



Variance and Power for Trend Assessment of Pilot Data

Integrated Upland Monitoring, Canyonlands National Park

Natural Resource Report NPS/NCPN/NRR—2010/171



ON THE COVER

Upland monitoring site, Canyonlands National Park. NPS photo.

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Prepared by

Dana Witwicki
Northern Colorado Plateau Network
National Park Service
P.O. Box 848
Moab, UT 84532

Editing and Design

Alice Wondrak Biel
Northern Colorado Plateau Network
National Park Service
P.O. Box 848
Moab, UT 84532

January 2010

U.S. Department of the Interior
National Park Service
Natural Resource Program Center
Fort Collins, Colorado

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Please cite this publication as:

Witwicki, D. 2010. Variance and power for trend assessment of pilot data: Integrated upland monitoring, Canyonlands National Park. Natural Resource Report NPS/NCPN/NRR—2010/171. National Park Service, Fort Collins, Colorado.

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Abstract

Power analysis provides an a priori understanding of our 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 uplands monitoring protocol at Canyonlands National Park (NP). Forty plots were monitored at Canyonlands 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 separately for shrub and grassland ecological site types, using linear mixed-effects models. We also examined power and precision of standard error of status for alternative revisit designs and sample sizes, as well as for the ability to detect different amounts of annual trend. The operational survey and revisit designs for Canyonlands NP are presented in the report. Graphs of power for trend are presented in Appendix A.

Acknowledgements

Many thanks to Steve Garman, former Northern Colorado Plateau Network quantitative ecologist, and Tom Philippi, national Inventory and Monitoring quantitative ecologist, for answering questions about analyses and providing thoughtful reviews of this document. I would also like to thank 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 own variance and power-for-trend assessments and allowing me to adapt their work for the Northern Colorado Plateau Network.

1 Introduction

The Northern Colorado Plateau Inventory and Monitoring Network (NCPN) implemented upland monitoring at Canyonlands National Park (CANY) during the 2006 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 among which the sample can be divided.

2 Survey Design

2.1 Sampling frame

Survey designs use explicitly mapped areas as the sampling frame. For CANY, we used feature-extraction 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.

The feature-extraction software used field reconnaissance points and spatial data layers to develop rules for where each ecological site occurred on aerial photos. It then used those rules to characterize the entire area of interest (i.e., accessible areas in Island in the Sky and Needles districts of the park). After field verification, the software used new data to improve the initial version of the

map (Garman et al. in review). The resulting map included the six ecological sites cover the greatest areal extent of CANY (Table 2-1).

Table 2-1. Ecological sites in Canyonlands NP pilot monitoring.

Ecological site #	Ecological site name	Ecological site type	Total area* (ha)
115	Desert Sand (sand sagebrush)	Grassland	1,647
118	Desert Sandy Loam (fourwing saltbush)	Grassland	1,706
212	Semidesert Sand (fourwing saltbush)	Grassland	319
215	Semidesert Sandy Loam (fourwing saltbush)	Grassland	621
133	Desert Shallow Sandy Loam (blackbrush)	Shrubland	2,212
236	Semidesert Shallow Sandy Loam (Utah juniper-pinyon)	Shrubland	2,181

*Total accessible area of ecological site in Island in the Sky and Needles districts of Canyonlands NP.

2.2 Site selection

A membership design specifies how sites in a survey design are chosen across space (McDonald 2003). For CANY, a Generalized Random Tessellation Stratified (GRTS) design (Stevens and Olsen 2004) was used to select spatially balanced random samples stratified by each target ecological site. In probability-based surveys, such as GRTS, the site-selection process allows unbiased estimation of both status and, with repeated visits, trend (Larsen et al. 1995). Our GRTS design was created in R using the “spsurvey” library (Kincaid 2005, ver. 2.0, available from <http://cran.r-project.org/>).

2.3 Pilot study

Using the ordered lists of points produced by GRTS, eight plots were established in each of five ecological sites for CANY pilot monitoring. (The Desert Sand ecological site was not included in the pilot study because it had much lower areal extent than predicted by soil and ecological site maps.) Thirty-one plots were established in 2006, and sampled for three consecutive years. The remaining nine plots were established in 2007, and sampled for two consecutive years. Plots were sampled between April and September 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 three 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 five years, allowing us 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 BSCs, and (5) percent cover of bare soil. Important response measurements for detecting shifts in vegetation include percent cover of (6) shrubs, (7) perennial grasses, and (8) annual grasses.

2.5 Linear models and variance components

Using the eight 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 9.1 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., dif-

ferent 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).

Our original intent was to analyze separate models for each response at each ecological site. However, our limited data set resulted in variances of 0 for year and/or site for more than one-quarter of the response variables. To achieve meaningful results, we combined all three grassland ecological sites and both shrubland ecological sites into ecological site types based on functional group, and reanalyzed the data (Table 2-3). For the three shrub responses (canopy gap size, crust cover, and bare soil cover) that still had a year variance of 0, year variances were substituted from the grassland ecological site type in order to give a more realistic estimate of year variance. Variances were also examined after data were detrended, but 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 two weather stations in CANY were examined to see if estimated variances from the 2006–2008 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 (2006–2008), and (2) for the history of the weather stations (1966–2008). Variance of yearly precipitation from 2006 to 2008 was higher than that for the history of the weather stations, so no additional corrections to variances were made.

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., regionwide climatic variation)
$\sigma^2_{\text{Residual}}$	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 approximately 48 plots per park for all large parks in the network (Black Canyon of the Gunnison National Park and Curecanti National Recreation Area, CANY, Capitol Reef National Park, Dinosaur National Monument, and Zion National Park), 24 plots per park for medium-size parks (Arches and Bryce Canyon national parks) and 3–8 plots for smaller parks (Cedar Breaks and Timpanogos Cave national monuments). This is based on an estimate of six field-crew members monitoring uplands full-time for 12 pay periods.

Although the total annual sample size for CANY is 48 plots, an affordable sampling size of 12 plots per year per ecological site was used to evaluate 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).

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 CANY 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 2–7 years between revisits. We also wanted to sample some sites two years in a row to understand year-to-year variation of shrub and annual grass cover. The four designs considered for NCPN upland monitoring in CANY are displayed in Figure 3-1.

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.

A preliminary analysis determined that split-panel designs, like those shown in Figure 3-1, pro-

Table 2-3. Site, year, and residual variance estimates for responses in grassland and shrubland ecological site types for CANY pilot plots.

Response	Variance		
	Site	Year	Residual
Grassland type			
Basal gap	0.71500	0.00449	0.04046
Canopy gap	0.67380	0.00141	0.02264
Soil stability	0.01314	0.00462	0.02384
Crust cover	0.01175	0.01246	0.03330
Bare soil cover	0.14390	0.28190	0.79940
Shrub cover	0.70600	0.01194	0.02806
Perennial grass cover	0.49130	0.05793	0.05028
Annual grass cover	0.00802	0.02491	0.06480
Shrubland type			
Basal gap	0.10470	0.00315	0.03779
Canopy gap	0.05868	0	0.00917
Soil stability	0.09466	0.00172	0.01884
Crust cover	0.59920	0	0.30530
Bare soil cover	0.21440	0	0.59920
Shrub cover	0.10670	0.01245	0.08471
Perennial grass cover	0.15880	0.00024	0.01417
Annual grass cover	0.00167	0.00426	0.01116

vided better precision of status and higher power to detect trend in early years by allocating more plots to panels where plots were visited for only one consecutive year (e.g., panels 6–10 in Design 1) than to panels where plots were visited for two consecutive years (e.g., panels 1–5 in Design 1). Therefore, all four designs analyzed in this power analysis were structured in this way. Design 2 was used to examine the effect of different sample sizes and annual trends (Figure 3-2).

When selecting an operational sampling design, it is important that the sampling frame be large enough to include all of the proposed unique plots in a design. For example, it would not be feasible to select Design 3 (99 unique plots) to monitor ecological site 212, due to the low areal extent of this ecological site in CANY (only 319 ha predicted by our map; Table 2-1) and a high sampling-frame error (only ¼ of plots have been correctly predicted by the map in this ecological site).

Design 1 (2-3),(1-4).										
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

45 unique plots
12 plots per ecological site per year

Design 3 (2-7),(1-8).										
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	

99 unique plots
12 plots per ecological site per year

Design 2 (2-5),(1-6).										
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			

63 unique plots
12 plots per ecological site per year

Design 4 (2-7),(1-2).										
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	

45 unique plots
12 plots per ecological site per year

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

Design 2a (2-5),(1-6).										
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
4				2	2					
5					2	2				
6						2	2			
7	2						2	2		
8	3							3		
9		3							3	
10			3							3
11				3						
12					3					
13						3				
14							3			
35 unique plots 7 plots per ecological site per year										

Design 2b (2-5),(1-6).										
Panel	Year									
	1	2	3	4	5	6	7	8	9	10
1	9	9						9	9	
2		9	9						9	9
3			9	9						9
4				9	9					
5					9	9				
6						9	9			
7	9						9	9		
8	18							18		
9		18							18	
10			18							18
11				18						
12					18					
13						18				
14							18			
189 unique plots 36 plots per ecological site per year										

Design 2c (2-5),(1-6).										
Panel	Year									
	1	2	3	4	5	6	7	8	9	10
1	12	12						12	12	
2		12	12						12	12
3			12	12						12
4				12	12					
5					12	12				
6						12	12			
7	12						12	12		
8	26							26		
9		26							26	
10			26							26
11				26						
12					26					
13						26				
14							26			
266 unique plots 50 plots per ecological site per year										

Figure 3-2. Variations of Design 2 used to analyze sample sizes of 7, 36, and 50 plots per ecological site 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 5.4% in 2006 to 14.7% in 2016. 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 by using thresholds of ecological sites, if known. Because no threshold values have been determined for target ecological sites in CANY, 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 10% change per year for meaningful ecological changes to occur. Changes in all other soil-related variables were meaningful at a 2–5% rate of annual 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.

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 (U.S. Environmental Protection Agency, 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 12 and the appropriate MDD (Figures A1 & A2 in Appendix A). In general, all four split-panel designs performed similarly. For some responses, Design 3 provided lower power in early years, and Designs 1 and 4 provided higher power in early years.

4.4 Effect of sampling size

Samples sizes of 7, 12, 36, and 50 plots per year were compared for each response in each ecological site type using Design 2 (see Figure 3-2)

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

Response	MDD (annual trend)	Mean (min–max)		Range
		Current status	After 10 years*	
Basal gap size	2–5% increase	427 cm (70–2,996 cm)	522 cm (86–3,659 cm)	0–5,000 cm
Canopy gap size	2–5% increase	228 cm (45–1,659 cm)	279 cm (55–2,026 cm)	0–5,000 cm
Soil stability	2–5% decrease	3.4 (1.1–5.8)	2.8 (0.9–4.7)	1–6
BSC cover	2% decrease	58.3% (0.2–90.5%)	47.7 (0.2–74.1%)	0–100%
Bare soil cover	10% increase	5.4% (0–47.7%)	14.7% (0–>100%)	0–100%
Shrub cover	10% increase	9.1% (0–20.3%)	24.7% (0–55.2%)	0–100%
Perennial grass cover	10% decrease	4.3% (0–24.7%)	1.6% (0–9.1%)	0–100%
Annual grass cover	20–25% increase	0.2% (0–2.3%)	1.5% (0–17.0%)	0–100%

*calculation uses lowest value for each row in the MDD (annual trend) column

and the appropriate MDD. For most responses, increasing sample size caused power for trend to increase and standard error of status to decrease for sample sizes of up to 36 plots (Figures A3 & A4 in Appendix A). Sample sizes above 36 plots provided little additional improvement in power for trend or standard error of status.

4.5 Effect of annual trend

A range of annual trends was compared for each response in each ecological site type using Design 2 and an annual sample size of 12 (Figures A5 & A6 in Appendix A). For responses with MDDs of 2–5% (basal and canopy gaps, soil stability, and percent crust cover), annual trends of 2%, 5%, and 10% were compared. For responses with MDDs of 10–20% (percent cover of bare soil, shrubs, perennial grass, and annual grass), annual trends of 5%, 10%, and 20% were compared. Most response variables in each ecological site type reached 80% power within 10 years. The exceptions were percent cover of bare soil and crust, which took approximately 13–25 years to reach a power of 80%. Varying MDD did not affect the standard error of status, so these results are not presented.

4.6 Effect of response type

Responses generally displayed acceptable levels of power for trend and standard error of status for the sampling designs, sample sizes, and rates of annual trend examined in this analysis. The most problematic responses were percent cover of bare soil and of crust. These two responses tended to take longer to reach a power of 80% and had higher standard errors of status than the other responses. It is likely that the high variance in these responses is primarily a result of measurement error. Methods of estimating bare soil and crust cover have been changed since pilot sampling, and we are optimistic that these changes will result in greater repeatability between observers. Using the pilot data to select a sampling design should give us a conservative estimate of power and standard error of status for percent bare soil and crust.

4.7 Discussion

The differences between the split-panel designs tested were relatively minor, which was unsurprising, given the similarity between the designs.

Any of these designs would probably be appropriate for upland monitoring in CANY. A more difficult question, however, is which annual sample size is appropriate for each ecological site. It is clear from the results presented here that for most responses, there is little to be gained by using an annual sample size of more than 36 plots, because at some point between 12 and 36, no significant improvements in trend and standard error of status are seen when plots are added.

Because the gains from increasing annual sample size seem relatively minor, and considering the affordable sample size, it may be more beneficial overall to monitor additional ecological sites in CANY than to implement the optimum sample size for a few of the ecological sites. The response that would appear to benefit most from increasing sample size is crust cover in the shrubland ecological site type (Appendix A, Figure A4-G.). However, the pilot data may be inflating variance of this response, because the two ecological sites combined for the shrubland ecological site type have very different amounts of crust cover. Ecological site 236 has high amounts of crust cover, while the soil surface in ecological site 133 is composed primarily of gravels, with small amounts of crust between the rocks.

Increasing the rest time between revisits from two to seven years resulted in a fairly minor increase in the time required to detect trend, and an extremely small decrease in standard error of status (Appendix A, Figures A1 & A2). There was a four-year delay in detecting trend in the worst-case scenario, but 80% power was reached by Year 7 (Appendix A, Figure A1-K.). We feel that the (2-5),(1-6) design (Design 2) is probably the best compromise for sampling uplands in CANY. Due to the sensitivity of BSCs to repeated trampling, we must consider 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.

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 GRTS 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 CANY will be based on Design 2, but modified to sample aggregated ecological site types. The six original target ecological sites will be combined into three ecological site types: grassland, blackbrush, and pj/blackbrush (Table 5-1).

We will use the sampling frames of all four original target grassland ecological sites but combine them into a single grassland sampling frame. Any of the four grassland ecological sites will be monitored if it occurs anywhere within the grassland sampling frame. This will give us a different number of 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. This sampling strategy was chosen due to the similarity of grassland ecological sites and the low areal extent of two of the grassland ecological sites.

The final design, outlined in Figure 5-1, calls for the following:

- Sampling 48 upland monitoring plots per year using the rotating split-panel designs.
- Establishing 252 plots over a seven-year period.
- Allowing 5–6 years of rest after sampling to give biological soil crust time to recover.
- Preferentially placing plots used in the three-year pilot study (2006–2008) in panels 6 and 14, to allow the maximum amount of rest after the initial three years of monitoring.

Park managers received an outline of the design in May 2009, and were given the opportunity to provide feedback. Full operational monitoring of uplands in CANY began in June 2009.

Table 5-1. Ecological site type groupings.

Ecological site type	Ecological site name
Grassland (4,293 ha)	Desert Sand (sand sagebrush) Desert Sandy Loam (fourwing saltbush) Semidesert Sand (fourwing saltbush) Semidesert Sandy Loam (fourwing saltbush)
Blackbrush (2,212 ha)	Desert Shallow Sandy Loam (blackbrush)
Pinyon-Juniper/ Blackbrush (2,181 ha)	Semidesert Shallow Sandy Loam (Utah juniper-pinyon)

**Final design for grassland ecological sites
(2-5),(1-6).**

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
4				6	6					
5					6	6				
6						6	6			
7	6						6	6		
8	12							12		
9		12							12	
10			12							12
11				12						
12					12					
13						12				
14							12			

126 unique plots sampled over 7 years
24 plots per year among all four target grassland ecological sites

**Final design for shrubland (blackbrush
and PJ/blackbrush) ecological sites
(2-5),(1-6).**

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			

63 unique plots sampled for each ecological site over 7 years
12 plots per ecological site per year

Figure 5-1. Final split-panel designs for integrated upland monitoring at Canyonlands National Park.

6 Literature Cited

- Garman, S. L., D. Witwicki, and A. Wight. In review. Mapping ecological sites for long-term monitoring in national parks. Proceedings of the 9th Biennial Conference of Research on the Colorado Plateau.
- Gerrodette, T. 1987. A power analysis for detecting trends. *Ecology* 68(5):1364–1372.
- Larsen, D. P., T. M. Kincaid, S. E. Jacobs, and N. S. Urquhart. 2001. Designs for evaluating local and regional scale trends. *BioScience* 51:1069–1078.
- Larsen, D. P., N. S. Urquhart, and D. L. Kugler. 1995. Regional scale trend monitoring of indicators of trophic conditions of lakes. *Water Resources Bulletin* 31(1):117–140.
- MacDonald, T. L. 2003. Review of environmental monitoring methods: survey designs. *Environmental Monitoring and Assessment* 85:277–292.
- Spilke, J., H. P. Piepho, and X. Hu. 2005. Analysis of unbalanced data by mixed linear models using the MIXED procedure of the SAS system. *Journal of Agronomy and Crop Science* 191:47–54.
- Stevens, D. L., and A. R. Olsen. 2004. Spatially balanced sampling of natural resources. *Journal of the American Statistical Association* 99(465):262–278.
- Urquhart, N. S., and T. M. Kincaid. 1999. Designs for detecting trend from repeated surveys of ecological resources. *Journal of Agricultural, Biological, and Environmental Statistics* 4:404–414.
- Urquhart, N. S., W. S. Overton, and D. S. Birkes. 1993. Comparing sampling designs for the monitoring of ecological status and trends: Impact of temporal patterns. Pages 71–85 in V. Barnett and K. F. Turkman, eds., *Statistics for the environment*. London, U.K.: John Wiley and Sons.
- Urquhart, N. S., S. G. Paulsen, and D. P. Larsen. 1998. Monitoring for policy-relevant regional trends over time. *Ecological Applications* 8:246–257.
- Witwicki, D. L., S. L. Garman, H. Thomas, A. Wight, R. H. Weissinger, T. E. O'Dell, and M. E. Miller. Draft integrated upland monitoring protocol for the park units in the Northern Colorado Plateau Network. National Park Service, Inventory and Monitoring Program, Northern Colorado Plateau Network, Moab, Ut.

Appendix A

Power for Trend Figures

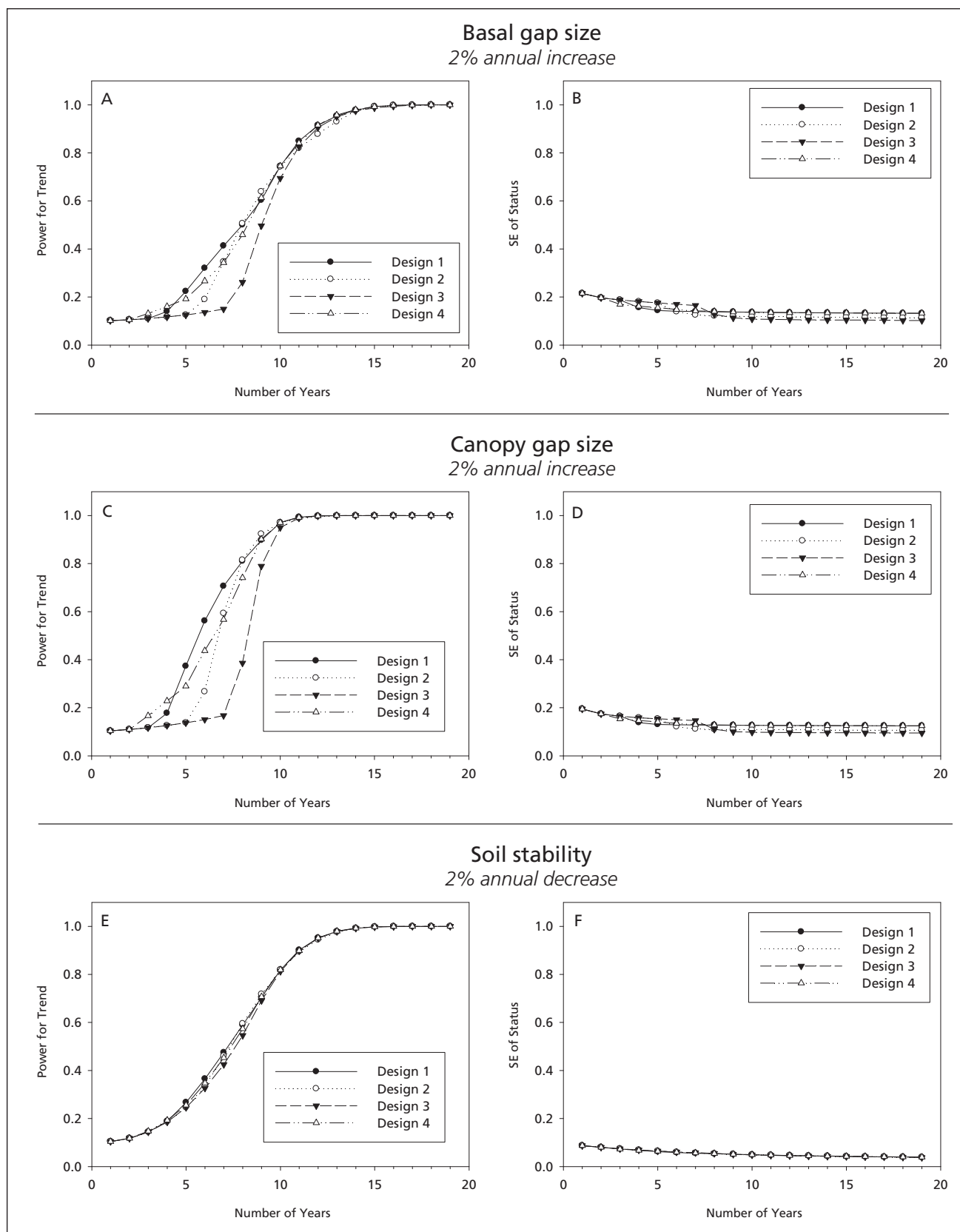


Figure A1. Power for trend and standard error of status for each sampling design (Figure 3-1) at grassland ecological sites (annual sample size = 12). Responses include basal and canopy gap size, soil stability, and percent cover of biological soil crusts, bare soil, shrubs, perennial grass, and annual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

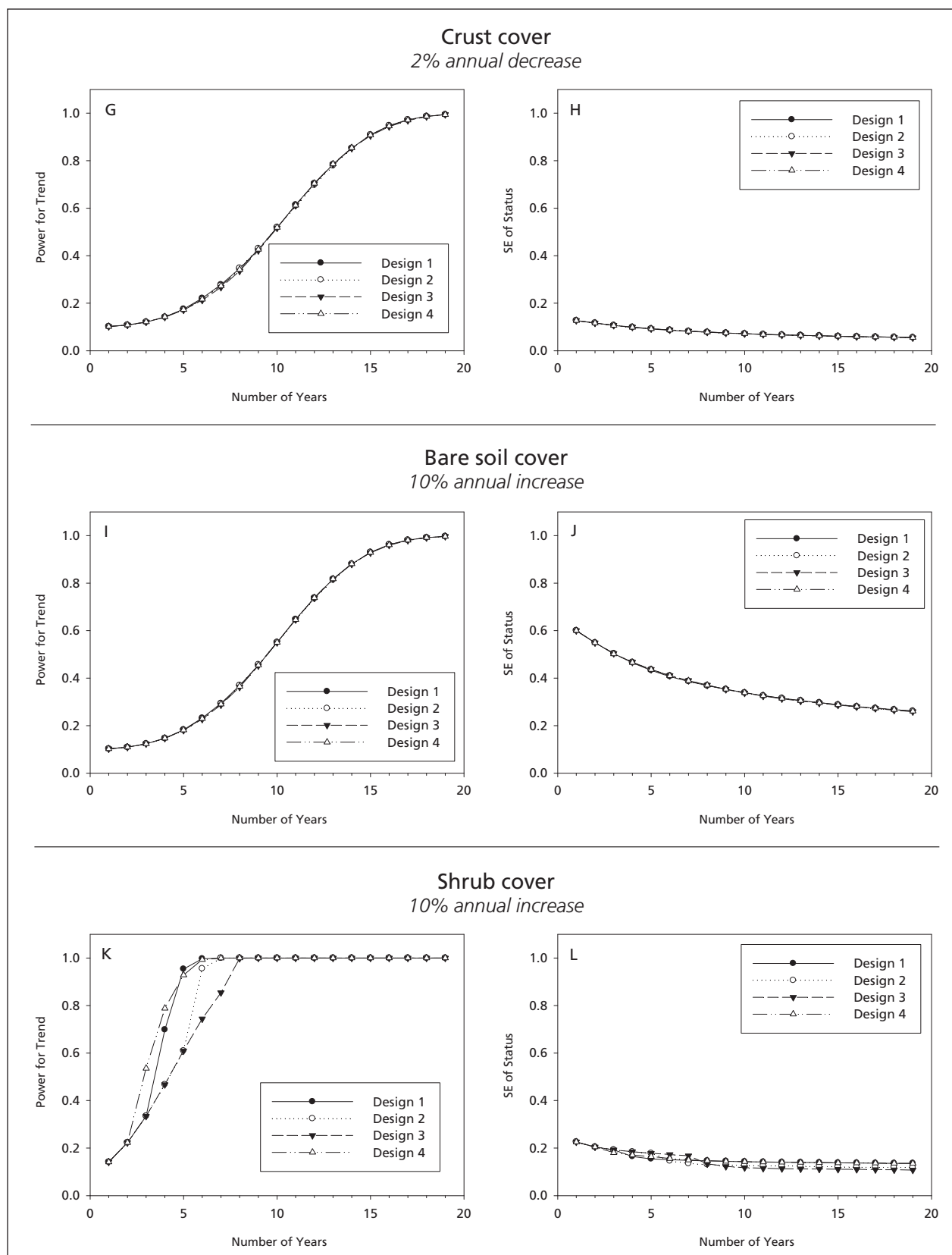
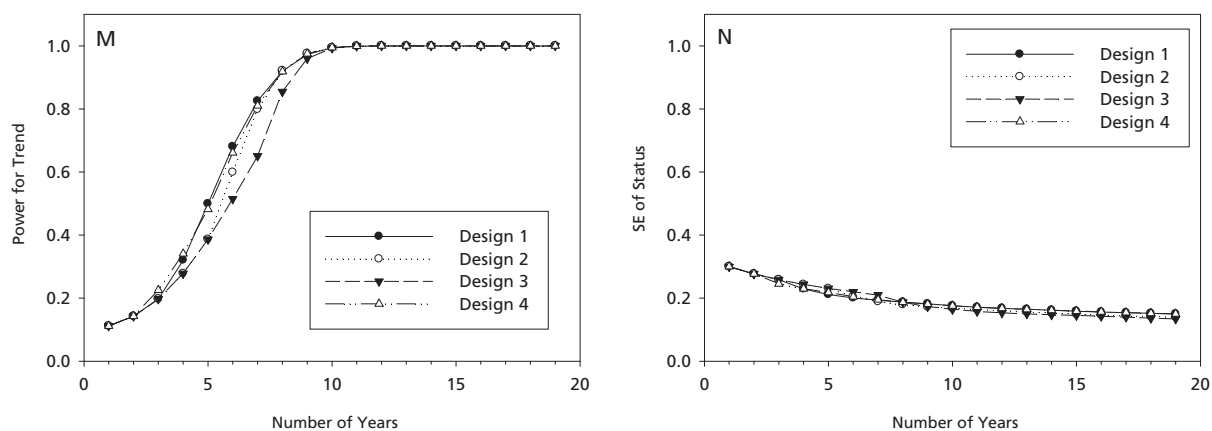


Figure A1, cont.

Perennial grass cover
10% annual decrease



Annual grass cover
20% annual increase

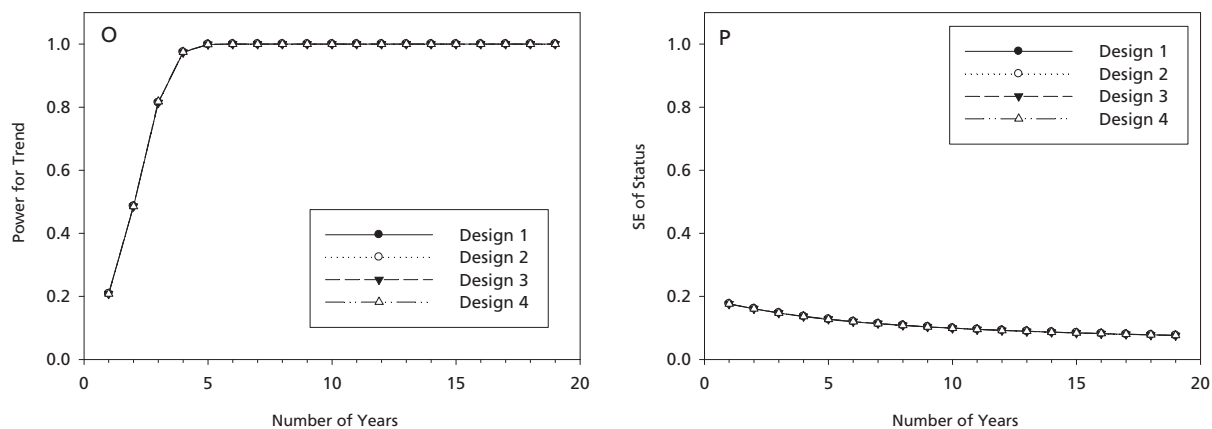


Figure A1, cont.

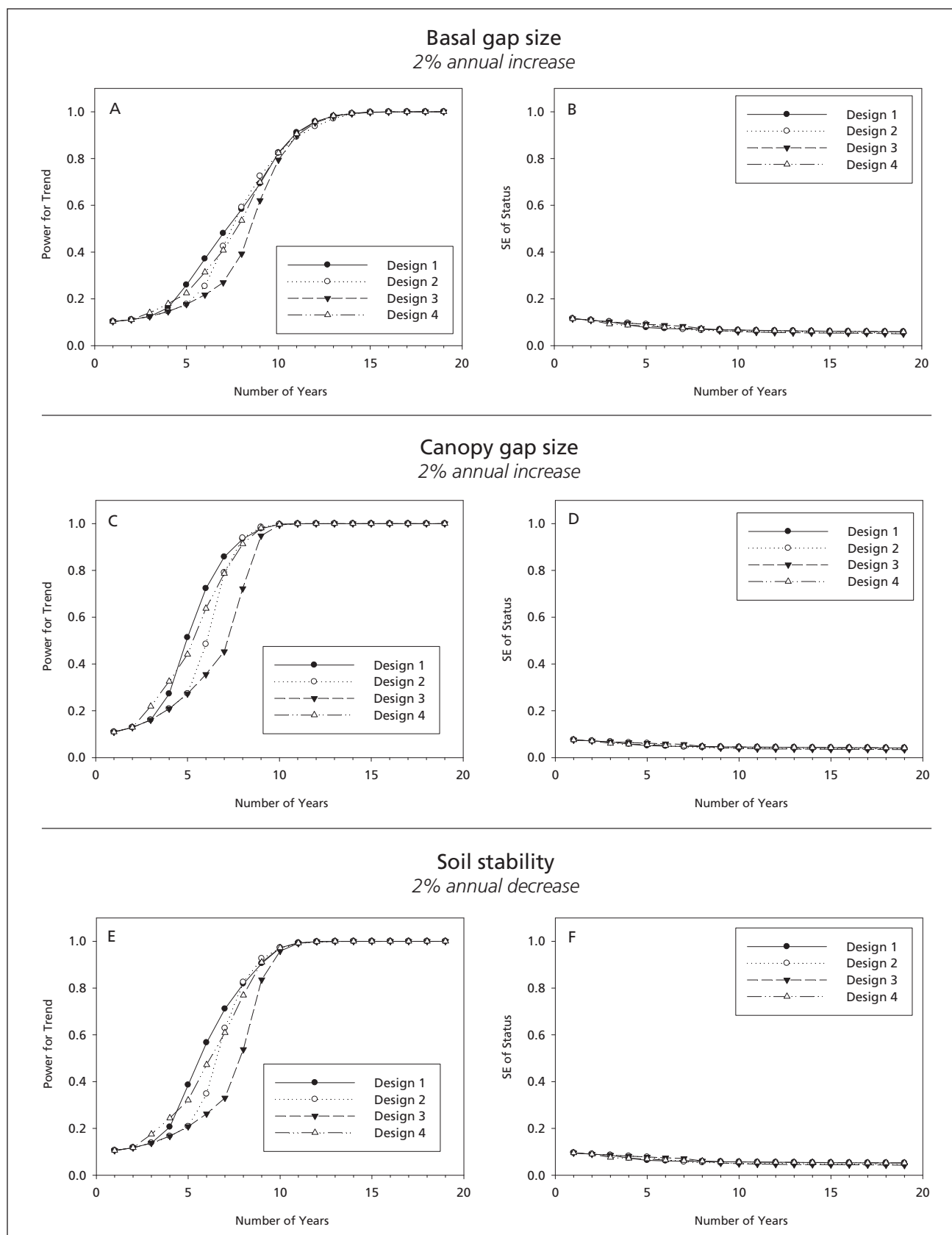
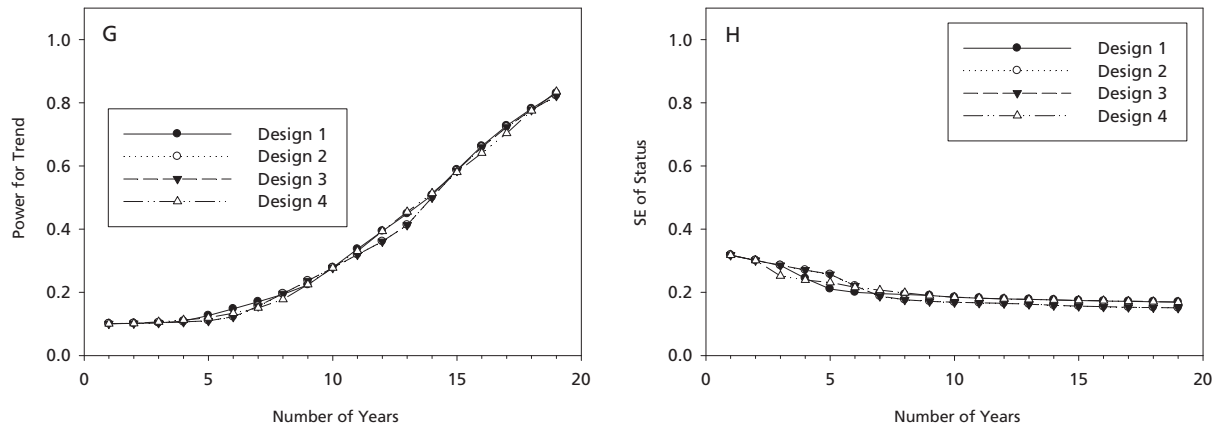
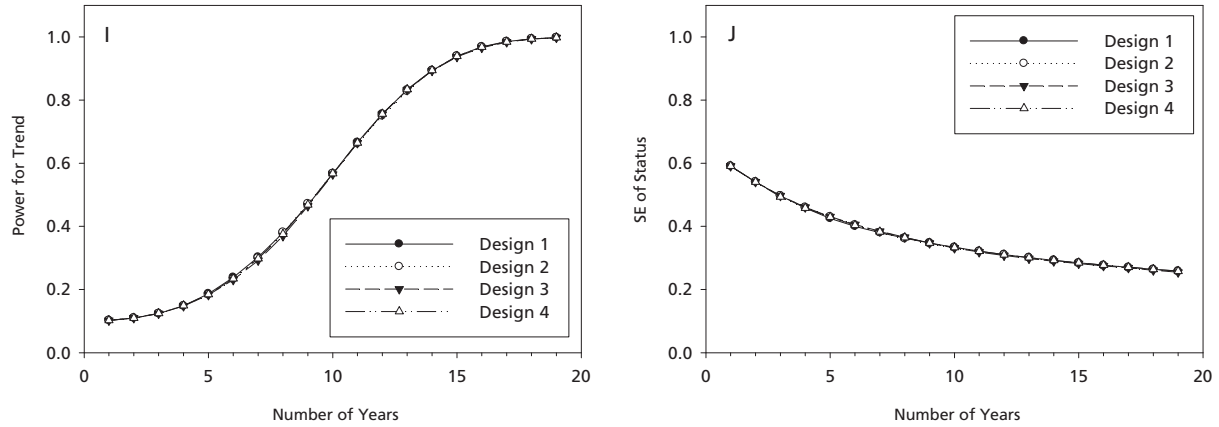


Figure A2. Power for trend and standard error of status for each sampling design (Figure 3-1) at shrubland ecological sites (annual sample size = 12). Responses include basal and canopy gap size, soil stability, and percent cover of biological soil crusts, bare soil, shrubs, perennial grass, and annual grass.

Crust cover 2% annual decrease



Bare soil cover 10% annual increase



Shrub cover 10% annual increase

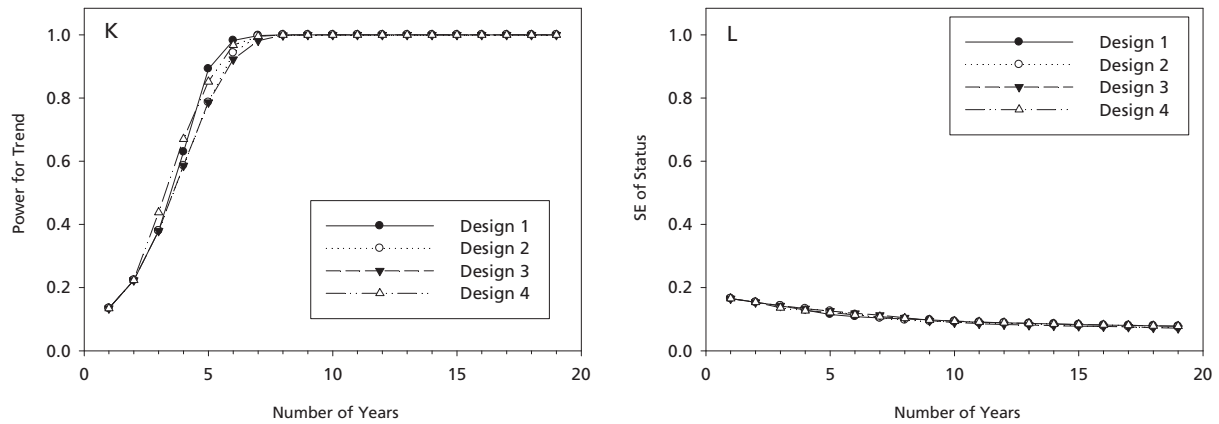
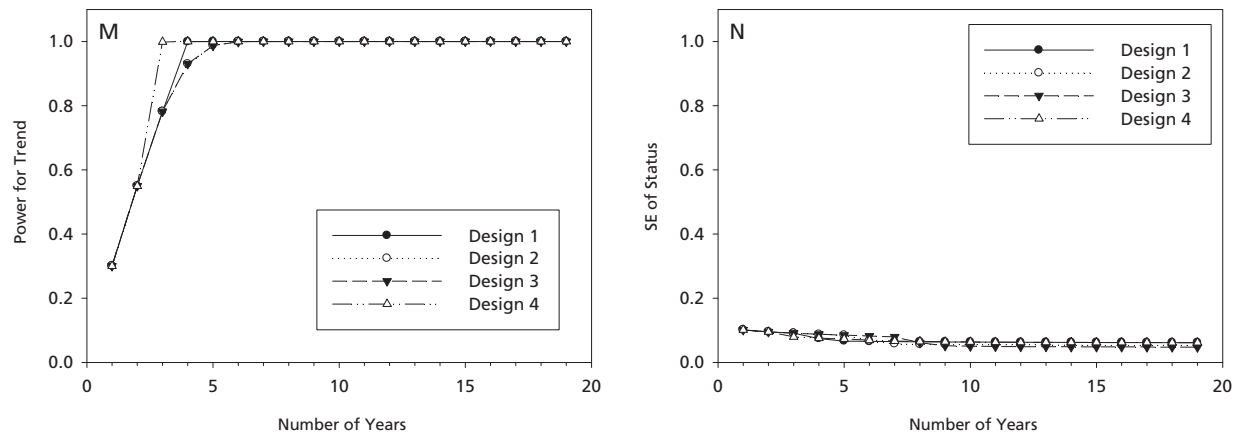


Figure A2, cont.

Perennial grass cover
10% annual decrease



Annual grass cover
20% annual increase

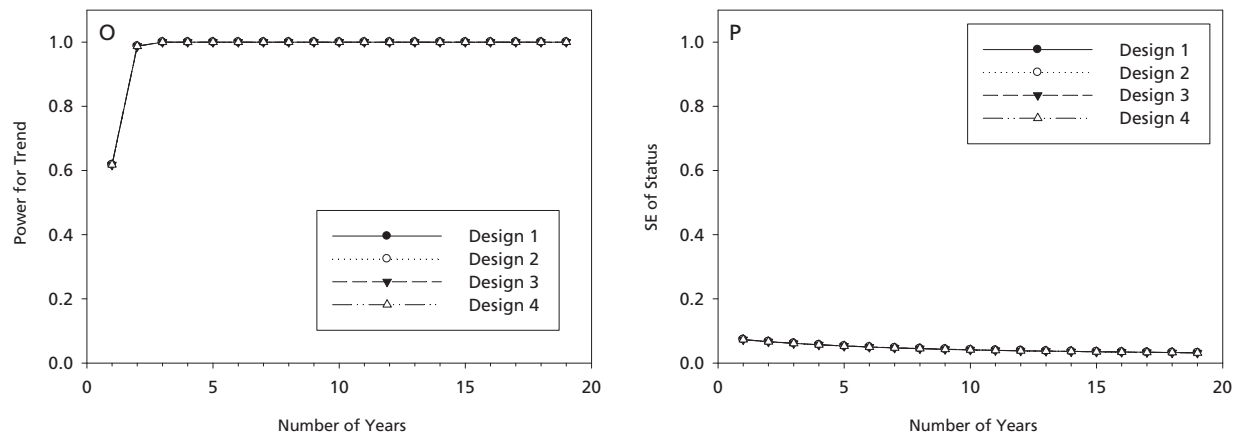


Figure A2, cont.

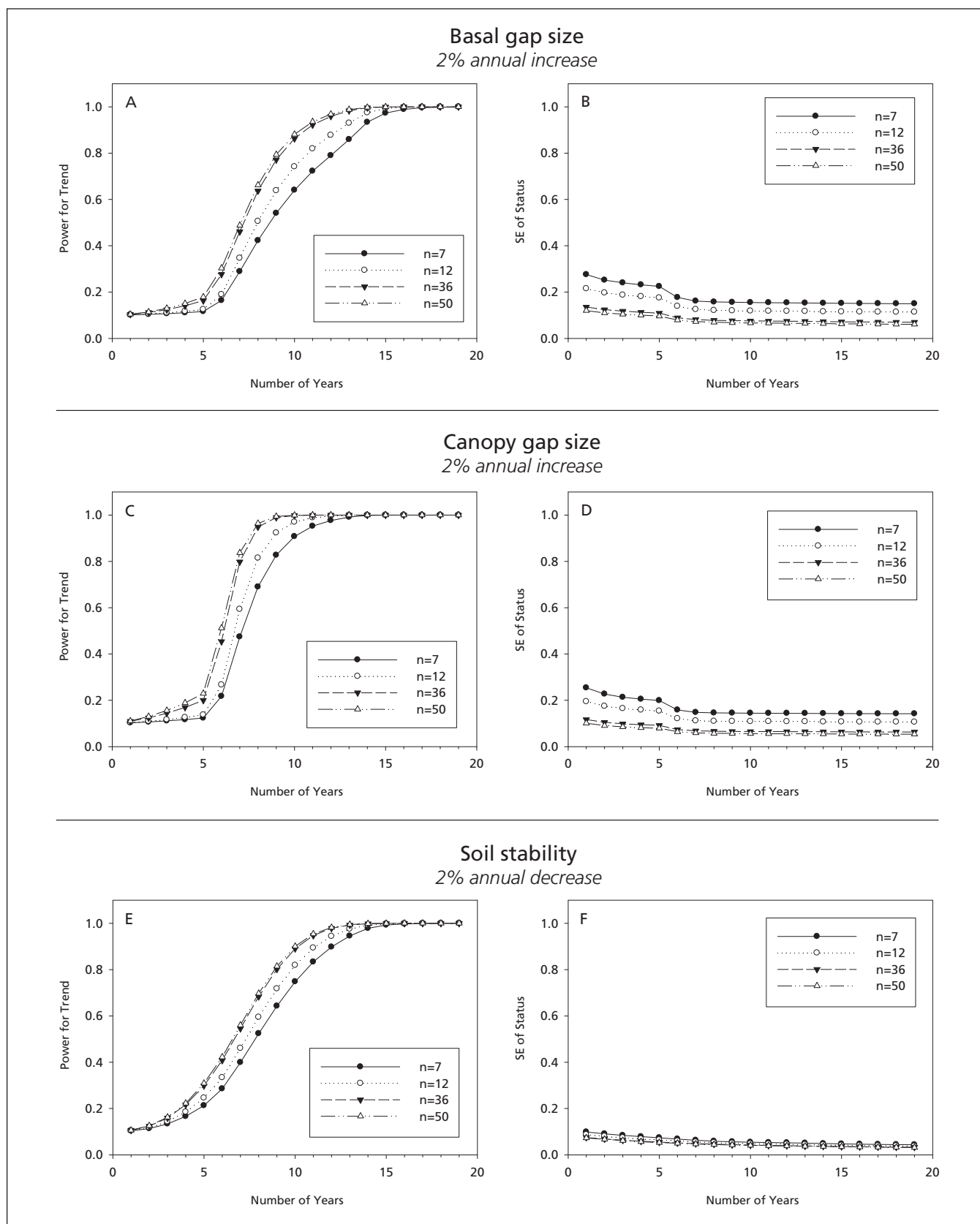
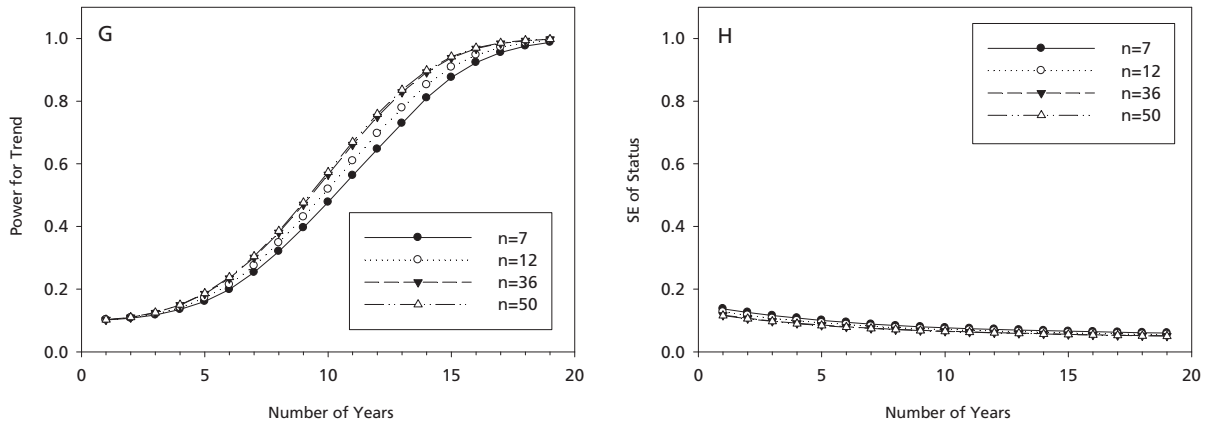
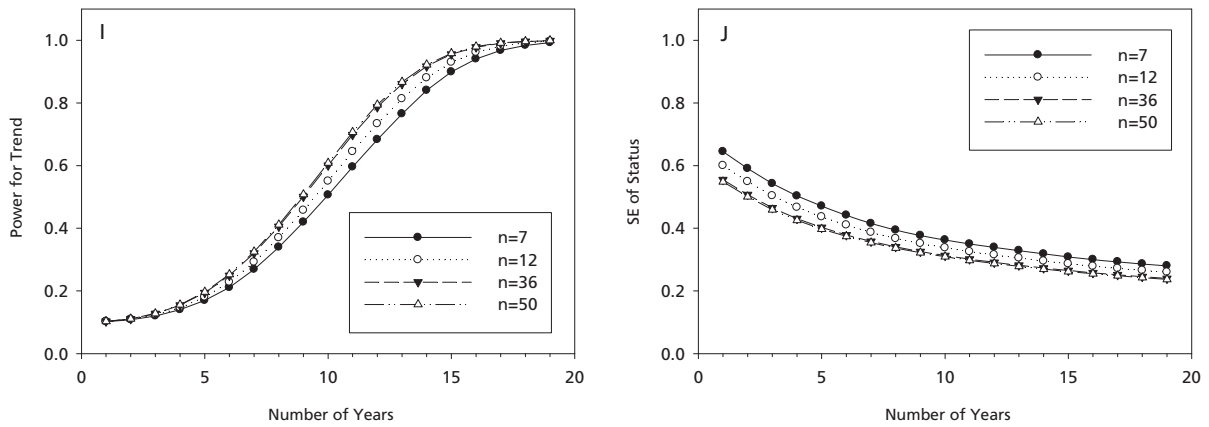


Figure A3. Power for trend and standard error of status for each response variable at grassland ecological sites comparing annual sample sizes of 7, 12, 36, and 50 plots per year using Design 2 (Figure 3-2). Responses include basal and canopy gap size, soil stability, and percent cover of biological soil crusts, bare soil, shrubs, perennial grass, and annual grass.

Crust cover
2% annual decrease



Bare soil cover
10% annual increase



Shrub cover
10% annual increase

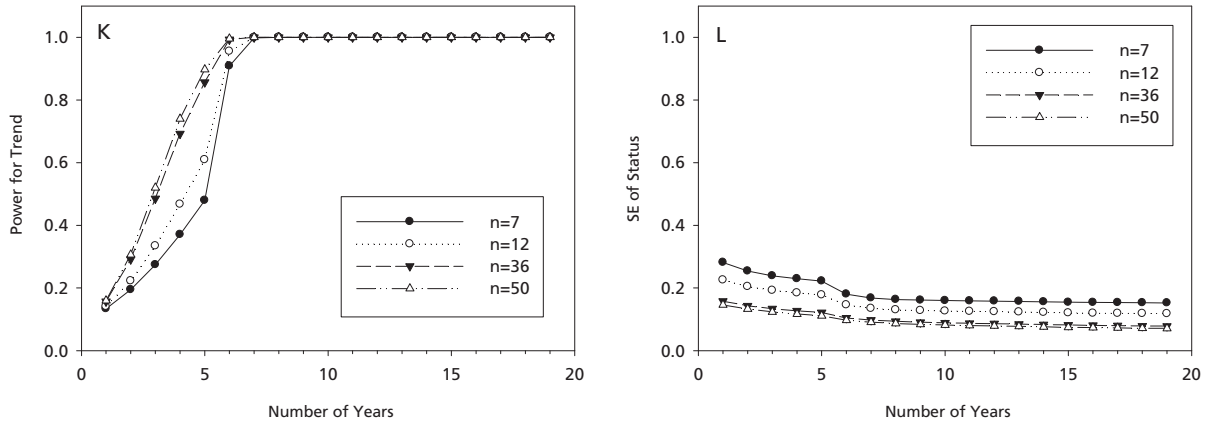
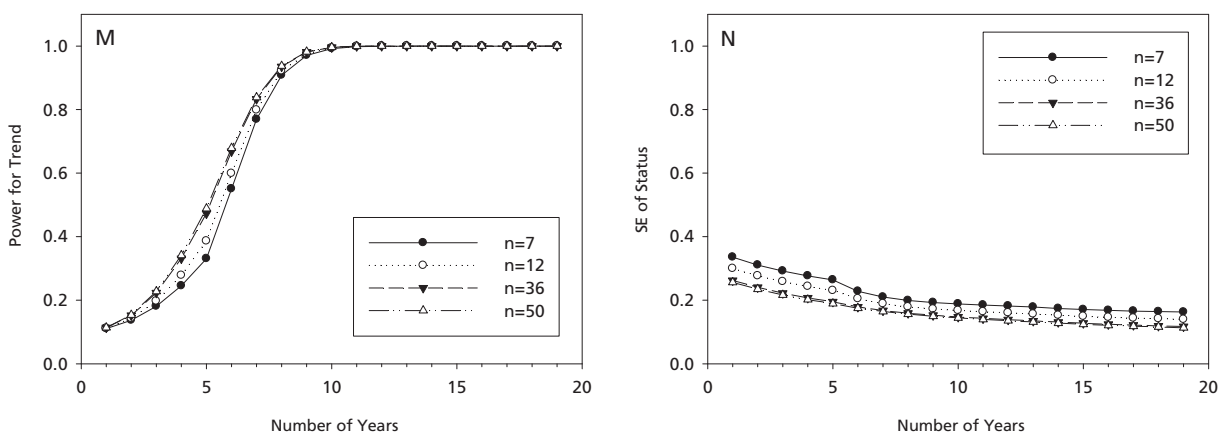


Figure A3, cont.

Perennial grass cover
10% annual decrease



Annual grass cover
20% annual increase

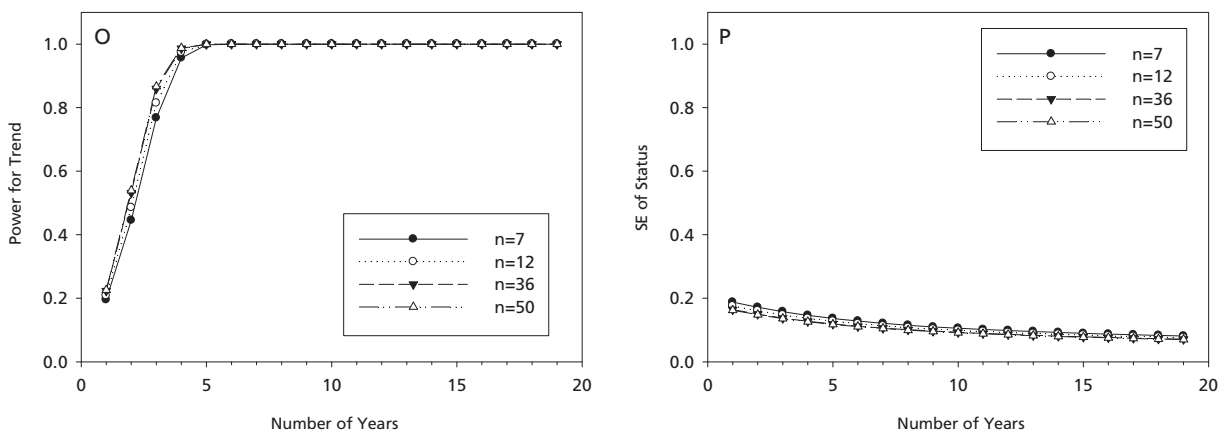


Figure A3, cont.

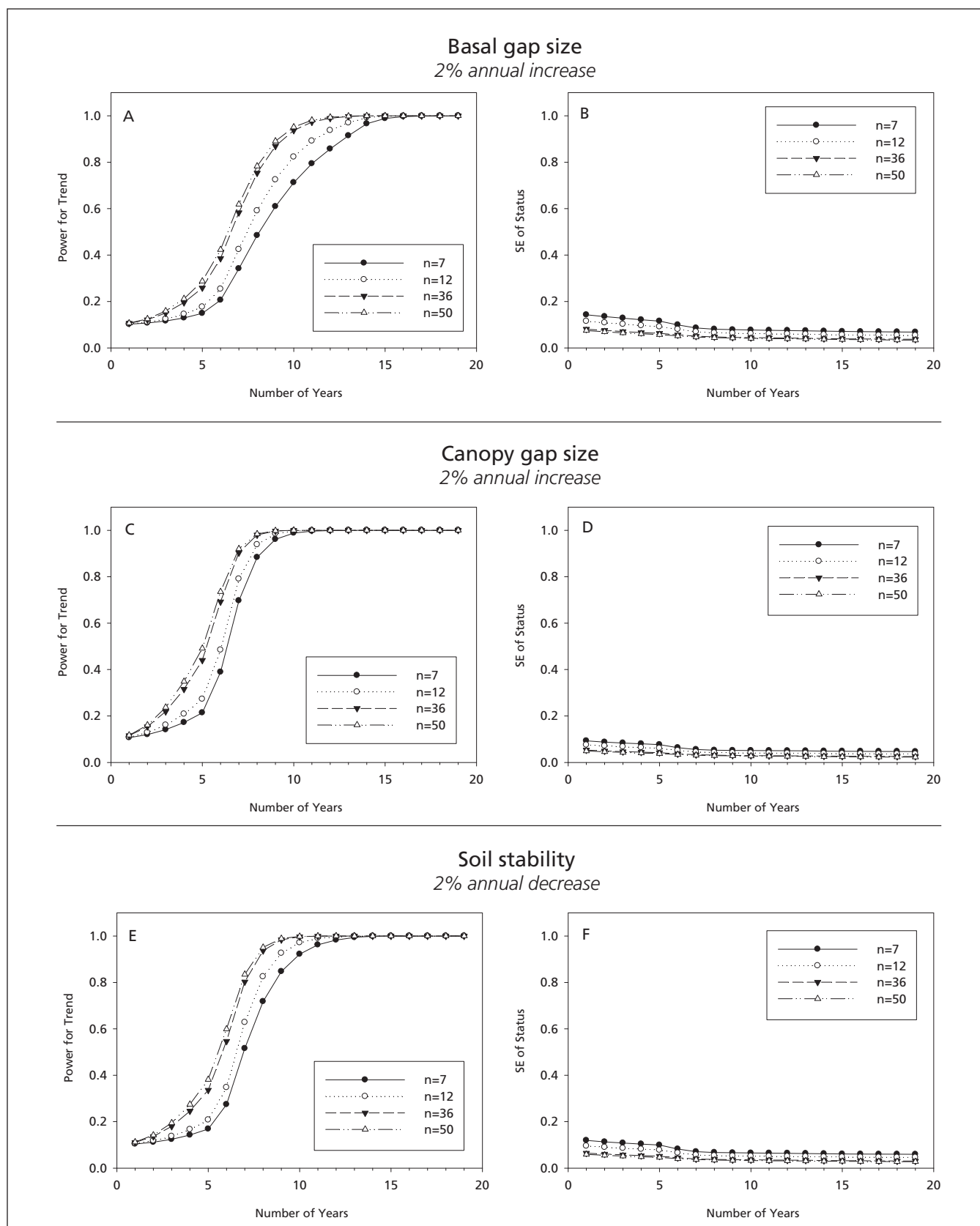
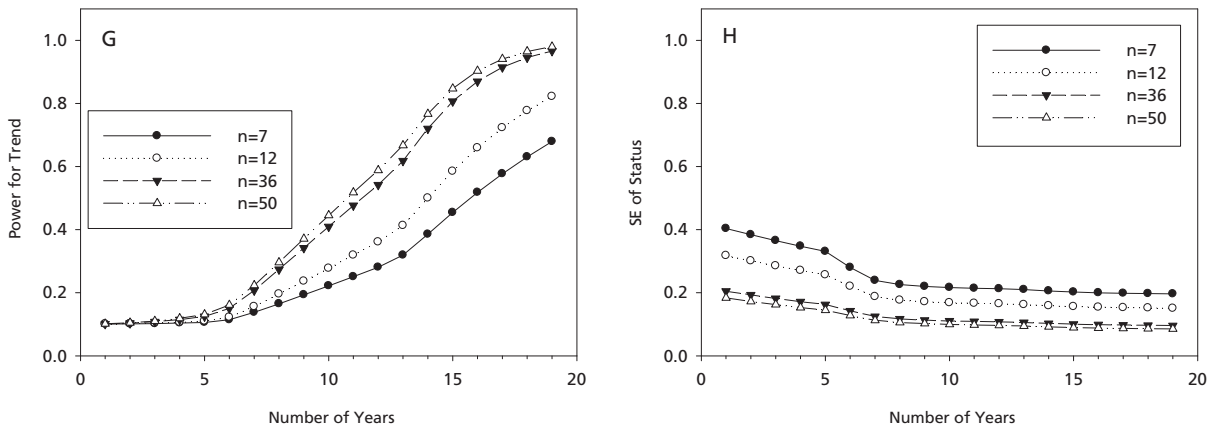
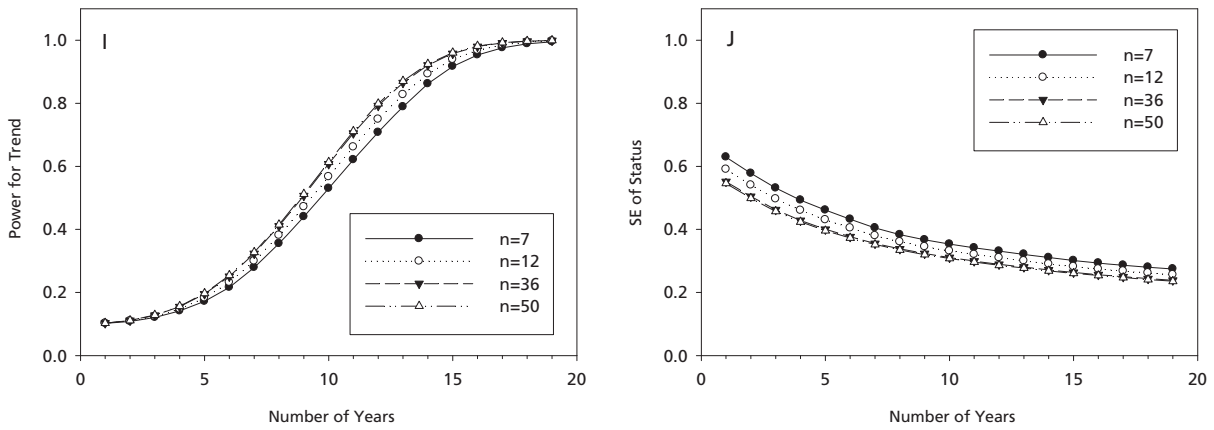


Figure A4. Power for trend and standard error of status for each response variable at shrubland ecological sites comparing annual sample sizes of 7, 12, 36, and 50 plots per year using Design 2 (Figure 3-2). Responses include basal and canopy gap size, soil stability, and percent cover of biological soil crusts, bare soil, shrubs, perennial grass, and annual grass.

Crust cover
2% annual decrease



Bare soil cover
10% annual increase



Shrub cover
10% annual increase

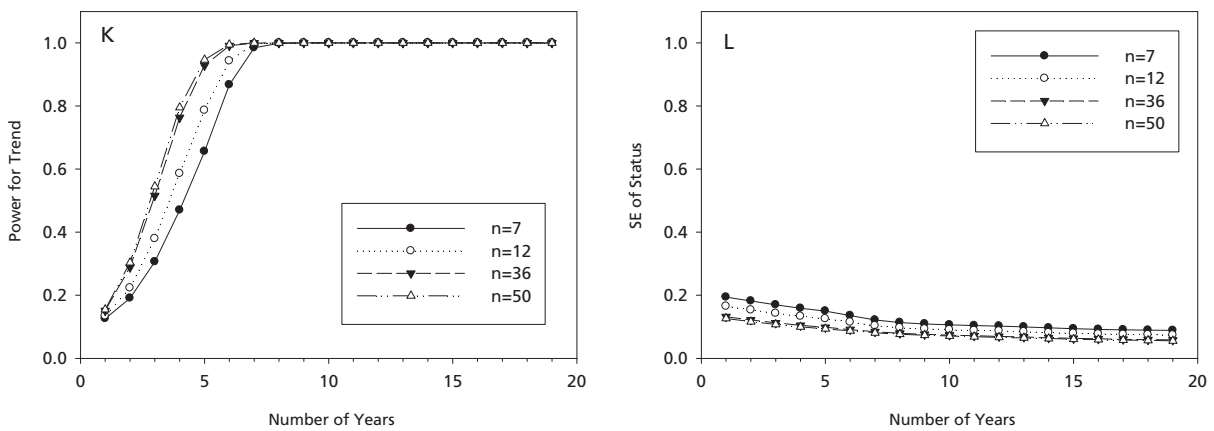
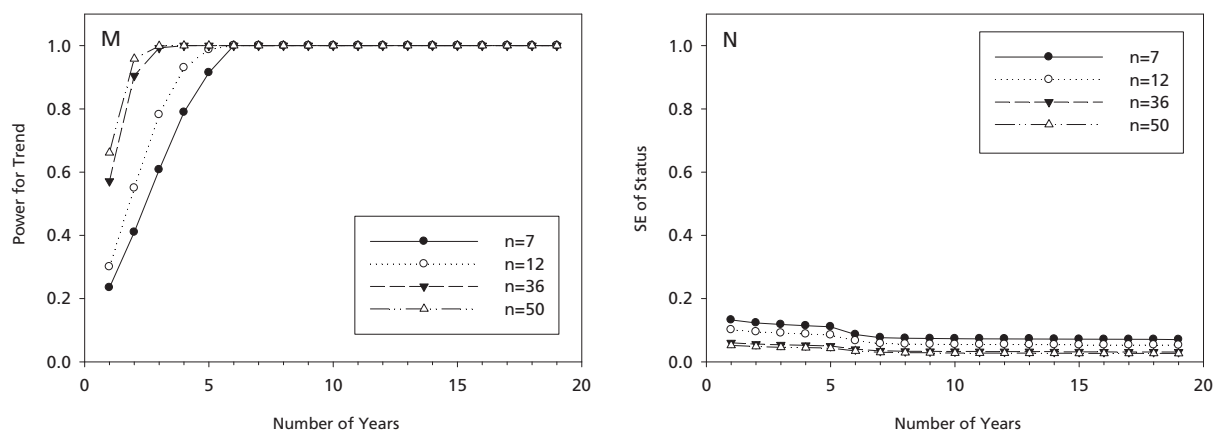


Figure A4, cont.

Perennial grass cover
10% annual decrease



Annual grass cover
20% annual increase

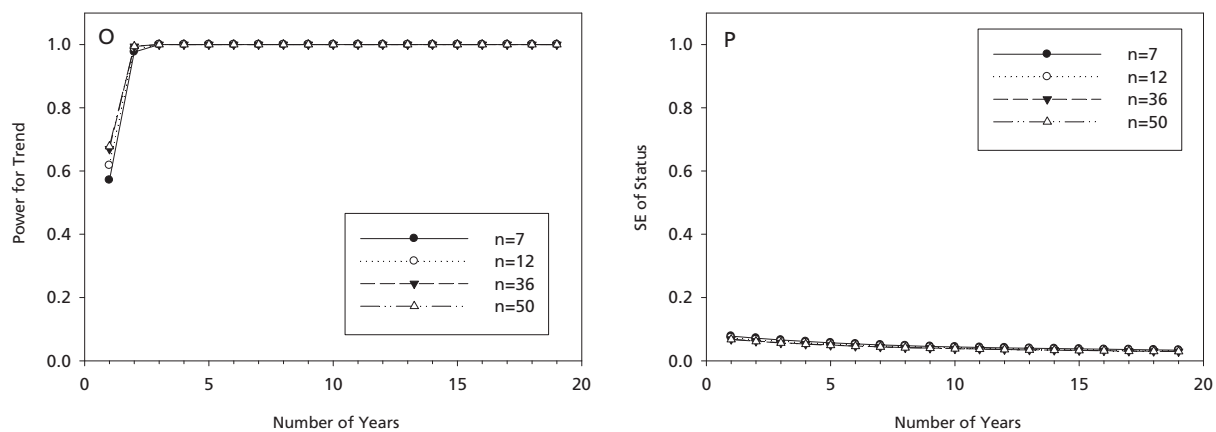


Figure A4, cont.

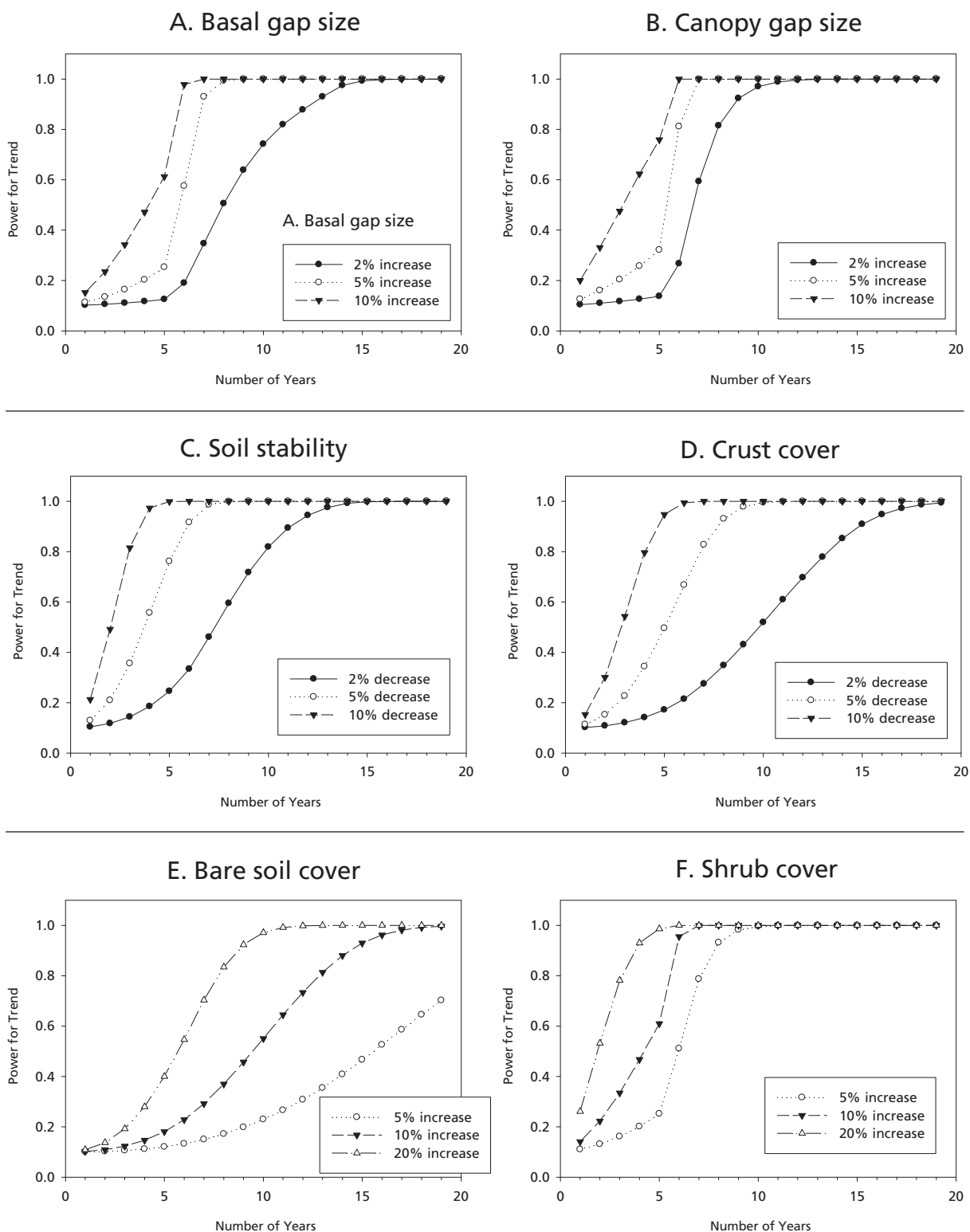


Figure A5. Power for trend for a range of annual increases or decreases in response variables at grassland ecological sites using Design 2 (Figure 3-1) and an annual sample size of 12. Responses include basal and canopy gap size, soil stability, and percent cover of biological soil crusts, bare soil, shrubs, perennial grass, and annual grass.

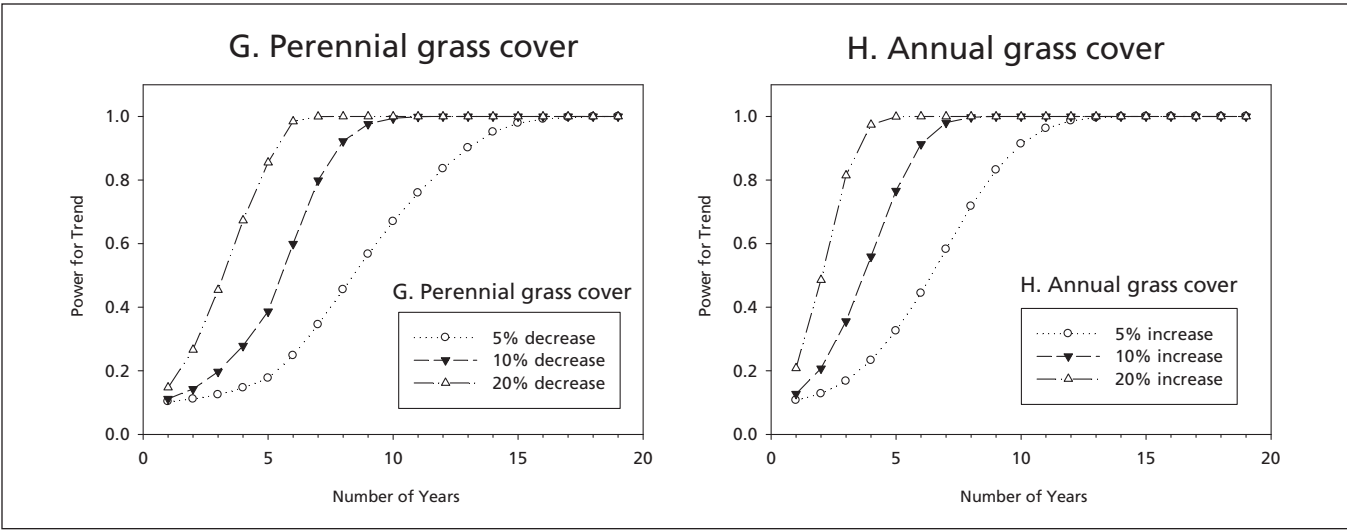


Figure A5, cont.

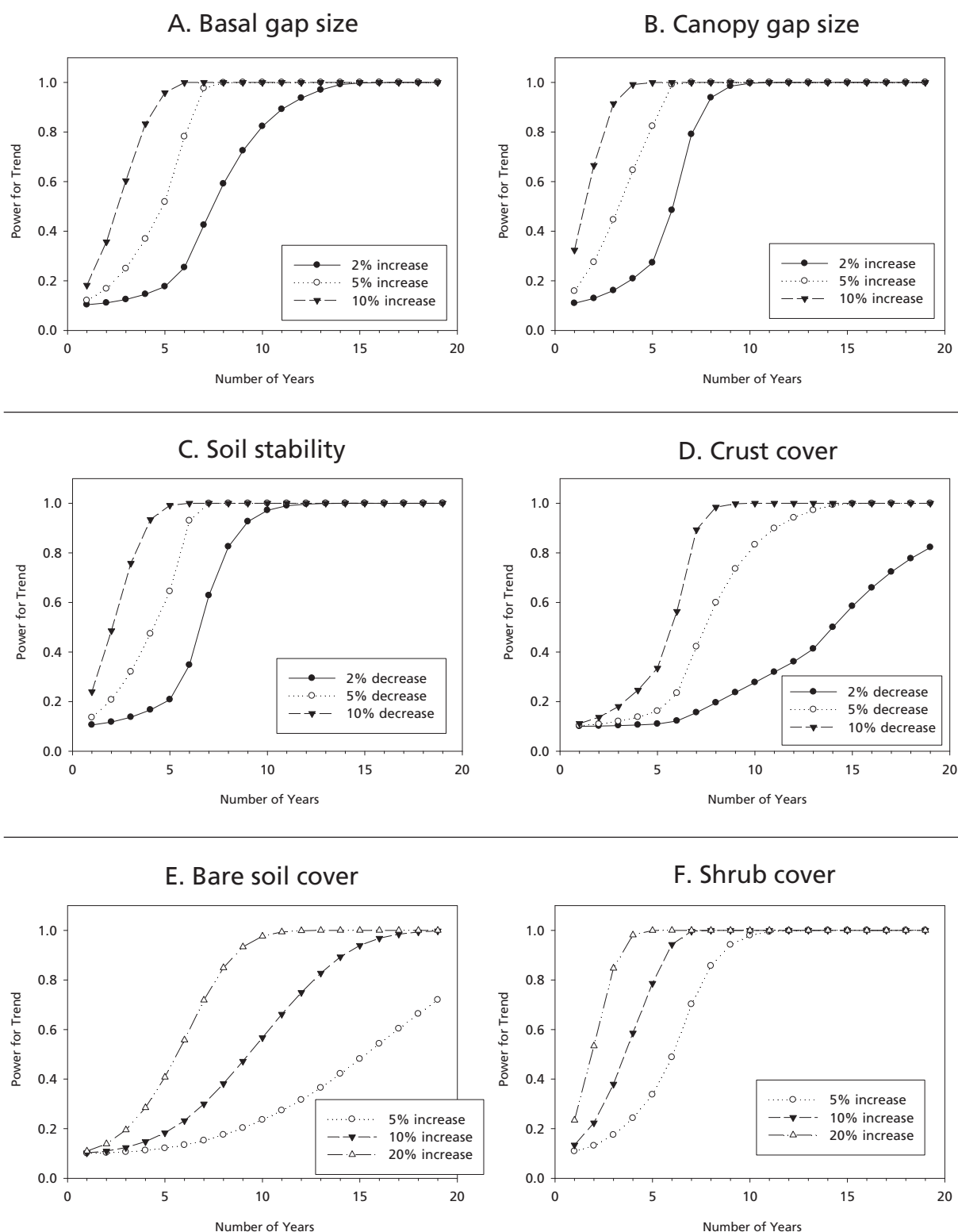


Figure A6. Power for trend for a range of annual increases or decreases in response variables at shrubland ecological sites using Design 2 (Figure 3-1) and an annual sample size of 12. Responses include basal and canopy gap size, soil stability, and percent cover of biological soil crusts, bare soil, shrubs, perennial grass, and annual grass.

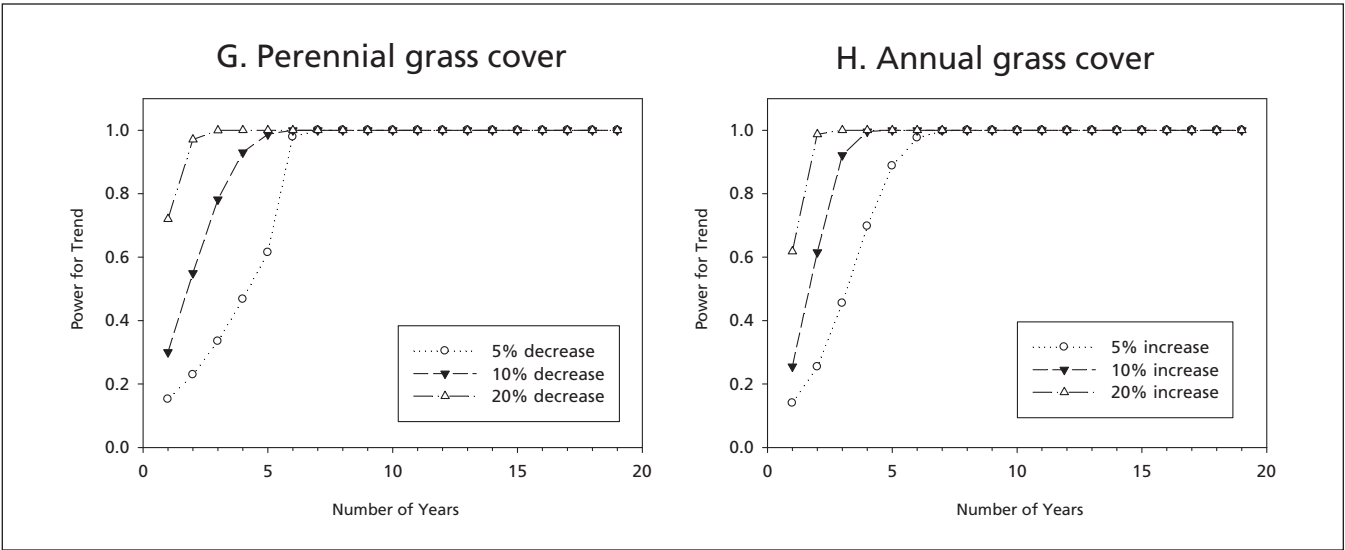


Figure A6, cont.

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NPS 164/100865, January 2010

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Natural Resource Program Center

1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

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