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Northern Colorado Plateau Network
Integrated Upland Monitoring

Capitol Reef National Park

Variance and Power-for-trend Assessment of 2007-2009 Pilot Data

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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 Capitol Reef National Park (NP). Sixty-one plots were monitored at Capitol Reef NP for three consecutive years. Key response measurements for (1) understanding the susceptibility of soil to wind and water erosion and (2) detecting shifts in vegetation were used in this analysis. For each key response, we estimated the variance for all grassland ecological sites combined using linear mixed-effects models. We also examined power and precision of standard error of status for four alternative revisit designs and sample sizes, as well as for the ability to detect different amounts of annual trend. The recommended revisit design for Capitol Reef NP samples plots for one or two years in a row and rests plots for 3-4 years. A total of 48 plots are sampled each year, with 16 plots per year in each ecological site type/allotment combination. Graphs of power for trend are presented in Appendix A.

Acknowledgements

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1 Introduction

The Northern Colorado Plateau Inventory and Monitoring Network (NCPN) implemented upland monitoring at Capitol Reef National Park (CARE) during the 2007 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 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 Northern Colorado Plateau Network 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 ecological sites that this sample can be divided.

2 Survey design

2.1 Sampling frame

Survey designs use explicitly mapped areas as the sampling frame. For CARE, we used classification and regression tree (CART) modeling to map the target ecological sites used to stratify upland monitoring. Ecological sites provide an effective way to stratify arid upland ecosystems by taking into consideration soil geomorphology, landform, and climate, in addition to vegetation characteristics. CART used field reconnaissance points and spatial data layers to develop rules for where each ecological site occurred on the landscape. We then used these rules to characterize the entire area of interest (Garman et al. in review). Similar ecological sites were combined and mapped as two ecological site type groups (Figure 2-1). The resulting map included five grassland ecological sites that cover the greatest extent of accessible area in Cathedral, Rock Springs, and Hartnet allotments (Table 2-1).

2.2 Site Selection

A membership design specifies how sites in a survey design are chosen across space (McDonald 2003). For CARE, Reversed Randomized Quadrat-Recursive Raster (RRQRR) (Theobald et al. 2007) was used to select spatially-balanced random samples stratified by each target ecological site 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).

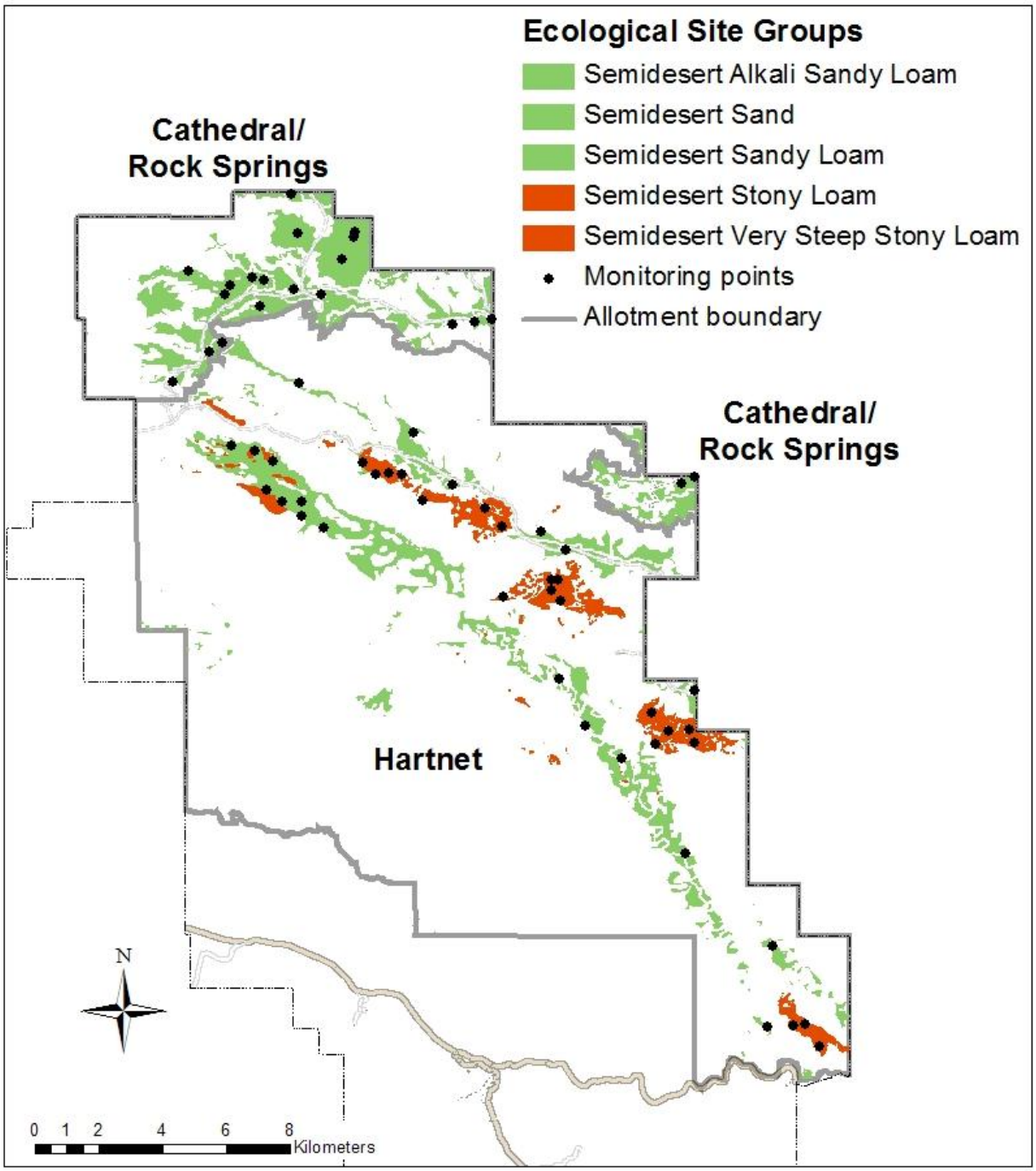

Figure 2-1. Ecological sites monitored in sampling frame for Capitol Reef NP pilot upland monitoring.

Table 2-1. Ecological sites in Capitol Reef NP pilot monitoring

			Total area* (ha)	
Ecological site type	**Ecological site #**	**Ecological site name**	**Cathedral/ Rock Springs**	**Hartnet**
deep grassland	201	Semidesert Alkali Sandy Loam (four-wing saltbush)	2206	2620
	212	Semidesert Sand (four-wing saltbush)		
	215	Semidesert Sandy Loam (four-wing saltbush)		
rocky grassland	242	Semidesert Stony Loam (shadscale)	na	1048
	260	Semidesert Very Steep Stony Loam (Salina wildrye)		

*Total accessible area of ecological site in each allotment.

2.3 Pilot study

Using the ordered lists of points produced by RRQRR, 10 plots were established in four of the five ecological sites for CARE pilot monitoring. Only one plot of Semidesert Sand ecological site was included in the pilot study because it had much lower areal extent than the other ecological sites. Nineteen plots were established in 2007, and sampled for 3 consecutive years. The remaining 42 plots were established in 2008, and sampled for 2 consecutive years. Plots were sampled between April and October each year. A broad sampling window was used to capture the maximum amount of 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 3 years of pilot data from 61 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 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 ecological sites. Although threshold values have not been defined for these ecological sites, it is well understood, through conceptual models, that biological soil crusts (BSCs) are a critical component of these systems, responsible for holding the soil in place and preventing erosion by wind or water. Four of the five target ecological sites are dominated by BSCs.

Key response measurements for understanding the susceptibility of soil to wind and water erosion include (1) basal gap size, (2) canopy gap size, (3) soil stability, (4) percent cover of BSC's, and (5) percent cover of bare soil. Important response measurements for detecting shifts in vegetation include percent cover of (6) shrubs and (7) perennial grasses.

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 five grassland ecological sites (Table 2-3) were combined for this analysis. This should provide a conservative estimate of power and standard error of status since we would expect variance within each ecological site type to be smaller than the variance for all sites combined. For the one response (crust cover) that had a year variance of 0, year variance was substituted from bare soil cover in order to give a more realistic estimate. 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 CARE Coop weather station were examined to see if estimated variances from the 2007-2009 pilot study needed to be further inflated to be comparable with historic variability in annual precipitation. Proc Mixed models in SAS were used to estimate variance of annual precipitation (1) for the three years of the pilot study (2007-2009), and (2) for the history of the weather station (1968-2009). Although variance of yearly precipitation from 2007-2009 was lower than for the history of the weather stations, no additional corrections to variances were made since the data varied so much already from sampling throughout the entire growing season.

Table 2-2. Variance components.

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 BSC's).

2.6 Affordable sample size

The NCPN has determined that the affordable annual sample size for upland monitoring is approximately 48 plots per park for all large parks in the network (Black Canyon of the Gunnison National Park and Curecanti National Recreation Area, Canyonlands National Park, CARE, Dinosaur National Monument, and Zion National Park), 24 plots per park for medium-size parks (Arch and Bryce Canyon national parks) and 3-8 plots for our smaller parks (Cedar Breaks and Timpanogos national monuments). This is based on an estimate of six field-crew members monitoring upland full-time for 12 pay periods.

Since the total annual sample size for CARE is 48 plots, we used an affordable sampling size of 16 plots per year per ecological site 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 all grassland ecological site types for CARE pilot plots.

Ecological site type	Response	Variance		
		site	year	residual
Deep and rocky grasslands	Basal gap	0.17630	0.04246	0.03394
	Canopy gap	0.16820	0.02600	0.03904
	Soil stability	0.02575	0.03011	0.03237
	Crust cover	0.28690	0	0.04000
	Bare soil cover	0.36160	0.11900	0.77740
	Shrub cover	0.15510	0.10570	0.12890
	Perennial grass cover	0.12830	0.17920	0.19130

3 Panel Designs

A serious concern of sampling arid/semiarid upland vegetation and soils is that sites may become fatigued if sampled too often. The most likely scenario of site fatigue at CARE is increased soil loss caused by repeated trampling of BSCs in 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 for upland monitoring. Instead, we investigated split-panel designs that rest plots for 2 to 7 years between revisits. We also considered whether repeated trampling at a lower total number of unique plots would be preferable to the impact of creating additional trails and new trampling to get a greater total number of unique plots.

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) 60 unique plots, 16 plots per ecological site 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	8					8				
7		8					8			
8			8					8		
9				8					8	
10					8					8

Design 2 (2-5),(1-6) 84 unique plots, 16 plots per ecological site 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					
5					4	4				
6						4	4			
7	4						4	4		
8	8							8		
9		8							8	
10			8							8
11				8						
12					8					
13						8				
14							6			

Design 3 (2-7),(1-8) 108 unique plots, 16 plots per ecological site type per year

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

Design 4 (2-7),(1-2) 60 unique plots, 16 plots per ecological site type per year

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

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

Design 1a (2-3),(1-4) 45 unique plots, 12 plots per ecological site 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 1b (2-3),(1-4) 70 unique plots, 18 plots per ecological site 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 1c (2-3),(1-4) 90 unique plots, 24 plots per ecological site 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

Design 1d (2-3),(1-4) 120 unique plots, 32 plots per ecological site 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. Variations of Design 1 used to analyze sample sizes of 12, 18, 24, and 32 plots per ecological site type per year.

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 10% annual increase equates to a 172% total increase over 10 years, or an increase in bare-soil cover from 6.7% in 2007 to 18.2% in 2017. 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 CARE, 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 vegetation types and bare soil 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. Because MDD's for the selected responses will also vary by ecological site, we strongly considered the most conservative estimates when selecting an MDD for a response.

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

Response	MDD (annual trend)	Mean (min – max)		Possible range
		Current status*	After 10 years**	
Basal gap size	2-5% increase	178 cm (49-647 cm)	217 cm (60-790 cm)	0-5000 cm
Canopy gap size	2-5% increase	129 cm (45-489 cm)	158 cm (55-597 cm)	0-5000 cm
Soil stability	2-5% decrease	3.0 (1.2-5.9)	2.5 (1.0-4.8)	1-6
BSC cover	2% decrease	62.2% (9.0-94.7%)	50.9 (7.4-77.6%)	0-100%
Bare soil cover	5-10% increase	6.7% (0-58.0%)	11.1% (0-95.7%)	0-100%
Shrub cover	5-10% increase	5.3% (0.2-20.3%)	8.7% (0.3-33.5%)	0-100%
Perennial grass cover	5-10% decrease	8.0% (0-25.9%)	5.7% (0-18.3%)	0-100%

*Status for first 3 years of data (2007-2009)
**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 ecological site type was compared using an annual sample size of 16 and the appropriate MDD (Figure A1 in Appendix A). All four split-panel designs performed similarly for all responses.

4.4 Effect of sampling size

Samples sizes of 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 four sample sizes performed similarly and adding plots did not improve power for trend or standard error of status (Figure A2 in Appendix A). Bare soil cover was the only response with a distinguishable difference between sample sizes. A sample size of 12 had lower power for trend and higher standard error of status than the other designs with higher sample sizes.

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 16 (Figure A3 in Appendix A). Varying MDD did not affect the standard error of status, so these results are not presented. For all responses, 80% power was reached in 10 years for a 10% annual change and in 20 years for a 5% annual change. At the current level of variability, it is unlikely that a 2% annual change would be detected at 80% power for a long time in crust, bare soil, shrub, or perennial grass cover.

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 except crust cover, the low estimate of MDD could be detected within 15 years at 80% power. Ideally, we would like to detect a 2% annual decrease in crust cover, however, it may take many years of monitoring to achieve this.

4.7 Discussion

The differences between the split-panel designs tested were extremely minor, which was not surprising, given the similarity between the designs. Any of these designs would probably be appropriate for upland monitoring in CARE. The more curious result was the similarity between the different annual sample sizes analyzed, ranging from 12 to 32. 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. Minimizing variance may be the best way to improve our ability to detect trends. We believe that much of the high variance in these responses was due to two issues that will be mediated when the full monitoring design is implemented: (1) measurement error in the early years of method development, and (2) extremely high seasonal variability in plant phenology between sampling dates.

The measurement errors mainly affected variance for bare soil and crust cover. Methods of estimating bare soil and crust cover were revised since pilot sampling, and we are optimistic that these changes will result in greater repeatability between observers. Some confusion occurred in early years when bare soil occurred on top of crust.

The extremely high seasonal variability mainly affected variance for shrub and perennial grass cover. These were based on the current years live growth and were most skewed by taking measurements too early in the growing season. In 2009, spring temperatures were cooler than average at CARE, and plots were visited in April and May, before bunchgrasses and shrubs had enough time to fully develop live photosynthetic tissue for the growing season. This resulted in extremely low shrub and perennial grass cover estimates for 2009. In order to avoid this problem in the future, we will schedule monitoring at CARE later in the growing season (late May or June at the earliest).

Increasing the rest time between revisits from two to seven years resulted in virtually no increase in standard error of status or time to detect trend in this analysis (Appendix A, Figure A1). However, visiting plots more often should enable us to detect trends sooner, assuming that we can decrease overall variance through the methods described above. We feel that the (2-3),(1-4) design (Design 1 in Figure 3-1) is the best option for sampling uplands at CARE.

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 sites into new structures.

5 Final design

The final split-panel design for integrated upland monitoring at CARE is Design 1 (see Figure 3-1). Sixteen plots will be monitored in each of the different ecological site type/allotment groups (deep grassland-Cathedral/Rock Springs, deep grassland-Hartnet, and rocky grassland-Hartnet; see Table 2-1). Any of the three deep grassland ecological sites will be monitored if it occurs anywhere within the Cathedral/Rock Springs sampling frame. Any of the 5 ecological sites (deep or rocky grassland) will be monitored if it is occurs anywhere within the Harnet sampling frame. This will give us a different number plots for each grassland ecological site, but these numbers should represent the area of each ecological site across the landscape. Ecological site information will be recorded for each plot and used in trend analyses; however, annual reports will summarize data by ecological site type.

The overall proposed design calls for the following:

- Sampling 48 upland monitoring plots per year using a rotating split-panel design.
- Establishing 180 plots over a five-year period.
- Allowing 3-4 years of rest at each plot to minimize the effects of repeated visits.
- Preferentially placing plots used in the three-year pilot study (2007-2009) in panels 4 and 10, to allow the maximum amount of rest after the initial three years of monitoring.

Park managers received an outline of the design in April 2010, and were given an opportunity to provide feedback. Full operational monitoring of uplands in CARE will begin in May 2010.

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Appendix A
Power for Trend Figures

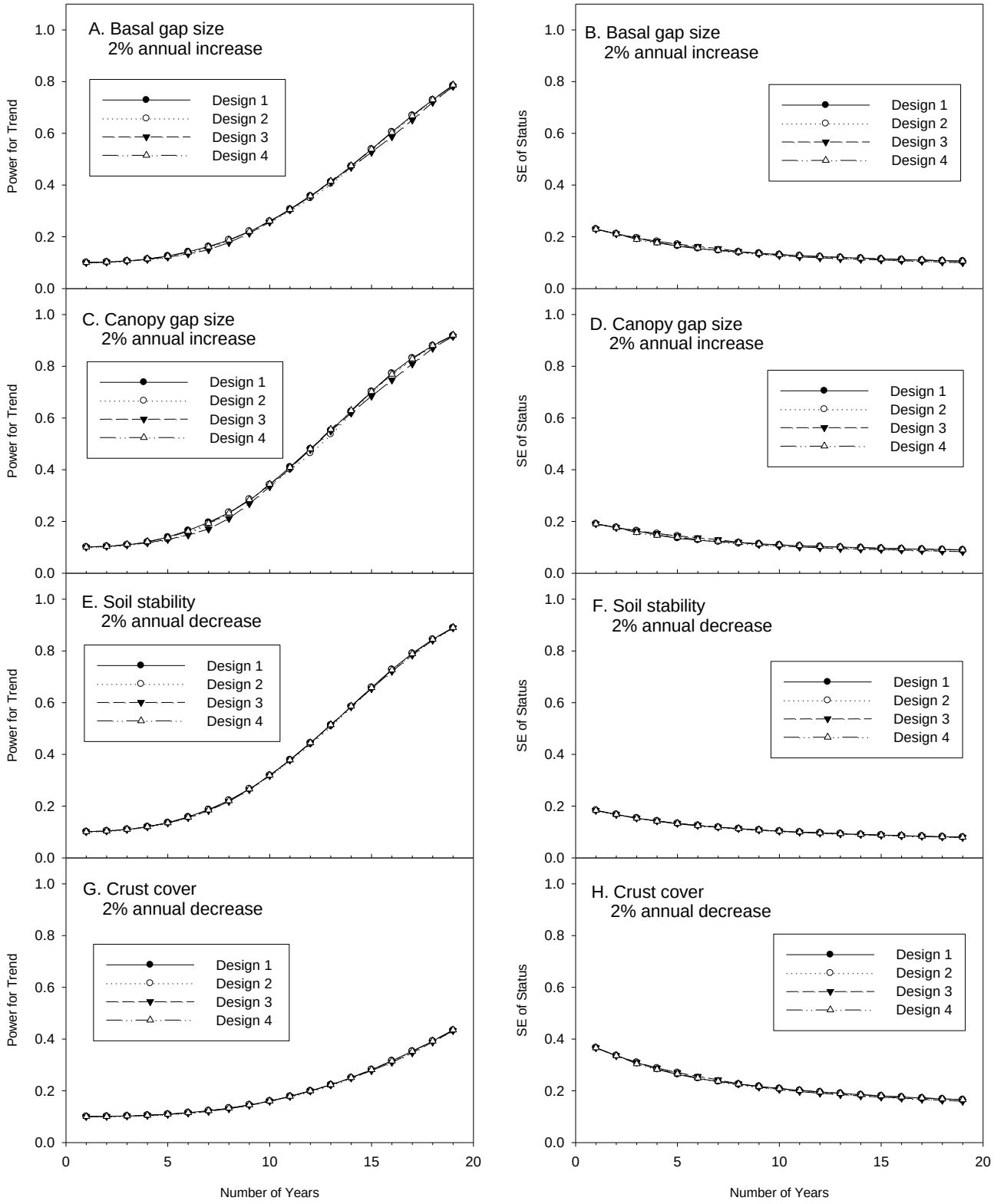

Figure A1. Power for trend and standard error of status for each sampling design (Figure 3-1) at all grassland ecological sites (annual sample size = 16). Responses include basal and canopy gap size, soil stability, and percent cover of biological soil crusts, bare soil, shrubs, and perennial grass.

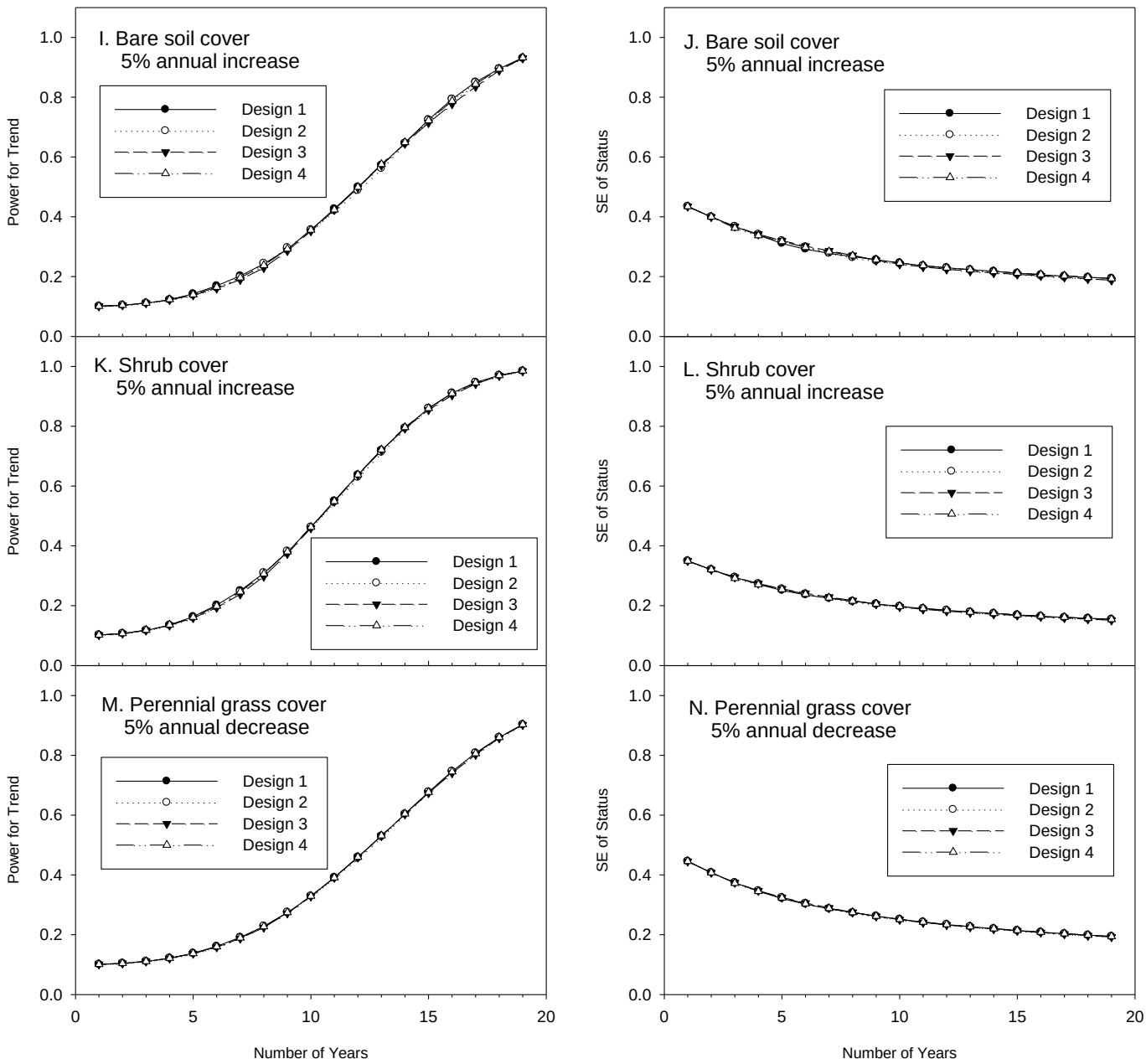

Figure A1. cont'd.

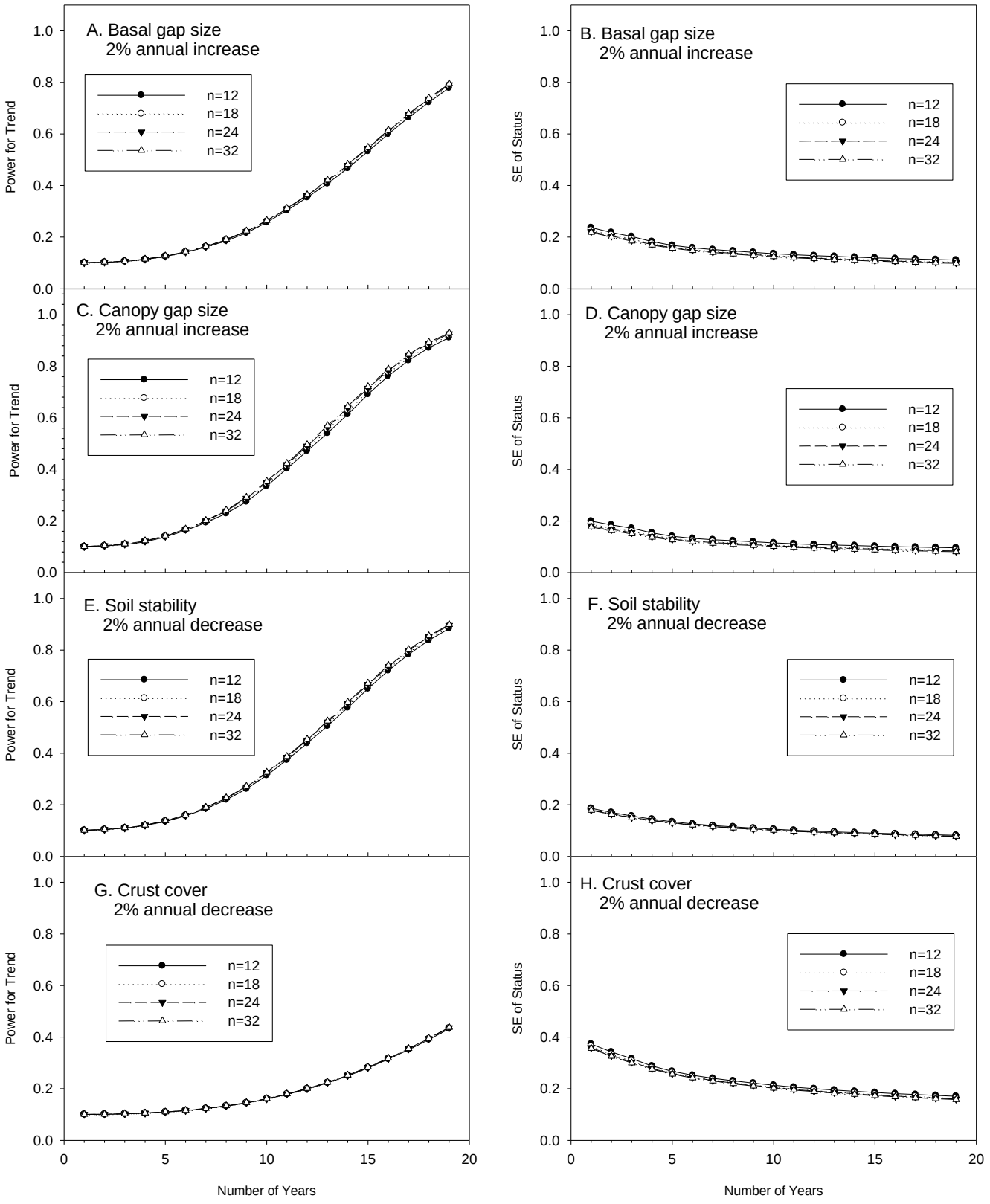

Figure A2. Power for trend and standard error of status for each response variable at all grassland ecological sites comparing annual sample sizes of 12, 18, 24, and 32 plots per year using Design 1 (Figure 3-2). Responses include basal and canopy gap size, soil stability, and percent cover of biological soil crusts, bare soil, shrubs, and perennial grass.

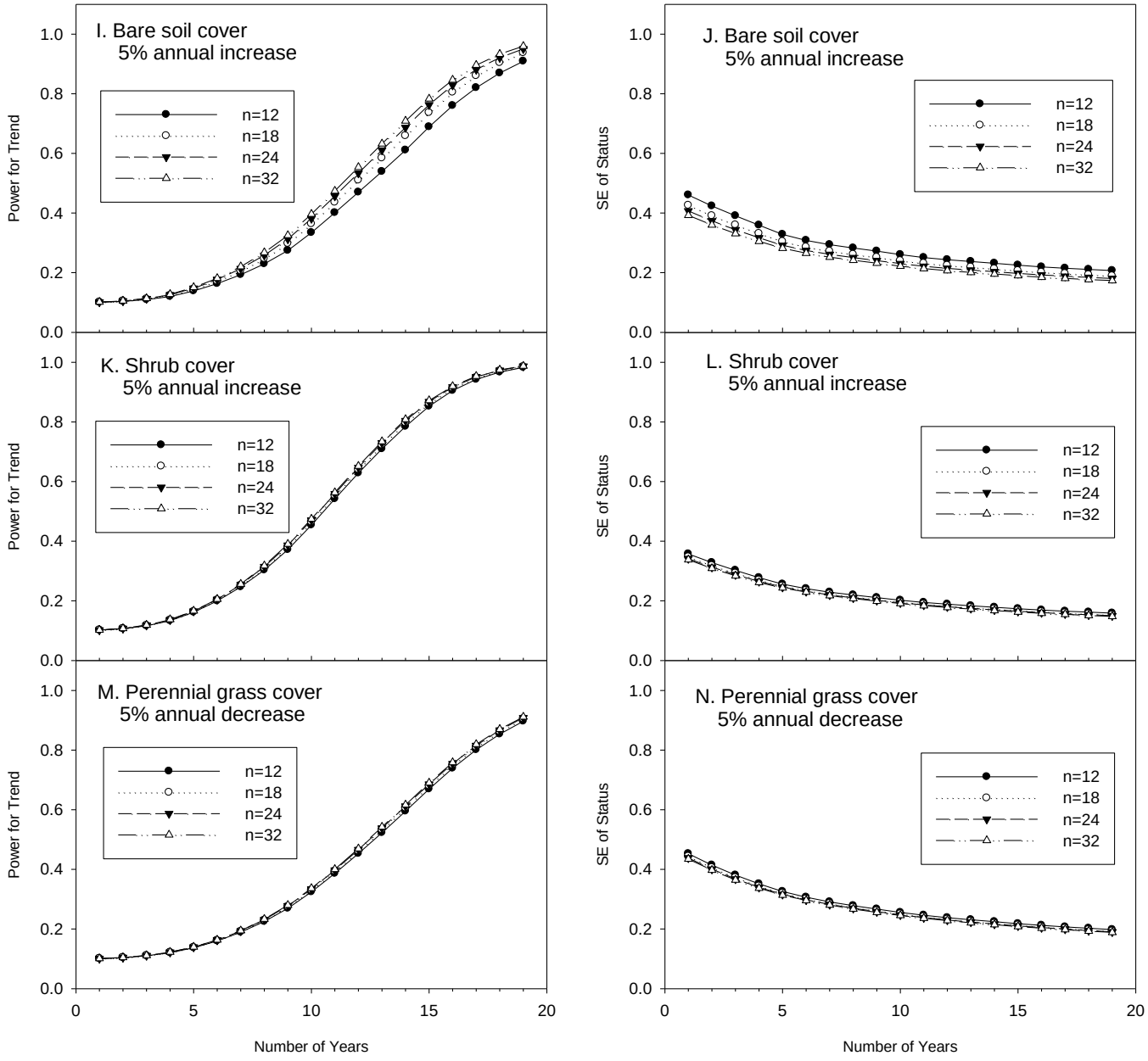

Figure A2. cont'd.

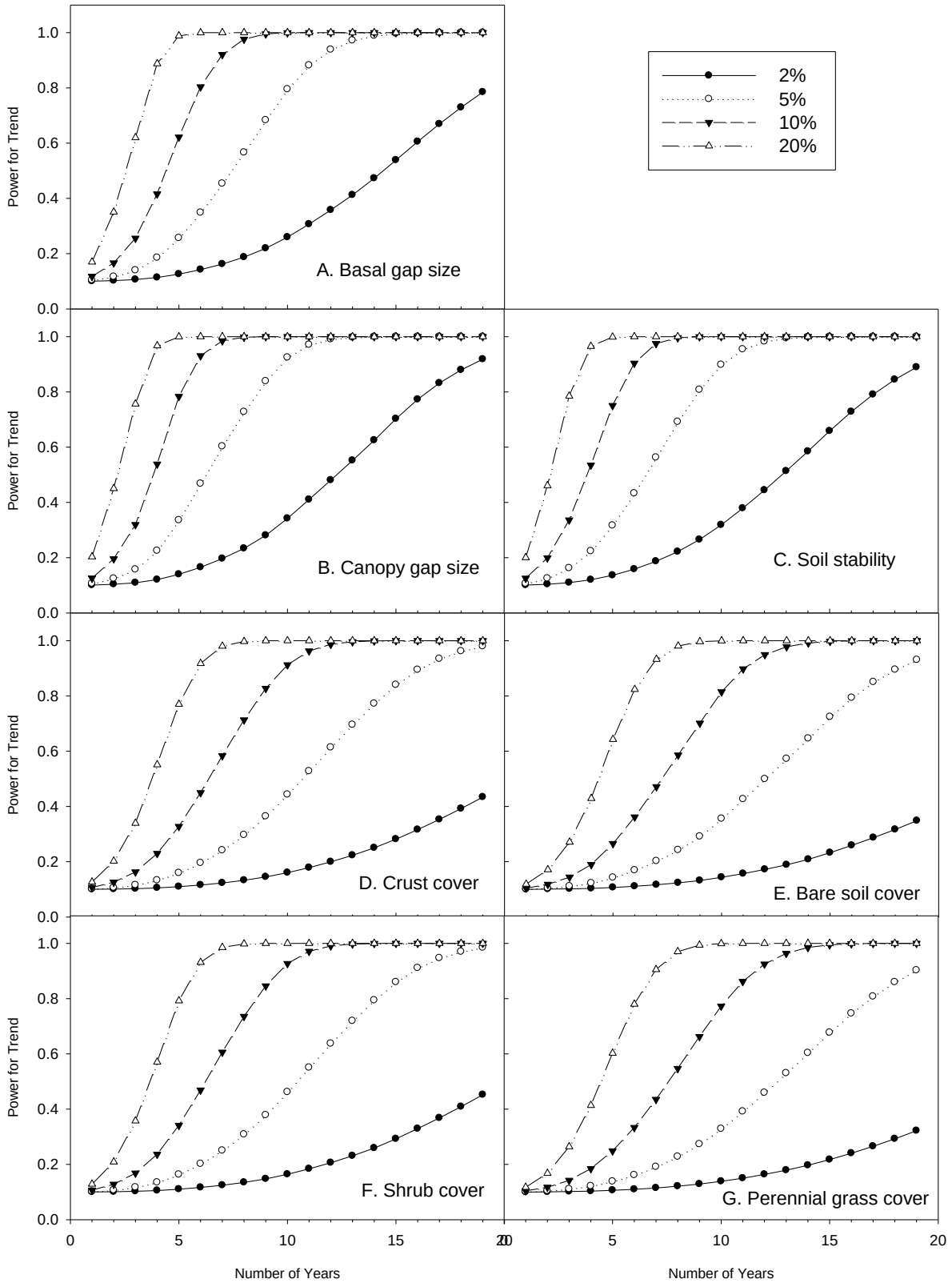

Figure A3. Power for trend for a range of annual increases or decreases in response variables at grassland ecological sites using Design 1 (Figure 3-1) and an annual sample size of 16. Responses include basal and canopy gap size, soil stability, and percent cover of biological soil crusts, bare soil, shrubs, and perennial grass.