Distribution and Abundance of Native Grasses in the Mountains of the Sonoran Desert National Monument and Adjoining Portions of the Barry M. Goldwater Range

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ABSTRACT

Native grasses have been identified as an important conservation element in the Sonoran Desert National Monument (SDNM) and adjacent areas. In particular, it has been noted that this area has an atypically high abundance and species richness of native grasses relative to other areas in the Sonoran Desert. This study was designed to further characterize and map the native grass conservation element in the mountains of the SDNM and adjacent areas. We collected additional field data on the distribution and abundance of native grasses and conducted further analysis of both this new data and data collected in 2003. Base on this data we refined a biophysical model that can be used as a basis for creating an efficient field sampling design for the Native Grass Group. Our analysis addresses both annual and perennial native grasses. Because of the substantial differences in the phenology, growth, persistence and ecology of these two basic grass types, we analyzed each type separately.

We found significant differences in the distribution of annual and perennial native grasses. Annual native grasses are more abundant in the Maricopa Mountains, while perennial native grasses are more abundant in the Sand Tank and Table Top Mountains. Likewise, we found that annual native grasses are more abundant in the *Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes* natural community while perennial native grasses are more abundant in the *Mountain Upland* natural community. Both of these findings are probably largely due to the highly significant preference of perennial native grasses to higher elevation areas and a slight preference of annual native grasses to lower elevation areas. Besides elevation, we analyzed the relationship of other topographic variables to the abundance of the native grass types. The abundance of annual native grasses has a moderately strong relationship to northness. Two multiple linear regression equations were developed to describe the abundance of each native grass type in relationship to topographic variables. These were then implemented in a GIS environment and two spatial models were created that depict the predicted abundance of native grasses in the study area.

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Introduction

In May 2003, a workshop coordinated by The Nature Conservancy (TNC) on conservation elements of the Sonoran Desert National Monument (SDNM) identified the Native Grass Group as an important conservation element.

“The native grass group was selected as a conservation element because several of the natural communities occurring on the SDNM include an atypically high abundance and species richness of native grasses relative to other areas in the Sonoran Desert. Although the native annual and perennial grass taxa found within the monument are not individually rare, their occurrence as diverse assemblages with high cover values is regionally rare and on this basis the group is considered a regionally vulnerable conservation element.” (Hall et al 2005)

TNC, Pacific Biodiversity Institute (PBI) and others determined that further information was needed on the extent and characteristics of the native grass element. To meet this need, TNC initiated a series of contracts with PBI to gather field information and to analyze field data on native grass abundance and distribution within the SDNM and parts of the Barry M. Goldwater Range (BMGR). Native and exotic grasses that were identified during our studies in the SDNM and BMGR are listed in Table 1.

The purpose of this project was to further characterize the native grass conservation element in the mountains of the Sonoran Desert. We also refined a biophysical model that can be used as a basis for creating an efficient field sampling design for the Native Grass Group. In addition, we have identified threats and conservation needs related to the native grass conservation element as it occurs in the desert mountains.

In our analysis we address both annual and perennial native grasses. Because of the substantial differences in the phenology, growth, persistence and ecology of these two basic grass types, we have analyzed each type separately.

Table 2 defines some of the terms inherent to the questions stated in the project introduction. It also includes some of the abbreviations contained in this report.

Table 1. Grass Species Found During Our Studies

Scientific Name	Abbreviation	Common Name	Duration	Alien
Aristida adscensionis	ARIADS	sixweeks threeawn	annual	
Aristida purpurea	ARIPUR	blue three awn	perennial	
Aristida ternipes	ARITER	spidersgrass	perennial	
Bothriochloa barbinodis	BOTBAR	cane bluestem	perennial	
Bouteloua aristidoides	BOUARI	needle grama	annual	
Bouteloua barbata	BOUBAR	sixweeks grama	annual	
Bouteloua curtipendula	BOUCUR	sideoats grama	perennial	
Bouteloua gracilis	BOUGRA	blue grama	perennial	
Bouteloua repens	BOUREP	slender grama	perennial	
Bromus carinatus	BROCAR	California brome	perennial	
Bromus catharticus	BROCAT	rescuegrass	perennial	X
Bromus rubens	BRORUB	red brome	annual	X
Digitaria californica	DIGCAL	Arizona cottontop	perennial	
Eragrostis cilianensis	ERACIL	stinkgrass	annual	X
Elymus elymoides	ELYELY	squirreltail	perennial	
Enneapogon desvauxii	ENNDES	nineawn pappusgrass	perennial	
Erioneuron pulchellum	ERIPUL	fluff-grass	perennial	
Heteropogon contortus	HETCON	tangelhead	perennial	
Hordeum murinum	HORMUR	mouse barley	annual	X
Hordeum pusillum	HORPUS	little barley	annual	X
Leptochloa panicea	LEPPAN	mucronate sprangletop	perennial	
Muhlenbergia microsperma	MUHMIC	littleseed muhly	annual	
Muhlenbergia porteri	MUHPOR	bush muhly	perennial	
Panicum hirticaule	PANHIR	Mexican panicgrass	annual	
Phalaris minor	PHAMIN	canary grass	perennial	
Pleuraphis mutica	PLEMUT	tobosa grass	perennial	
Pleuraphis rigida	PLERIG	big galleta	perennial	
Poa bigelovii	POABIG	Bigelow's bluegrass	annual	
Schismus spp.	SCHISMUS	mediterranean grass	annual	X
Setaria macrostachya	SETMAC	large-spike bristlegrass	perennial	X
Setaria vulpiseta	SETVUL	plains bristlegrass	perennial	
Sporobolus cryptandrus	SPOCRY	sand dropseed	perennial	
Tridens muticus	TRIMUT	slim tridens	perennial	
Vulpia octoflora	VULOCT	sixweeks fescue	annual	

Table 2. Terms, definitions and abbreviations

Term	Definition
species composition	The total number of species occurring within a given area or spatial element (i.e. natural community). This is a measure of species diversity.
species cover	The amount of area covered by a given species' above ground live vegetated canopy within a given area or spatial element (i.e. natural community). This is measured as the percent of the total area of a particular species canopy cover divided by the total given area.
species density	The amount of individual organisms of a given species present within a given area or spatial element (i.e. natural community). This is the number of individuals divided by the total given area.
natural community	A broad ecological association as described in Hall et al 2001 and Morrison et al 2003.
SDNM	Sonoran Desert National Monument
BMGR	Barry M. Goldwater Range (US Air Force)
PVMCR	*Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes* natural community (Morrison et al 2003)
MXR	*Mountain Xeroriparian Scrub* natural community (Morrison et al 2003)
MU	*Mountain Upland* natural community (Morrison et al 2003)
RO	*Rock Outcrop* natural community (Morrison et al 2003)
ANOVA	Analysis of variance

Methods

Augmentation of Ecological Condition Survey Plots from 2003

The data collected in Phase 4 of this contract was intended to supplement data collected in Phase 2 during the spring of 2003. We used the field data collected in 2003 together with the new data collected in 2005/2006 for the analyses reported and discussed later in this report.

Stratification and Distribution of Survey Plots

Three different survey plot types, each with similar yet unique data collection protocols were developed for this project. The three plot types consisted of natural community resample plots, permanent grass monitoring plots, and non-permanent grass observation plots. The natural community and permanent grass monitoring plots were established to be permanent plots that can be re-surveyed in the future. The number and distribution of these plot types were determined by guidelines described in our project work agreement. The non-permanent grass observation plots were not set up to be permanent plots and their distribution and number were not governed by our work agreement.

In observance of our contractual obligations, field surveys were conducted twice for each permanent plot type. Initial surveys were conducted in October and November of 2005, while the second round of surveys were conducted the following March in 2006. The same protocols were followed during both survey sessions for each plot type. The permanent plots distributions were governed by the following criteria according to our work agreement:

1. We sampled across three geographic locations: Sand Tank Mountains, Table Top Mountains, and Maricopa Mountains. Approximately 1/2 of the plots were located in the Sand Tank Mountains, 1/4 in the Table Top Area and 1/4 in the Maricopa Mountains.
2. We split the samples within the Sand Tank Mountains between sites on the BMGR and sites on the SDNM. Approximately ½ of the Sand Tank plots were in the BMGR.
3. We split the sampling between new sites and sites sampled previously by Pacific Biodiversity Institute during the spring of 2003 (these are the natural community resample plots). Approximately ½ of the plots sampled were new native grass observation plots.
4. We stratified the sample locations across geographic location, natural community type, and old and new sample sites to achieve a reasonable, though not necessarily statistically valid, representation of each stratification.

Plot locations of the permanent plot types were mapped before field surveys began based on the above criteria. Plot locations were mapped manually using GIS. We incorporated natural community maps from 2003, the grass distribution model we developed in 2004, digital elevation data from USGS, land ownership maps, and BLM roads and trails maps to determine plot locations that were efficiently accessible and met the needs of our survey criteria.

The non-permanent grass observation plot locations were not stratified or designated based upon any prerequisite sampling criteria. While in the field, observers would simply attempt to conduct non-permanent plot surveys along hill slopes and ridgelines facing different aspects and at different elevations in a relatively small area. The non-permanent plots were completed as desired by field crews as they traveled overland on foot from their vehicles or base camp to the permanent plot locations.

In the end, we sampled 19 natural community vegetation plots and 17 permanent grass monitoring plots during the course of this project, for a total of 36 permanent plots. We also obtained measurements from 66 non-permanent grass observation plots. Tables 3-5 and Figure 1 illustrate the stratification and distribution of all three plot types.

We also incorporated data from the remaining Phase 2 plots which were located in the mountain areas of the SDNM and BMGR. This resulted in a total sample database of 206 plots.

Table 3. Distribution of 2005-2006 sample plots by type and mountain range

Plot Type	Sand Tank Mts	Table Top Mts	N Maricopa Mts	S Maricopa Mts
Natural Community Resample Plot	11	3	1	4
Permanent Grass Monitoring Plot	7	6	2	2
Non-Permanent Grass Observation Plot	15	3	40	8

Table 4. Distribution of 2005-2006 sample plots by type and land management agency (note: the BLM is now the manager of Area A, which was part of the BMGR)

Plot Type	BMGR	SDNM
Natural Community Resample Plot	5	14
Permanent Grass Monitoring Plot	4	13
Non-Permanent Grass Observation Plot	10	56

Table 5. Distribution of 2005-2006 sample plots by type and natural community

Plot Type	Mountain Upland	Paloverde - Mixed Cactus - Mixed Shrub on Rocky Slopes
Natural Community Resample Plot	6	13
Permanent Grass Monitoring Plot	8	9
Non-Permanent Grass Observation Plot	5	61

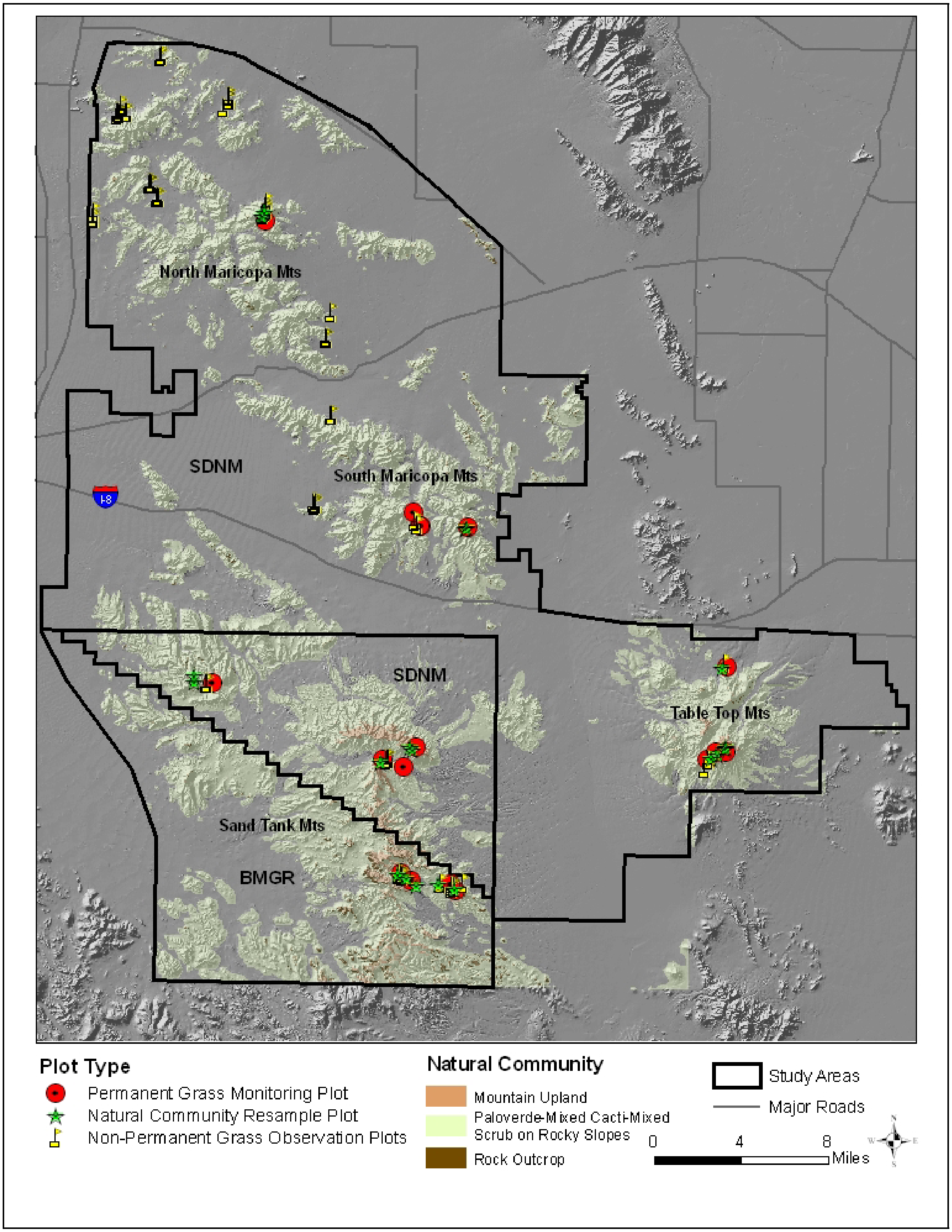

Figure 1. Distribution of plots sampled during the 2005 and 2006 field seasons.

Data Collection Methods of Survey Plots

Natural Community Resample Plots

Nineteen natural community resample plots were surveyed during this project. We incorporated the same methodology we developed in 2003 to re-inventory these plots (Morrison et al., 2003). We used GPS units to guide us to the plot locations, where the permanent plot center was marked with a steel rebar pole. The GPS coordinates for the plot were useful to guide us to the approximate location; however the accuracy of the coordinates were often not better than 10 meters in the steep mountainous terrain. From the location indicated by the GPS, we then used plot photographs, taken during the 2003 surveys to find the exact plot center. Using this method, we were able to relocate the rebar stake at the center of all of the resample plots. From the plot center, we measured out the circular boundary of the plot at 12.5 meters radius. The boundary was marked with survey flags and/or flagging tape. We used higher precision GPS units to capture a more accurate location for the plot center using waypoint averaging methods. This enabled us to obtain GPS plot centers with a locational accuracy between 1 and 4 meters.

Photo 1. Measuring plot boundary on a steep, rocky mountain slope.

Once the plot boundary was established, we took notes and measurements on the character of the substrate, including information about the surficial geology type and the dominant soil aggregate size. We estimated to the nearest percent the cover of different groups of abiotic and non-living plant or animal material. We recorded slope and aspect for the plot using a compass and inclinometer. We also recorded the presence of any apparent site disturbances or activities that had impacted the soil or the living plants, including fire, flooding, and livestock activity.

Photos were also taken at each plot location. At the very least, four photos were taken from just behind plot center aiming toward plot center in the cardinal directions.

Lastly, we estimated the total percent of the plot's area covered by each identifiable vascular plant species. This included all plant types, from spike mosses to trees. As a result, we ended up with a total vascular plant species inventory for each natural community plot, along with percent canopy cover estimates for each species present.

Appendix A contains an example of the natural community resample plot form.

During our fieldwork we used numerous botanical references to aid in the identification and verification of plant species encountered in natural community plots. These references include Baldwin et al (2002), Benson and Darrow (1981), Benson (1969), Felger (2000), Kearney and Peebles (1960), Turner et al (1995), Turner et al (2000), Hickman (1993), Epple and Epple (1995), Earle (1980), Jaeger (1941), and Arizona Rare Plant Committee (no date).

Photo 2. Identifying grass species in the field.

New Permanent Native Grass Monitoring Plots

Seventeen new permanent native grass monitoring plots were surveyed during this project. The field data collection methods for this plot type were similar to the natural community resample plots. Because these plots were new, we had to set new permanent rebar stakes into the plot centers to aide in locating the exact plot centers for future surveying. We used WAAS enabled GPS units (Garmin GPS 60) to capture a more accurate location for the plot center using waypoint averaging methods. This enabled us to obtain GPS plot centers with a locational accuracy between 1 and 4 meters. Photos were also taken at each plot location. At the very least, four photos were taken from just behind plot center aiming toward plot center in the cardinal directions.

The plot size and data collected were exactly the same as with the natural community resample plots, excluding the canopy cover estimates by individual species. Instead of a full species inventory, we only estimated total canopy cover of the plot by species for plants in the grass family. All other vascular plants' canopy cover was estimated by life form groups, consisting of the categories of trees, shrubs and vines, herbs – spike mosses and ferns, and cacti. All plant species with dominant cover within the plot were noted in the notes section of the survey form.

Appendix B contains an example of the new permanent native grass monitoring plot forms.

Non-Permanent Grass Observation Plots

Sixty-six non-permanent grass observation plots were surveyed during this project. These were called "quick plots" and designed to collect additional data on grass distributions as we moved from one permanent plot to another. As stated earlier, the location and distribution of these plots were determined by surveyors in the field, and no GIS data or prerequisite criteria were used in determining these sites. On a given day, a surveyor might complete two to six of these quick plots. The surveyor would attempt to place plots in a given area on slopes of different aspects and at different elevations. Figure 2 illustrates the placement of non-permanent quick grass observation plots in the North Maricopa Mountains directly south of Plug Tank.

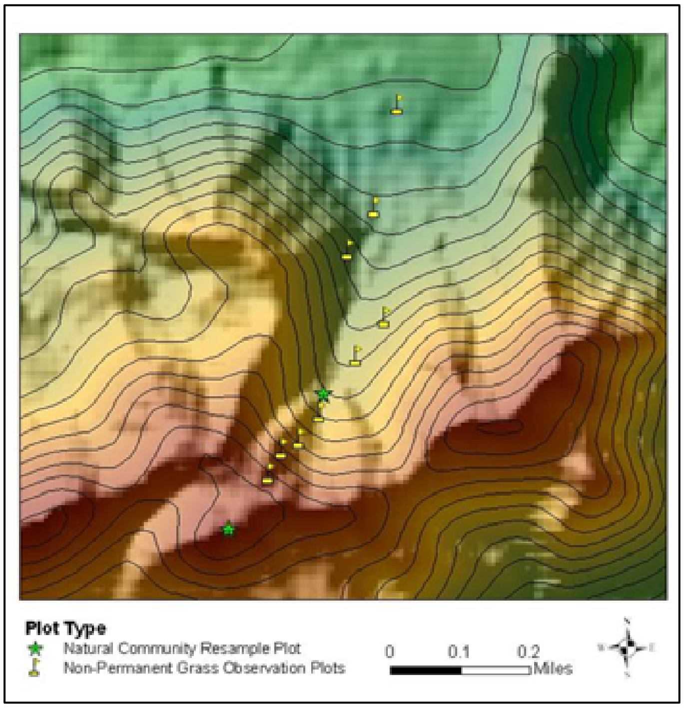

Figure 2. Detailed example of location of field plots established in 2005 in the North Maricopa Mountains.

The data collected in these types of plots was very similar to the permanent native grass observation plots, though in an abbreviated form. The plot center was simply marked with a backpack or GPS unit, and a GPS waypoint was taken at that point. The observer then estimated the plot boundary, which mimicked the project standard 12.5 meter radius circle. Within the observation area we recorded measurements such as canopy cover by growth form and percent native and exotic grass cover within the plot. Appendix C contains an example of the native grass quick plot forms.

Development of a biophysical model to predict native grass distribution and abundance in the mountains of the study area

To develop a native grass abundance biophysical model, we conducted a literature review, undertook extensive data exploration, developed a regression model, and translated the regression model into a spatial model.

Literature Review

First, we conducted a literature review of native grasses and their distributions to find out which variables, if any, other scientists had found to be correlated with native grass cover. Although there were a number of papers that referred to various native grasses, we found only one paper that was available in the ASU library system, and that related cover of some species of native grasses that are found in the SDNM, with biophysical variables.

Mata-Gonzalez et al. (2002) conducted a vegetation study on a low mountain (Mt. Summerford) in the Basin and Range country of southern New Mexico. In their study they found 3 species of native grass that also occur on the SDNM: *Bouteloua curtipendula, Muhlenbergia porteri,* and *Aristida ternipes.* They describe their findings as follows:

> "Grass cover was affected by the interaction of elevation and aspect. On the E aspect grass cover decreased significantly as elevation increased, but on the W aspect, in contrast, grass cover increased significantly as elevation increased. At the lowest elevation, E and N exposures had higher grass cover than S and W exposures. At the intermediate elevations, the N aspect supported higher grass cover than the other 3 aspects and the lowest grass cover was found in the S aspect. The differences between the EN and SW aspects were more marked at the lower parts of the mountain and these differences faded near the top of the mountain."

Investigation of Native Grass Distribution and Abundance in Relation to Topographic Variables

The second step of biophysical model development was to explore the relationship between native grass abundance and topographic variables. The topographic variables that we explored were elevation, slope steepness, slope aspect, slope profile curvature, and slope planform curvature. Profile curvature is the curvature of the surface in the direction of slope. Planform curvature is the curvature of the surface perpendicular to the slope direction.

In order to use the plot **aspect** (direction of slope) variable in linear regressions, we converted this to two separate continuous variables, eastness and northness, as follows (Zar 1999):

Eastness = sin ((aspect in degrees * PI)/180)
Northness = cos ((aspect in degrees * PI)/180)

Northness quantifies the degree to which an aspect is north, and eastness, the degree to which it is east. For example, northness for an angle of 360 degrees is 1, for 90 degrees is 0, and 180 degrees is –1.

We used Arc/INFO Grid to create the various topographic analysis layers from a 10-meter resolution digital elevation model (DEM) of the study area obtained from the US Geological Survey. After these layers were developed, we queried the spatial topographic layers, using an Arc/INFO AML to determine the appropriate topographic variables for each plot.

The advantage of using a 10-meter DEM is the high spatial resolution. But a disadvantage is that factors such as slope curvature or slope steepness may change in a very short distance and the grid value at any one specific location may not be representative of the environmental conditions affecting the ecology plot. Therefore, we developed more generalized slope steepness, curvature and northness/eastness layers by creating additional grids where the original grid values were smoothed with 3 and 5 cell moving circular focal windows. The FOCALMEAN function in

Arc/INFO Grid was used to accomplish this. These values were also obtained for each plot and added to the plot attribute database.

The plot attribute database was then imported into Microsoft Excel for further processing and analysis. We used the Analyze-It extension to Excel (www.analyse-it.com) to explore the data and conduct statistical analyses.

Results

In our earlier studies of native grasses in the SDNM (Snetsinger and Morrison 2004) we looked at the distribution of native grass cover across all communities and within each community to evaluate whether the 5% threshold for native grass cover suggested by The Nature Conservancy was reasonable in differentiating areas of high grass cover on the Monument. Through our analyses in 2004, we decided that 5% was a meaningful breaking point. In the current study we also looked at the distribution of perennial native grass cover in all mountain plots (2003 and 2005/2006) (Figure 3). As it did in our earlier study, it is apparent that most of the plots have less than 5% cover of perennial native grass; while a smaller fraction (17%) have native perennial grass cover over 5%. This subset of plots represents samples of the native grass conservation element discussed above.

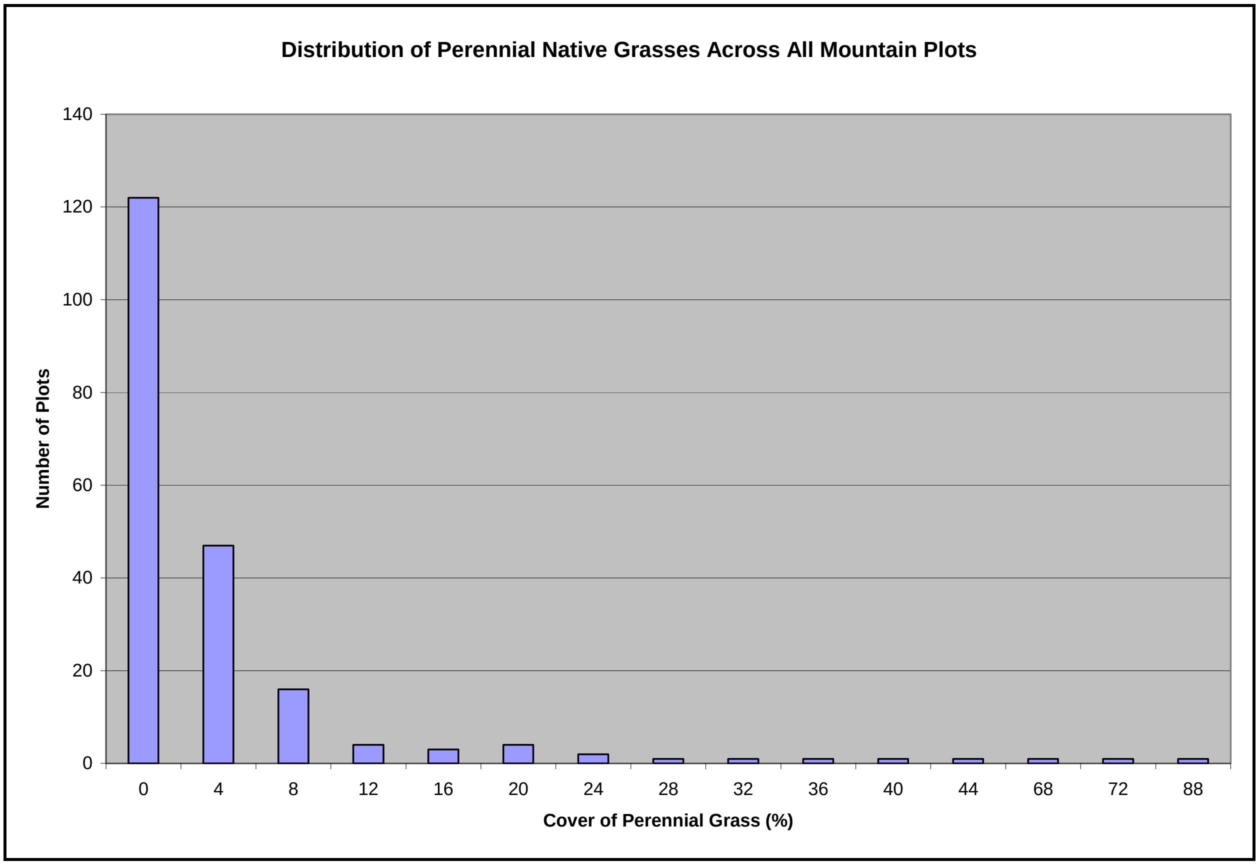

Figure 3. Distribution of perennial native grass cover across all mountain plots sampled in 2003, 2005 and 2006.

Distribution and abundance of native grass cover across the natural communities in the mountains of the study area

We analyzed the distribution and abundance of native grasses in the four natural communities that are found in the mountains of the study area. These natural communities are:

- *Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes* (PVMCR)
- *Mountain Xeroriparian Scrub (*MXR)
- *Mountain Upland* (MU)
- *Rock Outcrop* (RO)

Detailed descriptions of these communities can be found in reports by Morrison (2003) and Morrison et al (2003). We found that the MU community had by far the greatest amount of perennial native grass (Table 6, Figure 4). The difference between this community and the other mountain communities was also highly significant (Table 7). The differences between the other community types and each other was not statistically significant.

Table 6. Comparison of perennial native grass cover in various natural communities occurring in the Sonoran Desert mountains.

Test	Comparative descriptives				
	Mountain Grass Analysis - Topographic Combinations				
Variables	PERENNIAL by NATURAL COMMUNITY				
PERENNIAL by NATCOMM	n	Mean	SD	SE	95% CI of Mean
MU	45	13.161	20.8684	3.1109	6.892 to 19.431
MXR	16	2.578	5.1734	1.2934	-0.179 to 5.335
PVMCR	138	1.447	4.1758	0.3555	0.745 to 2.150
RO	7	0.679	1.1611	0.4389	-0.395 to 1.752

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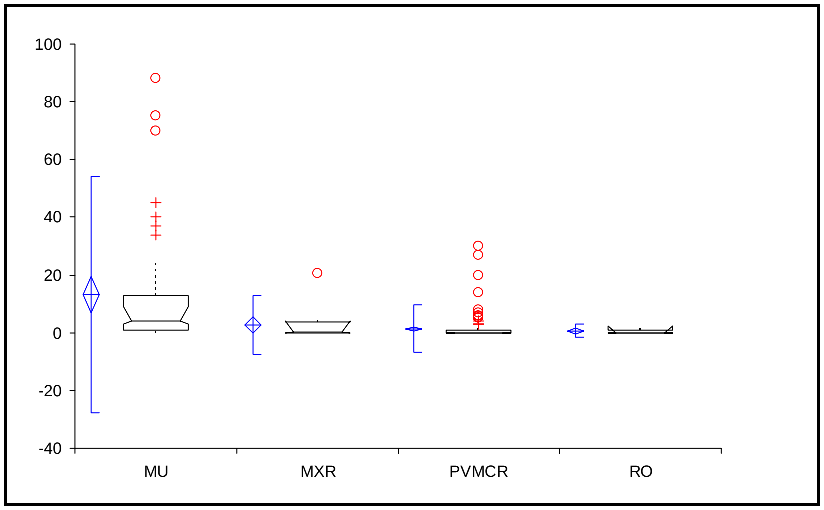

Figure 4. Distribution of all plots by natural community and percent cover of perennial native grass

Table 7. ANOVA of perennial native grass cover in various natural communities occurring in the Sonoran Desert mountains.

Test	**1-way between subjects ANOVA**
	Mountain Grass Analysis - Topographic Combinations
Comparison	PERENNIAL by NATCOMM: MU, MXR, PVMCR, RO

n	206

PERENNIAL by NATCOMM	**n**	**Mean**	**SD**	**SE**
MU	45	13.161	20.868	3.1109
MXR	16	2.578	5.173	1.2934
PVMCR	138	1.447	4.176	0.3555
RO	7	0.679	1.161	0.4389

Source of variation	**SSq**	**DF**	**MSq**	**F**	**p**
NATCOMM	4784.418	3	1594.806	14.67	<0.0001
Within cells	21960.005	202	108.713		
Total	26744.424	205			

Contrast	**Difference**	**Scheffe 95% CI**		
MU v MXR	10.583	2.027	to 19.139	(significant)
MU v PVMCR	11.714	6.668	to 16.760	(significant)
MU v RO	12.483	0.540	to 24.426	(significant)
MXR v PVMCR	1.131	-6.632	to 8.894	
MXR v RO	1.900	-11.421	to 15.220	
PVMCR v RO	0.769	-10.619	to 12.157	

Based on this comparison of mean values of perennial native grasses in the sample plots (Table 6, Figure 4) and the ANOVA results of perennial grass cover by community type (Table 7), we determined the following:

- First, we determined that there are significant differences in the abundance of perennial grasses between some of MU plots and plots in all the other mountain community types. Perennial native grasses were six times more abundant in the mountain uplands than in any other community.
- Second, we determined that the MXR, PVMCR and RO plots were not significantly different from each other, which is not surprising since they occur in the same portion of the landscape and all contain high amounts of rock.
- Third, we determined that the Rocky Outcrop natural communities had very low abundance of perennial grass. Native grass abundance did not pass our 5% threshold. Therefore, we dropped the plots in this community from further analysis and native grass abundance was not modeled in these communities.
- Fourth, we confirmed our previous results (Snetsinger and Morrison 2004) that nearly all the areas of high native grass abundance occur in the *Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes* and *Mountain Upland* natural communities. The exception to this was the Mountain Xeroriparian Scrub community which may also have moderate

perennial native grass abundance in certain locations. Sample plots in these communities were the subject of all our subsequent analyses.

We did not find any statistically significant difference between abundance of annual native grasses in the four different mountain communities (Tables 8 and 9, Figure 5). The abundance of annual native grasses was very low on the rock outcrops, but apparently, this difference wasn't significant when compared to other communities even using the least stringent comparison test (LSD). The lack of statistical significance may be due to the low number of plots that were placed on rock outcrops.

Table 8. Comparison of annual native grass cover in various natural communities occurring in the mountains of the Sonoran Desert National Monument.

Test	**Comparative descriptives**
	Mountain Grass Analysis - Topographic Combinations
Variables	ANNUAL by NATCOMM
Performed by	Peter Morrison

ANNUAL by NATCOMM	**n**	**Mean**	**SD**	**SE**	**95% CI of Mean**	
MU	45	2.411	2.5029	0.3731	1.659	to 3.163
MXR	16	3.859	3.7561	0.9390	1.858	to 5.861
PVMCR	138	3.699	5.3338	0.4540	2.801	to 4.597
RO	7	0.286	0.4661	0.1762	-0.145	to 0.717

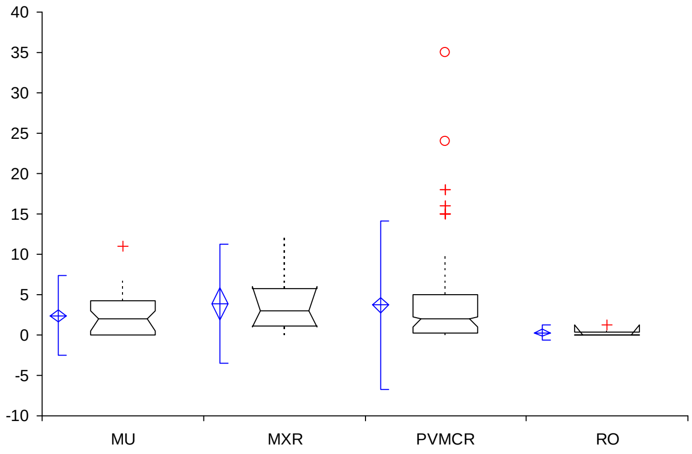

Figure 5. Distribution of all plots by natural community and percent cover of annual native grass

Table 9. ANOVA of annual native grass cover in various natural communities occurring in the Sonoran Desert mountains.

Test	**1-way between subjects ANOVA**
	Mountain Grass Analysis - Topographic Combinations
Comparison	ANNUAL by NATCOMM: MU, MXR, PVMCR, RO
n	206

ANNUAL by NATCOMM	n	Mean	SD	SE
MU	45	2.411	2.503	0.3731
MXR	16	3.859	3.756	0.9390
PVMCR	138	3.699	5.334	0.4540
RO	7	0.286	0.466	0.1762

Source of variation	SSq	DF	MSq	F	p
NATCOMM	126.121	3	42.040	1.94	0.1249
Within cells	4386.089	202	21.713		
Total	4512.210	205			

Contrast	Difference	LSD 95% CI
MU v MXR	-1.448	-4.123 to 1.226
MU v PVMCR	-1.288	-2.865 to 0.289
MU v RO	2.125	-1.608 to 5.858
MXR v PVMCR	0.160	-2.266 to 2.587
MXR v RO	3.574	-0.590 to 7.737
PVMCR v RO	3.414	-0.146 to 6.973

Distribution and abundance of native grass cover across the three mountain ranges in the study area

There was a distinctive difference between the perennial native grass composition within the three major mountain ranges we sampled (Table 10, Figure 6). The plots within the Table Top Mountains had the most perennial grass (mean 10.6% cover) followed by the Sand Tanks (5.5%). The plots in the Maricopa Mountains had much less grass (mean 0.3% cover) than the two southern mountain ranges. These results were statistically significant (Table 11). But the difference between the Sand Tanks and Table Top was not significant in three of the most stringent comparison tests that we ran (Tukey, Scheffe and Bonferroni). Only in the LSD comparison test was there a significant difference between the Sand Tanks and Table Top Mts. It is important to note that due to restrictions in total sample size based on what we were able to accommodate within our contract budget, we did not sample as extensively in the Table Top area, hence more of our plots were located near the top of the mountain where grasses are most abundant. This factor likely explains the apparent difference between the Table Top Mountains and the Sand Tanks. Based on the lack of significance according to the stringent comparison tests and the possible bias built into the Table Top Mountains plot distributions, we consider the Table Top locations to be very similar to what is occurring in the Sand Tanks. But the difference between both Table Top and the Sand Tanks compared with the Maricopa Mountains is very real. It was highly significant in all three of the stringent comparison tests and this result is useful in building a predictive model for perennial native grasses.

Table 10. Comparison of perennial native grass cover in three mountain ranges of the study area.

Test	**Comparative descriptives**
	Mountain Grass Analysis - Topographic Combinations
Variables	PERENNIAL by MTNRANGE

PERENNIAL by MTNRANGE	n	Mean	SD	SE	95% CI of Mean
Maricopas	84	0.330	1.1701	0.1277	0.076 to 0.584
Sand Tanks	82	5.540	11.2350	1.2407	3.071 to 8.008
TableTop	33	10.644	20.5699	3.5808	3.350 to 17.938

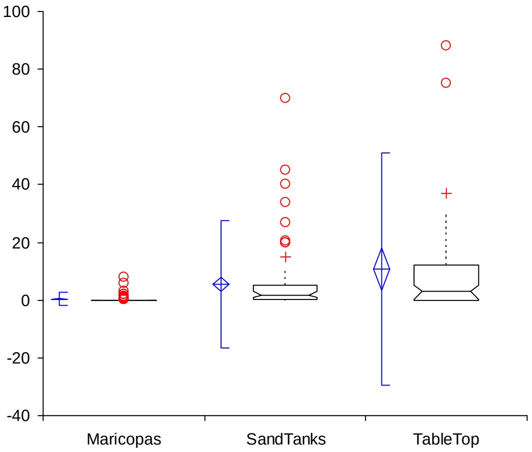

Figure 6. Perennial native grass cover (y axis) of all mountain plots in relationship to the three mountain ranges.

Table 11. ANOVA of perennial native grass cover in three mountain ranges of the study area.

Test	**1-way between subjects ANOVA**
	Mountain Grass Analysis - Topographic Combinations
Comparison	PERENNIAL by MTNRANGE: Maricopas, SandTanks, TableTop
n	199

PERENNIAL by MTNRANGE	n	Mean	SD	SE
Maricopas	84	0.330	1.170	0.1277
SandTanks	82	5.540	11.235	1.2407
TableTop	33	10.644	20.570	3.5808

Source of variation	SSq	DF	MSq	F	p
MTNRANGE	2775.257	2	1387.629	11.39	<0.0001
Within cells	23877.833	196	121.826		
Total	26653.090	198			

Contrast	Difference	LSD 95% CI	
Maricopas v SandTanks	-5.209	-8.588 to -1.830	(significant)
Maricopas v TableTop	-10.314	-14.786 to -5.842	(significant)
SandTanks v TableTop	-5.104	-9.592 to -0.617	(significant)

Annual native grasses do not show the same pattern as perennial native grasses. In fact, their abundance is actually greatest in the Maricopa Mountains (Table 12, Figure 7). But the difference between mountain ranges is only significant between Table Top and the Maricopas (Table 13). This significance shows up in all four comparison tests (Tukey, Scheffe, Bonferroni and LSD). The difference between mountain ranges in annual native grass cover can probably be explained by the preference for annuals to occupy lower elevation habitats, which are more abundant in the lower Maricopa Mountains. The most common native annual grass, *Vulpia octoflora*, sometimes occurs in considerable abundance on the lower mountain slopes and comprises the majority of the native annual grass cover.

Table 12. Comparison of annual native grass cover in three mountain ranges of the study area.

Test	**Comparative descriptives**
	Mountain Grass Analysis - Topographic Combinations
Variables	ANNUAL by MTNRANGE

ANNUAL by MTNRANGE	**n**	**Mean**	**SD**	**SE**	**95% CI of Mean**
Maricopas	84	4.292	5.7681	0.6293	3.040 to 5.543
SandTanks	82	3.201	3.9531	0.4365	2.333 to 4.070
TableTop	33	1.750	2.8360	0.4937	0.744 to 2.756

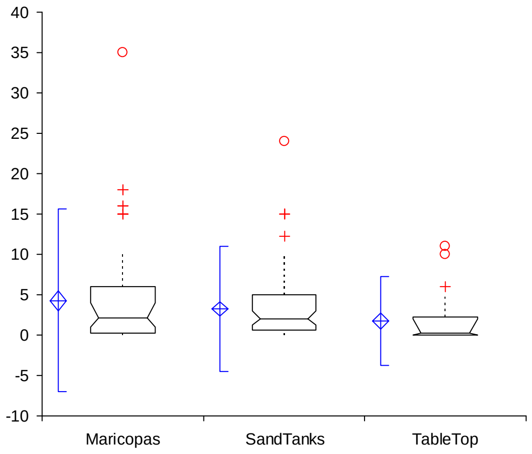

Figure 7. Perennial annual grass cover (y axis) of all mountain plots in relationship to the three mountain ranges.

Table 13. ANOVA of annual native grass cover in the three mountain ranges of the study area.

Test	**1-way between subjects ANOVA**
	Mountain Grass Analysis - Topographic Combinations
Comparison	ANNUAL by MTNRANGE: Maricopas, SandTanks, TableTop
n	199

ANNUAL by MTNRANGE	n	Mean	SD	SE
Maricopas	84	4.292	5.768	0.6293
SandTanks	82	3.201	3.953	0.4365
TableTop	33	1.750	2.836	0.4937

Source of variation	SSq	DF	MSq	F	p
MTNRANGE	159.782	2	79.891	3.65	0.0277
Within cells	4284.659	196	21.861		
Total	4444.441	198			

Contrast	Difference	Tukey 95% CI	
Maricopas v SandTanks	1.090	-0.624 to 2.805	
Maricopas v TableTop	2.542	0.273 to 4.810	(significant)
SandTanks v TableTop	1.451	-0.825 to 3.728	

Relationship between topographic variables and native grass cover

After exploring the relationships between natural community, mountain range and native grass cover, we explored the relationships between native grass cover and topographic variables of elevation, slope steepness, slope aspect, slope profile curvature, and slope planform curvature. It is a well know fact that vegetation often responds to these topographic variables, since these variables can control temperature, moisture, soil depth and solar radiation levels upon which plants depend. We analyzed perennial native grass cover and annual native grass cover separately, as their growth, persistence and habitat requirements are quite different.

We found that the main topographic variable that affects perennial native grass cover is elevation. There is a significant positive correlation between elevation and perennial native grass cover. A linear regression analysis of all the mountain plots (excluding the Rocky Outcrop Plots) indicated the relationship was highly significant with an adjusted R squared value of 0.17 and P value of <0.0001 (Table 14, Figure 8).

Table 14. Linear regression of perennial native grass cover vs. plot elevation.

Test	Linear regression
	Mountain Grass Analysis - Topographic Combinations
Fit	PERENNIAL v ELEVATION
n	199
R^2	0.17
Adjusted R^2	0.17
SE	10.5865

Term	Coefficient	SE	p	95% CI of Coefficient	
Intercept	-10.0807	2.3560	<0.0001	-14.7270	to -5.4345
Slope	0.0058	0.0009	<0.0001	0.0040	to 0.0075

Source of variation	SSq	DF	MSq	F	p
Due to regression	4574.377	1	4574.377	40.82	<0.0001
About regression	22078.713	197	112.075		
Total	26653.090	198			

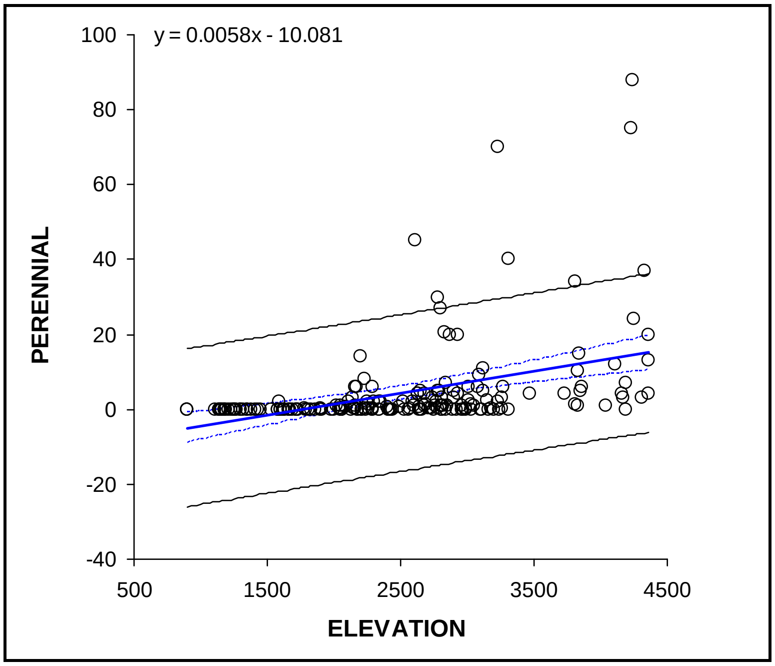

Figure 8. Perennial native grass cover in relationship to elevation with regression line.

Annual native grass cover did not show as strong a relationship with elevation (Table 15, Figure 9). There was only a weak negative correlation with an adjusted R square value of 0.03 and a P value of 0.0137. It is interesting to note that the relationship is slightly reversed from that demonstrated for perennial grasses. More annual native grasses are found at lower elevations and more perennial native grasses at higher elevations, but this is a very weak relationship.

Annual native grass cover did show a significant relationship with northness (Table 15, Figure 9).

Table 15. Linear regression of annual native grass cover vs. plot elevation.

Test	**Linear regression**
	Mountain Grass Analysis - Topographic Combinations
Fit	ANNUAL v ELEVATION
n	199

R^2	0.03
Adjusted R^2	0.03
SE	4.6770

Term	**Coefficient**	**SE**	**p**	**95% CI of Coefficient**	
Intercept	5.8743	1.0409	<0.0001	3.8217	to 7.9270
Slope	-0.0010	0.0004	0.0137	-0.0018	to -0.0002

Source of variation	**SSq**	**DF**	**MSq**	**F**	**p**
Due to regression	135.262	1	135.262	6.18	0.0137
About regression	4309.179	197	21.874		
Total	4444.441	198			

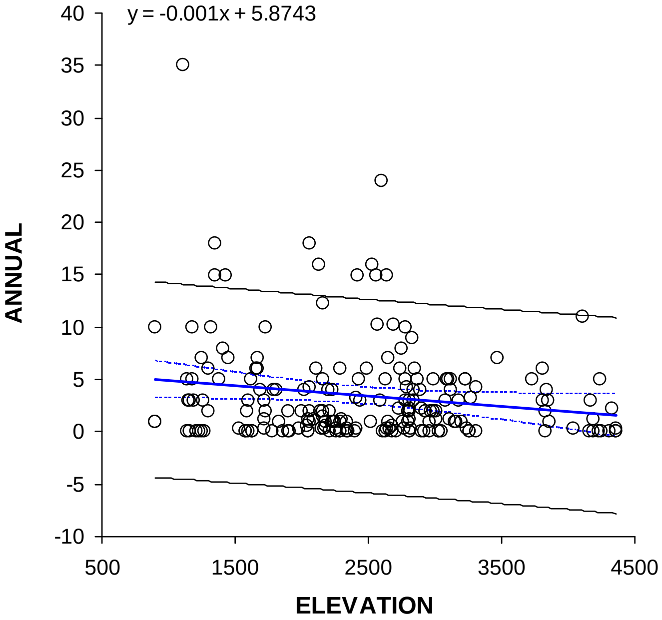

Figure 9. Annual native grass cover in relationship to elevation with regression line.

Table 16. Linear regression of annual native grass cover vs. plot northness.

Test	**Linear regression**				
	Mountain Grass Analysis - Topographic Combinations				
Fit	ANNUAL v NORTHNESS30				
n	199				
R^2	0.13				
Adjusted R^2	0.12				
SE	4.4405				
Term	**Coefficient**	**SE**	**p**	**95% CI of Coefficient**	
Intercept	2.7915	0.3362	<0.0001	2.1284	to 3.4545
Slope	2.4855	0.4664	<0.0001	1.5656	to 3.4053
Source of variation	**SSq**	**DF**	**MSq**	**F**	**p**
Due to regression	559.900	1	559.900	28.39	<0.0001
About regression	3884.541	197	19.718		
Total	4444.441	198			

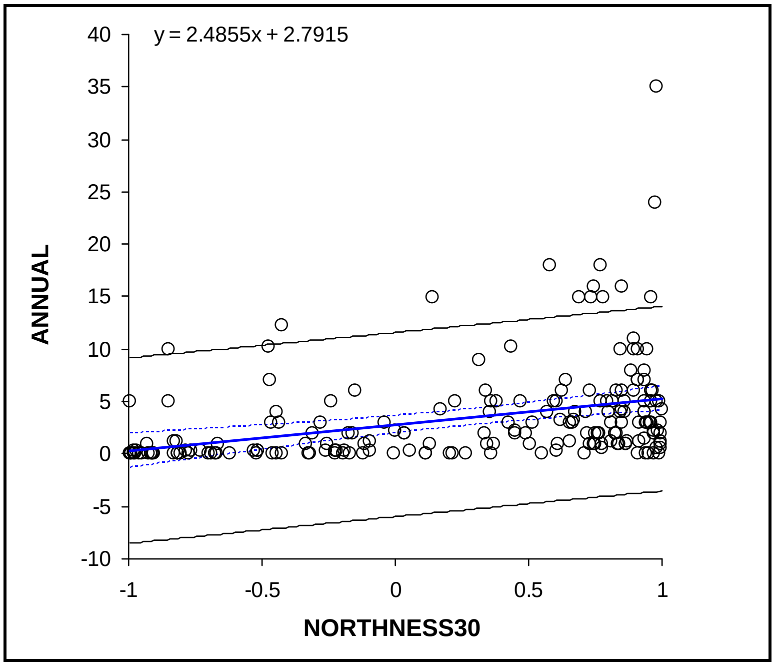

Figure 10. Annual native grass cover in relationship to northness with regression line.

Development of the perennial native grass biophysical model

The relationship between perennial native grass cover and the other topographic variables was explored. Elevation was the primary topographic variable that showed a fairly strong correlation to perennial grass cover. No other topographic variable showed a strong correlation to perennial native grass cover. Several topographic variables showed weak relationships. These included slope, profile curvature and northness. For all three of these topographic variables the strongest relationship was with the smoothed topographic grids created by the 30 meter circular focal mean GIS process. These variables were then used to develop a multiple linear regression formula. Three outlier values were also removed from the dataset and 14 high perennial cover values were truncated to improve the linear regression fit. The results of this multiple linear regression analysis are presented in Table 17 and Figure 11. The adjusted R square value of the multiple linear regression fit is 0.35 and an overall P value of < 0.0001. But only the elevation variable is highly significant, with lower significance for profile curvature (PROCURVE30), slope (SLOPE30). Northness (NORTHNESS30) surprisingly had a dubiously significant relationship with perennial grass cover (P = 0.2060).

Table 17. Multiple linear regression analysis of perennial native grass cover vs. four topographic variables.

Test	**Multiple linear regression**				
	Mountain Grass Analysis - Topographic Combinations				
Fit	Perennial - Truncated v GISELEV, SLOPE30M, NORTHNESS30, PROCURVE30				
n	196	(cases excluded: 3 due to missing values)			
R^2	0.37				
Adjusted R^2	0.35				
SE	3.4759				
Term	**Coefficient**	**SE**	**p**	**95% CI of Coefficient**	
Intercept	-5.0967	0.9332	<0.0001	-6.9374	to -3.2559
GISELEV	0.0110	0.0011	<0.0001	0.0089	to 0.0131
SLOPE30M	-0.0570	0.0279	0.0422	-0.1121	to -0.0020
NORTHNESS30	0.4860	0.3830	0.2060	-0.2694	to 1.2415
PROCURVE30	1.3232	0.4799	0.0064	0.3765	to 2.2698
Source of variation	**SSq**	**DF**	**MSq**	**F**	**p**
Due to regression	1330.737	4	332.684	27.54	<0.0001
About regression	2307.573	191	12.082		
Total	3638.310	195			

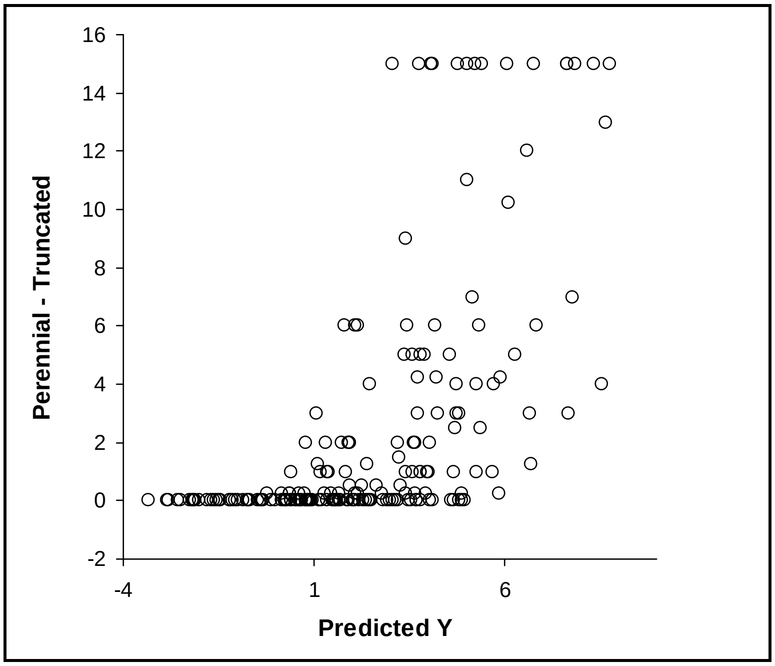

Figure 11. Perennial grass cover vs. predicted Y values from multiple linear regression analysis of perennial native grass cover vs. four topographic variables.

We built a GIS model to implement the following linear regression formula as suggested by the above multiple linear regression analysis:

> **Predicted Abundance of Perennial Grass = -5.0967 + 0.0110* GISELEV + -0.0570 * SLOPE30M + 0.4860 * NORTHNESS30 + 1.3232* PROCURVE30**

This formula was implemented in ArcGIS Model Builder to facilitate implementation and potential future modifications (Figure 12). A GIS layer of predicted perennial grass abundance was produced through this process. This GIS layer was reclassed into 13 discrete classes using a one-standard deviation reclassification method. The resulting reclassified GIS dataset, of predicted native perennial grass abundance, is displayed in Figures 13 and 14. Dataset values of 12 or higher indicate areas with higher probabilities of containing native perennial grass abundance equal to or exceeding 5% cover. The areas with values of 11 represent areas with a moderate probability of containing native perennial grass abundance equal to or exceeding 5% cover. The areas with values of 8 to 10 represent areas with a low probability of containing native perennial grass abundance equal to or exceeding 5% cover. And the areas with values of 7 or less represent areas with a very low (approaching zero) probability of containing native perennial grass abundance equal to or exceeding 5% cover.

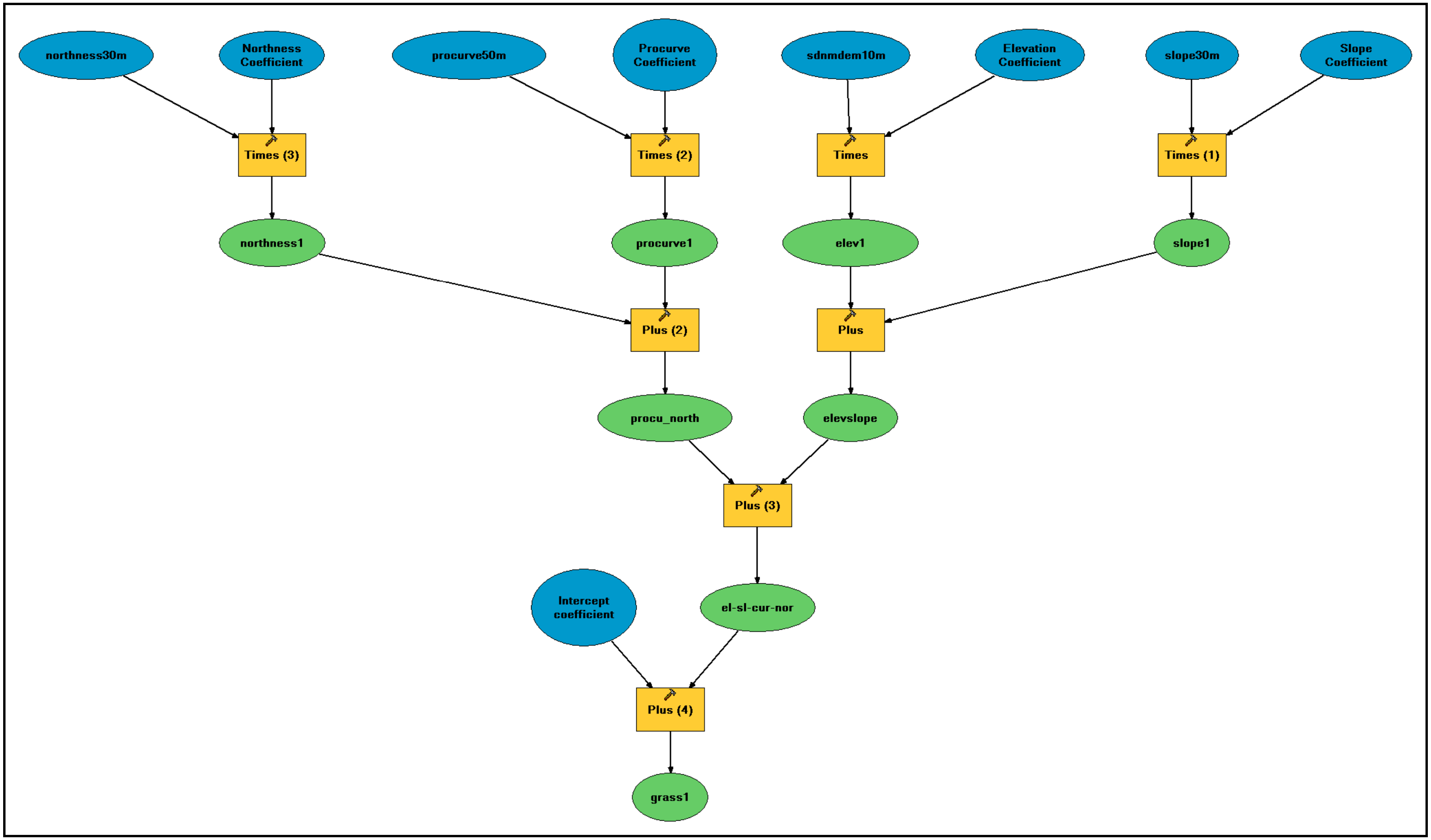

Figure 12. Diagram of predictive model for perennial native grasses in study area as implemented in ArcGIS using Model Builder.

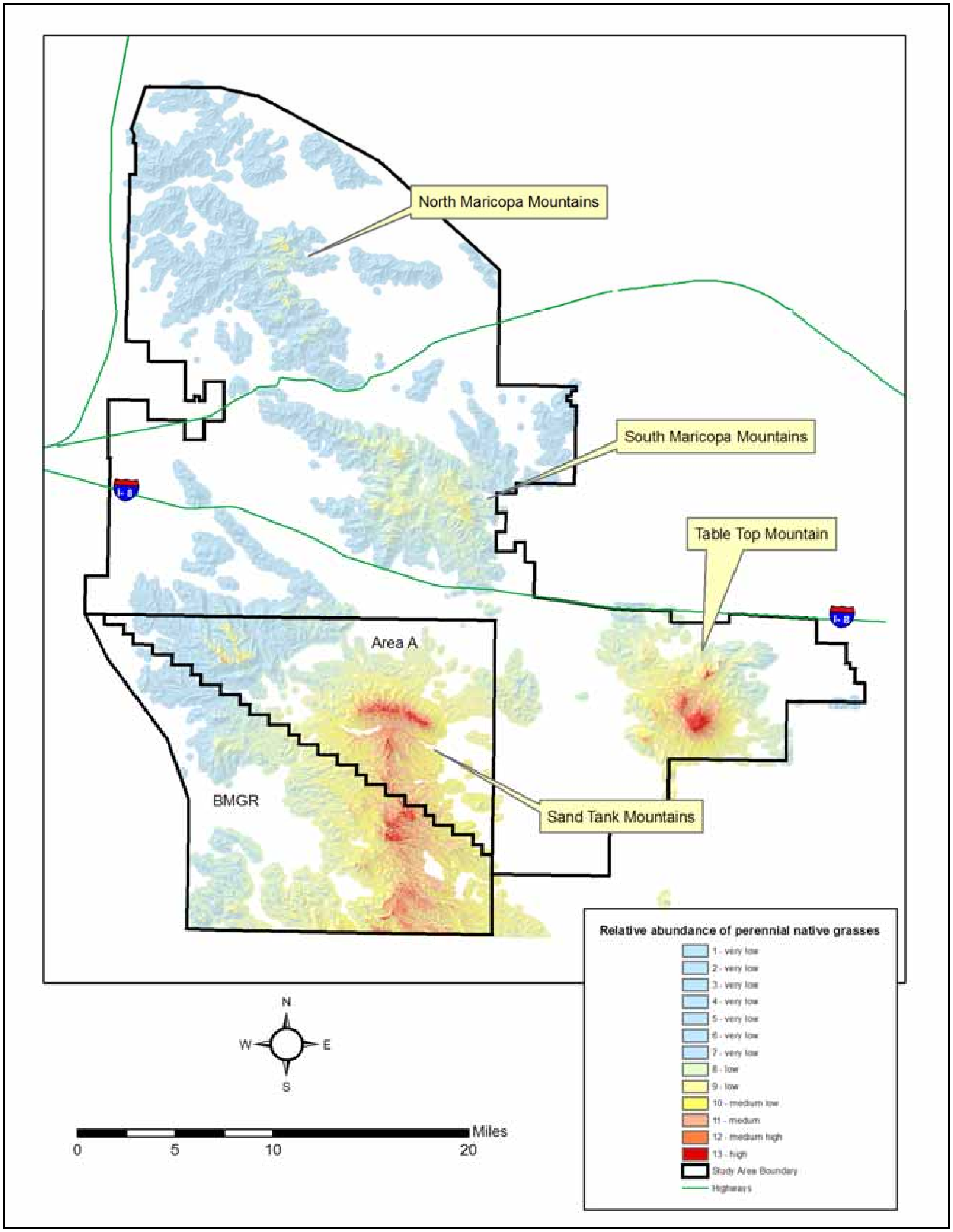

Figure 13. Biophysical spatial model of relative perennial native grass abundance.

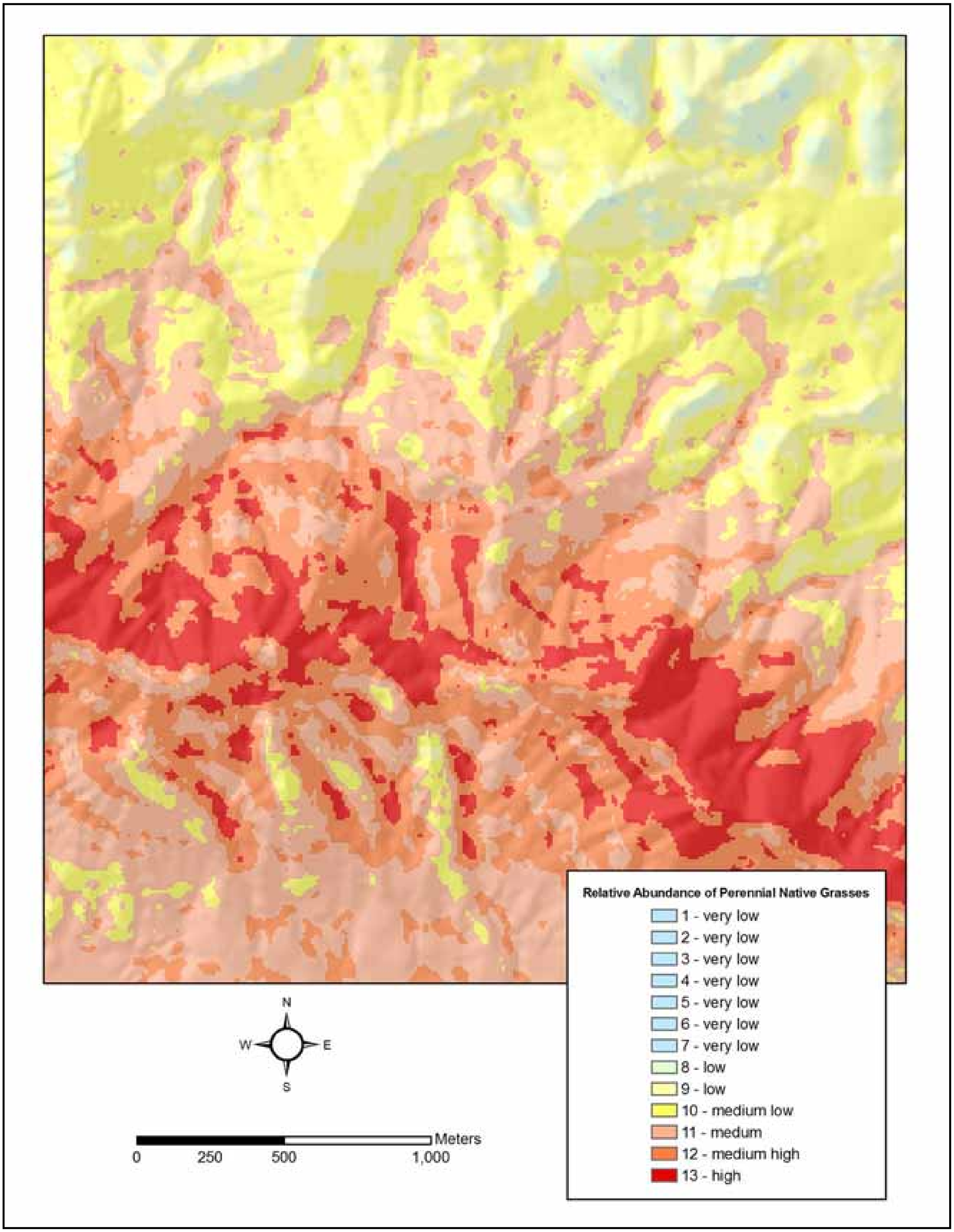

Figure 14. Biophysical spatial model of relative perennial native grass abundance – detailed view of north and south slopes of Javelina Mountain.

Development of the annual native grass biophysical model

The relationships between native annual grass cover and the other topographic variables were also explored. Northness (smoothed with a 30-meter focal mean) was the primary variable that showed a strong correlation. No other topographic variable showed a strong correlation to either annual native grass cover. Two topographic variables did show weak relationships however. These included elevation and planform curvature. These three variables were used to develop a multiple linear regression formula. The results of this multiple linear regression analysis are presented in Table 18 and Figure 15. The adjusted R square value of the multiple linear regression fit is 0.16 and an overall P value of < 0.0001. But only the northness variable (NORTHNESS30) is highly significant. Elevation is a moderately significant variable. Planform curvature (PLANCURVE) has slightly lower significance.

Table 18. Multiple linear regression analysis of annual native grass cover vs. three topographic variables.

Test	**Linear regression**
Fit	Mountain Grass Analysis - Topographic Combinations ANNUAL v ELEVATION, NORTHNESS30, PLANCURVE
Performed by	Peter Morrison
n	199
R^2	0.17
Adjusted R^2	0.16
SE	4.3425

Term	**Coefficient**	**SE**	**p**	**95% CI of Coefficient**	
Intercept	5.1096	0.9777	<0.0001	3.1814	to 7.0378
ELEVATION	-0.0010	0.0004	0.0101	-0.0017	to -0.0002
NORTHNESS30	2.4741	0.4566	<0.0001	1.5736	to 3.3746
PLANCURVE	0.6360	0.2905	0.0298	0.0631	to 1.2090

Source of variation	**SSq**	**DF**	**MSq**	**F**	**p**
Due to regression	767.218	3	255.739	13.56	<0.0001
About regression	3677.223	195	18.858		
Total	4444.441	198			

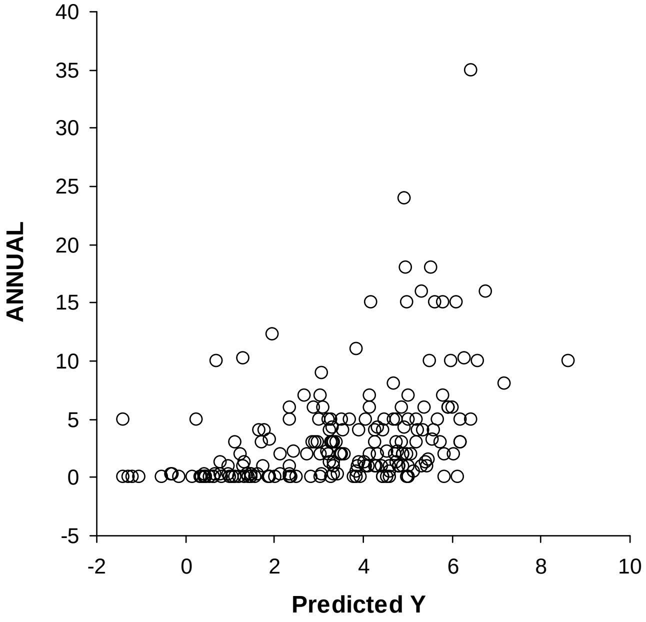

Figure 15. Annual grass cover vs. predicted Y values from multiple linear regression analysis of annual native grass cover vs. three topographic variables.

We built a GIS model to implement the following linear regression formula as suggested by the above multiple linear regression analysis:

> **Predicted Abundance of Annual Grass = 5.1096 + -0.0010 * GISELEV + 2.4741 * NORTHNESS30 + 0.6360 * PLANCURVE**

This formula was implemented in ArcGIS Model Builder to facilitate implementation and potential future modifications (Figure 16). A GIS layer of predicted annual grass abundance was produced through this process. This GIS layer was reclassified into 7 discrete classes using a one-standard deviation reclassification method. The resulting reclassified GIS dataset of predicted annual grass abundance is displayed in Figures 17 and 18. The areas with values of 6 or higher represent areas with a high probability of containing native annual grass abundance equal to or exceeding 5% cover. The areas with values of 4 or 5 represent areas with a moderate probability of containing native annual grass abundance equal to or exceeding 5% cover. And the areas with values of 3 or less represent areas with a low probability of containing native annual grass abundance equal to or exceeding 5% cover.

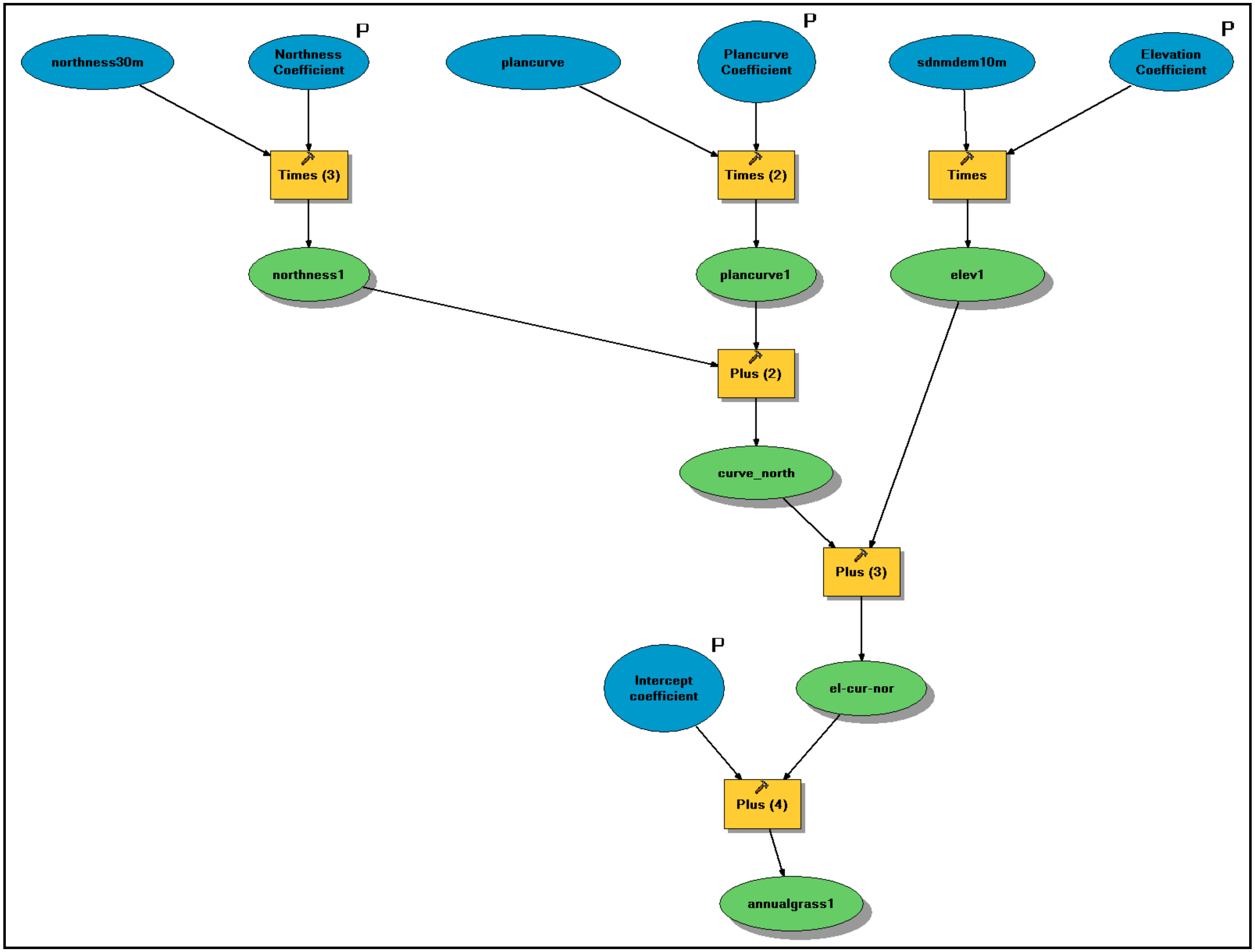

Figure 16. Diagram of predictive model for annual native grasses in study area as implemented in ArcGIS using Model Builder.

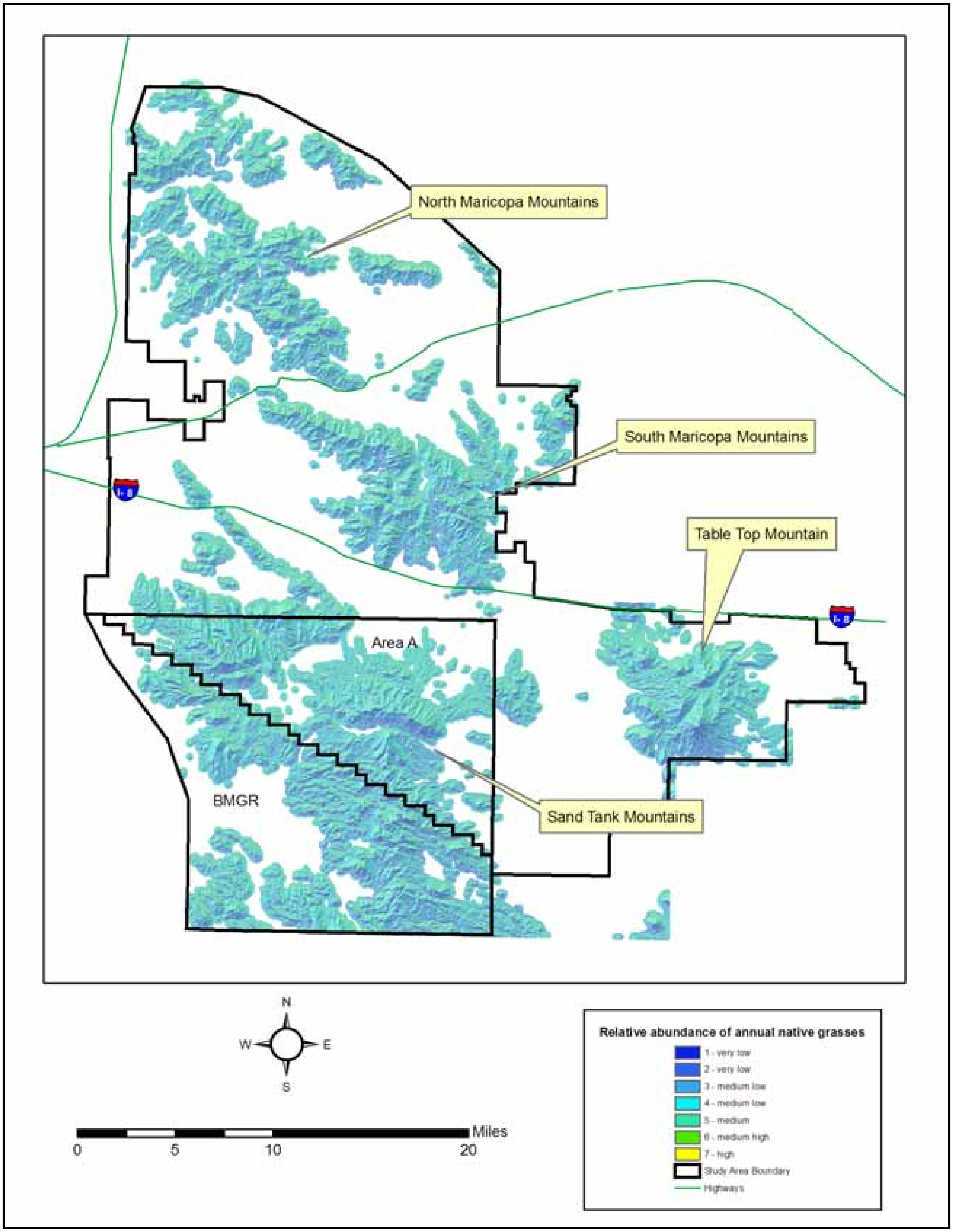

Figure 17. Biophysical spatial model of relative annual native grass abundance.

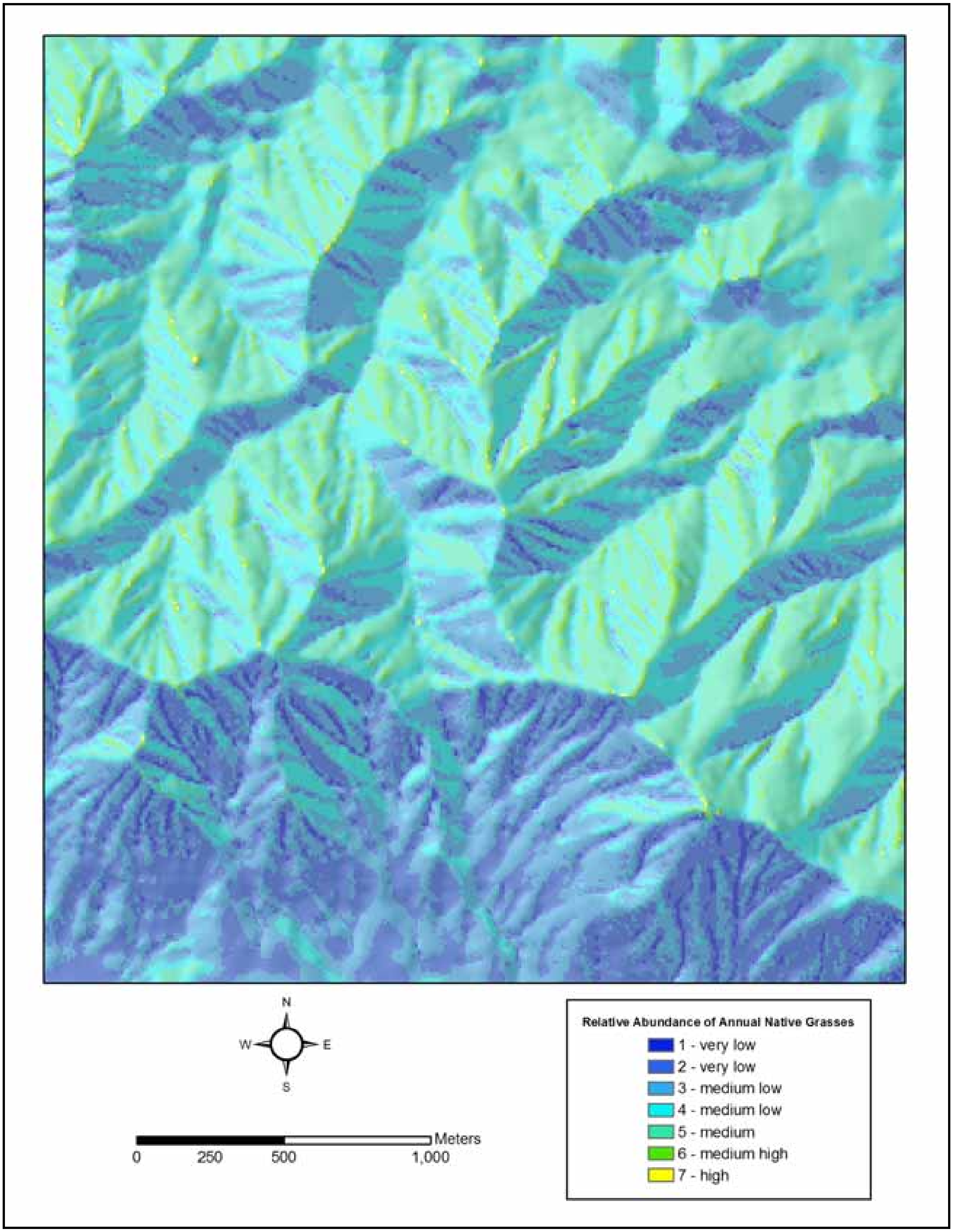

Figure 18. Biophysical spatial model of relative annual native grass abundance – detailed view of north and south slopes of Javelina Mountain.

Discussion

Annual vs. perennial native grasses in the Sonoran Desert Mountains

Both annual and perennial native grasses occur within the desert mountains of the SDNM, sometimes in considerable abundance. However, neither of these basic grass groups occur in great abundance throughout most areas of the desert mountains. The goal of this project was to better define the areas where native grasses do occur in greater abundance. To do this we conducted separate analyses for annual vs. perennial grasses. Exotic grasses were excluded from this analysis. We found that the pattern of distribution between the annual and perennial native grasses is quite different.

This seems to correspond well to known differences in the ecology of these two grass types. Annual grasses are by their very nature ephemeral, responding to winter, spring or summer rains. Their abundance can vary greatly from one year to the next. A good example of this is the difference between 2005 and 2006. The ample winter rains of the winter of 2004-2005 produced a lush growth of annual native (and exotic) grasses during the spring of 2005. In many areas, annual grasses achieved higher cover in the spring of 2005 than they have for many years. In contrast to this, the lack of any precipitation for the last half of 2005 and early 2006 resulted in essentially zero annual grass growth and zero annual grass cover during our March 2006 field sampling. The contrast between years could not be starker.

Perennial grasses, on the other hand, are more persistent and vary less from year to year. Some perennial species are relatively short-lived and behave more like annual grasses, but the perennial bunchgrass species of the Sonoran Desert tend to be long-lived and can persist over many years. Intense disturbance and longer-term drought can significantly impact perennial grass species. These factors can extirpate species from large or small areas and play a significant role in determining the overall distribution of perennial native grass species.

Distribution and abundance of native grass cover across the natural communities in the mountains of the study area

When we compared the abundance of native perennial grasses within the four natural communities occurring in the desert mountains, it was quite clear that most of the perennial grasses are found in the *Mountain Upland* natural community. This community had nearly six times more perennial native grass cover than the *Mountain Xeroriparian Scrub* community which had the second highest perennial native grass cover. Most interesting, the *Mountain Upland* natural community had over nine times more perennial native grass cover than the adjacent *Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes* natural community, which occurs below the mountain uplands. One could easily argue that an abundance of perennial native grass (over 5% mean cover) is a good indicator of the mountain uplands.
In contrast to the perennial native grasses, the abundance of annual native grasses in the four different mountain communities did not show a statistically significant difference. The mean cover value for annual native grasses in all plots was actually a little less in the *Mountain Upland* natural community than in the adjacent MXR and PVMCR communities.

The reason for the very significant difference in the distribution of perennial vs. annual native grass may be explained by precipitation and soil patterns in the desert mountains. The mountain uplands receive considerably greater precipitation than the other communities. They also tend to have somewhat deeper soils. Both these factors favor the establishment and persistence of perennial grasses. In contrast, annual grasses respond better to short-term bursts of moisture and can flourish in areas that may be largely devoid of vegetation during dry periods. They usually can not compete successfully in areas covered by native bunchgrasses. In the mountain uplands, the annual grasses are largely found in areas that are not covered by perennial grasses.

Distribution and abundance of native grass cover across the three mountain ranges in the study area

The difference in the perennial native grass abundance of the three major mountain ranges is notable. While the difference between the Sand Tanks and Table Top was not statistically significant in the most stringent comparison tests that we ran there is a very real and highly significant difference between the Table Top / Sand Tanks mountain group and the Maricopa Mountains to the north.

This difference is most likely related to the varying abundance of each natural community within the three mountain ranges, as discussed earlier in this report. There is no *Mountain Upland* natural community found in the Maricopa Mountains. The Maricopa Mountains are of lower elevation than the southern mountain groups and also are in an area with lower precipitation. Both these factors limit the abundance and persistence of native perennial grass.

In contrast to the distribution of perennial grasses, annual native grasses were significantly more abundant in the Maricopas than in the southern mountains. This difference was statistically significant when comparing the Maricopas to the Table Top Mountain area. Even though the mean value for annual native grass cover in the Maricopas is 34% higher than the Sand Tanks, this difference is not statistically significant.

The same factors favoring annual grasses discussed above in the natural community section apply to their distribution by mountain range. They appear to be more abundant in areas with lower mean precipitation and lower persistent vegetation cover. The Maricopa Mountains meet these criteria.

Relationships between topographic variables and native grass cover

The difference that we describe above between annual and perennial native grass persisted when we considered a variety of environmental variables. Perennial native grass abundance was positively correlated with elevation, with increasing abundance at higher elevations. Annual native grass cover, however, showed a very weak negative correlation with elevation, with slightly higher annual cover at lower elevations.

Annual native grass cover showed a fairly strong positive correlation with northness, but the correlation between northness and perennial grass cover was weak at best. Annual grass cover showed a weak correlation to planform curvature (curvature parallel to the slope), while perennial grass cover had a very weak correlation to profile curvature (curvature perpendicular to the slope). Slope steepness was weakly negatively correlated to perennial grass cover, but not correlated with annual native grass cover.

The differences between the grass types in response to topographic variables highlight some of the ecological differences between the two grass types. These differences also highlight the reason why it is important to create separate biophysical models for the two grass types.

Native grass biophysical models

As we did in our earlier work (Snetsinger and Morrison 2004), we created native grass biophysical models for the two native grass types based upon multiple regression analysis of the topographic variables. In the 2004 study, we did not attempt to separate annual and perennial grasses. In this study we decided it would be best to create two separate models, rather than one model that lumps both grass types. If one is interested in total native grass abundance, it is possible to sum the resulting spatial layers that result from each model to get a model of overall native grass abundance.

The resulting models of annual and perennial native grass abundance are only best approximations for where native grasses will be found with abundance. The areas where the grasses can be found in abundance should be considered areas that represent the native grass assemblage that was identified in the May 2003 workshop as an important conservation target.

Cattle Grazing in Mountain Areas

In our studies of the SDNM and adjacent areas during 2002, 2003 and 2004 we did not observe any significant sign of cattle grazing above the desert flats and bajada surfaces. During that time period, it appeared that the cattle which grazed the lowland areas of the SDNM did not wander into the steeper, rougher, more inhospitable rocky slopes above the bajadas. But in the 2005 and 2006 field seasons, we found several notable examples of cattle grazing well up on the rocky slopes, and in some cases on the very tops of the highest mountains. We observed both live and dead cattle in the mountains of the study area. Some of the plots that we established in 2003 in the mountain areas had been impacted by cattle grazing. One of these plots showed signs of significant additional impact between our fall 2005 and spring 2006 visits.

We did not observe signs of cattle grazing in the Sand Tank Mountains of the BMGR. The mountain grazing was limited to the Table Top Mountains and parts of the Maricopa Mountains – all within the SDNM.

Other threats and conservation issues affecting the native grass conservation element in the desert mountains

Global warming and persistent regional drought present one of the greatest threats to the native grass conservation element in the desert mountains of the study area. The perennial grasses will not persist in abundance if regional temperatures continue their upward climb and there is persistent and repeated regional drought. Both these factors can limit the abundance of perennial native grasses. Annual native grasses may also be affected, but they have greater ability to respond to fluctuating environmental conditions.

Recommendations for Further Studies

Additional Analyses Based on Existing Data

A great wealth of data has been collected by PBI during four years of study of the SDNM and surrounding areas. Further analysis of these data would produce products that could be useful to BLM's management of the SDNM and to others that have interest in the management of the larger study area. Some of the possibilities for further study using existing data are listed below.

Conduct analysis of grass distribution and abundance by species rather than by general grass types

Each grass species has unique preferences for moisture, temperature, shade, sunlight and soil conditions. In this study we separated exotic grasses from native grasses and annual grasses from perennial grasses. Although these gross separations into basic grass types help reveal patterns in the distribution and abundance of grasses, a much better way to conduct the analyses presented here would be to analyze each species separately. Although this analysis would be more time consuming, it is quite possible that significant relationships between factors would be revealed for some species that are masked by lumping the grasses into basic grass types. This analysis would include:

- Maps of the occurrence and relative abundance of each native grass species.
- Analysis of the factors that influence the distribution and abundance of each native grass species.
- Ranking of the native grass species by rarity and sensitivity to disturbance factors

Analyze the resample data collected for 19 Phase 2 plots to determine trends in ecological condition

We recommend that the data collected in 2005 and 2006 for the 19 mountain resample plots be compared to the data collected in these plots during 2003. These plots were resurveyed but the data was not analyzed in comparison with the earlier data as this analysis was outside of the scope of our current contract. Analysis of the resample data could yield a more comprehensive view on the population dynamics of native and exotic grass species and insight into the ecological effects of climate changes.

Develop of a set of management recommendations for maintenance of native grass diversity and the native grass conservation element within the study area

A clear set of recommendations should be developed to guide management of the SDNM and adjacent areas to ensure the maintenance of the diversity and abundance of native grasses. These management recommendations can be developed through a synthesis of PBI's existing studies of the area and other relevant literature.

Future Research Requiring Additional Data Collection

This study has identified data gaps and areas where future research is needed. Future research that expands the results of this study could be useful to the BLM's management program for the SDNM, and to others that have interests in the management of the larger study area. Some of the possibilities for future research are listed below.

Conduct further sampling in the Table Top Mountains to better determine distribution of native grasses in all topographic situations

Because of access issues as well as project design and budget constraints, all the topographic variation within the Table Top Mountain area was not adequately sampled. Most of the plots were located near the top of Table Top or along the trail to the top. Other sides of Table Top are difficult to access and plots were not placed in these areas. Additional plots in the Table Top Mountain area that were distributed across the entire range of topographic variation would create a more robust dataset for statistical analysis and modeling. This would help reveal if the Table Top Mountain has any unique characteristics not found in other areas and it would help enhance the biophysical model as it applies to Table Top.

Conduct further sampling in all mountain areas based on stratification into discrete topographic units

Because the relationship between native grass abundance and topographic variables is complex, multiple linear regression analyses may not be the best method for development of a biophysical model. The terrain can be subdivided into discrete topographic units based on similarities with regard to elevation, slope steepness, northness, and curvature. These topographic units could then be considered sampling strata. If one were to sample a sufficient number of randomly placed plots within each of these topographic units, the differences between each topographic unit with respect to native grass abundance could then be tested for statistical significance. A more robust predictive model with the capacity to predict the actual probability of occurrence of the native grass conservation element at any specific location would also result from this additional data and analysis.

Conduct studies to determine effect of mountain grazing on mountain grass communities

This study was not designed to investigate the effects of livestock grazing in the mountain areas. Since grazing had not been observed in the mountains during our previous studies, we did not think to include procedures to measure the ecological affects of grazing in the current study. A comparative study of grazed and ungrazed mountain areas would provide information about the effects of grazing on the ecological condition of the mountain communities. Management decisions about the mountain areas and the conservation elements contained in them would benefit from such a study.

Expanded sampling program to monitor the native grass conservation element and the ecological condition of natural communities within the SDNM and BMGR

During the course of our studies, we have observed extreme fluctuations in precipitation and plant growth. Much of the data we collected represented the ecological condition during a period of severe long-term local and regional drought and the condition of vegetation throughout the study area was substantially influenced by this phenomenon. We recommend that all (or many) of the plots be resurveyed in subsequent years to collect data on the response of the vegetation to either continued drought, or abatement of drought as well as the influence of other factors such as grazing or global warming. Repeated sampling of these permanent plots should be part of a long-term management strategy for the SDNM and BMGR. Analysis of the resample data can yield a more comprehensive view on the population dynamics of native and exotic grass species and insight into the ecological effects of climate changes.

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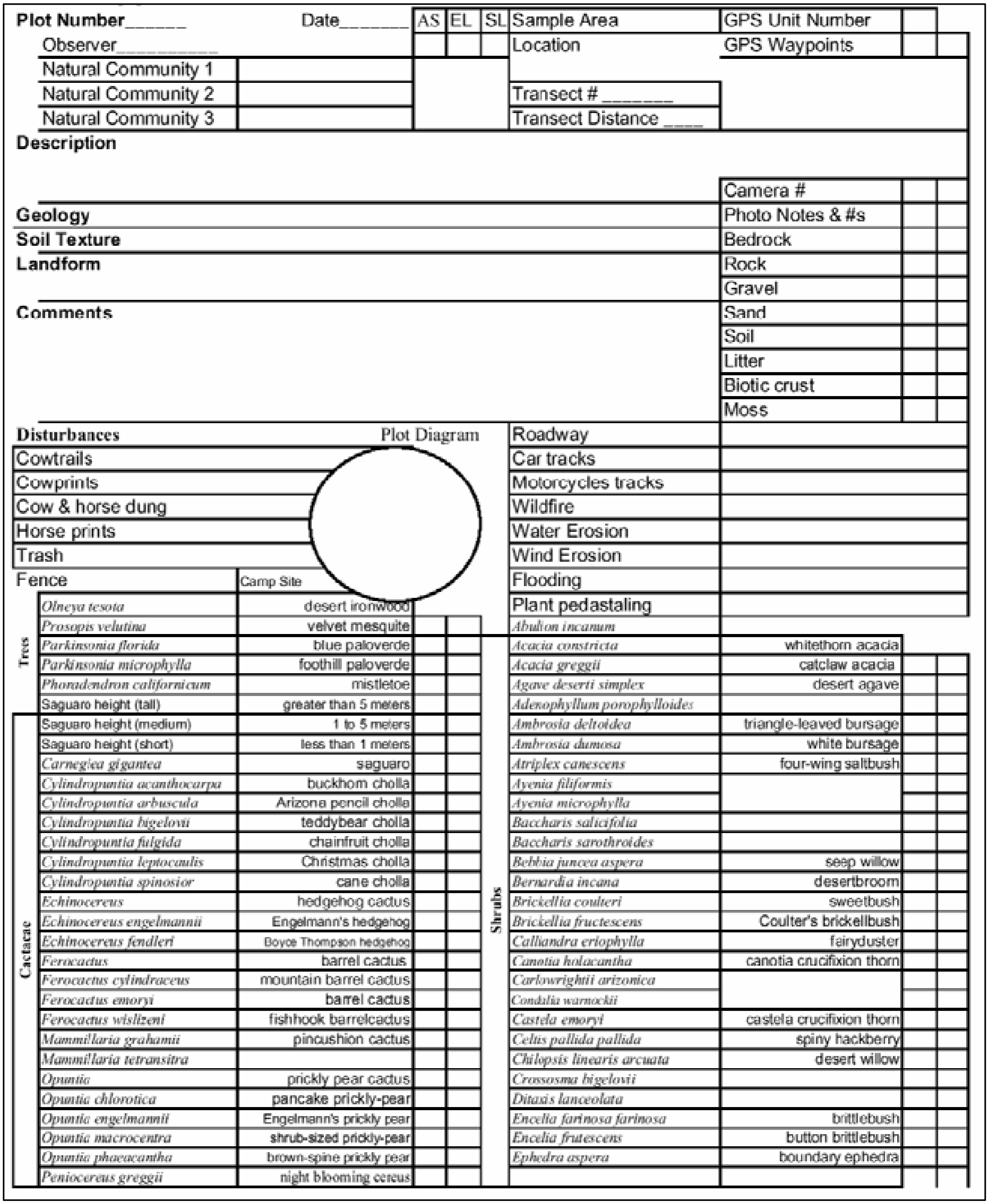
Appendix A - Natural community resample plot form



Plot Number______	Date______	AS	EL	SL	Sample Area	GPS Unit Number	
Observer__________					Location	GPS Waypoints	
Natural Community 1							
Natural Community 2					Transect # _______		
Natural Community 3					Transect Distance ____		

Description

	Camera #		
Geology	Photo Notes & #s		
Soil Texture	Bedrock		
Landform	Rock		
	Gravel		
Comments	Sand		
	Soil		
	Litter		
	Biotic crust		
	Moss		

Disturbances

Plot Diagram

Cowtrails		Roadway	
Cowprints		Car tracks	
Cow & horse dung		Motorcycles tracks	
Horse prints		Wildfire	
Trash		Water Erosion	
Fence	Camp Site	Wind Erosion	
		Flooding	
		Plant pedastaling	

Trees	*Olneya tesota*	desert ironwood		
	Prosopis velutina	velvet mesquite		
	Parkinsonia florida	blue paloverde		
	Parkinsonia microphylla	foothill paloverde		
	Phoradendron californicum	mistletoe		
	Saguaro height (tall)	greater than 5 meters		
Cactacae	Saguaro height (medium)	1 to 5 meters		
	Saguaro height (short)	less than 1 meters		
	Carnegiea gigantea	saguaro		
	Cylindropuntia acanthocarpa	buckhorn cholla		
	Cylindropuntia arbuscula	Arizona pencil cholla		
	Cylindropuntia bigelovii	teddybear cholla		
	Cylindropuntia fulgida	chainfruit cholla		
	Cylindropuntia leptocaulis	Christmas cholla		
	Cylindropuntia spinosior	cane cholla		
	Echinocereus	hedgehog cactus		
	Echinocereus engelmannii	Engelmann's hedgehog		
	Echinocereus fendleri	Boyce Thompson hedgehog		
	Ferocactus	barrel cactus		
	Ferocactus cylindraceus	mountain barrel cactus		
	Ferocactus emoryi	barrel cactus		
	Ferocactus wislizeni	fishhook barrelcactus		
	Mammillaria grahamii	pincushion cactus		
	Mammillaria tetransitra			
	Opuntia	prickly pear cactus		
	Opuntia chlorotica	pancake prickly-pear		
	Opuntia engelmannii	Engelmann's prickly pear		
	Opuntia macrocentra	shrub-sized prickly-pear		
	Opuntia phaeacantha	brown-spine prickly pear		
	Peniocereus greggii	night blooming cereus		

Shrubs	*Abulion incanum*			
	Acacia constricta	whitethorn acacia		
	Acacia greggii	catclaw acacia		
	Agave deserti simplex	desert agave		
	Adenophyllum porophylloides			
	Ambrosia deltoidea	triangle-leaved bursage		
	Ambrosia dumosa	white bursage		
	Atriplex canescens	four-wing saltbush		
	Ayenia filiformis			
	Ayenia microphylla			
	Baccharis salicifolia			
	Baccharis sarothroides			
	Bebbia juncea aspera	seep willow		
	Bernardia incana	desertbroom		
	Brickellia coulteri	sweetbush		
	Brickellia fructescens	Coulter's brickellbush		
	Calliandra eriophylla	fairyduster		
	Canotia holacantha	canotia crucifixion thorn		
	Carlowrightii arizonica			
	Condalia warnockii			
	Castela emoryi	castela crucifixion thorn		
	Celtis pallida pallida	spiny hackberry		
	Chilopsis linearis arcuata	desert willow		
	Crossosma bigelovii			
	Ditaxis lanceolata			
	Encelia farinosa farinosa	brittlebush		
	Encelia frutescens	button brittlebush		
	Ephedra aspera	boundary ephedra		

Shrubs (continued)	*Eriogonum fasciculatum*	flattop buckwheat		
	Eriogonum wrightii	Eriogonum wrightii		
	Fagonia laevis	California fagonbush		
	Forestiera phillyreiodes			
	Fouquieria splendens	ocotillo		
	Gallium stellatum			
	Hibiscus coulteri			
	Hymenoclea salsola	cheesebush		
	Hyptis emoryi	desert lavender		
	Isocoma acradenia			
	Keckiella antirrhinoides			
	Koeberlinia spinosa	allthorn		
	Jatropha cardiophylla	limberbush		
	Justicia californica	chuparosa		
	Krameria erecta	range ratany		
	Krameria grayi	white ratany		
	Larrea divaricata tridentata	creosotebush		
	Lycium	desertthorn		
	Lycium andersonii	desert wolfberry		
	Lycium berlandieri	Berlandier's wolfberry		
	Lycium exsertum	Arizona desertthorn		
	Lycium parishii	Parish's desertthorn		
	Machaeranthera pinnatifida			
	Menodora scabra			
	Petalonyx thurberi			
	Polygala macrodemia			
	Porophyllum gracile			
	Psilostrophe cooperi			
	Sebastiania bilocularis	Mexican jumping bean		
	Senna covesii			
	Simmondsia chinensis	jojoba		
	Sphaeralcea ambigua	desert globemallow		
	Stephanomeria pauciflora	desert straw		
	Tamaricaceae ramosissima	salt cedar, tamarisk		
	Thymophylla concinna			
	Thymophylla pentachaeta			
	Tiquilia canescens			
	Tragia nepetifolia var dissecta			
	Trixis californica	California trixis		
	Viguiera deltoidea			
	Viguiera parishii			
	Yucca baccata	banana yucca		
	Yucca elata	soap tree yucca		
	Ziziphus obtusifolia canescens	graythorn		
Vines	*Asclepias subulata*	rush milkweed		
	Clematis drummondii	clematis		
	Commicarpas scandens			
	Janusia gracile	janusia		
	Lyrocarpa coulteri	banana scent vine		
	Rhynchosia texana	rosary bean		
	Sarcostemma cynanchoides			
Ferns, etc.	*Astrolepis cochisensis*			
	Astrolepis sinuata sinuata			
	Notholaena standleyi			
	Pellaea truncata			
	Selaginella arizonica			

Grasses and Sedges	*Aristida*	3 awn		
	Aristida adsensionis			
	Aristida purpurea			
	Bouteloua	gramma		
	Bromus			
	Bromus arizonica			
	Bromus catharticus @			
	Bromus rubens	red brome		
	Carex	sedge		
	Cynodon dactylon @	Bermuda grass		
	Elymus elymoides			
	*Eragrostis lehmanniana @**	Lehmann lovegrass		
	Erioneuron pulchellum	fluff-grass		
	Hordeum pusillum			
	Heteropogon contortus			
	*Melinis repens @**	natal grass		
	Muhlenbergia microsperma			
	Muhlenbergia porteri			
	*Pennisetum ciliare @**	buffelgrass		
	*Pennisetum setaceum @**	fountain grass		
	Phalaris minor @	canary grass		
	Poa			
	Poa bigeloviii			
	*Pleuraphis jamesii **			
	Pleuraphis mutica	tobosa grass		
	Pleuraphis rigida	big galleta		
	Schismus arabicus @	mediterranean grass		
	Schismus barbatus @	mediterranean grass		
	*Sorghum halepense @**	Johnson grass		
	Tridens muticus			
	Vulpia octoflora			

Appendix B - Mountain Native Grass New Plot Form

Plot Number______	**Date**	**AS**	**ELEV**	**SL**	Sample Area	GPS Unit Number		
Observer___________					Location	GPS Waypoints		
Matrix Community 1						Camera #		
Matrix Community 2						Photo #s	n	e
Description						(take 4 photos @ cardinal directions)	s	w

Geology		
	Bedrock		
	Rock		
Soil Texture	Gravel		
Landform	Sand		
	Soil		
Comments	Litter		
	Biotic crust		
	Moss		

Plot Diagram

Disturbances

Cowtrails	
Cowprints	
Cow & horse dung	
Horse prints	Camp Site
Trash	
Fence	

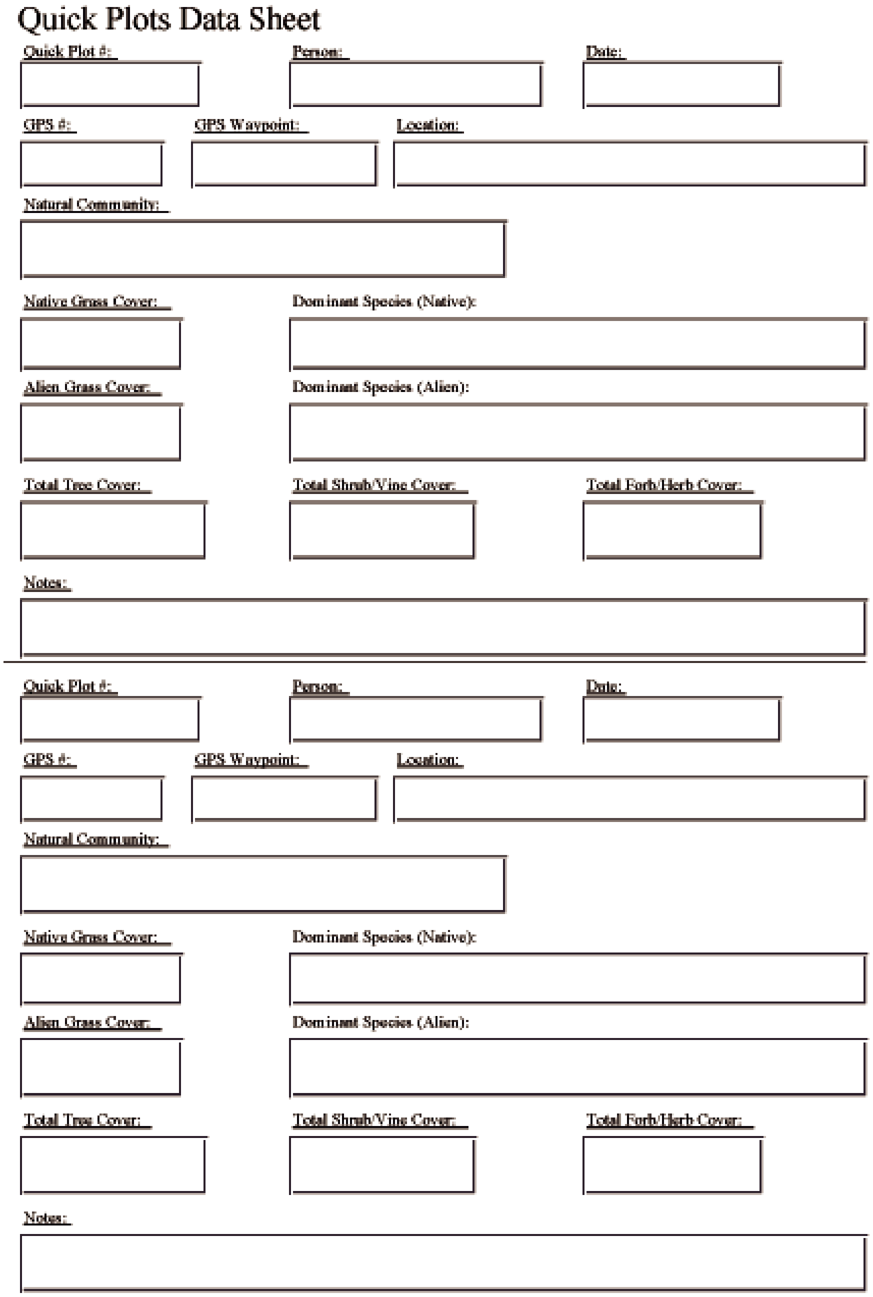
Roadway	
Car tracks	
Motorcycles tracks	
Wildfire	
Water Erosion	
Wind Erosion	
Flooding	
Plant pedestaling	

Plant Growth Form	**Canopy Cover**
All Grasses	
Herbs / Forbs / Ferns	
Shrubs / Vines	
Cacti	
Trees	

Grasses

Status	Species Name	Common Name	Cover	Density1	Density2	Density3	Density4	Density5
	Aristida adscensionis							
	Aristida parishii							
	Aristida purpurea var. nealleyi							
	Aristida ternipes var. gentiles							
	Aristida ternipes var. ternipes							
@	*Avena fatua*	wild oat						
	Bothriochloa barbinodis							
	Bouteloua aristidoides							
	Bouteloua barbata							
	Bouteloua curtipendula							
	Bouteloua repens							
	Bouteloua gracilis							
	Bromus arizonica							
@	*Bromus catharticus*	California brome						
	Bromus carinatus							
@	*Bromus rubens*	red brome						
@	*Cynodon dactylon*	Bermuda grass						
	Digitaria californica							
	Elymus elymoides							
	Enneapogon desvauxii							
	Eragrostis cilianensis							
@	*Eragrostis lehmanniana*	Lehmann lovegrass						
	Erioneuron pulchellum	fluff-grass						
	Hordeum murinum	mouse barley						
@	*Hordeum pusillum*	little barley						
	Heteropogon contortus							
	Leptochloa mucronata							
	Leptochloa panicea ssp. brachiata							
@	*Melinis repens*	natal grass						
	Muhlenbergia microsperma							
	Muhlenbergia porteri							
	Panicum hirticaule							
@	*Pennisetum ciliare*	buffelgrass						
@	*Pennisetum setaceum*	fountain grass						
@	*Phalaris minor*	canary grass						
	Poa bigeloviii							
	Pleuraphis jamesii							
	Pleuraphis mutica	tobosa grass						
	Pleuraphis rigida	big galleta						
@	*Schismus arabicus*	mediterranean grass						
@	*Schismus barbatus*	mediterranean grass						
	Setaria macrostachya							
@	*Sorghum halepense*	Johnson grass						
	Sporobolus cryptandrus							
	Tridens muticus							
@	*Triticum aestivum*	common wheat						
	Trisetum interruptum							
	Vulpia octoflora							

Appendix C - Native grass quick plot form



Quick Plots Data Sheet

Quick Plot #:
Person:
Date:

GPS #:
GPS Waypoint:
Location:

Natural Community:

Native Grass Cover:
Dominant Species (Native):

Alien Grass Cover:
Dominant Species (Alien):

Total Tree Cover:
Total Shrub/Vine Cover:
Total Forb/Herb Cover:

Notes:

Quick Plot #:
Person:
Date:

GPS #:
GPS Waypoint:
Location:

Natural Community:

Native Grass Cover:
Dominant Species (Native):

Alien Grass Cover:
Dominant Species (Alien):

Total Tree Cover:
Total Shrub/Vine Cover:
Total Forb/Herb Cover:

Notes: