1-5.7)	3.8 (2.5-4.7)	1-6

*Status for first 3 years of data (2009-2011)
**Calculation uses lowest value for each row in the MDD (annual trend) column

4.2 Estimating power for trend and precision of status

Power to detect a specified trend and precision of status were estimated using an unpublished function written by Tom Kincaid (US EPA, Corvallis, Oregon) for R. This function uses MDD, variance components, desired Type 1 error (alpha), the selected panel design, and two additional correlation values (site.rho = 1; year.rho = 0) set to these default values based on Urquhart et al. (1993). We set alpha = 0.10 and examined power for trend and standard error of status over a 20-year time frame. We used a less conservative alpha because we do not want to risk missing trends that may be important to park managers.

4.3 Effect of panel design

In Designs 1-4 (Figure 3-1), each response in each vegetation type was compared using an annual sample size of 12 and the appropriate MDD (Figures A1 and A2 in Appendix A). For nearly all responses (and especially those with high site variance), Designs 1 and 4 provided more power in early sampling years. In addition, design had little effect on standard error of status.

4.4 Effect of sampling size

Sample sizes of 8, 12, 18, 24, and 32 plots per year were compared for each response using Design 1 (see Figure 3-2) and the appropriate MDD. For most responses, all five sample sizes performed similarly and adding plots did not substantially improve power for trend (Figures A3 and A4 in Appendix A). Standard error of status was slightly higher in some responses with sample sizes of 8 and 12, especially in shrub and perennial grass cover. Higher standard error of status at low sample sizes appeared to correspond with higher site variances for responses.

4.5 Effect of annual trend

A range of annual trends (2%, 5%, 10%, and 20%) was compared for each response using Design 1 and an annual sample size of 12 (Figures A5 and A6 in Appendix A). Varying MDD did not affect the standard error of status, so these results are not presented. Except for perennial grass cover at PJ sites, 80% power was reached in 5 years for a 10% annual change, in 10 years for 5% annual change, and in 15 years for a 2% annual change. For some responses, 80% power was reached more rapidly than this.

4.6 Effect of response type

The variance of each response type, especially year variance, had the strongest influence on power for trend and standard error of status. For all responses, the low estimate of MDD could be detected in 5-10 years at 80% power.

4.7 Discussion

The differences between the split-panel designs tested were relatively minor, which was not surprising, given the similarity between the designs. Designs 1 and 4 performed best in early years, with Design 4 tending to have the highest power for trend in years 3 and 4 and Design 1 tending to have the highest power for trend in years 5, 6, and 7. Both designs performed similarly in subsequent years. Either of these designs would be appropriate for upland monitoring at Dinosaur NM.

The difference between annual sample sizes analyzed, ranging from 8 to 32, was also relatively small. We expect to gain power for trend and decrease standard error of status by increasing annual sample size, however, variance of each response, especially year variance, seemed to have an overriding influence for most sample sizes. In around half of the responses, a sample size of 8 had slightly higher standard error of status compared to the larger sample sizes. A couple of the responses showed a similar improvement by increasing the sample size from 12 to 18. For all responses, a sample size greater than 18 did not substantially improve power for trend or standard error of status.

Although we were not able to compare the variance of precipitation during the pilot study with variance of precipitation over the historic record of either Dinosaur NM Coop weather station, we would expect to see more variability in vegetation cover over long-term monitoring than we detected in this pilot study. Therefore, we should consider a more conservative revisit design to maximize our ability to detect trends with even more variable precipitation in future monitoring years.

High variance in the responses can also be caused by sampling at different times of the year. Total (live + dead) cover was used in this analysis to help minimize these differences since sampling occurred in October of 2009 and in mid-summer during the 2010 and 2011 field seasons. Dinosaur NM uplands will be sampled between early June and late July each year for long-term operational monitoring to minimize seasonal variability in plant phenology between sampling dates. This smaller sampling window should help reduce year variance and improve the power to detect trends in live plant cover data.

We think that the (2-3),(1-4) design (Design 1 in Figure 3-1) is the best option for sampling uplands at Dinosaur NM, and this design has been implemented in other NCPN park units for upland monitoring. This design ensures the best power for trend after year 4 and has a similar standard error of status to other designs.

When we are able to expand these analyses to include simulations and numerous additional years of data, we may see meaningful changes and need to alter the revisit design. While we do not expect this to happen, a key advantage of a RRQRR design is the ability to recast the panel membership of existing plots into new structures.

5 Proposed revisit design and revisions to sampling design

The proposed revisit design for integrated upland monitoring at Dinosaur NM is Design 1 (Figure 5-1). Twelve plots will be monitored each year in each of the following vegetation types: high elevation sagebrush, low elevation sagebrush, and pinyon-juniper. Since grazing allotments in the monument may change over time, these will not be included as strata in the long-term design. This allows for comparisons between grazed and ungrazed areas of the monument in future analyses, which is still a high priority of resource managers, but also allows more

flexibility in design of these analyses. Using this design, a different number of plots in each ecological site and in grazed and ungrazed areas will be monitored each year within a vegetation type, but these numbers should represent the area of each ecological site and grazing use across the landscape.

Another revision to the sampling design is the number of ecological sites that will be monitored. Originally, we decided to include all possible big sagebrush ecological sites since the Dinosaur NM Soil Survey left a mix of similar ecological sites from Utah and range sites from Colorado. After a large effort to visit potential upland plots across Dinosaur NM, we decided to limit our monitoring effort to the dominant big sagebrush ecological sites in the monument (Table 5-1). These include deep sandy loam, silt loam, and loam Wyoming and mountain big sagebrush sites. Shallow, rocky (gravelly or stony), clayey, or very sandy sites were the extreme conditions where big sagebrush communities existed in Dinosaur NM, but they were not common across the landscape and were excluded from the long-term monitoring design. In addition, all four-wing saltbush ecological sites were removed from the long-term sampling design. Although big sagebrush was a common species at some of the four-wing saltbush ecological sites that we visited, these sites are typically grassland sites and do not have the potential to be dominated by big sagebrush. These changes to the sampling design retained 62% of the sites accepted by the site clearing crew (see Table 5-1), and should provide more consistency and lower site variance.

An additional modification was the elimination of the East Cactus area from the long-term sampling design. Access to this area has been unreliable over the last few years due to uncooperative private landowners in the area.

The overall proposed design calls for the following:

- Sampling 36 upland monitoring plots per year using a rotating split-panel design.
- Establishing 135 plots over a five-year period.
- Allowing 3-4 years of rest at all sagebrush and pinyon-juniper plots to minimize the effects of repeated visits.
- Preferentially placing plots used in the three-year pilot study (2009-2011) in panels 4 and 10, to allow the maximum amount of rest after the initial three years of monitoring.
- Concentrating monitoring of remote areas of the monument to certain sampling years to maximize efficiency of travel time. Zenobia is sampled in years 2, 3, and 4, while all other outlying areas are sampled in years 1 and 5.

Park managers were given an outline of the design and an opportunity to provide feedback in March 2012. Full operational monitoring of uplands in Dinosaur NM will begin in June 2012.

Panel↓/Year→	1	2	3	4	5	6	7	8	9	10
1	3	3				3	3			
2		3	3				3	3		
3			3	3				3	3	
4				3	3				3	3
5	3				3	3				3
6	6					6				
7		6					6			
8			6					6		
9				6					6	
10					6					6

Figure 5-1. Proposed revisit design (2-3) (1-4) for upland monitoring of each vegetation type (high elevation big sagebrush, low elevation big sagebrush, and pinyon-juniper) at Dinosaur National Monument. This design monitors 45 unique plots in each vegetation type, with a total of 12 plots per vegetation type per year.

Table 5-1. Target Wyoming and mountain big sagebrush ecological sites for upland monitoring at Dinosaur National Monument.

Community type	Ecological site #	Ecological site name	Estimated area (ha)	% of total park unit area	# of plots accepted during site clearing	Target ecological site / Reason for exclusion from the sampling design
Wyoming big sagebrush	**R034XY298CO**	**Rolling Loam**	**4384.5**	**5.3**	**50**	**Target ecological sites**
	R034XY327CO	**Semidesert Loam**	**36.2**	**0.0**	**0**	
	R034XY212UT	**Semidesert Loam (Wyoming Big Sagebrush)**	**1041.1**	**1.3**	**23**	
	R034XY310CO	Sandy Foothills	113.0	0.1	2	Very sandy sites
	R034XY330CO	Sandyland	524.5	0.6	5	
	R034XB328CO	Semidesert Clay Loam	167.8	0.2	3	Clayey site
	R034XY206UT	Semidesert Gravelly Sandy Loam (Wyoming Big Sagebrush)	648.0	0.8	9	Gravelly site
	R034XY214UT	Semidesert Sand (Four-wing Saltbush)	613.2	0.7	1	Four-wing saltbush sites
	R034XY216UT	Semidesert Sandy Loam (Four-wing Saltbush)	1780.2	2.1	6	
	R034XB326CO	Semidesert Sandy Loam	493.9	0.6	10	
	R034XY225UT	Semidesert Shallow Loam (Wyoming Big Sagebrush)	233.0	0.3	5	Shallow site
Mountain big sagebrush	**R047XC430UT**	**Mountain Loam (Mountain Big Sagebrush)**	**3661.9**	**4.4**	**58**	**Target ecological site**
	R047XC446UT	Mountain Shallow Loam (Mountain Big Sagebrush)	862.5	1.0	6	Shallow site
	R047XY378CO	Mountain Stony Loam	240.3	0.3	0	Stony sites
	R047XC460UT	Mountain Stony Loam (Bitterbrush)	473.6	0.6	3	

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Appendix A
Power for Trend Figures

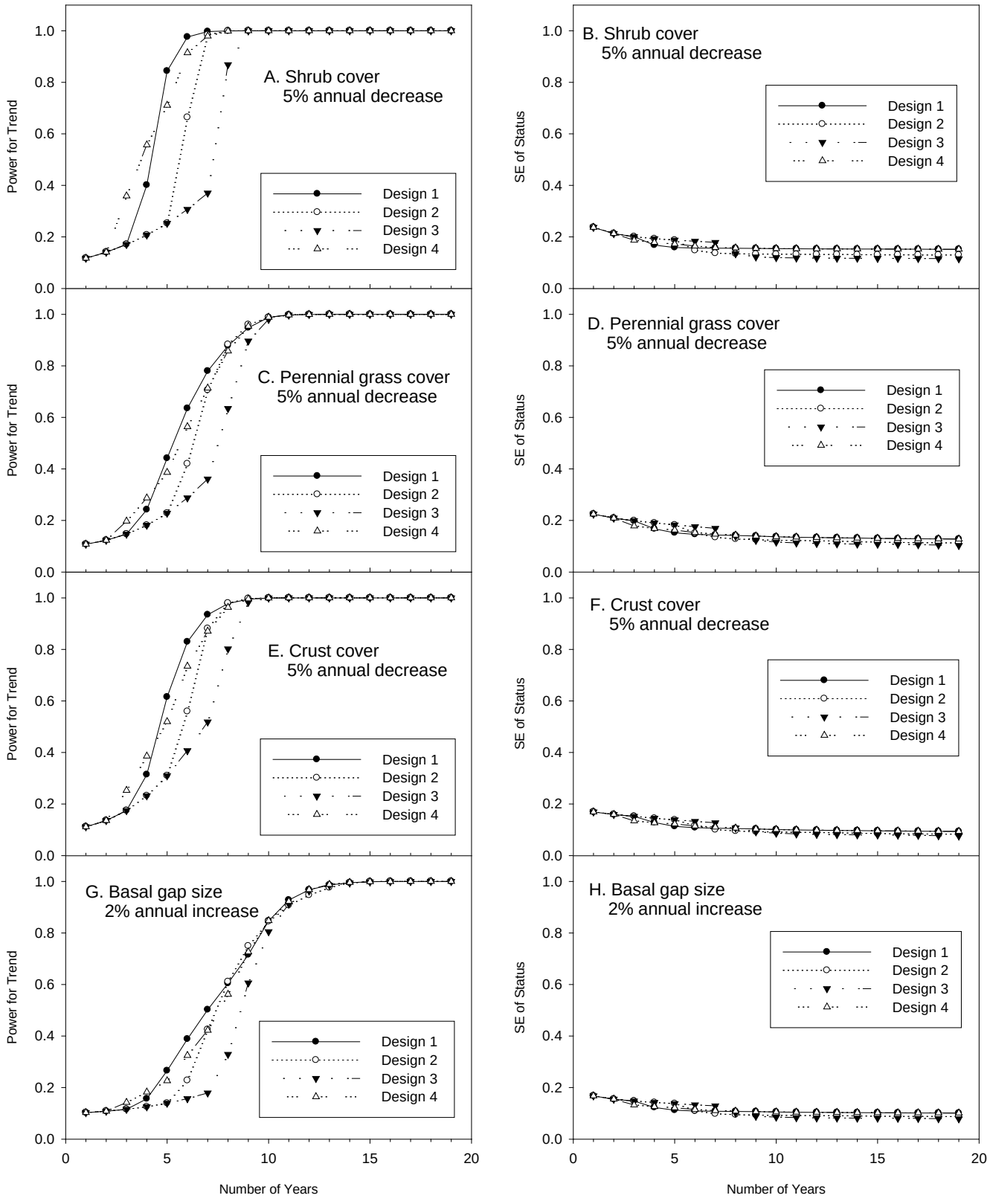


Figure A1. Power for trend and standard error (SE) of status for each sampling design (Figure 3-1) at all big sagebrush sites (annual sample size = 12). Responses include percent cover of shrubs, perennial grass, and biological soil crust cover, basal and canopy gap size, and soil stability.

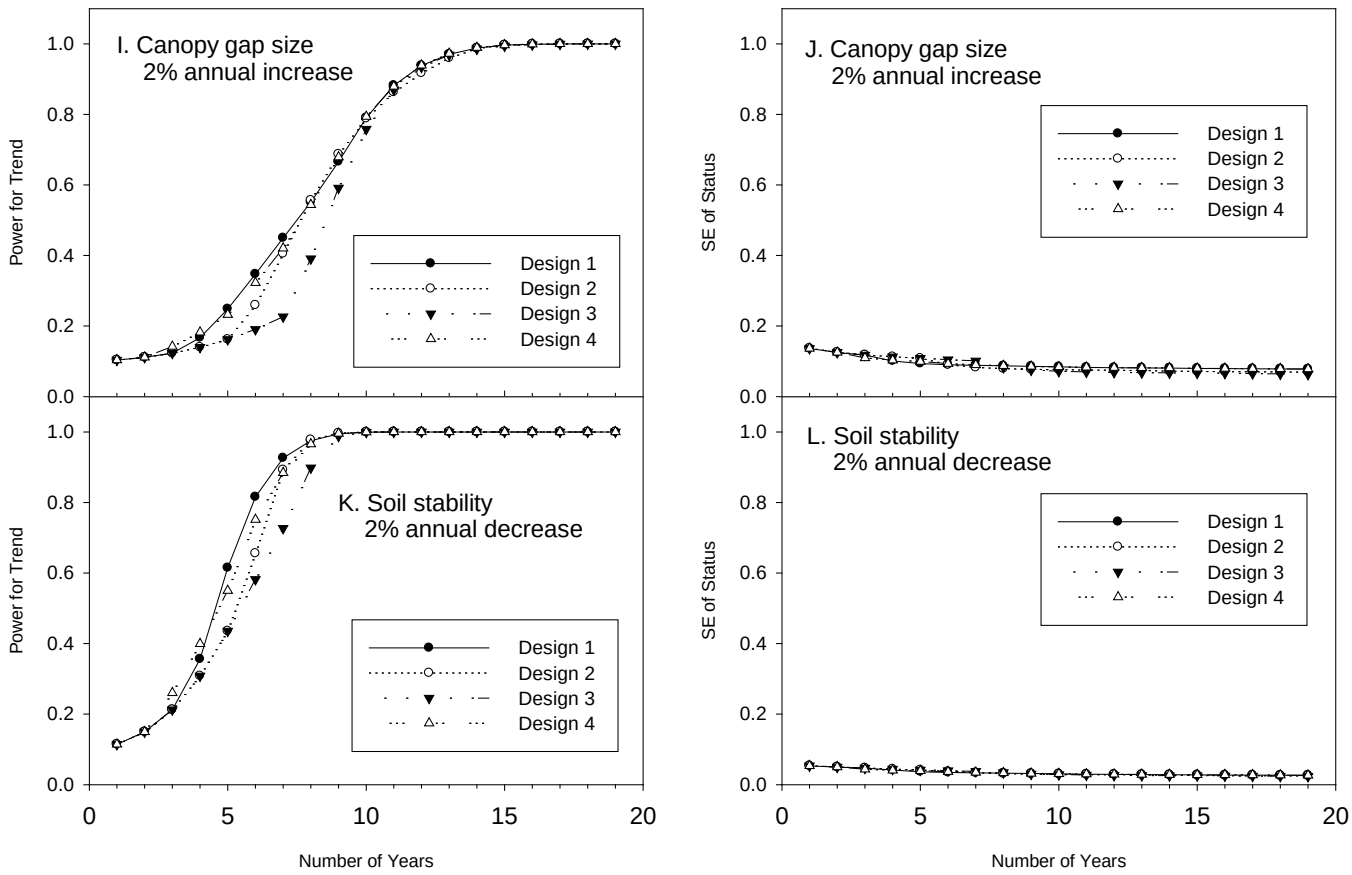


Figure A1. cont'd.

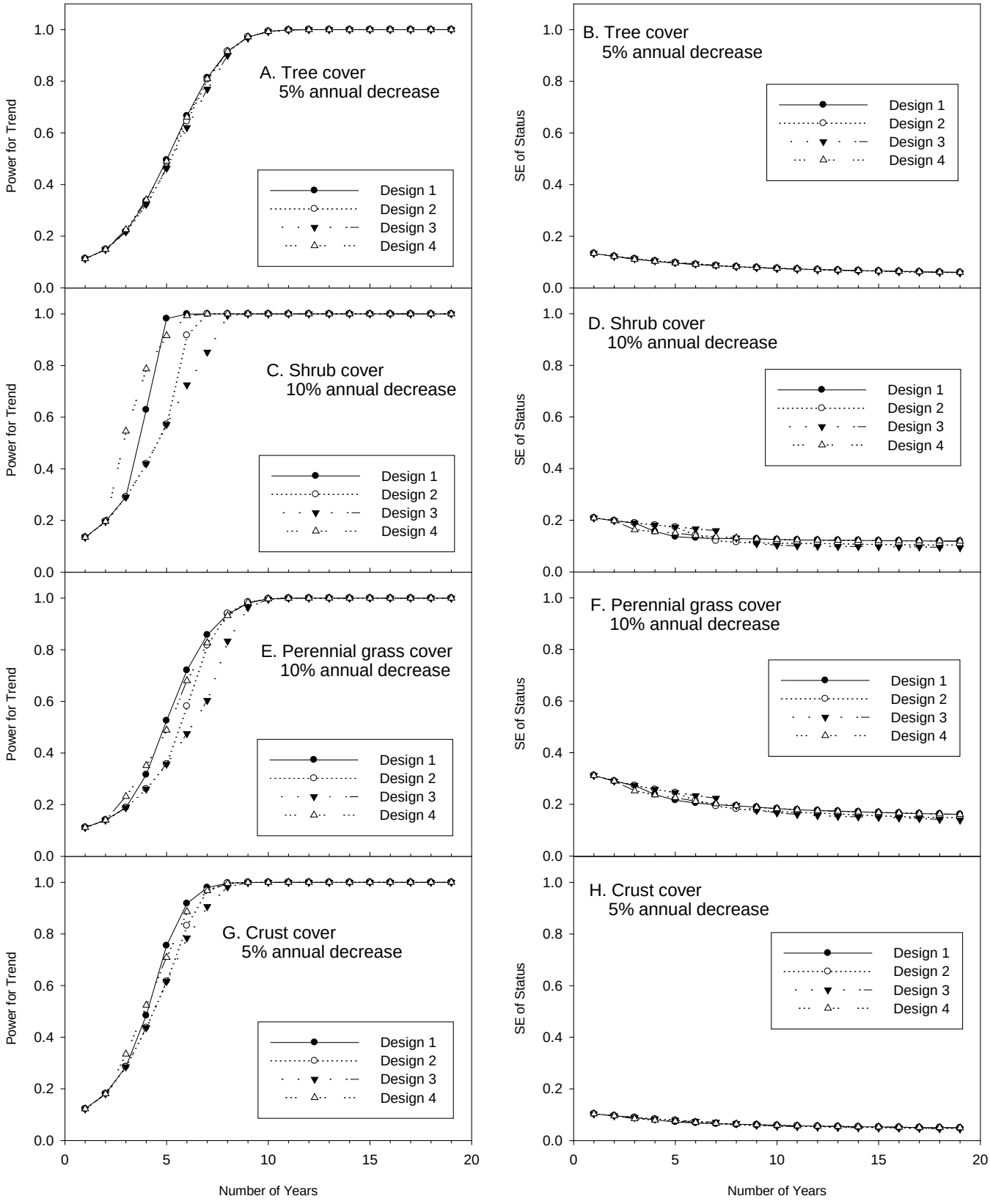


Figure A2. Power for trend and standard error of status for each sampling design (Figure 3-1) at all pinyon-juniper sites (annual sample size = 12). Responses include percent cover of trees, shrubs, perennial grass, and biological soil crust, and soil stability.

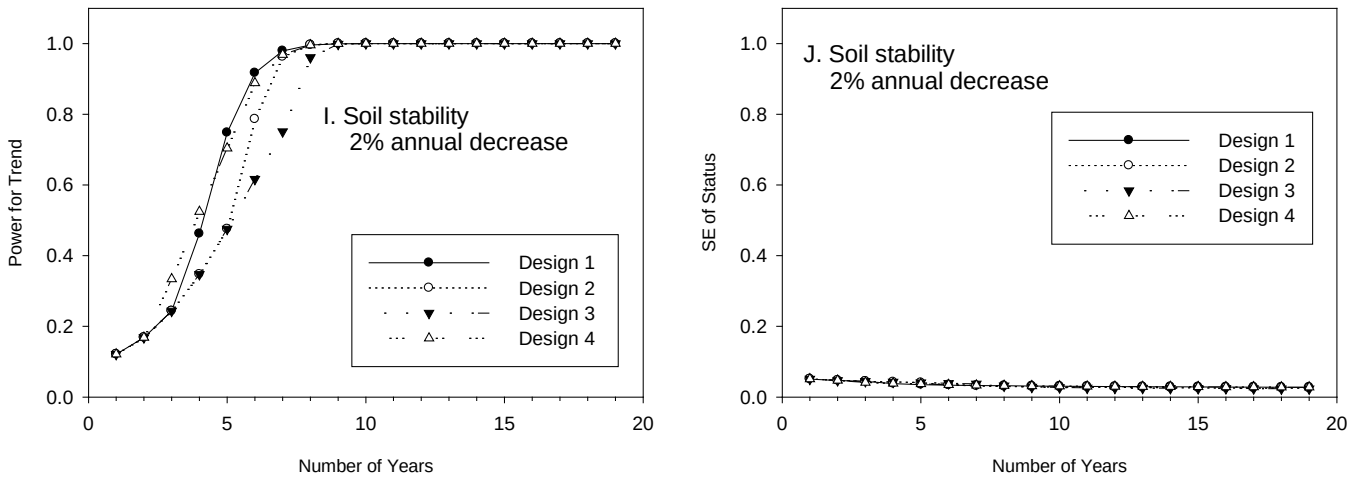


Figure A2. cont'd.

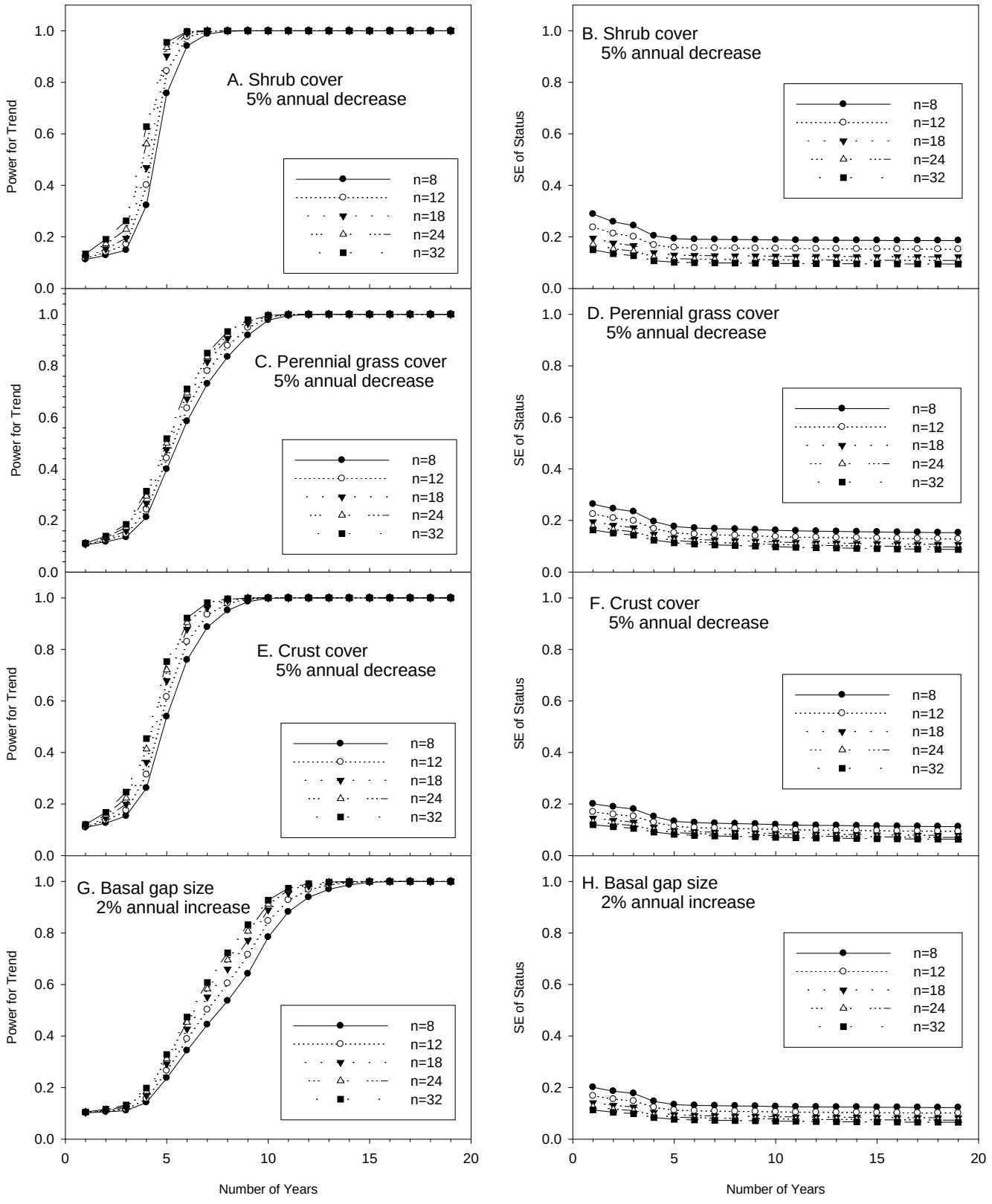


Figure A3. Power for trend and standard error of status for each response variable at all big sagebrush sites comparing annual sample sizes of 8, 12, 18, 24, and 32 plots per year using Design 1 (Figure 3-2). Responses include percent cover of shrubs, perennial grass, and biological soil crust, basal and canopy gap size, and soil stability.

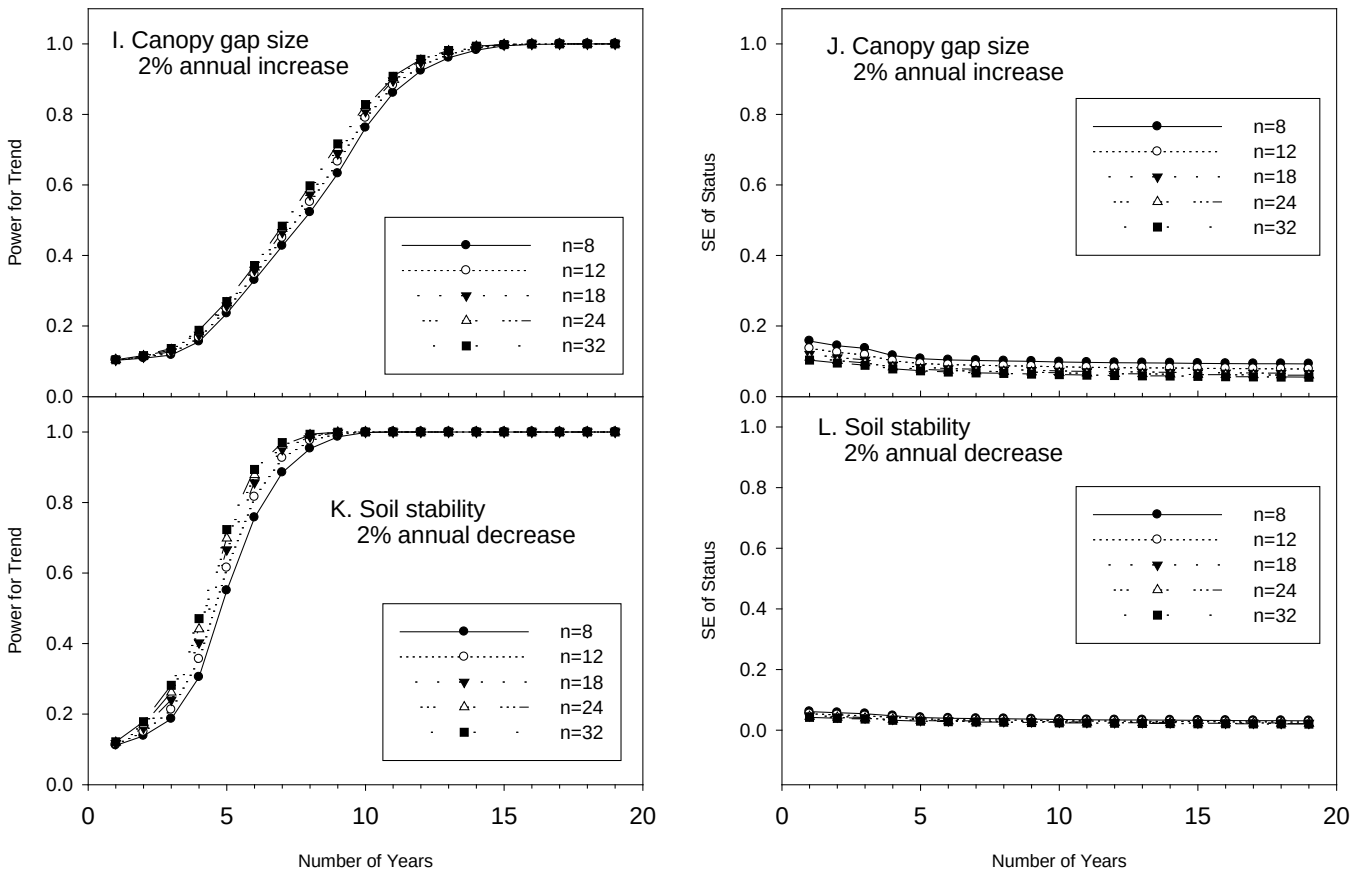


Figure A3. cont'd.

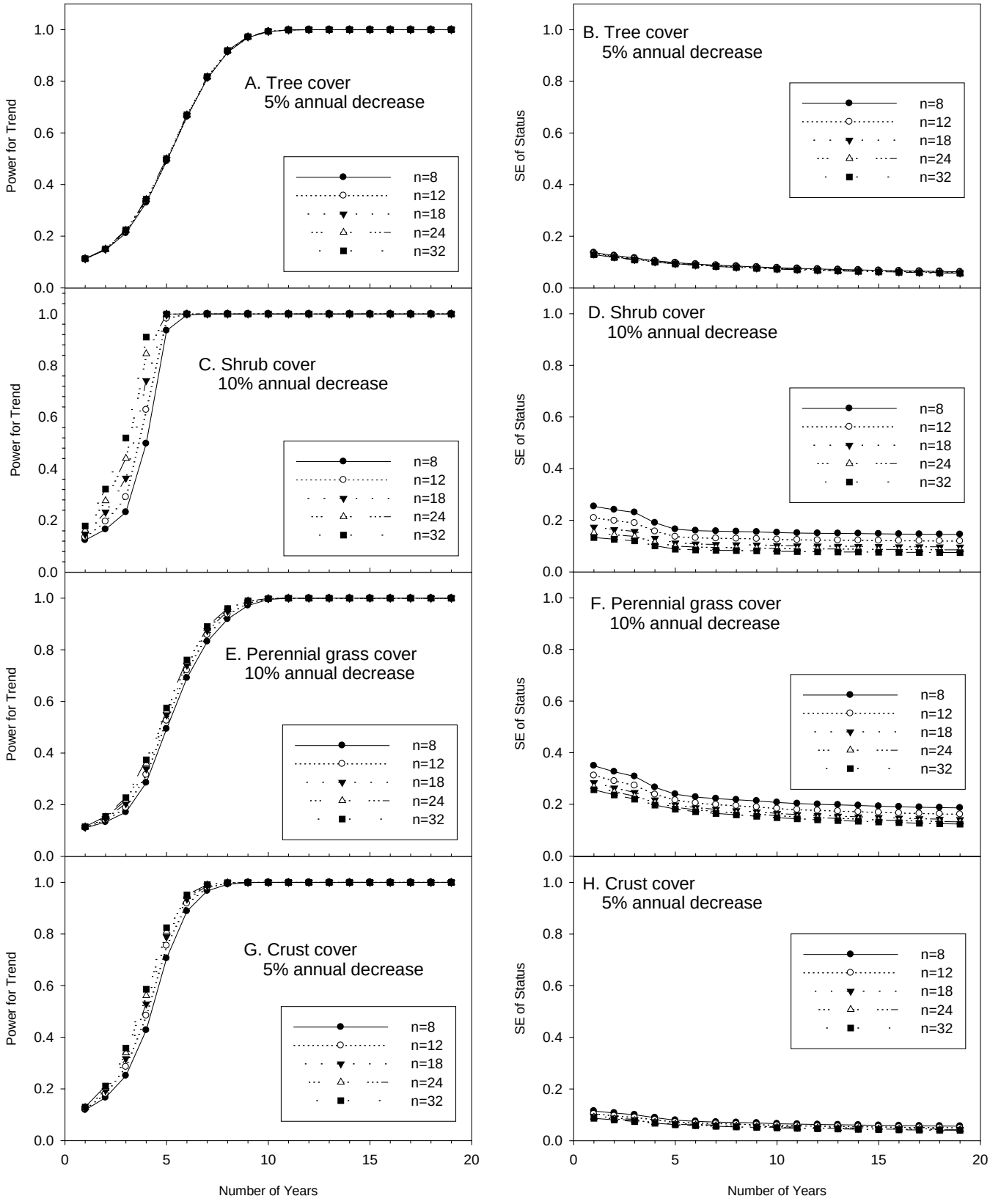
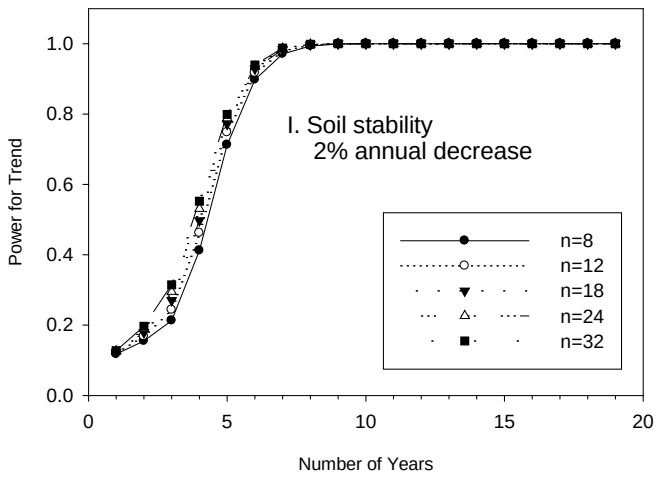


Figure A4. Power for trend and standard error of status for each response variable at all pinyon-juniper sites comparing annual sample sizes of 8, 12, 18, 24, and 32 plots per year using Design 1 (Figure 3-2). Responses include percent cover of trees, shrubs, and perennial grass, and soil stability.



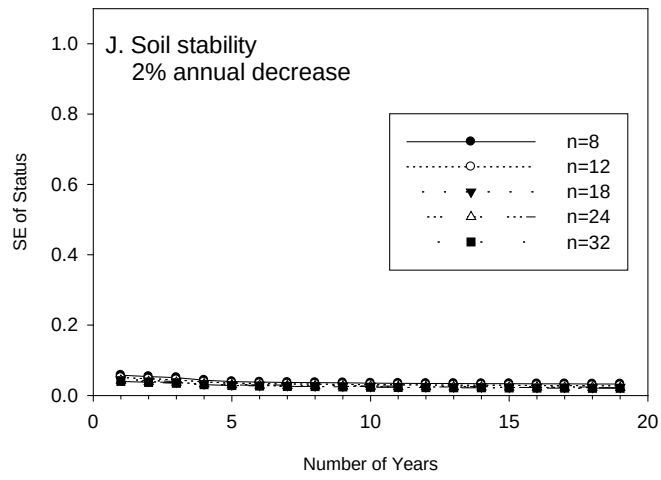


Figure A4. cont'd.

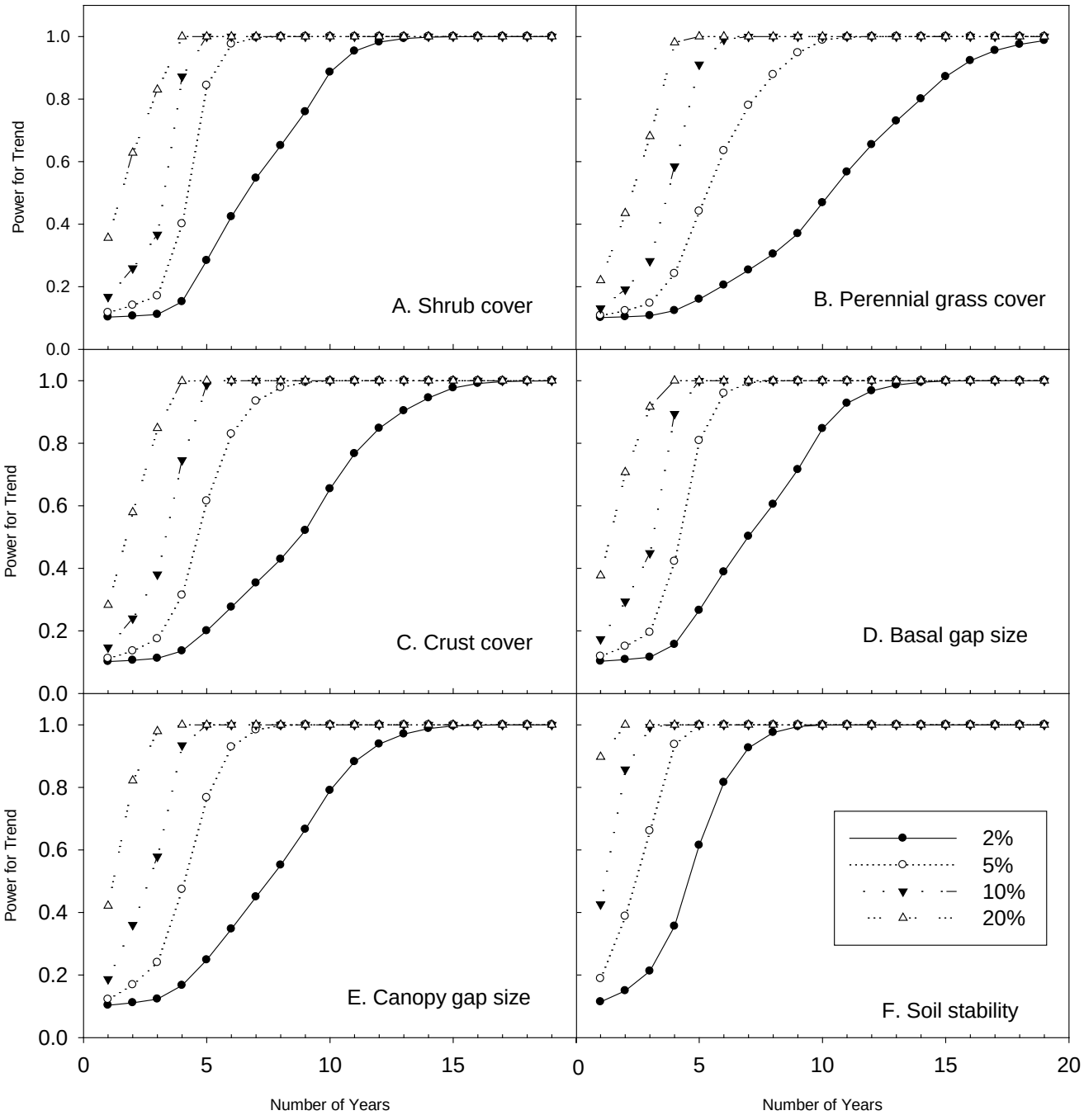


Figure A5. Power for trend for a range of annual increases or decreases in response variables at big sagebrush sites using Design 1 (Figure 3-1) and an annual sample size of 12. Responses include percent cover of shrubs, perennial grass, and biological soil crust, basal and canopy gap size, and soil stability.

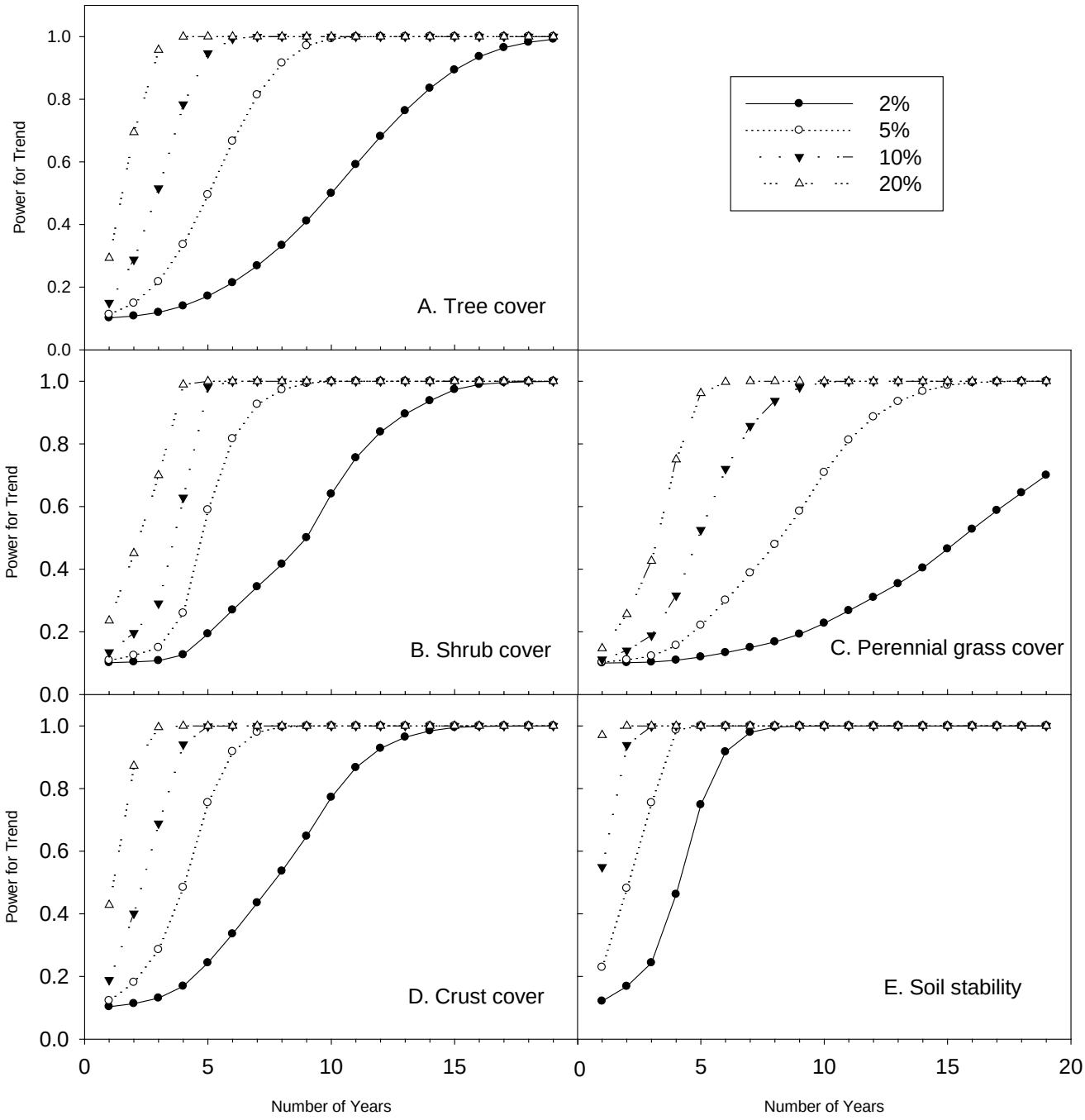


Figure A6. Power for trend for a range of annual decreases in response variables at pinyon-juniper sites using Design 1 (Figure 3-1) and an annual sample size of 12. Responses include percent cover of trees, shrubs, perennial grass, and biological soil crust, and soil stability.