Overview of the methods and process used to designate vegetation and soils monitoring sites at SODN parks.

The sampling design for Terrestrial Vegetation and Soils monitoring protocol in Sonoran and Chihuahuan Desert Network parks employs permanent sampling sites allocated using a Reversed Randomized Quadrant-Recursive Raster (RRQRR) spatially balanced design (Theobold 2007) stratified by elevation and surface soil rock fragment classes. The STARMAP Spatial Sampling toolbox was used to allocate plots for the Sonoran Desert Network. Subsequently, ESRI incorporated RRQRR into its Geostatistical Analyst Tools as “Create Spatially Balance Points.” RRQRR is similar to the General Randomized Tessellation System (GRTS) and is increasingly being applied to ecological monitoring (EPA and Prairie Cluster & Heartland Network) as it provides the advantages of a probabilistic design (Stehman 1999) but ensures spatial balance regardless of the overall sample size. The primary difference between the RRQRR tool and the R stats code developed for drawing a GRTS-based sample is that GRTS is feature-based (point, line, or area) and the RRQRR algorithm runs on raster grids within a GIS environment. Technical details on the RRQRR algorithm can be found in Theobald et al. (2005).

System Requirements

- ArcGIS 10.1
- Add in Spatial Analyst extension (Tools → Extensions, put check mark next to Spatial Analyst) and Geostatistical Analyst (Tools → Extensions, put check mark next to Geostatistical Analyst)
- Set project workspace (Tools → Options → Geoprocessing… Environments → General Settings… Current Workspace)

Preparing input raster layers

NOTE: All raster layers used to construct models must be the same extent and resolution. The easiest way to accomplish this is to have one layer which reflects the extent and resolution you would like the models to follow (in this case, the 20m DEM). Then, as you create new grid layers, you can specify that they match up with this layer.

<u>Preparing the elevation raster</u>

Most of the DEMs available for SODN parks are 10m in resolution. To better match up with our plots, we want to convert the DEM to 20m in resolution by right clicking on the DEM name → Data →Export Data and setting the cell size at 20 and the format type to grid. Most of the DEM’s cover areas much larger than the park unit so you will need to clip the DEM to the park boundary. Do this using (Arc Toolbox → Spatial Analyst Tools → Extraction → Extract by mask) where the 20m DEM is the input and the park boundary is the mask layer. Note that if the DEM you have available is at a greater resolution (i.e. 30m) it is not prudent to decrease the cell resolution as conversion in this direction loses quality and data integrity. In this instance you should work with the DEM as is and make all other layer match this resolution.

Next, we want to change the values associated with the raster to break out our elevation zones. Use the “Reclassify” command (Arc Toolbox → Spatial Analyst Tools → Reclass → Reclassify). Select the values field you wish the grid to be classified on (elevation), then type new values into the “New values” column in the table using the table below. Save the output raster as “parkcode_elev” to an appropriate location.

Biome	Elev meter	Elevation ft	Score
Desert	<762.195	< 2500’	100
Thornscrub	762.195 to 1128.05	2501’ to 3700’	200
Semi-desert Grassland & Chaparral	1129 to 1371.95	3701’ to 4500’	300
Encinal Woodland	1372 to 1829.27	4501’ to 6000’	400
Coniferous Forest	>1829.27	> 6000’	500

Also using the new 20m DEM (unclassified version) you need to calculate slope for use later. (Arc Toolbox → Spatial Analyst Tools → Surface → Slope). Input raster is DEM clipped to park boundary; output raster can be called parkcode_slop. Output measure should be ‘degrees’ and the ‘Z-factor’ should be 1 if your x, y and z measures are all equal (i.e. all meters).

This raster should be reclassified by changing the values associated with the raster to break out our slope classes. Use the “Reclassify” command (Arc Toolbox → Spatial Analyst Tools → Reclass → Reclassify). Slope values between 0-35 degrees = 1 and values > 35 degrees = 0.

Preparing the soil raster

Surface soils are classified by rock fragment: Soil survey shapefiles are available on the SODN server (G:\ drive). Most attribute tables for soil surveys do not include information such as the soil type name, surface texture, or rock fragment class. This information must be added to the attribute table using the Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx). Navigate to the appropriate soil survey using the map and set your AOI using the appropriate tool.

- click on the “Soil Data Explorer” tab at the top of the window.
- Click on the “Soil properties and qualities” tab in the second row of tabs
- Expand the “Soil Physical Properties” menu at the left of the page
- Select “Surface Texture” and click view rating. This will give you the information required to match the map unit symbol with the map unit name and the dominant soil surface texture (which includes information about the surface rock fragments).
- Add this information to the appropriate shapefile attribute table. You should have four columns total
    - Map unit symbol
    - Map unit name
    - Surface texture
    - Rock fragment class (next step)
- Assign each map unit to a rock fragment class using surface texture and the table below

Rock Fragment	Fragment Content %	Score

Modifier	by Volume	
None or adjective (e.g., loam or gravelly loam)	< 35	1
“very” or “extremely”	35 to 90	2
Bedrock or rock outcrop	--	3

Convert soil shapefile to raster using the “Feature to Raster” command (Arc Toolbox → Conversion Tools → To Raster → Feature to Raster). Select the soil layer of interest for “Input features”, select the rock fragment class field for the grid to be classified with, and specify the output location for the grid naming it “parkcode_soil.” Finally, select the grid you determined above which reflects the extent and resolution of interest (ie, DEM) under “Output cell size (optional)”. This will ensure that your new layer will match up with it. Output cell size should be 20.

<u>Preparing the exclusion area raster</u>

We need to buffer areas around roads, trails, washes, and buildings to ensure that our plots do not land in the middle of a parking lot. Create a 100m buffer around roads, trails, and buildings and a 50m buffer around washes and streams (hydrology layer often). Add the “Buffer Wizard” to your project (Tools → Customize → Commands tab) and click and drag the buffer wizard to your toolbar. Start the buffer wizard and follow the prompts choosing the appropriate layer to buffer and the appropriate buffer distance. When all layers have been buffered, merge them into a single layer (parkcode_buf_merge). If necessary clip this merged layer to the park boundary, then use the ‘dissolve’ tool (Arc Toolbox → Data management tools → Generalization → Dissolve) to dissolve interior boundaries. Call this parkcode_dissolve. Next you need to union the dissolved layer to the park boundary (Analysis tools → Overlay → Union), name this new layer ‘parkcode_buffer’.

Add a “score” column to the layer and assign a zero to each buffer area record and a 1 to all non-buffered areas. Convert the buffer layer to a raster using the “Feature to Raster” command (Arc Toolbox → Conversion Tools → To Raster → Feature to Raster). Select the buffer layer of interest for “Input features”, select the score field for the grid to be classified with, and specify the output location for the grid naming it “parkcode_buffer.” Finally, select the grid you determined above which reflects the extent and resolution of interest (ie, DEM) under “Output cell size (optional)”. This will ensure that your new layer will match up with it. Output cell size should be 20.

Now you need to multiply the parkcode_buffer raster by the parkcode_slop raster. Use the raster calculator (Spatial analyst toolbar) to construct this equation. The resulting calculation will appear in the table of contents; right click on this → data → make permanent and call this raster parkcode_bufslop. You will need to add in this new layer and can then remove the calculation from your workspace.

Preparing the sampling frame raster

Once all individual input grids are created, we are ready to create the sampling frame raster. The first step involves summing the elevation and soils input grids and then multiplying by the buffer grid. To run RRQRR, we need a contiguous raster (without nodata holes) for the entire park. To do this, we'll use the Raster Calculator (go to "Spatial Analyst" pull-down menu, select "Raster Calculator". Construct the equation,

(parkcode_elevation + parkcode_soil) * parkcode_bufslop

and press "Evaluate". This will create a temporary raster layer titled "Calculation". We want to save this Calculation grid as a raster layer for reference in the future, so right-click on the grid and select "Make Permanent". Then specify a grid name ("parkcode_zones") and file location. You will have to add that grid layer into the view, it will not automatically load after this operation. We also want to save the new grid as a shapefile for easier display. To do this go to "Spatial Analyst" pull-down menu, select "Convert" → "Raster to Feature" and save the shapefile as "parkcode_zones."

Going back to our "parkcode_zones" raster, we're ready to assign probability values for inclusion in our sampling design. We need to reclassify the raster first and then convert it to a floating point raster. Use the "Reclassify" command (Arc Toolbox → Spatial Analyst Tools → Reclass → Reclassify). Select the values field you wish the grid to be classified on (value), then type new values into the "New values" column in the table using the table below. Save the output raster as a temporary raster. This method requires that the desired strata have a value of one. It will single out this one area when the point tool is run. An issue encountered with the Reclassify tool was the default number of classes doesn't always reflect the total number of classes in the raster. The correction for this is to click the classify option and change the number of classes in the dropdown to match the correct total number. Once that is corrected single out the desired strata and change the new value to 1. All the others need to be 0.

Value/ Score	New Value
0	0
101	1
102	0
103	0
201	0
202	0
203	0
301	0
302	0
303	0
401	0
402	0
403	0
501	0
502	0
503	0

Next run the Float tool on the resulting raster from the reclassify tool and save the resulting raster in V:\Uplands\Data_Spatial\Processed_Data\RRQRR_results\parkcode. Go back to the reclassify step and create that raster and the Float Raster for all the stratas that the park has. There needs to be one Float raster for every strata. From these newly created rasters the spatially balanced points will be created.

Before running the tools creating the points, each strata must have the number of plots needed to be sampled identified. Extract the table from the parkcode_zones shapefile and open it as an excel document. This table contains the acreage for each zone. Determine the total park acreage and then calculate the percent of each strata over the park. Then rule out the excluded area and calculate the percent cover for each strata in the sampling frame. The strata that have less than 5% cover will not be sampled. Every other strata over 5% will have their percentage area of the plot points. So a 50% cover strata would have 50 of 100 plots if that is the total number of plots that the refuge needs. It also needs to be noted that each strata needs a minimum of five plots.

Sample EXCEL table

GRIDCODE	acres	% park	% sampling frame	plots
0	33576	0.289271222	0	0
201	57554	0.495851677	0.697666525	70
202	15746	0.135658347	0.190872174	19
301	544	0.004686787	0.006594339	0
401	8	6.89233E-05	9.69756E-05	0
402	778	0.006702794	0.009430875	0
302	7865	0.06776025	0.095339111	9
	116071			

<u>Running the Create Spatially Balanced Points tool</u>

After determining how many plots each strata will have the tool "Create Spatially Balanced Points" needs to be run. Remember when specifying how many output points to create to do three times the desired amount. This is to safeguard against some plots being thrown out when the field crews get out there and determine it is not possible to sample at that location. In addition, set the seed number for the random number generator to a non-zero value and record the seed number in the metadata (Environments → Radom Numbers). This allows you to recreate the output points and additional points, if necessary. Save the sampling point shapefile in the appropriate location.

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Terrestrial Vegetation and Soils Monitoring Protocol and Standard Operating Procedures

Sonoran Desert and Chihuahuan Desert Networks, Version 1.1

Natural Resource Report NPS/SODN/NRR—2012/509

ON THE COVER

Example vegetation monitoring plot, Coronado National Memorial, Arizona. All photos NPS/A. Wondrak Biel.

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Natural Resource Report NPS/SODN/NRR—2012/509

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April 2012

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

This report is available from the Sonoran Desert Network website, http://www.nature.nps.gov/im/units/sodn, as well as at the Natural Resource Publications Management web site, http://www.nature.nps.gov/publications/nrpm.

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Abstract

This protocol outlines the justification, objectives, and procedures developed for long-term monitoring of terrestrial vegetation and soils throughout the National Park Service (NPS)'s Sonoran Desert Network (SODN) and Chihuahuan Desert Network (CHDN). The protocol narrative describes the (1) background and rationale for monitoring of terrestrial vegetation and soils, (2) program goals and objectives, (3) sampling design, (4) field methods, (5) data management, (6) analysis and reporting, (7) personnel requirements and training, (8) operational requirements, and (9) procedures for revising and reviewing the protocol. Detailed standard operating procedures that describe how all aspects of the protocol are implemented are electronically attached to this document, along with copies of field data sheets.

Monitoring of terrestrial vegetation and soils provides information on several high-priority vital signs in CHDN and SODN parks, including vegetation dynamics, plant lifeform abundance, status and trends of established invasive exotic plants, soil compaction, soil aggregate stability, soil cover (including bare ground), and biological soil crust cover. Because vegetation and soils are closely interrelated, it is necessary to monitor them in conjunction with each other in order to achieve a more complete picture of ecological function.

The overall goal of SODN/CHDN terrestrial vegetation and soils monitoring is to ascertain broad-scale changes in vegetation and dynamic soils properties in the context of changes in other ecological drivers, stressors, and processes, as well as focal resources of interest. The monitoring of vegetation and soils described in this document closely follows the work of Herrick and others (2005a and 2005b) and Belnap and others (2001) in design and approach. The locations of permanent monitoring plots are determined in each SODN and CHDN park through a stratified, random, spatially-balanced sampling design. Plots are sampled on a five-year panel design, in which one panel containing one-fifth of a park's total plots is sampled each year for large parks. For small units, we will sample all plots within the same year, and not sample again until the five-year interval is complete. In the field, data are collected on vegetation and soil cover, vegetation frequency and density, biological soil crust cover and frequency, surface soil aggregate stability, and soil and site characteristics. Field methods, training, laboratory analysis, and data management procedures are described in detail in 14 standard operating procedures electronically attached to this document.

Acronyms

General	
ASTM	American Society for Testing and Materials
BoD	Board of Directors
CHDN	Chihuahuan Desert Network
CPR	cardiopulmonary resuscitation
EC	electrical conductivity
GIS	geographic information system
GPS	global positioning system
GRTS	generalized random tessellation stratified design
I&M	inventory and monitoring
LCAS	Learning Center of the American Southwest
NHP	national historical park
NHS	national historic site
NM	national monument
NMEM	national memorial
NP	national park
NPS	National Park Service
NRA	national recreation area
QA/QC	quality assurance/quality control
RRQRR	reversed randomized quadrant-recursive raster design
SBS	spatially balanced sample
SCA	Student Conservation Association
SODN	Sonoran Desert Network
SOP	standard operating procedure
STARMAP	Space-Time Aquatic Resource Modeling and Assessment Program
SWNC	Southwest Network Collaboration
SWReGAP	Southwest Regional Gap Analysis Project
TC	Technical Committee
VK#	Version Key Number
WSR	wild and scenic river
Sonoran Desert Network Parks	
CAGR	Casa Grande Ruins National Monument
CHIR	Chiricahua National Monument
CORO	Coronado National Memorial
FOBO	Fort Bowie National Historic Site
GICL	Gila Cliff Dwellings National Monument
MOCA	Montezuma Castle National Monument
ORPI	Organ Pipe Cactus National Monument
SAGE	Saguaro National Park–East
SAGW	Saguaro National Park–West
TONT	Tonto National Monument
TUMA	Tumacácori National Historical Park
Chihuahuan Desert Network Parks	
BIBE	Big Bend National Park
CAVE	Carlsbad Caverns National Park
FODA	Fort Davis National Historic Site
GUMO	Guadalupe Mountains National Park
WHSA	White Sands National Monument

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Protocol Narrative

Revision History Log

Previous Version #	Revision date	Author	Changes made	Section and paragraph	Reason for change	New Version #
1.0	4/9/2012	A. Hubbard, C. McIntyre, S. Studd, K. Beaupre	CHDN parks added	Throughout protocol	Protocol extended to CHDN parks	1.1
			Density objective added	Sections 2.1.3 and 4.2, SOP #5	Columnar cacti and ocotillo were not adequately addressed in version 1.0	
			Plant association objective dropped	Section 2.1.3, SOPs #4 and #5	Objective was unrealistic given budget contraints	
			Fuels and fire-related measures added	Sections 2.2.1, 4.1, SOP #5	Identified as high priority during climate change workshop	
			Set minimum number of plots per stratum	Section 3.2.3, Appendix A	Within-stratum power not sufficient with fewer than 5 plots per stratum	
			Reduced number of soil samples	Section 4.5, SOP #4	Decrease should not produce in significantly different results	
			Identified research topics	Section 1.4	To enhance value of monitoring information	
			See section 1.3 for additional information			

1 Background

The core mission of the National Park Service (NPS), as outlined in the agency's 1916 Organic Act, is to protect and conserve natural and cultural resources for future generations. Responding to criticism that it lacked basic knowledge of natural resources within parks, the NPS initiated the Inventory and Monitoring (I&M) Program to detect long-term changes in physical and biological resources (NPS 1992). Parks with significant natural resources were assigned to one of 32 monitoring networks, each based on ecological similarity and geographic proximity. Each network was charged with developing a monitoring program capable of detecting long-term changes in physical and biological resources within each network.

The Sonoran Desert Network (SODN) includes 11 parks in southern Arizona and New Mexico: Casa Grande Ruins National Monument (NM), Chiricahua NM, Coronado National Memorial, (NMEM) Fort Bowie National Historic Site (NHS), Gila Cliff Dwellings NM, Montezuma Castle NM, Organ Pipe Cactus NM, Saguaro National Park (NP), Tonto NM, Tumacácori National Historical Park (NHP), and Tuzigoot NM. These units range in size from 144 hectares (Tumacácori NHP) to 133,882 hectares (Organ Pipe Cactus NM) (Table 1-1). Collectively, these parks are representative of most of the ecological communities present within the greater Sonoran Desert ecoregion (NPS 2005).

The Chihuahuan Desert Network (CHDN) includes seven NPS units in New Mexico and Texas: Amistad National Recreation Area (NRA), Big Bend NP, Carlsbad Caverns NP, Fort Davis NHS, Guadalupe Mountains NP, Rio Grande Wild and Scenic River (WSR), and White Sands NM (Table 1-1). These parks are primarily located within the Chihuahuan Desert ecoregion (NPS 2010), which lies to the east of the greater Sonoran Desert ecoregion.

In 2005, SODN staff completed a monitoring plan that identified "vital signs," or parameters, representing a diverse range of natural resources, including air, water, climate, soils, plants, invertebrates, and vertebrates (NPS 2005). Within each of these categories, vital signs were chosen by a workgroup of between four and eight regional and national experts. The vegetation and ecosystem function workgroups evaluated high-priority issues and identified candidate vital signs on the basis of ecological significance, feasibility, and relevance to management (NPS 2005). The CHDN also identified terrestrial vegetation and soils (also referred to here as "uplands") as a high priority for ecosystem monitoring (NPS 2010). Uplands vegetation and soils monitoring will be implemented at nine SODN parks (10 park units):

- Casa Grande Ruins NM
- Chiricahua NM
- Coronado NMEM
- Fort Bowie NHS
- Gila Cliff Dwellings NM
- Montezuma Castle NM (Castle unit)
- Organ Pipe Cactus NM
- Saguaro NP (Rincon Mountain [East] and Tucson Mountain [West] districts)
- Tonto NM

Monitoring will be implemented at five CHDN parks:

- Big Bend NP
- Carlsbad Caverns NP
- Fort Davis NHS
- Guadalupe Mountains NP
- White Sands NM

SODN and CHDN (hereafter, "network" or "the networks") parks where vegetation and soils monitoring will be conducted under this protocol are shown in bold in Table 1-1.

Vegetation dynamics, plant lifeform abundance, and exotic-plant status and trends were considered to be among the most important and feasible parameters for long-term vegetation monitoring. Soil compaction, soil aggregate stability, soil cover (including bare ground), and biological soil crust cover were selected for long-term monitoring of soils. Because vegetation and soils are closely interrelated, it is necessary to monitor them in conjunction with each other in order to achieve a more complete picture of ecological function.

1.1 Terrestrial vegetation and soils as a focus for monitoring efforts

Vegetation composition, distribution, and production are highly influenced by edaphic factors, such as soil texture, mineralogy depth, and landform type (McAuliffe 1999). Especially as they relate to water, these influences are magnified at local scales in the Sonoran Desert, Apache Highlands, and Chihuahuan Desert ecoregions (Bailey 1998), as described by pioneering desert ecologist Forrest Shreve:

> The profound influence of soil upon desert vegetation is to be attributed to its strong control of the amount, availability and continuity of water supply. This fundamental requisite in plants is the most effective single factor in the differentiation of desert communities (Shreve 1951).

As such, a fundamental understanding of soils and landforms is essential for evaluating vegetation patterns and processes (McAuliffe 1999).

Vital signs monitoring of vegetation and soils supports a comprehensive understanding of terrestrial ecosystems. This integrated approach is based on the tenet that the behavior of complex ecosystems cannot be fully understood by studying their individual pieces because, when considered in aggregate, those systems exhibit emergent properties (Keddy 2001). While still providing individual answers as to the condition of specific vital signs, our approach to monitoring vegetation and soils is based on this holistic paradigm.

1.1.1 Terrestrial vegetation

Generating more than 99.9% of Earth's biomass (Whittaker 1975), plants are the primary producers of life on our planet. Vegetation therefore represents much of the biological foundation of terrestrial ecosystems, and it comprises or interacts with all primary structural and functional components of these systems. Vegetation dynamics can indicate the integrity of ecological processes, productivity trends, and ecosystem interactions that can otherwise be difficult to monitor. For instance, community and lifeform composition can offer great insight into subtle shifts in nu-

Table 1-1. Parks of the Sonoran Desert and Chihuahuan Desert networks.

				Elevation			
		Area		Relief		Range	
Park	Ecoregion (TNC 2008)	Acres	Hectares	Meters	Feet	Meters	Feet
Sonoran Desert Network Parks							
Casa Grande Ruins NM	Sonoran Desert	472	191	5	15	431–436	1,415–1,430
Chiricahua NM	Apache Highlands	11,984	4,852	815	2,675	1,570–2,385	5,150–7,825
Coronado NMEM	Apache Highlands	4,750	1,923	914	3,000	1,433–2,347	4,700–7,700
Fort Bowie NHS	Apache Highlands	1,000	404	183	600	1,417–1,600	4,650–5,250
Gila Cliff Dwellings NM	Arizona-New Mexico Mountains	533	216	52	170	2,027–2,079	6,650–6,820
Montezuma Castle NM	Apache Highlands	858	347	140	460	963–1,103	3,160–3,620
Organ Pipe Cactus NM	Sonoran Desert	330,688	133,882	1,158	3,800	305–1,463	1,000–4,800
Saguaro NP	Sonoran Desert and Apache Highlands	102,011	41,300	2,012	6,600	610–2,621	2,000–8,600
Tonto NM	Sonoran Desert	1,120	453	524	1,720	695–1,219	2,280–4,000
Tumacácori NHP	Apache Highlands	356	144	104	340	994–1,097	3,260–3,600
Tuzigoot NM	Apache Highlands	373	149	12	40	1,024–1,036	3,360–3,400
Chihuahuan Desert Network Parks							
Amistad NRA	Tamaulipan Thornscrub	57,292	23,195	82	269	282–364	925–1,194
Big Bend NP	Chihuahuan Desert	801,863	324,641	1,839	6,033	548–2,387	1,798–7,831
Carlsbad Caverns NP	Chihuahuan Desert and Arizona-New Mexico Mountains	46,766	18,934	896	2,940	1,096–1,992	3,596–6,535
Fort Davis NHS	Chihuahuan Desert	474	192	135	443	1,487–1,622	4,879–5,322
Guadalupe Mountains NP	Chihuahuan Desert and Arizona-New Mexico Mountains	86,416	34,986	1,562	5,125	1,105–2,667	3,625–8,750
Rio Grande WSR	Chihuahuan Desert	5,164	2,091	256	840	360–616	1,181–2,021
White Sands NM	Chihuahuan Desert	143,733	58,191	105	344	1,185–1,290	3,888–4,232

Parks where uplands monitoring occurs appear in bold.

trient and water availability, disturbance, and climatic conditions.

1.1.1.1 Community perspective

A plant community comprises the plants that coexist on a relatively homogeneous patch of land. Plant communities are an important subset of the broader community of organisms, which is itself a subdivision of the ecosystem at a local scale. Plant communities are holistic, reflecting the synthesis of the relative abundance, physiognomy, demography, and productivity of each member species.

The community concept in plant ecology has been defined by the holistic views of Clements (1916) versus the reductionist views of Gleason (1926). Clements proposed that plant communities had synthetic properties that interacted between consecutive stages of development, such that succession of different plant assemblages on a site is determined by disturbance and species interactions and is, therefore, directional and predictable. Gleason argued that each species responds individually to specific environmental constraints, and that coexistence in "plant associations" is driven by the chance combination of species with particular affinities for the environmental conditions of a specific time and place.

The dominant contemporary view of plant communities (Keddy 2001) falls between the two extremes of these ecologists, though leaning closer to Gleason than Clements:

plant communities (or associations) are the product of local biotic interactions (competition, facilitation, predation) and disturbance occurring against a broad background of environmental constraints.

Beyond the debate over the apparent dichotomy of holistic versus reductionist views of plant ecology, resource management goals and actions are often focused on plant communities rather than individual species. Examples include assessments of wildlife habitat suitability, riparian system function, and production of extractive renewable natural resources.

1.1.1.2 Individual-species or lifeform perspective

Determining patterns in individual species abundance, demography, and morphology is central to understanding and managing terrestrial ecosystems. Ecologists and managers have sought to identify and focus on "keystone" species (Mills et al. 1993) within communities: individual species that have a disproportionate effect on their environment relative to their abundance or biomass. Similarly, "indicator" species are individual species that track overall community condition or the integrity of an ecological process. Though hard to identify, indicator species may provide a more efficient way for tracking and estimating these parameters than community-scale monitoring.

Whereas identifying and monitoring all individual species can be costly, technically challenging, and may obscure ecosystem-level patterns that are of interest to managers, grouping species into "lifeforms" (Raunkier 1937) based on their morphology and key life history characteristics can be more useful and efficient than segregating all individuals by floristics. By adding considerations of the role each plant plays in the ecosystem, the "functional group" approach seeks to categorize plants by what they do (e.g., "sprouting, perennial shrub capable of symbiotic N fixation"), rather than just with what they breed (e.g., "*Prosopis glandulosa* and many other species with similar characteristics"). Both concepts are useful for monitoring and management and apply to both the keystone-species and indicator-species approaches (i.e., "keystone functional group," "indicator lifeform").

1.1.1.3 Established exotic plant species

Exotic invasive plants are a leading resource-management concern in network parks (NPS 2005, 2010). To maximize the efficiency of status and trends monitoring and the effectiveness of management control, it is useful to categorize exotic invasive plants based on the degree to which they are currently embedded in native ecosystems. Species that are already well established within native communities can best be monitored within the context of those overall vegetation types. In this fashion, exotic plants can be monitored similarly to common native species and accounted for in analyses of overall community composition and productivity. Existing exotic plant inventories (see http://www.southwestlearning.org/topics/biological/vegetation/invasive for examples), the Arizona Wildlands Invasive Plant Working Group's categorized list of 71 species (http://sbsc.wr.usgs.gov/research/projects/swepic/SWVMA/sbscmain.asp), and statewide and individual park exotic species lists provide a baseline for monitoring known problematic, non-native plants in SODN and CHDN parks.

Species that are not well-established within a given park or area are addressed in a separate Exotic Plants–Early Detection protocol (Folts-Zettner et al. in review) that covers all units of the Chihuahuan Desert, Sonoran Desert, and Southern Plains networks. Similarly, established exotic plants that occur within aquatic and riparian habitats are monitored through other established monitoring activities, such as the SODN streams and washes protocols and the CHDN/SODN seeps, springs, and tinajas protocol. See the NPS protocol database (http://science.nature.nps.gov/im/monitor/VitalSigns/BrowseProtocol.aspx) for more information on these monitoring projects.

1.1.2 Soils

Soil is a thin layer of mineral and organic material capable of supporting living plants, microbes, and vertebrate and invertebrate soil fauna. Soils play a central role in the cycling of nutrients, water, and energy in terrestrial ecosystems (Strahler and Strahler 1984) and are primary determinants of ecosystem productivity. The product of base geology, climate, and biological processes, soil forms relatively slowly as compared to biological communities, and is sensitive to human perturbation. Because soil development is very slow relative to most biological processes and land-management cycles (Brady and Weil 2002), SODN and CHDN will focus instead on dynamic soil processes and soil biota that can change over relatively short periods of time and are directly influenced by management actions. Because of the fundamental importance of water in these landscapes, we are most concerned with dynamic soil attributes that influence key ecohydrologic processes, such as soil erosion, infiltration, and nutrient cycling. Dynamic soil characteristics provide a functional assessment of critical ecosystem processes, such as soil erosion and site fertility. In addition to providing an actual measure of current and past site conditions, measures of dynamic soil properties can also help predict potential future conditions under different management and ecological settings.

Biological soil crusts, a highly specialized community of cyanobacteria, algae, microfungi, lichens, and bryophytes living on or near the soil surface, typically cover the open spaces in arid and semiarid regions. They provide key ecosystem services, such as increasing erosion resistance, generally increasing infiltration, contributing organic matter, and fixing atmospheric nitrogen. Subterranean cyanobacteria weave through the top few millimeters of soil, providing stability and fixed nitrogen. Lichens (a composite, symbiotic organism comprised of a fungus and either a cyanobacteria or a green algae) and bryophytes (small, non-vascular plants, including mosses and liverworts) occur on the surfaces of soil. Bryophytes are typically indicators of moist habitats.

Biological soil crusts are only metabolically active when wet and, thus, favor moister habitats, such as under a plant canopy or a northern exposure (Belnap et al. 2003). While biological soil crusts can be found on almost all soil types, their distribution is influenced by soil chemistry, elevation, timing of precipitation, vascular plant structure, and disturbance (Belnap et al. 2001). In the Sonoran Desert, cyanobacteria dominate biological soil crusts and short mosses, gelatinous lichens, and squamulose lichens are common (Rosentreter and Belnap 2003; Belnap et al. 2001). In the Chihuahuan Desert, cyanobacteria and short mosses dominate (Belnap et al. 2001).

Cover, function, and species composition of biological soil crusts are affected by disturbance. The type, timing, and severity influence the impact of a given disturbance (Belnap and Eldridge 2003). Recovery of disturbed biological soil crusts depends on several factors, including the type of disturbance, soil type, and the climatic regime. In general, disturbed crusts recover slowly in areas with high annual temperature and low annual precipitation (Belnap and Eldridge 2003), as in much of the Sonoran and Chihuahuan deserts. However, crusts appear to form quickly at White Sands NM (NPS 2008), which may decrease recovery times. Following disturbance, biological soil crusts typically follow a recovery sequence in which cyanobacteria first colonize a site, followed by cyanolichens, other lichens, and then moss (Belnap et al. 2001).

1.1.2.1 Soil and biological soil crust cover

Soil cover is the percentage of material (e.g., litter, duff, bedrock, gravel, rocks, vegetation, and biological soil crusts) covering the soil surface. Patterns of soil cover can be used to estimate actual soil erosion within a site and are leading indicators of potential soil erosion under different climate and management regimes. Raindrop impact is the primary initiator of water erosion through soil detachment, destruction of soil granules, and local transportation (Brady and Weil 2002).

The amount of soil cover, and its inverse, the amount of exposed bare ground, are important for estimating erosion potential. The total amount of soil cover is the single most important dynamic factor affecting water erosion; most soil loss occurs in “unprotected” areas (bare patches) (Herrick et al. 2005b; Davenport et al. 1998). As exposed bare ground increases, the erosion rate increases (Davenport et al. 1998). When the soil surface is not protected by plants, litter, gravel, rock, or biological soil crusts (which slow the flow of water and give it more time to soak into the soil) its soil aggregates can be easily broken apart by raindrops. In addition, an increase in the amount of bare ground also increases the velocity of surface-water flow (Herrick et al. 2005b). Wind erosion is similarly mitigated by soil cover (Herrick et al. 2005b).

Biological soil crusts increase water and wind erosion resistance. Cyanobacteria bind soil particles together by secreting polysaccharides. In addition to reducing water erosion, the polysaccharides also contribute to soil aggregate structure, which is directly correlated with soil erosion resistance (Belnap et al. 2003; Herrick et al. 2005b). Mosses and lichens have small, anchoring structures that help them protect the soil surface (Belnap et al. 2003). On most soils, biological soil crusts increase infiltration. However, on soils with more than 80% sand-sized particles, biological soil crusts tend to reduce infiltration rates (Warren 2003). This underscores the need to characterize the soils at each monitoring location. The occurrence and types of biological soil crusts and litter also provide insights into nutrient cycling, soil fertility, and infiltration. Biological soil crusts contribute fixed carbon to soil through decaying and leaching processes (Lange 2003). Cyanobacteria and cyanolichens have the ability to fix atmospheric nitrogen. This process reduces atmospheric nitrogen (N_2) to ammonia (NH_4^+), which is usable by vascular plants (Belnap 2003). Biological soil crusts can be the dominant source of nitrogen for desert ecosystems.

1.1.2.2 Soil aggregate stability and bulk density

As the product of physical, chemical (particularly for small aggregates), and biological processes (large aggregates), soil aggregates provide an integrated measure of soil biological integrity, hydrologic function, and nutrient cycling (Herrick et al. 2005b). Development of aggregates is a key indicator of soil age and stability because in-situ time is required for formation. Surface soil aggregates play a critical role in the movement of water, nutrients, and gases through the soil–atmosphere interface and in resisting wind and water erosion.

Soil bulk density (mass of a per-unit volume of soil) is indicative of soil porosity and is highly sensitive to soil compaction (Brady and Weil 2002). Soil compaction limits infiltration, soil water-holding capacity, and the development of root systems (Herrick et al. 2005b). Bulk density is also a function of soil texture and organic matter inputs. Bulk densities that are high or low for a given type of soil material can indicate stability and susceptibility of a site to erosion and other impacts like drought. Soil texture and chemistry are important determinants of soil-water relationships, nutrient cycling, and potential and actual site fertility.

Collectively, soil aggregate stability and bulk density provide insight into current and past site disturbance and an efficient measure of site stability in the context of potential management actions.

1.1.2.3 Soil and site characterization

Proximate soil and landform factors are known to influence vegetation and dynamic soil function parameters at local scales (McAuliffe 1999). Electrical conductivity is a surrogate measure of the salinity of moisture contained in the soil matrix (soil solution), with focus on sodium ion concentration and osmotic pressure. Sodium tends to disperse soil structure, resulting in decreased water infiltration capacity and storage (porosity). High ionic strengths can damage the cells of plants as osmotic potential draws water across cell membranes. At extremely high or low levels, pH, a measure of hydrogen ion concentration (in soil solution), can be toxic to both plants and soil fauna. pH also mediates the availability of many soil nutrients to plants and soil microbes contained in solution. Soil organic matter acts as “glue” for soil aggregates and helps retain nutrients and water in the soil matrix. Soil organic matter also enhances water infiltration rates through its role in aggregate formation (Brady and Weil 2002).

Particle-size distribution and rock-fragment quantification are similar measures of the same attribute. Both characterize the size of particles in a soil profile. Measures of particle-size distribution focus on the finer soil particles (sand, silt, and clay) that are most important for retaining plant-available water and nutrients. Rock-fragment quantification addresses coarser particles (gravel and larger), providing insights into soil porosity (and, therefore, water infiltration and storage). Increasing proportions of rock fragment result in fewer pores for water movement and storage in a soil profile. However, rock fragments also “armor” a soil against erosion and disturbance (Brady and Weil 2002).

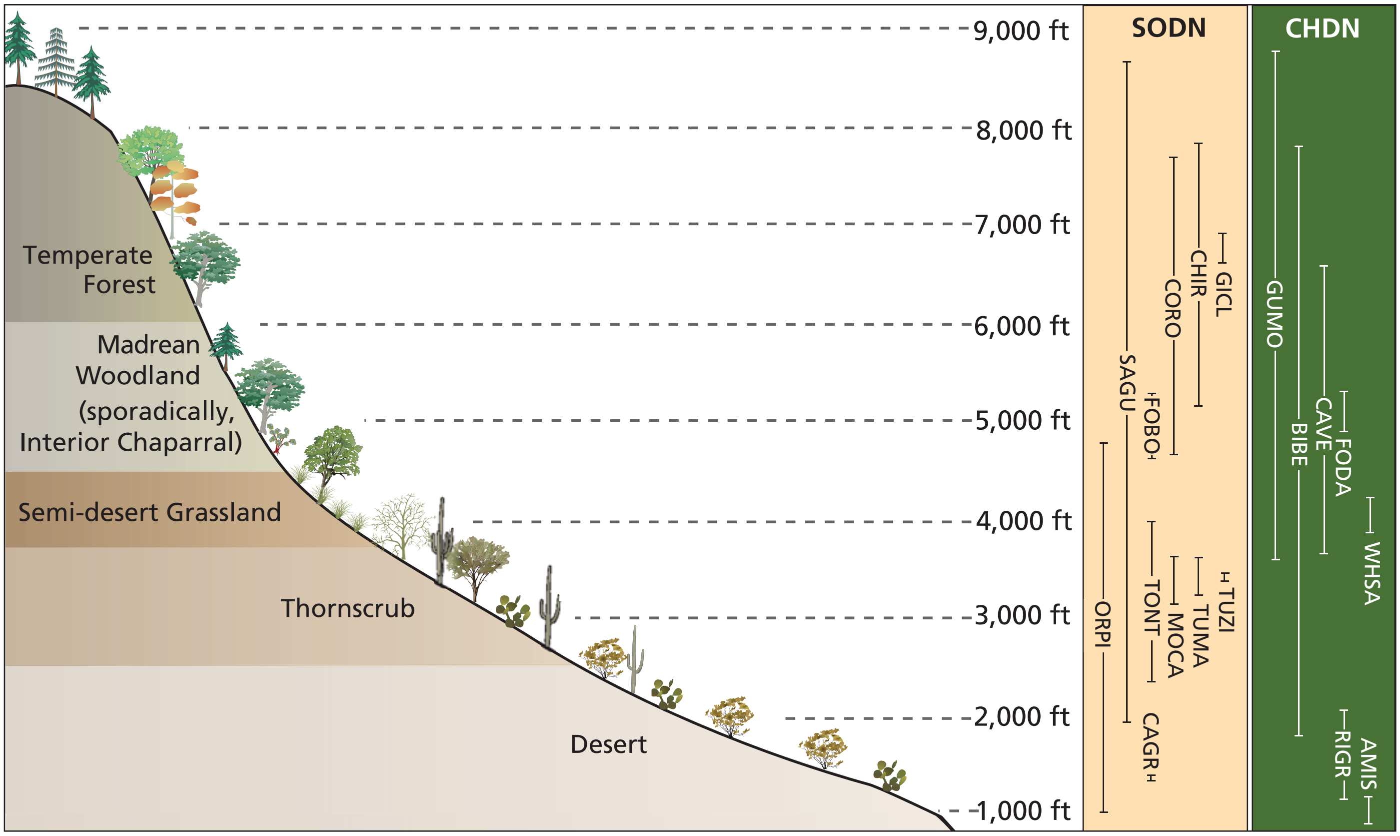

Figure 1-1. Biomes of the Sonoran Desert and Chihuahuan Desert networks. See Acronyms list for park acronyms.

1.2 Key terrestrial biomes in network parks

Sonoran and Chihuahuan Desert network parks contain nearly all of the major biomes of the American Southwest. Biomes (basic, widespread classes of habitats) are determined principally by temperature and precipitation, which are influenced by elevation, aspect, wind patterns, and latitude (Dimmitt 2000). The large topical relief within the Sonoran Desert, Apache Highlands, and Chihuahuan Desert ecoregions creates wet, cold climates that increase the diversity of biomes within the region (Dimmitt 2000).

Sky islands (mountain ranges isolated by intervening valleys of grass or desert) are areas of remarkable biological diversity—the result of great habitat diversity. The sky-islands complex of the southwestern U.S. extends from subtropical to temperate latitudes, hosting species from the Sierra Madre of Mexico and the U.S. Rocky Mountains (Warshall 1994). Because sky islands are isolated by inhospitable territory, genetic interchange between populations is limited. Speciation is common in the area and has resulted in high numbers of endemic species. Biotic communities found along sky-island gradients include desert, thornscrub, semi-desert grassland, interior chaparral, Madrean evergreen woodland, and temperate forest (Figure 1-1; Marshall 1957).

1.2.1 Desert and thornscrub

Aridity is the primary determinant of vegetation in desert and thornscrub (Figure 1-2),

Figure 1-2. Desert and thornscrub.

Figure 1-3. Semi-desert grassland.

Figure 1-4. Madrean evergreen woodland.

the driest biomes in the networks, as well as the lowest in elevation. The desert biome typically occurs at less than 2,500 feet in elevation, while thornscrub ranges from 2,500 to 3,700 ft. Vegetation within the thornscrub biome is typically taller and denser than desert vegetation (Dimmitt 2000). Net primary productivity is relatively low, even though lifeform diversity is high, with plants from all three photosynthetic pathways (C3, C4, and CAM) represented. Plants are well-spaced and typically exhibit microphyllous leaf phenologies.

Sonoran and Chihuahuan desert variants of desert and thornscrub communities contain a variety of phreatophytic (deep-rooted) shrubs, such as velvet mesquite (*Prosopis velutina*), acacias (*Acacia* spp.), paloverdes (*Parkinsonia* spp.), and creosote bush (*Larrea tridentata*). Succulents are ubiquitous in desert and, to a lesser degree, thornscrub, with agave (*Agave* spp.), yucca (*Yucca* spp.), barrel cactus (*Ferocactus* and *Echinocactus* spp.), hedgehog cactus (*Echinocereus* spp.), pricklypear (*Opuntia* spp.), and cholla (*Cylindropuntia* spp.) common. Warm- and cool-season annual grasses and forbs, both native (e.g., woolly plantain [*Plantago patagonica*]) and introduced (e.g., red brome [*Bromus rubens*]) are common following rainfall.

The introduction of non-native species, such as red brome and buffelgrass (*Cenchrus ciliare*), to the Sonoran and Chihuahuan deserts has had far-reaching impacts. Historically, desert and thornscrub rarely burned, as continuous fine fuels were lacking. Consequently, most desert and thornscrub species are not adapted to fire (Dimmitt 2000). However, following rains, introduced species grow prolifically in mats, providing ample fuel for fires to race across the desert. Drought-tolerant invasive grasses are a serious threat for this arid ecosystem, as they are tolerant of fire and promote fire extent, frequency, and severity through the production of continuous fine fuels. By contrast, most native desert species are very susceptible to even low-intensity burns, resulting in a positive feedback cycle of Invasion → Fire → Invasion.

1.2.2 Semi-desert grassland

In contrast to those of the Great Plains, grasslands in the Sonoran and Chihuahuan deserts (Figure 1-3) are semi-desert in nature and typically composed of perennial short- and mid-grass species. Annuals and geophytes are also common, with occasional shrubs or trees. Most grasses in semi-desert grasslands use the C4 photosynthetic pathway, which provides for greater water-use efficiency than the C3 photosynthetic pathway of most other plants.

Fire is a relatively common and necessary occurrence in semi-desert grassland, historically burning every 5–10 years. Fire maintains the open structure of the vegetation, conferring a competitive advantage to graminoids (grasses, sedges, and rushes) over most woody plants. Fire suppression, intensive grazing, and soil erosion have degraded many of the grasslands in this region (Gori and Enquist 2003), leading to encroachment

Figure 1-5. Interior chaparral.

Figure 1-6. Temperate forest.

by woody species and drought-resistant, non-native grasses, such as Lehmann lovegrass (*Eragrostis lehmanniana*). Climate also influences grassland production and composition, both directly and through interactions with grazing, fires, or fire suppression. Semi-desert grasslands are typically found at elevations of 3,700–4,500 feet.

1.2.3 Madrean evergreen woodland

Madrean evergreen woodland (Figure 1-4) is the most extensive woodland type in the Apache Highlands ecoregion and is ubiquitous at mid-elevations (4,500–6,000 ft) in SODN and CHDN parks. Madrean evergreen woodland is characterized by evergreen oaks with sclerophyllous leaves, such as emory oak (*Quercus emoryi*), Arizona white oak (*Quercus arizonica*), and Mexican blue oak (*Quercus oblongifolia*). Mexican pinyon pine (*Pinus cembroides*) and alligator juniper (*Juniperus deppeana*) are common gymnosperms (vascular plants whose seeds are not enclosed in fruit). Understory perennial grasses are usually abundant, and woodlands may grade into tree savannas due to disturbance, local climate, or topoedaphic factors. Madrean evergreen woodland is typically bounded by semi-desert grasslands and savanna at lower-elevation, warmer and drier sites and by evergreen and broadleaf forests on more mesic and cooler sites (either by increasing elevation, aspect, or occurrence of a riparian area).

1.2.4 Interior chaparral

Interior chaparral (Figure 1-5) is a semi-arid shrubland type that occurs on the west coast of every continent between 30 and 40°N latitude. Chaparral in the American Southwest is found along the Mogollon Rim and in smaller patches at mid-elevation in other montane systems. This interior variety of chaparral has fewer species than the coastal variety in California. Interior chaparral is composed of dense stands of manzanita (*Arctostaphylos* spp.) and shrub live oak (*Quercus turbinella*). These species have thick, sclerophyllous (hard, thick) leaves containing large quantities of volatile compounds. The natural fire regime for chaparral includes intense, fast-moving fires that are often stand-replacing. Manzanita requires charrate (burned, woody material) for sexual reproduction, and each of these species sprouts vigorously following fire (Epple 1995).

1.2.5 Temperate forest

Occurring at high elevations (>6,000 ft) in the American Southwest, temperate forests (Figure 1-6) are dominated by conifers, such as pines (*Pinus* spp.), spruces (*Picea* spp.), and firs (*Abies* spp.). Cold deciduous woody plants, such as Gambel oak (*Quercus gambelii*), trembling aspen (*Populus tremuloides*), and maples and boxelder (*Acer* spp.), are common in the understory of coniferous forests. At sites with particularly cool and moist microclimates (often on north or east-facing slopes), cold-deciduous trees may dominate the overstory, particularly following fire and or other disturbances that create canopy openings and permit these species to emerge from the understory.

Temperate forest represents the most cold-hardy vegetation type in the montane systems of the American Southwest. Confined to cooler sites (a function of elevation, aspect, and local geomorphology) under the current warm interglacial climate, temperate forest occurs upslope from Madrean evergreen woodland, typically at elevations greater than 6,000 feet.

Most conifer forests in the networks are dominated by ponderosa pine (*Pinus ponderosa*), with a grassy understory where canopies are relatively open and subdominant trees and shrubs where canopies coalesce. Douglas-fir (*Pseudotsuga menziesii*) and true firs occur at higher elevations, with spruce at the highest elevations. Conifer forests are fire-adapted, with natural, low-intensity fires occurring every 9–15 years in ponderosa pine and mixed-conifer forests (Dimmitt 2000). Suppression of fires by humans has disrupted the natural cycles within many of these communities.

1.3 Changes from Version 1.0

The current protocol builds on the unpublished Terrestrial Vegetation and Soils Protocol for the Sonoran Desert Network, Version 1.0 (Hubbard et al. 2009). Major changes for this version are:

1. **The protocol has been extended to include CHDN parks.** Through the Southwest Network Collaboration (SWNC), the SODN Terrestrial Vegetation and Soils protocol has been extended to include five Chihuahuan Desert Network parks: Big Bend NP, Carlsbad Caverns NP, Fort Davis NHS, Guadalupe Mountains NP, and White Sands NM. This change is evident throughout the narrative and appendices.
2. **Monitoring the density of columnar cacti and ocotillo has been added as a monitoring objective.** Columnar cacti (saguaro, senita, organ pipe cactus in the Sonoran Desert) and ocotillo (in both deserts) are iconic focal species of the Sonoran and Chihuahuan deserts. However, foliar cover and frequency do not effectively capture important changes in the relative abundances of these species of management interest. To address this gap, we have added an additional monitoring objective: to monitor the density (individuals by height class/hectare). See Section 2.1.3 and SOP#5 (SOPs can be found in a folder attached to the electronic version of this document; a list is provided in Appendix C).
3. **The optional objective of monitoring plant associations has been dropped.** Based on pilot work conducted from 2007 to 2011, this optional objective proved unrealistic, given cost and time constraints. These issues were identified as problematic by the external reviewers of version 1.0, as well.
4. **Fuels and other fire-related measures have been incorporated into the soil cover monitoring objective.** Climate change is expected to have important consequences for fire regimes in ecosystem of the American Southwest (USCCSP 2008). Adding key fire and fuels measures to terrestrial vegetation and soils sampling was identified as a high priority for monitoring during the 2010 Desert Southwest Climate Change Monitoring Workshop (Sonoran Institute 2010). As such, fuels measures have been added to this protocol, a geodatabase was created to track fires and other disturbances within the target parks, and a vegetation and soils severity module (drawn from the NPS Fire Monitoring Handbook, NPS 2003) was added to assess fire effects on long-term monitoring plots. See Section 2.2.1, SOP#5, SOP#13.
5. **The minimum sample size for any stratum has been set at five plots.** In version 1.0, plots were allocated to strata proportional to their area within the park. As a result, a relatively small stratum might have only 2–3 plots, introducing some sample-size limitations into the analysis. Examples of this have occurred at Montezuma Castle NM (McIntyre et al. in prep.[2]), Saguaro National Park (Rincon Mountain District) (Hubbard et al. 2010), and Tonto NM (McIntyre

et al. in prep.[3]); in each case, additional plots were added to ensure that sampling intensities were adequate to assess the within-stratum estimates. To address this issue, we now set a minimum sample size for any stratum at five plots, with a few exceptions (see Section 3.2.3).

6. **The number of soil samples per plot was reduced.** In version 1.0, we collected 48 soil aggregate samples and 3 soil bulk density samples per plot. After analyzing the first four years of monitoring data, we determined that we could reduce the number of soil aggregate stability samples to 18 per plot and only collect a single soil bulk density sample per plot (McIntyre in prep).
7. **We identified high-priority topics for future research.** To enhance the value of the monitoring information, we have identified some key research pathways that can leverage the information value of the monitoring information. These research topics may be pursued by cooperators, network staff, or some combination thereof, as funds, time, and interest permit. See Section 1.4.

1.4 Directions for complementary research

During the development, testing, and implementation of this protocol, three key areas for additional research were identified that would leverage monitoring results to better inform management decisions:

1. **Quantifying habitat characteristics that define habitat condition for species of management interest.** In addition to maintaining overall integrity of ecological systems, park managers are charged with managing for particular species of interest, or species with additional legal protections, such as those listed under the U.S. Endangered Species Act. As habitat quality is an important factor for sustaining these species through management action, linking vegetation monitoring parameters with documented descriptions of "good," "acceptable," and "poor" habitat for species of management concern would greatly enhance the information value of this protocol.

   For example, parks that manage for lesser long-nosed bat (*Leptonycteris nivalis*) habitat (semi-desert grassland with a particular structure and composition) could better assess their success if research has quantified the specific vegetation structural characeristics required by this important species. That is, knowing that (say) >15% cover of agave species is required to support this species within the park would be far more useful than simply knowing that "lesser-long nosed bats need lots of agave," and would extend the value of monitoring results.
2. **Understanding the distribution, abundance, and species composition of biological soil crusts.** In general, there is limited information on the distribution, abundance, and species composition of biological soil crusts at SODN and CHDN parks. While several parks have been the site of research studies on particular attributes of biological soil crusts (e.g., Saguaro NP, Organ Pipe Cactus NM, and White Sands NM), those studies did not inventory biological soil crusts. Tuzigoot and Montezuma Castle NMs are an exception, due to modeling done by Bowker and Belnap (2008) on the potential for biological soil crusts at the monuments and other Flagstaff-area parks.
3. **Understanding the relationships between field-based vegetation and soils parameters and watershed condition/erosion potential.** In semi-arid and arid systems, soil erosion is one of the leading threats to ecosystem integrity and productivity. Multi-scale research that examines linkages between plot-based monitoring parameters and watershed-scale erosion factors is needed to adequately address this important stressor, particularly in the context of disturbance (such as fires, floods, and droughts) and climate change.

2 Program Goals and Measurable Objectives

The overall goal of the SODN/CHDN terrestrial vegetation and soils monitoring program is to ascertain broad-scale changes in vegetation and dynamic soils properties in the context of changes in other ecological drivers, stressors, and processes, as well as focal resources of interest. The following sections describe these objectives in detail.

2.1 Terrestrial vegetation

For the terrestrial vegetation monitoring effort, we will record the vegetative cover of common perennial species (>10% canopy cover), including non-native plants and a small suite of non-native species; and the frequency of uncommon perennial species (including non-native) and annual non-native species.

2.1.1 Monitor vegetation cover

We will determine the status of and detect trends in vegetative cover (%) of common (>10% absolute cover) native and non-native perennial plant species and a small suite of non-native annual plant species that occur in terrestrial ecosystems of network parks. Measuring vegetative cover of common perennial species is an effective and traditional approach for monitoring plant populations (Elzinga et al. 1998). Cover is the percentage of ground surface covered by vegetation material (Bonham 1989), providing both an absolute and relative measure of species and lifeform abundance. This approach allows determination of status and detection of trend within a single species of interest, facilitating the use of "keystone" and "indicator" species and providing focused information on species of management concern (e.g., established exotic invasive species or "flagship" species, such as saguaro cacti). Determining the foliar cover of all common perennial species permits direct contrasts of species of interest and ensures that information is not lost if future research or management objectives focus on a species that is currently a lower priority. The disadvantage of collecting multi-species foliar cover data in this fashion is that it requires considerable field effort and methods that are effective across all lifeforms (from large tree to small herb).

2.1.2 Monitor species frequency

We will determine the status of and detect trends in the frequency (%) of uncommon (10% cover) native and non-native species (perennial and select annual) in terrestrial ecosystems of network parks. This is our most easily achieved monitoring objective for terrestrial vegetation. Plant frequency is the number of times a plant species/lifeform is encountered in a given number of plots or sample points (Bonham 1989), providing a measure of the occurrence and distribution of species within a landscape or stratum of interest. Frequency provides an effective index of change over time and space, and can efficiently provide information on species and lifeforms that are uncommon or have highly variable year-to-year distributions, such as most desert annuals (Elzinga et al. 1998). However, frequency is affected by plant density and spatial arrangement, as well as plot size and arrangement, and is difficult to visualize across a landscape.

2.1.3 Monitor density of selected plant species

We will determine the status of and detect trends in the density (individuals/hectare) of columnar cacti and ocotillo as they occur in network parks. Columnar cacti, such as saguaro (*Carnegia gigantea*), organ pipe (*Stenocereus thurberi*), and senita (*Pachycereus schottii*) are emblematic species of the Sonoran Desert, and ocotillo (*Fouquieria* sp.) is a common flagship plant in both the Chihuahuan and Sonoran deserts (Dimmitt 2000). However, the foliar cover and frequency (as collected for this protocol) of these important species may not consistently represent their relative abundance or condition within park plant communities. Instead, we will complement our cover and frequency monitoring of these focal plant species with density measurements by height class.

Plant density is an efficient measure of mortality and recruitment, particularly for species in which vigor or foliage production correspond weakly with plant condition (Elzinga et al. 1998), as is the case with columnar cacti and ocotillo. The disadvantages of density are that (1) it can be very time-consuming to collect over broad areas or with a large number of target species; (2) observer error can be high if individual plants are difficult to distinguish; and (3) density is insensitive to dramatic fluctuations in annual productivity (Elzinga et al. 1998; Bonham 1989). As columnar cacti and ocotillo are relatively slow-growing, generally single-stemmed or with an obvious single-basal growth point, and have very restricted canopy growth compared to plant age, biomass, and condition, density should provide useful supplemental monitoring information for these important focal species.

2.2 Soils

To track dynamic soil function, we will monitor the cover of soil by biological soil crusts, vegetation, litter, and abiotic materials that influence soil movement; the stability of surface soil aggregates; and, when and where warranted by declines in these soil properties, the bulk density of near-surface soils.

2.2.1 Monitor soil cover, fuels, and biological soil crust cover and frequency

We will determine the status of and detect trends in soil cover (percent by type) and cover and frequency of biological soil crusts (percent by lichen growth form and morphological group for cyanobacteria and bryophytes) in terrestrial ecosystems of network parks. Soil cover is the percentage of the soil surface covered by substrate class (e.g., litter, duff, bedrock, gravel, rocks, and vegetation; Herrick et al. 2005b), providing an absolute and relative measure of these objects that influence erosion resistance. By subdividing the litter substrate into standard fuel classes as used by the NPS Fire Ecology program (NPS 2003), additional data about fire potential and fuel models can be obtained.

Biological soil crust cover is a subset of soil cover and is similar in concept, with the categories of interest being growth forms for all lichens and morphological groups for bryophytes and cyanobacteria. Bryophytes and cyanobacteria serve profoundly different ecological functions but are difficult to identify in the field. Therefore, they are identified to the morphological group level. In general, lichens with the same growth form have similar ecological functions and are therefore identified by growth form (gelatinous, crustose, squamulose, foliose, and fruticose). Biological soil crust frequency is the number of times a lichen growth form/morphological group is encountered in a given number of plots or sample points.

2.2.2 Monitor soil aggregate stability

We will determine the status of and detect trends in surface soil aggregate stability (by stability category, 1–6) in terrestrial ecosystems of network parks. Surface soil aggregate stability is the resistance of soil aggregates on and near the soil surface to degradation (Herrick et al. 2005b). Soil aggregate stability provides both an indicator of site disturbance and site resistance to soil erosion and provides insights into soil water-holding capacity and infiltration rates.

2.2.3 Estimate baseline soil characteristics: bulk density, texture and chemistry

We will determine the status of and document dramatic shifts in soil bulk density (mass per unit volume of the bulk soil matrix) in terrestrial ecosystems of network parks. We will collect soil samples during the establishment of each new plot to estimate soil bulk density, texture, and basic chemistry for these permanent sites. This baseline soils information is useful for interpreting data on soil aggregate stability, biological soil crust, and vegetation monitoring. Due to the destructive nature of sampling techniques and the resistance of these parameters to change, bulk density, texture, and chemistry will only be re-measured if observations indicate substantial disturbance, such as from fire, landslide, or severe erosion.

Information from these samples serves a vital purpose in answering questions about the dynamic soils vital signs. Relative surface age and stability, material source and mineralogy, and disturbances of both natural and anthropogenic origins will leave a signature in this suite of parameters that will greatly help us to interpret patterns and trends in vegetation and cover, and especially to make comparisons between plots.

3 Sampling Design

3.1 Overview

3.1.1 Co-location of vegetation and soils measures

We will use permanent plots in which all vegetation and soils vital signs will be measured (Figure 3-1). Because all of these vital signs are highly interdependent in terrestrial ecosystems, measuring them in close temporal and spatial proximity will likely add to our understanding and interpretation of the data. Co-location also provides substantial logistical advantages; for instance, crews trained in all data collection procedures can simultaneously collect several kinds of information while minimizing travel and other operational costs. The primary disadvantage of co-location is that the sampling and survey design are necessarily a compromise, whereas approaching each element individually might allow for more optimal designs for each. For example, soil aggregate stability is best sampled when soils are dry, but vegetation is best sampled during or just following the primary growing season. We contend that this disadvantage is more than offset by the substantial advantages of co-location.

3.1.2 Sampling intervals

Vegetation and soils development is a function of the relatively slow influence of broad-scale drivers and stressors (e.g., climate patterns, plant demography, human development) punctuated by intense disturbances (e.g., fire, acute temperature and moisture extremes, human disturbance) that can create rapid (albeit usually local) changes (Hastings and Turner 1965).

This protocol focuses on tracking broad-scale changes while maintaining some flexibility for assessing the effects of stochastic disturbance events, which are difficult to predict in their occurrence, location, extent, and intensity. We assume that meaningful ecological change typically occurs on time scale intervals of five or more years, and have therefore designed our sampling strategy to determine trends over five-year intervals.

3.1.3 Stochastic disturbance events

Documenting the effects of disturbances on terrestrial vegetation and soils is important for effective park management and accurate interpretation of long-term vegetation and soils data. We will address disturbance effects using the following strategies.

3.1.3.1 Document the occurrence and spatial extent of disturbances

Network staff and cooperators have developed a geodatabase to track common disturbances, such as fires, floods, insect and pathogen outbreaks, and mass soil-movement events. Park and network staff will enter spatial data and disturbance characteristics. Information on human disturbances will be derived from park-based efforts, such as the Border Impacts Rapid Assessment Tool developed by ORPI to document the impacts of border crossings and subsequent enforcement activities. All of these outlets will be used to document disturbances so that, for example, if Plot #17 burns between sample periods 1 and 2, we can flag that plot prior to sample period 2 to ensure that we take supplemental soil bulk density measurements in order to help with data interpretation and avoid confounding the assessment of broader ecosystem change. Data from Plot #17 might also be used to describe the effects of the fire in this context, though interpretation of fire effects may be limited by sampling intensity.

3.1.3.2 If deemed important, investigate disturbance effects on selected vegetation and soils plots

In conjunction with park staff, other NPS programs (e.g., fire ecology), and/or researchers, selected events and sites may be investigated through additional sampling and research. The network's level of involvement might vary greatly, from data sharing to active involvement in data collection and analysis, depending on available time and funding, and on the priorities set by the network's board of directors. While valuable for supporting park management, such activities must not preclude routine monitoring

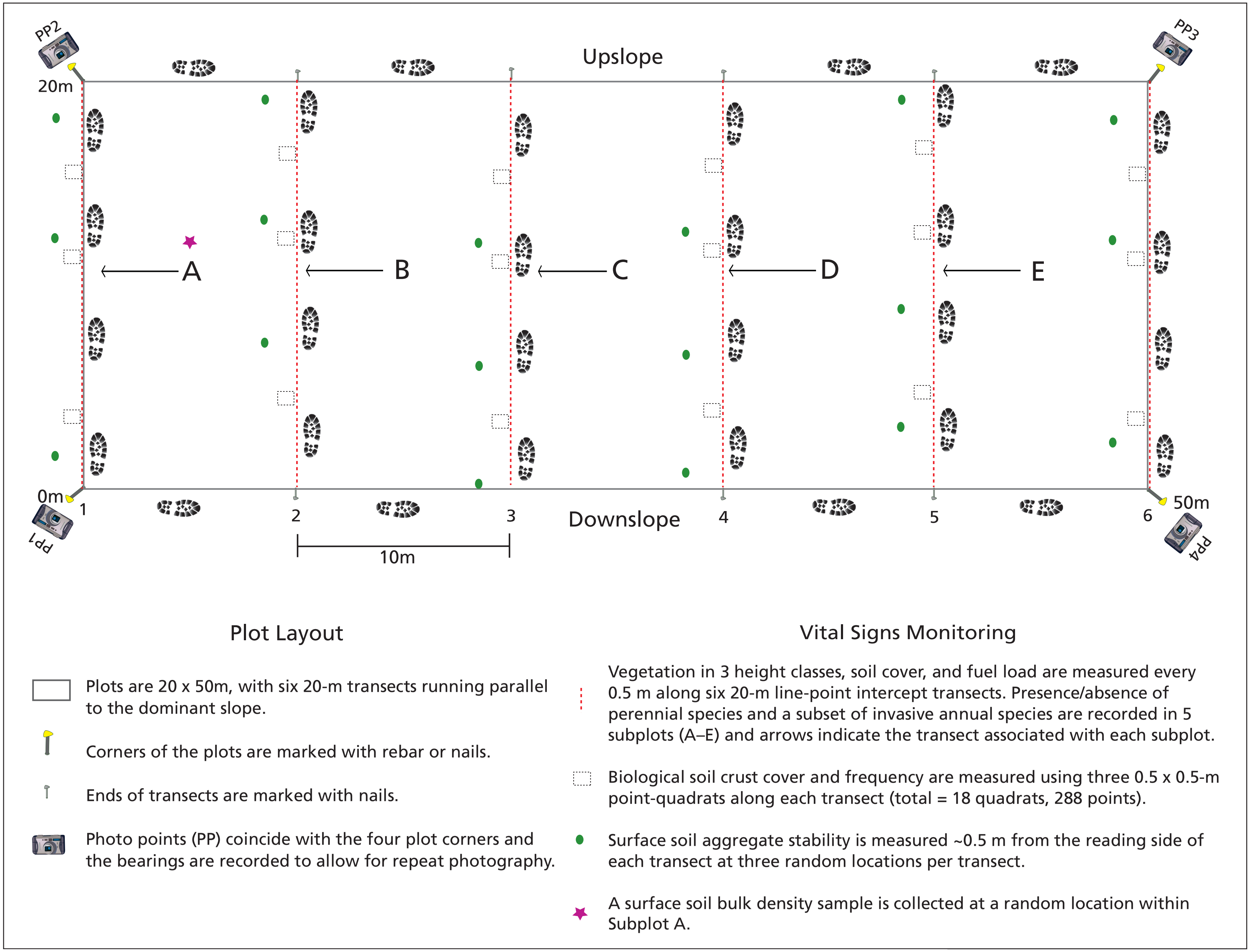

Figure 3-1. Upland plot survey design.

activities by network staff. Using the example from Section 3.1.3.1, intensive monitoring of fire effects, fuel reduction, or other ecological parameters of interest could be initiated (perhaps by a cooperator) at Plot #17 to document recovery of the site.

Our first application of this contingency is occurring after the major wildfires of 2011, during which Chiricahua NM (Horseshoe 2 Fire), Coronado NMEM (Monument Fire), and Gila Cliff Dwellings NM (Miller Fire) sustained intensive landscape-scale burns to upland locations. Through collaboration with the NPS Fire Program, SODN staff has assessed immediate post-fire vegetation and soil severity on terrestrial vegetation and soils plots, and plans to re-read (ahead of schedule) a subset of burned monitoring plots to ascertain the impacts of these important events on the vegetation and dynamic soil vital signs.

3.2 Spatial sampling design

3.2.1 Spatial balance

The spatial sampling design for this protocol employs permanent, 20 × 50-m sampling plots, allocated through a random, spatially balanced approach: the Reversed Randomized Quadrant-Recursive Raster (RRQRR) method (Theobald et al. 2007). For SODN parks, we used the "spatially balanced sample" function in the STARMAP Spatial Sampling Toolbox in ArcGIS 9.0 (http://www.spatialecology.com/htools/index.php). For CHDN parks, we used the Create Spatially Balanced Points tool (Geostatistical Analyst) in ArcGIS 10, based on the algorithm developed by Theobald and others (2007). These tools produce designs that are spatially well-balanced, probability-based, flexible, and simple (Theobald et al. 2007). Because its goal is to maximize the spatial independence between plots, a spatially balanced sampling design should provide more information per plot, thus increasing efficiency (Theobald et al. 2007).

Spatially balanced designs, such as RRQRR (Theobald et al. 2007) and the Generalized Random Tessellation Stratified approach (GRTS; Stevens and Olsen 2004), are increasingly being applied to ecosystem monitoring (e.g., Environmental Protection Agency Ecological Monitoring and Assessment Program) because they provide the advantages of a probabilistic design (Stehman 1999) and also ensure spatial balance regardless of overall sample size. RRQRR designs facilitate the addition or removal of sites in a spatially balanced manner if statistical power, financial considerations, or additional monitoring objectives warrant adjusting the sample size. This scaling ability is an important advantage, as (1) the number of plots per park cannot be adequately estimated *a priori* (see Section 3.4.2) and (2) future changes in technology, objectives, and budgets may necessitate increasing or decreasing sample sizes.

3.2.2 Sampling frame

The sampling frame for all network parks includes all terrestrial areas within park boundaries, except for the following:

- Slopes of ≥45° (for crew safety)
- Roads and buildings (including 100-m buffer for SODN, 50-m for CHDN)
- Trails, washes, and streams (including 50-m buffer)
- Fragile cultural features (e.g., Casa Grande "big house")

3.2.3 Stratification

All parks were stratified based on elevation and soil rock-fragment class (see Appendix A). Rock-fragment class refers to how much material present in the soil profile is composed of particles greater than two millimeters in diameter (i.e., gravel or larger). Varying quantities and types of rock fragments contribute to controls on environmental stresses on vegetation in different landforms, and landform-scale studies have linked geomorphology to vegetation patterns, especially on surficial materials sourced from different lithologies (Parker 1991, 1995; McAuliffe 1999). Soil rock-fragment class has been determined to be a proxy for water availability for plants and infiltration, and varies by landform to influence actual and potential vegetation types.

Soil rock-fragment classes were determined based on the rock-fragment modifier from the most recent soil survey. When describing soil texture, a rock-fragment modifier term is typically used to describe the shape and size as well as the amount of rock fragment present.

Table 3-1. Descriptive modifiers according to rock-fragment volume.

Rock fragment by volume	Modifier/Class
<15%	no modifier is used
15–35%	The dominant type of rock is used (gravelly, cobbly, etc.)
35–60%	The type of rock term preceded by the word "very" (very gravelly)
>60%	The type of rock term preceded by the word "extremely" (extremely gravelly)
>90%	bedrock or rock outcrops

Table 3-1 shows the modifiers associated with different amounts of rock fragment by volume (Schoeneberger et al. 2002). For example, a sandy loam soil that contains 22% cobble would be described as cobbly sandy loam.

These rock-fragment modifiers were combined into three soils strata:

- <35% rock fragment
- 35–90% rock fragment
- >90% rock fragment (bedrock or rock outcrop)

Because the scale of available biome maps is too coarse (1:100,000) to be useful at the park level, elevation was used as a proxy for biome.

Strata for elevation are:

- Desert: <2,500'
- Thornscrub: 2,501–3,700'
- Semi-desert Grassland and Interior chaparral: 3,701–4,500'
- Madrean Evergreen Woodland: 4,501–6,000'
- Temperate Forest: >6,000'

The combination of the elevation and soils strata results in 15 potential strata. Plots are allocated to strata proportional to the amount of area they occupy within the sampling frame. To ensure adequate sampling intensity, a minimum of five plots will generally be sampled in each stratum. Exceptions to this rule are made when subsequent-year analyses show that two or more strata do not have any significant differences, indicating that they could be combined in the future to increase time and cost efficiencies or when the park and strata are very small, for example, Casa Grande Ruins NM. In these cases, fewer than five plots will be sampled in each stratum.

3.3 Temporal sampling design

3.3.1 Annual sampling

Using permanent plots dramatically increases our ability to efficiently detect trends, because doing so causes spatial and temporal variability to be explicitly partitioned (Elzinga et al. 1998). The disadvantages of permanent plots are that (1) sampling across landscapes (space) is reduced as resources are dedicated to revisiting existing plots; (2) plots must be extensively marked and mapped to ensure that they can be reliably relocated in the future; and (3) repeat visits to a plot may influence future measurements. For example, because biological soil crusts are very sensitive to trampling, repeat visits may artificially decrease this cover. The issue of precise relocation of permanent plots can be overcome through the application of high-resolution GPS technology, buried markers, and good survey practices. The problem of plot degradation due to repeat visits can be addressed by increasing the time between sampling intervals and ensuring that field crews take great care to avoid walking on measurement transects. The spatial sampling disadvantage can be improved through the use of a simple rotating panel design (McDonald 2003).

Our rotating panel design allocates plots annually, such that each plot is revisited every five years [1,4], in line with our assumptions regarding the timing of biologically meaningful change (see Section 3.1.2). The five-year revisit interval described above is our preferred design and our intent is to revisit plots every five years. However, if funding levels were reduced, we would implement a 10-year revisit design [1,9].

For relatively large units (Table 3-2), the total population of plots is apportioned evenly per year (e.g., 50 plots over a five-year period = 10

Table 3-2. Portion of plots sampled per park per year, based on a five-year rotation.

Park	Network	Monitoring initiated
Large parks (1/5 of plots sampled per year)		
Big Bend NP	CHDN	2011
Carlsbad Caverns NP	CHDN	2012
Chiricahua NM	SODN	2007
Coronado NMEM	SODN	2009
Guadalupe Mountains NP[1]	CHDN	2010
Organ Pipe Cactus NM[2]	SODN	2010
Saguaro NP (East)	SODN	2008
Saguaro NP (West)	SODN	2009
White Sands NM	CHDN	2011
Small parks (all plots sampled during just one year of 5-year period)		
Casa Grande Ruins NM	SODN	2008
Fort Bowie NHS	SODN	2008
Fort Davis NHS	CHDN	2011
Gila Cliff Dwellings NM	SODN	2009
Montezuma Castle NM	SODN	2010
Tonto NM	SODN	2009

[1] Monitoring piloted in 2010; plots from that year are combined with 2011 plots in the panel design.

[2] Monitoring restarted within revised sampling frame due to concerns about safe access to border areas.

plots/year). The advantages of this design are that (1) the influence of interannual variation ("noise") is less pronounced for the analysis of five-year trends; and (2) there are tremendous efficiency gains from the perspective of fielding and funding sampling crews, as effort is spread evenly over the five-year intervals. The disadvantages are that (1) the effects of individual stochastic events may be difficult to evaluate (see Sections 3.1.2–3.1.3) and (2) detecting trends requires at least 10 years of data collection (i.e., two sampling intervals for all plots).

For small, relatively accessible units with modest sample sizes, the logistical advantages of sampling one-fifth of the plots annually is reversed; it would be costly and inefficient to hire, train, and send a crew to a unit in which only 1–3 plots would be sampled annually. In effect, there is a "critical mass" of sample units that needs to be reached to make annual sampling efficient. Consequently, we will sample all plots within the same year for small parks, and not sample again until the five-year interval is complete. Table 3-2 lists the small parks that are sampled using this design.

Rotating-panel designs generally allow trend detection over shorter time periods (particularly when a subset of the plots is monitored continually), but sampling intensity is unlikely to meet our statistical power and species-detection goals (see Section 3.4). We ruled out intensive annual monitoring of a subset of plots due to concerns over plot degradation, as discussed in the SODN natural and cultural resource compliance effort (NPS 2005).

3.3.2 Seasonal sampling

Common plants and plant communities occurring in the networks exhibit tremendous variation in physiognomy, phenology, and season of growth (see Section 1.2). To best capture the autecological (across the plant community) and synecological (within a population) patterns of perennial plants, field-sampling schedules will coincide with the season of peak production for major biomes. This will also allow field crews to sample various communities throughout the year, a logistical advantage.

Soil aggregate stability samples must have similar soil-moisture values to be valid for comparison (Herrick et al. 2005b). Field efforts will avoid aggregate stability sampling during or just following major precipitation events. Biological soil crust sampling is also best done in dry conditions, because biological soil crusts may swell following major precipitation events, potentially causing increases in cover. Variation in soil moisture is not an issue for bulk-density sampling.

3.4 Sample size

Adequate sample size is important for (1) detecting all species of interest and (2) determining our ability and confidence in detecting a trend of a given magnitude. Both detectability and power to detect trend in univariate parameters can be estimated before initiating sampling (*a priori*) using legacy data, and refined during the first few sampling intervals.

3.4.1 Species detection

Sample size, plot arrangement, and actual population size and distribution determine our ability to detect a given species within our vegetation and biological soil crust objectives (see Section 2). An effective method for determining if sample sizes are adequate at plot and landscape scales is to develop species accumulation curves (Clarke and Warwick 2001). If the curves approach the asymptote at the specified within-plot or across-plot (landscape) scales, then we can be confident that we are detecting the majority of common species. Species accumulation curves are based on legacy data; initial monitoring results have been presented in the annual reports for 2008–2010 (see Section 6.3).

3.4.2 Power to detect landscape-level trends in univariate parameters

Estimating statistical power to detect trends is important for both protocol design (especially determining sample sizes) and data interpretation. Adequate sample size (n) for detecting a trend of a given size across a landscape with permanent plots is determined by the following equation (from Herrick et al. 2005a):

$$n = \frac{(S_{diff})^2 (Z_\alpha + Z_\beta)^2}{(MDC)^2}$$

Where:

S_{diff} = Standard deviation of the differences between paired samples

Z_α = Z-coefficient for false-change (Type I) error

Z_β = Z-coefficient for missed-change (Type II) error

MDC = minimum detectable change size.

Note that the sample sizes are determined by strata; therefore, parks containing many strata, such as Saguaro National Park's Rincon Mountain District, will require proportionately more sampling effort to meet our sampling objectives. Bonham (1989), Elzinga and others (1998), and Herrick and others (2005a) provide detailed discussions of statistical power to detect trend.

3.4.3 Power to detect plot-level trends in univariate parameters

Adequate sample size (n) for detecting differences between two means within a permanent plot is determined by the equation in Section 3.4.2. The equation below (Elzinga et al. 1998) is used to determine the number of samples necessary to detect differences between two proportions:

$$n = \frac{(Z_\alpha + Z_\beta)^2 (p_1 q_1 + p_2 q_2)}{(p_2 - p_1)^2}$$

Where:

Z_α = Z-coefficient for false-change (Type I) error

Z_β = Z-coefficient for missed-change (Type II) error

p_1 = The value of the proportion for the first sample as a decimal

q_1 = 1-p_1

p_2 = The value of the proportion for the second sample as a decimal

q_2 = 1-p_2

We use the equation above, which determines sample size for temporary sampling units, to detect change in vegetation, soil, and biological soil crust cover, because the transects and quadrats used to collect the cover data may not be placed in exactly the same location over time. This equation overestimates the number of samples needed within permanent plots.

3.4.4 Use of legacy data to evaluate detectability and power

A few key "legacy" (extant) vegetation datasets exist for SODN parks. We will use these data to evaluate species detectability and trend detection by applying the equations in Sections 3.4.2 and 3.4.3 and estimating the "between-year" variance from single-year data as (from Herrick et al. 2005a):

Where:

$$S_{diff} = (S_1)(\sqrt{(2)(1 - corr_{diff}}))$$

S_{diff}= estimated standard deviation of the differences between paired samples

S_1 = sample standard deviation for first sample period

$corr_{diff}$ = correlation coefficient between samples in successive sample periods.

Results from these analyses will be evaluated, incorporated at landscape and plot levels, and may be used to adjust sample sizes.

3.4.5 *Oversampling during initial monitoring*

Between-year variance can be best estimated via repeated sampling of the same plots (Elzinga et al. 1998). For the first three years of implementation (2008–2010), we sampled additional plots within each stratum and park to improve our estimates of power and detectability. To minimize potentially confounding effects of sampling impact on annually visited sites, these "oversampling plots" were not drawn from the actual long-term monitoring population. Rather, they were selected from well down the ordered, RRQRR "long list" (Section 3.2.1). Results from this effort were reported in data summaries and status and trends reports (see Sections 6.2 and 6.3) and, in some cases, have been used to adjust landscape and plot-level sample sizes.

4 Field Methods

Monitoring of terrestrial vegetation and soils in network parks closely follows the work of Herrick and others (2005a and 2005b) and Belnap and others (2001) in design and approach. The response design for this protocol employs permanent, 20 × 50-m sampling plots. The 50-m edges of the plot run parallel with the contours of the site. Vegetation sampling is done in conjunction with soil cover, biological soil crust cover and frequency, and stability measures along six transects within the plot. In the space between the transects (subplots), perennial woody vegetation is recorded by species. Soil and site characterization occurs within and surrounding the plot. SOP #3 describes plot establishment.

4.1 Vegetation and soil cover: Line-point intercept

Line-point intercept is a common and efficient technique for measuring vegetation cover. Line-point intercept measures the number of "hits" of a given species out of the total number of points measured. Vegetation is recorded within three height categories along each of the six transects using the line-point intercept method, with points spaced every 0.5 m (240 points total). The three height categories are field (0.025–0.5 m), sub-canopy (>0.5–2 m), and canopy (>2 m). Perennial vegetation is recorded to species and annual vegetation is recorded to life form, with the exception of a suite of annual non-native plants that are recorded to the species level (SOP #5).

Soil cover is recorded to substrate class (e.g., rock, gravel, litter) with biological soil crusts recorded to morphological group (light cyanobacteria, dark cyanobacteria, lichen, moss). Litter is subdivided by fuel class to assess potential fire characteristics (SOP #5).

4.2 Vegetation frequency and density (selected species): Subplots

The area between any two adjacent transects forms the boundary of 10 × 20-m subplots used to estimate within-plot frequency of native perennial plant species and exotic plants (perennials and a suite of annual species). The occurrence of any species not measured on the adjacent line-point transect will be recorded to determine a within-plot frequency of 0–5. In addition, columnar cacti and ocotillo will be counted by individual and height class within each subplot to provide an estimate of density for these species, where they occur. Figure 3-1 explains the relationship between each subplot and its corresponding adjacent transect (see SOP #5).

4.3 Biological soil crust cover and frequency: Point-quadrats

Biological soil crust cover is measured using two techniques: (1) as part of the soil cover measurements described in Section 4.1 and (2) in 0.25-m^2 point-quadrats placed adjacent to the transects. Three quadrats are measured per transect using the point-quadrat method (similar in concept to line-point intercept), with 16 intercept measurements per quadrat, resulting in 18 quadrats and 288 measurements per plot. At each intercept, biological soil crusts are recorded as light cyanobacteria, dark cyanobacteria, bryophytes (mosses and liverworts), and lichen by growth forms (crustose, gelatinous, foliose, fruticose, and squamulose). The observer then visually surveys the quadrat for any lichen growth form or morphological group that is present. Soil crust frequency by lichen growth form and morphological group is determined by the number of quadrats occupied relative to the total number of quadrats (i.e., 18). SOP #6 provides a detailed description of the point-quadrats. Biological soil crusts are monitored at all parks addressed in this protocol except for Coronado NMEM, Fort Bowie NHS, and Gila Cliff Dwellings NM (see SOP #6).

4.4 Soil aggregate stability

Surface soil aggregate stability is measured using a modified wet aggregate stability method (Herrick et al. 2001, 2005a). Within each plot, samples are attempted at 18 predetermined points along the six line-point intercept transects. The uniformly sized (2–3 mm thick and 6–8 mm on each side) samples are tested per plot. The samples are tested in one group of 18. Each sample is placed on a screen and soaked in water for five minutes.

After five minutes, the samples are dipped slowly up and down in the water, with the remaining amount of soil recorded as an index of the wet aggregate stability of the sample. Samples are scored from 1 to 6, with 6 being the most stable. See SOP #7 for a detailed description of field methods.

4.5 Soil and site characterization

To characterize each plot, landscape attributes are recorded, flow patterns and site diagrams are drawn, and soil samples are collected. Landform, slope position, and parent material are recorded at each plot. Slope measurements (%) and descriptions (type and position) depict the surface-flow patterns of the hillslope within each plot. Five photographs (one at each plot corner) are taken as supplementary data. Additional details can be found in SOP #4.

When plots are initially established, one soil sample is excavated, according to a compliant cavity method, to determine in-situ bulk density (Blake and Hartge 1986). The sample is randomly located within Subplot A (see Figure 3-1, SOP #4). The sample is transported to the network laboratory, where bulk density and additional analyses are performed. In-house and external laboratory tests will determine organic-matter content, rock-fragment (>2 mm diameter) content, pH, electrical conductivity (EC; surrogate for salinity), and particle-size distribution. Standard techniques from Burt (2004) will be used for characterization for electrical conductivity, organic matter, rock-fragment content, and pH (see SOP #12). Particle-size distribution will be determined by the hydrometer method, using techniques from Craze and others (2003) and Gavlak and others (1994); see SOP #12.

5 Data Management

Effective data management to ensure data quality, interpretability, security, longevity, and availability is critical to the success of the uplands monitoring program. Data management for this monitoring effort is a cyclic process that starts in mid-June before field sampling begins and continues until the season close-out in mid-June of the following year. The cycle is repeated each year monitoring data are collected.

This section presents an overview of the monitoring database and general procedures for organizing, entering, verifying, validating, certifying, documenting, distributing, and archiving the data collected under this protocol. Additional information and context may be found in each network's data management plan. Further details and instructions for the tasks in each stage of the data management cycle are contained in SOPs #10 and 11.

5.1 Data organization

This long-term monitoring project generates large quantities of data and numerous products, and a well-organized digital file structure is critical to avoid confusion and potential data corruption. Any organization that implements this monitoring project should have a formalized directory structure to manage ongoing data collection. Appropriate staff and partners involved in this project are granted edit access to data for the current field season. At the end of each field season, certified data, completed products, and other seasonal files are transferred to the permanent project folder, where they are stored in read-only format. Each network or organization should and will provide documentation and training on its own specific directory structure, its purpose and use, and links to other information relevant to the project.

5.2 Data model

To appropriately manage vegetation and soils data, the dataset should be stored and managed in a normalized relational database. This protocol may also leverage other databases common to workflow throughout the office. These databases could include (1) a database containing the data tables that store core vegetation and soils data and (2) a database(s) containing other data relevant to operational and project needs, which are integrated through a user interface. This configuration allows for improvements and revisions to the database user application without altering the actual data structure or any of the records in the back-end database data tables.

The database containing the core vegetation and soils data should have indicators to show where data are in the data life cycle. The database should also have an automated log file that tracks the users who access it, as well as any modifications they might make to either the database structure or data. The database should have metadata or documentation that articulates the data dictionary, management of the database, and versioning procedures.

The user interface should contain forms for data entry and modification; queries for verification, validation, and data export; and code for creating custom features designed to maintain efficient workflow. The application should have documentation that articulates procedures for management and versioning, as well as easy-to-understand user instructions.

The database created by the authors of this protocol is based on the NPS Natural Resource Database Template (a set of relational database tables in Microsoft Access recommended by the NPS I&M program for these types of databases). The design includes standardized core tables for elements (such as Locations and Events) that are common to most monitoring datasets, as well as a field data table that can be duplicated and customized to meet individual project data requirements.

The project leader should have a thorough understanding of the project database structure and procedures for using the application. Any and all documentation requested by the project lead, staff, or partners should be made available in read-only format.

5.3 Data-entry procedures

Uplands sampling data are acquired as specified in the protocol SOPs, using three different methods: (1) data are entered directly into the project database on ruggedized field laptop or tablet computers, (2) data are manually recorded on paper field-data sheets, or (3) data are downloaded from handheld or automated sensors.

Transcription errors are minimized and efficiency is increased when data are entered directly into the digital database. Data collected on field computers are subject to a series of backups in the field and office (SOP #11) to ensure that adequate data redundancy is achieved. In the event of equipment failure in the field, paper data sheets are completed to avoid lost information. To facilitate accuracy, QA/QC mechanisms are built into the database to eliminate as many potential data-entry errors as possible.

Digital data-entry forms serve as the user's portal into the database. Location and sampling event information are entered first; then, associated vegetation, soils, or landscape data may be entered into the targeted tables. Where appropriate, pick lists limit values entered into a field to ensure that only valid names or measures are entered.

Data recorded on paper field-data sheets are entered into the digital database as soon as possible following collection (beginning data entry after the field season ends is not acceptable). Keeping current with data entry facilitates finding and correcting errors while the information is still fresh in the minds of the field crew.

Data downloaded from electronic sensors are processed as specified in SOP #10.

5.4 Data-certification process

Data verification is the process of checking the accuracy of digital data against copies of original paper data sheets. This critical but time-consuming step has been largely eliminated through the use of field computers for direct data entry. However, data recorded on and entered from paper data sheets will still need to be verified.

Data validation is the process of reviewing digital data for range and logic errors. Although some validation features, such as range limits, are built into the database itself via data-entry forms (see above) and queries, the project leader or another person familiar with the data must further review the dataset for these types of errors. For data that were directly input into the database in the field, a paper version of each completed data form should be printed for archival purposes after data validation has been completed. Spatial data are validated according to the procedures specified in SOPs #10 and 11 using the latest version of ArcGIS software (ESRI, Inc.).

Data certification is the process of ensuring that the dataset (i.e., the database containing all of the records for that year) has been verified and validated for accuracy, is complete, and is fully documented. Data certification is completed annually for all tabular and spatial data and photographs. This process should be documented by the project leader in order to notify the data manager that data are ready for archiving and storage. After the dataset is certified, it can be used in analysis and reporting.

5.5 Metadata procedures

Any data produced by the uplands monitoring project should have accompanying metadata, especially if any data are going to be distributed. Metadata help users to locate and use their own data resources and those of others. Metadata also help to preserve data history, allow the data life cycle to be effectively managed, identify the effective and administrative limits of data use, and instill data accountability by requiring producers to state what they do and do not know about the dataset.

At the most basic level, metadata ensure the longevity and usability of the dataset. When changes in personnel cause an organization to lose institutional knowledge, undocumented data can lose their value. Subsequent employees may be left with minimal understanding of the contents and uses of a digital database and may be unable to trust the results generated from those data. Also, lack of knowledge about data produced by other organizations can lead to duplication of effort. For these reasons, in the long term, metadata are well worth the investment of time and resources required to generate them (FDGC 2011; http://www.fgdc.gov/metadata/).

5.6 Product integration and distribution

In addition to the completed dataset, multiple products will be generated from data collected through this monitoring effort: repeat photography, field summaries, data summaries, status and trends reports, and synthesis reports (see Section 6). All data and reports should be assessed for sensitive content or proprietary purposes. All data, metadata, and reports judged to be non-sensitive and non-proprietary should be made available to all interested parties. Other datasets, including those containing sensitive data, may be requested in writing from the data steward. Sensitive data are released only with a signed confidentiality agreement. Each network or organization is responsible for ensuring that data are stored in the appropriate location and format, and are obtainable by all person(s) interested and authorized to access the dataset(s).

5.7 Data maintenance and archiving

The project databases are archived on a secure server with regularly scheduled backups. To ensure data compatibility with other existing or newly developed software programs, each database table should be exported to an ASCII file. These ASCII files are stored on a secure server drive. All archived files are designated as read-only.

Before making revisions to either the application or database schema, a copy of the current version must be stored to facilitate tracking of changes over time. The file name for the database includes a number indicating the version of the database appended to the file name (e.g., Uplands_be_Master_v100). After the copy is stored, the version number of the database undergoing revision is changed and "_Draft" is added to the end of the file name. When the revisions have been approved, the "_Draft" designation is removed. Frequent users of the data are notified of the updated version by data management staff.

After data have been certified and archived, they may be edited only under the following conditions: (1) changes must improve or update the data while maintaining data integrity, (2) all changes must be documented in the database change/version log, and (3) a backup copy of the certified data must be made before making changes, so that the original certified dataset can be recovered if needed. Printed data records must not be altered; rather, they are reconciled to the database through the use of the edit table. Any editing of archived data must be accomplished jointly by the project leader and data manager.

6 Reporting and Analysis

6.1 Field summaries

Each network will be responsible for producing its own field summaries. Upon completion of the field season for each park, network staff will submit a short, non-technical "field summary" to the corresponding park's SODN/CHDN Board of Directors (BoD), Technical Committee (TC), or other designated representatives. These summaries will be produced by network staff under the leadership of the vegetation ecologist/physical scientist and crew leader. The purpose of these qualitative summaries is to quickly highlight observed resources of management concern and general ecological observations of interest that were noted by the crew. Examples might include noting a new plant species in the park, observing a previously undiscovered exotic plant infestation, or discovering evidence of a new social trail or illegal border crossing. Field summaries are intended to quickly route important and interesting field observations to park staff without the delay of producing an annual report based on verified data and quantitative analysis and interpretation. An example field summary can be found in Appendix B.

6.2 Data summaries

For larger parks that are sampled proportionately over a five-year period, as well as any single-year park that requires additional sampling to meet our objectives, park-specific data summaries will be submitted to park staff by the end of June for the previous field season. These summaries describe field effort, evaluate progress toward monitoring objectives, suggest any sampling modifications, and briefly summarize results for that year. Data summaries for both networks are produced through a combined effort of the SODN vegetation ecologist and program manager (vegetation analysis and interpretation) and CHDN physical scientist (soils analysis and interpretation).

Data summaries are generally not produced until at least two years of data have been collected; thereafter, data summaries are generated annually until a status and trends report (see Section 6.3) is warranted. At time of writing, data summaries had been completed for Coronado NMEM (Hubbard et al. 2011a), Saguaro NP (Rincon Mountain District; Hubbard et al. 2010b and 2011c), and Saguaro NP (Tucson Mountain District; Hubbard et al. 2011b).

6.3 Status and trends reports

At the end of the five-year sampling period, each park will receive a complete status and trends report. These reports will be prepared by network staff under the leadership of the SODN program manager, vegetation ecologist, and physical scientist. Status and trends reports are intended to (1) describe the current conditions (status) and trends (where possible) of vegetation and soils using standard univariate and multivariate descriptive statistics, graphical techniques, and (where appropriate) conceptual diagrams; (2) interpret these conditions in the context of other resources of interest and management objectives; and (3) explain the sampling techniques, effort, and level of certainty upon which the data and interpretations are based.

Draft status and trends reports will be reviewed by the corresponding park's SODN/CHDN Board of Directors (BoD), Technical Committee (TC), or other designated representatives for sensitive data and policy implications as per NPS Director's Order #66. During this review, draft reports will be available to NPS employees only via the SWNC Sharepoint site (http://inpchdnms03/SWNCCP/Uplands/Reports). If any reports are deemed to include restricted data, they will be made available only through internal servers, whereas edited versions may be distributed to the public. Based on our past experience, very few reports will be determined to contain restricted data.

Pending successful peer review, final status and trends reports will be submitted for publication in the NPS Natural Resources Technical Report Series and posted on the appropriate network's website (www.nature.nps.gov/im/unit/sodn, www.nature.nps.gov/im/units/chdn). At time of writing, status and trends reports had been produced for Casa Grande Ruins NM (McIntyre et al. 2011), Fort Bowie NHS (Hubbard et al. 2010a), Gila Cliff Dwellings NM (Hubbard and Studd

2010), Tonto NM (McIntyre et al. in prep. [3]), and Chiricahua NM (McIntyre et al. in prep.[1]).

6.4 Synthesis reports

Every 10 years, the networks will produce a synthesis report just prior to the end of the calendar year. The appropriate program manager will direct the production of these reports, which will involve network staff as well as external subject-matter experts. These reports are intended to (1) describe trends (if any) in vegetation and soils vital signs using univariate and multivariate time series analytical techniques, (2) use modeling and other data-exploration techniques to evaluate potential explanatory variables and covariates over broad thematic and spatial scales, and (3) synthesize this wide-ranging information to explore patterns and better understand processes of vegetation and soil functional dynamics. Status information for that year will also be presented in the synthesis report.

Draft synthesis reports will be reviewed by the appropriate network's BoD and TC. In addition, these reports will undergo an external science review, to be coordinated by the network and IMR regional coordinators. The purposes of this review are to (1) ensure that the report and its conclusions are founded on sound science and (2) encourage additional input on candidate explanations and approaches for additional synthesis and suggest high-priority research.

Upon successful completion of all reviews, final synthesis reports will be submitted for publication in the NPS Natural Resources Technical Report Series and/or peer-reviewed scientific publications. The first synthesis report will be produced for SODN in 2017, and for CHDN in 2021. These reports will be distributed to park staff, cooperators, and the interested public. The report and derived communication products will be served on the appropriate network's website and on the Learning Center of the American Southwest website (http://www.southwestlearning.org/). The Learning Center of the American Southwest (LCAS) provides a means for storing, organizing, and reporting information that results from science conducted in national park units of the SODN, CHDN, and two other I&M networks. Designed to reach a varied audience (agency managers and resource specialists, university scientists and students, educators and guides, members of the public and press, and other stakeholders), LCAS presents data in a hierarchy of increasing detail, allowing users to access both general concepts and project-specific results.

7 Personnel Requirements and Training

7.1 Roles and responsibilities

7.1.1 Project coordination and oversight

The SODN vegetation ecologist organizes and oversees the vegetation and soils monitoring effort for both networks and reports to the SODN program manager. The CHDN physical scientist, supervised by the CHDN program manager, works very closely with the SODN vegetation ecologist. The vegetation ecologist and physical scientist must have in-depth knowledge of this protocol and associated SOPs in order to successfully plan and execute field work and complete analysis and reporting requirements appropriately. The vegetation ecologist and physical scientist will coordinate the project, train the crew leaders, and lead some of the field data collection.

7.1.2 Data collection and entry

SODN and CHDN crew leaders lead field data-collection and entry activities. The SODN field crew leader coordinates scheduling of field work with the vegetation ecologist and park staff. The SODN crew leader and vegetation ecologist share recruitment and training duties for the field crew, with assistance from the CHDN physical scientist as needed (see SOP#2).

The CHDN field coordinator coordinates scheduling of field work with the physical scientist and park staff. The CHDN field coordinator and physical scientist share recruitment duties. Training duties for the field crew are shared among the CHDN physical scientist, field coordinator, crew leader and SODN vegetation ecologist (see SOP#2).

7.1.3 Data quality and management

The SODN data manager leads the development of data entry and QA/QC procedures and develops and maintains relevant databases and supporting data management systems. The respective network data managers manage both raw and processed information. The data managers report to their respective program managers. The data managers must have in-depth knowledge of the data types and end-user requirements for the vegetation and soils protocol.

7.1.4 Analysis and reporting

The SODN vegetation ecologist, CHDN physical scientist, and SODN program manager share analysis and reporting responsibilities. The crew leaders are the leads for producing field summaries (see Section 6.1), whereas the vegetation ecologist, physical scientist, and program manager lead the development of data summaries, status and trends reports, and synthesis reports (see Sections 6.2–6.4), with support from the network staff and cooperators.

7.2 Qualifications and training

7.2.1 Crew composition

To facilitate effective, efficient data collection and equipment transport, field crews are ideally composed of at least three people: one crew leader and two or more crew members. However, there will be times when four people are optimal and times when four people are too many, depending on the composition and density of the vegetation. The experience level of the crew (i.e., the ability of each member to work independently or together for each sampling activity) will, to some extent, dictate the ability of the crew to function optimally.

The crew leader is responsible for assigning tasks to each person based on his/her expertise and the skills of the group as a whole. As a rule, soils measurements can be conducted by a single individual. Line point-intercept data is most efficiently collected when one person reads the line and another records in the database. This also allows for on-the-spot checks against misidentification by having two people agree on the species.

7.2.2 Qualifications and training for data collection and entry

Prior to data collection, crews should become intimately familiar with all SOPs and park-specific materials, such as park plant-species lists, soils maps, and geological maps. Each person should be trained in all protocol-specific data-collection methods, such that s/he can independently perform any necessary task.

The most critical skill for conducting uplands vegetation sampling is the ability to perform accurate and consistent plant identification. Each crew member must be familiar with the local flora or, at least, highly competent at utilizing botanical keys to identify plants to the species level. Where such skills are lacking, the vegetation ecologist will provide training. Knowledge of herbarium-quality plant-specimen collection and preservation is also needed, as unknown species are collected for later identification. The plot design and set-up were designed to minimize observer bias and maximize repeatability; therefore, it is imperative that crews maintain good sampling techniques as outlined in the SOPs, and that the crew leader periodically checks for consistency among observers.

Each member must also be trained in the necessary soil-measurement techniques, including identification of lichen growth forms. The methods used for other soil measures, such as surface soil sampling for bulk density, soil biological crust cover, and soil stability, can be easily learned by observers at any level of knowledge.

A basic knowledge of geologic formations and soils terminology is necessary; however, this can be learned quickly in the field. Field guides are available for reference and a presentation has been developed for initial training on how to identify these different landscape descriptors.

7.2.3 Safety training and qualifications

The crew leaders are responsible for ensuring that all crew members read and understand the appropriate network Safety Plan prior to the field season.* Additional, park-specific, backcountry travel plans, if available, will be strictly followed to ensure compliance with park guidelines and safety amongst crew members. Wilderness or basic first-aid training is not required for all crew members, but is recommended. At least one person, preferably the crew leader, should be currently certified in first-responder care and cardiopulmonary resuscitation (CPR). All crew members must be proficient with the use and etiquette of park radios (and, where necessary, SPOT trackers and satellite phones), as these are often the only reliable form of communication between the field crew and park staff. Each crew member is responsible for safeguarding him/herself at all times. At a minimum, each member should receive training on how to adequately prevent environmental illness and injury, as well as on team safety awareness.

*The SODN Safety Plan is located on the SODN server at P:\Operations\Safety\SODN_Safety_Plan. The CHDN Safety Plan is located on the SWNC Sharepoint site at http://inpchdnms03/CHDN/AdminDocs/Forms/AllItems.aspx

8 Operational Requirements

8.1 Annual schedule and project workflow

The annual workload for this protocol consists of field data collection from late-summer through autumn, data verification and validation in early winter, and analysis and reporting in the spring and early summer (Figure 8-1). Each annual cycle begins at the previous year's evaluation and close-out meeting in mid-June. Any operational needs (e.g., revisions to SOPs, equipment repairs, updates to park species lists) identified during the close-out are addressed during a training and field season preparation phase that occurs from mid-June to mid-July, when field data collection commences (see SOPs #1, 2, 9). All field staff (including long-term and seasonal employees and Student Conservation Association [SCA] interns) complete training in plant and soil crust identification, plot setup and data collection, safety, and data entry during this period. These training and field season preparation tasks are led by the crew leader.

8.1.1 Data collection

To maximize the capture of phenological response to the summer monsoon season, most field data collection occurs from mid-July to mid-December of each year (Table 8-1), with spring field data collection in select parks to capture floristically important events. The field season begins with a kick-off meeting to ensure coordination and smooth organization between the field, data management, and data analysis and reporting staff. The bulk of the field workload is borne by the crew leader and field staff, with support from other network staff. Data entry and basic QA/QC procedures are incorporated into field data collection through the use of field computers, although these efforts are supported by planned days in the office and herbarium to identify unknown specimens and resolve any data management issues. To ensure that the overall program is staying on track, brief pace meetings with field, data management, and analysis and reporting staff are held in early September and early November.

8.1.2 Data verification and validation

The field season closes in mid-December with a season close-out meeting, at which the current year's database status is discussed and plans are made to verify, validate, and certify the complete annual database under the leadership of the network data manager. These tasks are completed from mid-December through the end of January. A data close-out meeting occurs at the end of January to make certain that the data processing is complete, queries are functional, and the final data matrices and spatial layers are ready for analysis.

8.1.3 Analysis and reporting

The vegetation ecologist and physical scientist lead analysis and reporting efforts, as described in Sections 6.2–6.3, with all scheduled draft final reports ready for park review by mid-May. Any data that may be considered sensitive or may contain policy implications are addressed in accordance with the corresponding Director's Orders and NPS policy. Final reports and data products are published and distributed by mid-June, when the vegetation ecologist and physical scientist lead an evaluation and close-out meeting for their respective networks to identify any future protocol changes and document the project year.

8.2 Field and facility equipment needs

8.2.1 Field equipment

Field equipment needs fall into four general categories: (1) plot layout and measurement equipment, (2) site navigation and mapping instruments, (3) data entry and validation systems, and (4) safety and general camping equipment. Equipment costs and complexity vary greatly, and are summarized in Table 8-2.

Plot layout and measurement activities rely on robust, simple, and relatively inexpensive instruments, such as measuring tapes, densiometers, and plot frames. The most expensive equipment required for this phase is a quality digital camera for collecting repeat

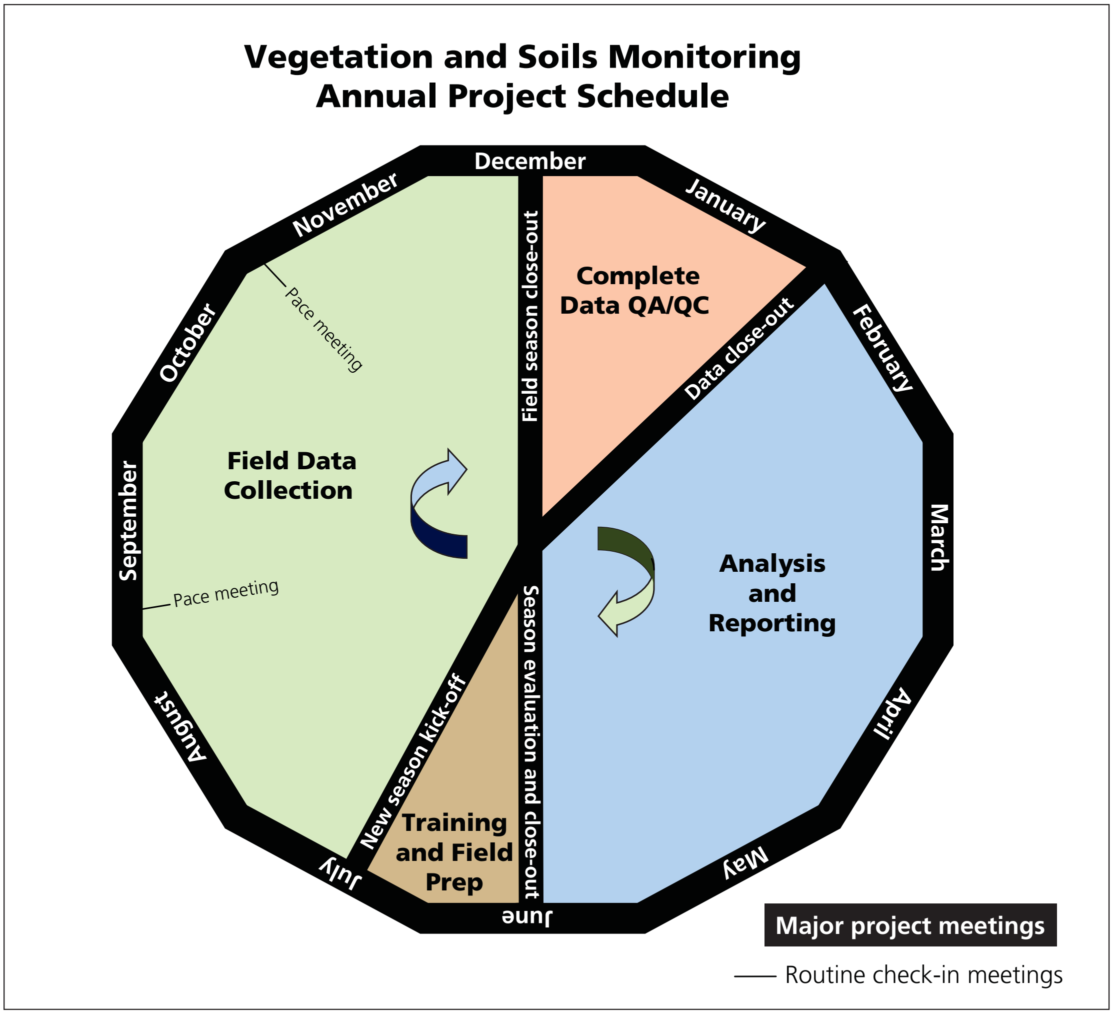

Figure 8-1. Annual project schedule for terrestrial vegetation and soils monitoring.

Table 8-1. Annual sampling schedule for terrestrial vegetation and soils monitoring.

	Parks sampled every year									Parks sampled every 5 years					
Month	**BIBE**	**CAVE**	**CHIR**	**CORO**	**GUMO**	**ORPI**	**SAGE**	**SAGW**	**WHSA**	**CAGR**	**FOBO**	**FODA**	**GICL**	**MOCA**	**TONT**
July		X			X								X		
August		X		X	X		X								
September	X	X	X		X	X	X					X			
October	X		X			X			X		X				
November	X						X		X					X	X
December							X	X		X				X	X
January								X							
February															
March	X					X									

See acronym list in Table of Contents for park acronyms.

Table 8-2. Estimated initial and recurring costs for vegetation and soils monitoring, per network.

Need/Purpose		Start-up/ Year 1	Annual
Field equipment			
Plot layout and measurement equipment		$4,000	$200
Site navigation and mapping instruments		$2,350	$200
Data entry and validation systems		$1,500	$525
General fieldwork, safety and camping equipment		$1,650	$200
	subtotal	*$9,500*	*$1,125*
Laboratory equipment			
Scales		$4,000	-
Oven & muffle furnace		$3,000	-
Glassware and general laboratory equipment		$2,500	$1,200
(Optional laboratory analyses		$8,500	$20–40/plot)
	subtotal	*$9,500*	*$1,200*
Personnel			
Field, laboratory & data entry: One crew of one GS-07 biological technician, one GS-05 biological technician (40 weeks), and two SCA interns (24 weeks)		$75,347	$75,347
Travel and pack support, including mule packer, for accessing backcountry sites		$3,000	$3,000
Data management: GS-11 data manager and GS-09 cartographic technician		$4,000	$4,000
Analysis & reporting: GS-13 program manager, GS-11 vegetation ecologist, GS-11 physical scientist, and GS-09 writer-editor (5 weeks)		$30,612	$30,612
	subtotal	*$112,959*	*$112,959*
Total		**$131,959**	**$115,284**

photos. This equipment is common to ecological research and monitoring studies, and represents a nominal cost to implementing the protocol.

Site navigation and mapping require accurate GPS units (minimum of one unit per crew) and the skills to successfully operate them for navigation and data recording. Integrated handheld mapping units with GPS are best, as numerous shapefiles can be loaded onto them and viewed, assisting in visualization and orienteering. Revisiting a previously established site also requires the use of a quality metal detector to relocate buried survey nails. Site-navigation costs can be reduced by using aboveground, permanent plot markers and employing lower-cost (and lower-accuracy) GPS units for navigation. However, extensively marking a plot can detract from wilderness values, encourage site disturbance, and represent a safety hazard for visitors and field staff alike.

Equipment used for field data entry (ruggedized computers and external memory backups) is the most costly and complex of the protocol, and could be replaced solely with the paper data sheets currently used as a backup and a system for later data entry and verification in the office. However, our experience indicates that the benefits of performing electronic data entry in the field (i.e., the savings in office time and reduction in data-transcription errors) greatly outweigh the cost and complexity of fielding the computers. The field computers have the added advantage of providing access to reference materials, such as detailed plant lists, previously collected site photographs, and GIS files.

Equipment related to general fieldwork, safety, and camping is also needed to support field crews for this protocol. Safety equipment includes first-aid kits, snake chaps, and communication systems, such as park radios and cell phones. Backpacks and other basic field equipment, including tents and other camping equipment, are shared with other monitoring efforts and represent a nominal cost for implementing this protocol. Additional detail on field equipment is provided in the Standard Operating Procedures (SOPs).

8.2.2 Facility and lab equipment

Analysis and processing of soil samples require a variety of initial, permanent, purchases of laboratory equipment. Primary laboratory equipment includes open-face, large-capacity (0.1-gram precision) and covered, analytical-grade (0.0001-gram precision) scales. A drying oven is needed for moisture removal and moisture correction of samples for different procedures. Each of these items requires a significant initial investment (see Table 8-2) and adequate dry-lab space. Glassware, including 1,000-mL volumetric flasks, various sizes of glass and plastic beakers, stirrers, graduated cylinders, and other pieces are generally necessary. Spatulas, scoops, and squirt bottles are also indispensable for sample management and cleaning. Soil samples are generally oven-dried in soil tins (5.08 × 7.62 cm), and processed using 2-mm soil sieves. A desiccator must be used to allow oven-dried samples to cool before weighing.

Basic soil chemistry parameters are measured using a portable pH/EC meter. Many models on the market provide accurate readings for much less money than full laboratory-grade meters. For these procedures, disposable (but re-useable) plastic cups can be used to avoid buying expensive sample cups from laboratory-equipment companies.

Determining soil particle-size distribution requires a suite of more specialized labware. Each sample must be suspended in a 1,000-mL graduated cylinder and measured with a 152-H ASTM soil hydrometer with units of grams per liter (Bouyoucos scale). Samples must initially be well-mixed with a high-sodium dispersing solution for this procedure. This requires either a commercial-grade blender with specialized soil-mixing cups (mixes in five minutes) or an overnight shaker. The SODN uses a blender. A 50-micron sieve is also used to determine final sand percentages. The soil samples may be sent to an external laboratory for particle size analysis at the discretion of the SODN or CHDN program manager.

Determining soil organic matter content requires a muffle furnace to bring samples to a sufficiently high temperature for organic matter to combust. Specialized, small, high-temperature crucibles must also be used for sample combustion. The soil samples may be sent to an external laboratory for organic matter analyses at the discretion of the SODN or CHDN program manager.

8.3 Startup costs and budget

The costs described below are for each network.

Initial field equipment costs per network are approximately $9,500 (Table 8-2) for items described in Section 8.2.1, including specialized backcountry equipment, such as solar panels. Field items that require constant refreshment and incidental replacement costs are estimated to be $1,125 on an annual basis. While ruggedized equipment initially costs more, it is recommended, as it has been proven to last through several field seasons.

Start-up costs for laboratory equipment described in Section 8.2.2 that is specific to the protocol are approximately $9,500 (Table 8-2). This includes only items specific to the protocol; furniture and general lab set-up costs are not included. With an actively running lab, regular supplies and costs, such as paper towels, chemicals (specified in SOPs), sample cups, and repairs, should not exceed $1,200 per year, depending on workload, laboratory arrangements, and equipment performance.

Annual personnel costs to fully implement the vegetation and soils protocol at each network are estimated at approximately $113,000 (Table 8-2). This includes personnel for field and laboratory work, data management, analysis, and reporting. Because data will be collected in the field, managed, analyzed, and reported every year, personnel costs will remain constant year after year.

Overall, start-up costs for the vegetation and soils monitoring protocol are approximately $132,000, and costs for subsequent years are estimated at approximately $115,500. These initial costs do not include vehicle purchase and maintenance, computer IT assessments, training costs, database development, or project management, as these are understood to be available within the existing network infrastructure.

9 Procedure for Revising the Protocol and Program Review

9.1 Revising the protocol

This sampling protocol consists of a protocol narrative and 14 separate SOPs. The protocol narrative provides the history and justification for the program and an overview of sampling methods. The protocol narrative will be revised only if major changes are made to the protocol. The SOPs, in contrast, are specific, step-by-step instructions for performing each task. They are expected to be revised more frequently than the protocol narrative.

Careful documentation of such revisions, including an archive of previous versions, is essential for maintaining consistency in data collection, analyses, and reporting. To summarize changes, the monitoring database for each component contains a field to identify the protocol version used to gather and analyze data. The steps for changing any aspect of the protocol are outlined in SOP #14. The narrative and each SOP contain a Revision History Log that should be completed each time the narrative or an SOP is revised. The purpose of this log is to explain why changes were made and to track document version numbers. Former and active versions of the protocol narrative and SOPs are stored on separate drives on the network server.

The networks use a Master Version Table and Version Key Number (VK#) to track which versions of the narrative and SOPs are used in each version of the monitoring protocol. The VK# is essential if project information is to be properly analyzed and interpreted. ***The protocol narrative, SOPs, and data should never be distributed independently of the Master Version Table.***

9.2 Program review

A thorough analysis and review of the monitoring protocol will be conducted every 10 years, under the direction of the network program managers and regional I&M coordinator. This review will include external experts and will focus on the monitoring approach, methods, and results obtained using the protocol, in much the same manner as the initial external review required of all NPS I&M protocols.

At the end of each field season, all relevant staff and cooperators will complete a less-formal review of the protocol in the context of the field season, in an effort to ensure the efficacy of the protocol. If major concerns are identified, this informal review may trigger a more-formal external review (as described above), at the discretion of the network program managers.

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Appendix A. Overview of the Methods and Process Used to Designate Vegetation and Soils Monitoring Plots

See Protocol Narrative for descriptions of the GIS tools used. GIS data layers used for and created by this process are archived at the SODN I&M office. Maps created by this process are found at the end of this appendix. Plot locations and sampling year are tentative until they are established in the field.

A.1 General process

Parks were stratified based on elevation and rock fragment content using the following approach:

1. Elevation was reclassified based on biomes:

Biome(s)	Elevation		Score
	Feet	Meters	
Desert	<2,500′	<762	100
Thornscrub	2,501–3,700′	762.1–1,127.76	200
Semi-desert Grassland	3,701–4,500′	1,127.77–1,371.6	300
Madrean Woodland & Interior Chaparral	4,501–6,000′	1,371.61–1,828.8	400
Temperate Forest	>6,000′	>1,828.8	500

2. Soil was reclassified based on descriptive modifiers according to rock-fragment volume:

Rock fragment modifier	Fragment content % by volume	Score
None or adjective (e.g., loam or gravelly loam)	<35	1
"very" or "extremely"	35–90	2
Bedrock or rock outcrop	--	3

3. Areas of the park were excluded based on proximity to roads, trails, buildings, culturally sensitive sites and for crew safety:

- Roads and buildings (including 100-m buffer for SODN, 50-m for CHDN)
- Trails, washes, and streams (including 50-m buffer)
- Selected fragile cultural features (e.g., Casa Grande "big house")
- Slopes of ≥45°

4. The rasters generated in steps 1–3 were combined to generate the strata. For each park, each stratum was extracted as a separate raster with scores of 1 falling within the strata and scores of 0 falling outside the strata. There were 15 possible strata, not including the areas that were excluded from the sampling frame (which have a score of 0):

Score	Biome	Elevation	Rock fragment modifier	Fragment content % by volume
101	Desert	<2,500′	None or adjective	<35
102	Desert	<2,500′	"very" or "extremely"	35–90
103	Desert	<2,500′	Bedrock or rock outcrop	--
201	Thornscrub	2,501–3,700′	None or adjective	<35
202	Thornscrub	2,501–3,700′	"very" or "extremely"	35–90
203	Thornscrub	2,501–3,700′	Bedrock or rock outcrop	--
301	Semi-desert Grassland	3,701–4,500′	None or adjective	<35
302	Semi-desert Grassland	3,701–4,500′	"very" or "extremely"	35–90
303	Semi-desert Grassland	3,701–4,500′	Bedrock or rock outcrop	--
401	Madrean Woodland & Interior Chaparral	4,501–6,000′	None or adjective	<35
402	Madrean Woodland & Interior Chaparral	4,501–6,000′	"very" or "extremely"	35–90
403	Madrean Woodland & Interior Chaparral	4,501–6,000′	Bedrock or rock outcrop	--
501	Temperate Forest	>6,000′	None or adjective	<35
502	Temperate Forest	>6,000′	"very" or "extremely"	35–90
503	Temperate Forest	> 6000′	Bedrock or rock outcrop	--

5. For each stratum within a park, the raster generated in step 4 was used as the inclusion probability for the spatially balanced sample (SBS) tool of the RRQRR algorithm (ArcGIS 9.0) or the Create Spatially Balanced Points tool (Geostatistical Analyst) in ArcGIS 10. Except for Saguaro National Park (NP) and Organ Pipe Cactus National Monument (NM), all areas within each stratum had equal probability of being included within the sample. For Saguaro NP and Organ Pipe Cactus NM, a cost-surface raster, described in the following section, was used as the inclusion probability raster.

A.2 Cost surfaces

Cost surfaces are used in GIS to determine a most efficient route between two points. Path Distance, a tool in the ArcGIS Spatial Analyst extension, generates a cost surface and gives a "distance" value for the best route to every pixel from a set of possible starting points. Distances are based on the units as specified in the input rasters. In our analysis, units of time per distance (miles per hour) were used for the cost raster. A hiking time for each pixel was generated using the Path Distance tool.

Slope and vegetation type were used to create cost surfaces for Saguaro NP (East and West) and Organ Pipe Cactus NM. We assumed that an estimated optimum hiking speed (with gear) of two miles per hour (mph) would be slowed on steeper slopes and/or areas of dense vegetation.

Cost surfaces were generated using the following approach:

1. Resistance was reclassified based on slope:

Slope classes (%)	Resistance (%)
0–2	1
2–5	10
5–10	20
10–15	30
15–20	50
20–25	60
25–30	70
30–35	80
35–40	90
40–50	95
>50	99

2. Resistance was reclassified based on vegetation. Field-based maps with interpretable detail were available for Organ Pipe Cactus NM and Saguaro NP (East). A local vegetation map was not available for Saguaro NP (West); therefore, Southwest Regional Gap Analysis Project (SWReGAP) land-cover data were used. SWReGAP is available for the entire southwestern U.S.(http://earth.gis.usu.edu/swgap/). Resistance classifications were as follows:

A.2.1 Vegetation resistance reclassification for Organ Pipe Cactus NM

Field survey name	Veg type	Resistance (%)
Juniperus coahuilensis-Vauquelinia californica sonorensis mixed scrub	1	60
Quercus turbinella-mixed scrub	2	65
Prosopis velutina riparian woodland	3	70
Ribes quercetorum-Ptelea trifoliata	4	50
Larrea divaricata tridentata-Ambrosia dumosa	5	25
Larrea divaricata tridentata-Ambrosia mixed scrub	6	30
Larrea divaricata tridentata-Ambrosia deltoidea-Fouquieria splendens	7	35
Larrea divaricata tridentata-Annuals	8	25
Larrea divaricata tridentata-Prosopis velutina floodplain	9	35
Ambrosia deltoidea-Parkinsonia microphylla middle bajada	10	35
Ambrosia deltoidea-Parkinsonia microphylla pediment mixed shrub	11	40
Parkinsonia microphylla-Ambrosia deltoidea-Simmondsia pediment	12	35
Acacia-Ambrosia ambrosioides	13	45
Prosopis velutina-Parkinsonia floridana	14	55
Parkinsonia microphylla-Ambrosia deltoidea-Olneya tesota	15	30
Simmondsia-Encelia-Fouquieria	16	35
Simmondsia-Viguiera-Eriogonum	17	35
Simmondsia-Atriplex polycarpa	19	40
Parkinsonia microphylla-Encelia-Stenocereus-Jatropha	20	40
Parkinsonia microphylla-Encelia-Ambrosia deltoidea	21	35
Parkinsonia microphylla-Encelia-Ambrosia dumosa	22	30
Parkinsonia microphylla-Encelia-Stenocereus-Bursera	23	35
Parkinsonia microphylla-Ambrosia deltoidea-Stenocereus-Jatropha	24	40
Atriplex polycarpa-A. linearis-Larrea divaricata tridentata	25	25
Atriplex polycarpa-A. linearis-Suaeda nigra	26	30
Atriplex polycarpa-A. linearis-Prosopis velutina	27	35
Typha domingensis-Scirpus americanus	28	70
Distichlis spicata-Juncus-mixed herbs	29	60
Larrea divaricata tridentata-Ambrosia dumosa / L. divaricata tridentata-Prosopis velutina floodplain	30	40
Larrea divaricata tridentata-Ambrosia mixed scrub / *L. divaricata tridentata-Prosopis velutina* floodplain	31	35
Larrea divaricata tridentata-Prosopis velutina floodplain / *Larrea divaricata tridentata-Ambrosia dumosa*	32	40
Distichlis spicata-Juncus-mixed herbs / Prosopis velutina riparian woodland	33	50
Ambiguous Great Basin scrub	34	40
Unknown association	35	30
Larrea divaricata tridentata-Prosopis velutina floodplain / *Acacia-Ambrosia ambrosioides*	36	40
Bare ground	37	25
Campground	38	25
Lukeville	39	45
No attributes	40	45

A.2.2 Vegetation resistance reclassification for Rincon Mountain District, Saguaro NP (East)

Field survey key	Veg type	Resistance (%)
None	0	20
Barren	1	20
Grassland	3	30
Sagebrush	4	35
Saguaro	5	25
Sonoran Chaparral	6	45
Semi-Desert Chaparral	7	35
Timberland Chaparral	8	45
Woodland-Grass	10	40
Woodland	11	55
Pinyon, Juniper, or Cypress	12	65
Douglas Fir	13	30
Pine	14	25
Pine-Douglas-fir	15	25
Pine--fir-Douglas-fir	16	30
Woodland-Chaparral	17	80

A.2.3 Vegetation resistance reclassification for Tucson Mountain District, Saguaro NP (West)

SWReGAP label	Type ID	Resistance (%)
Madrean Encinal Forest and Woodland	51	55
Colorado Plateau Pinyon-Juniper Shrubland	52	55
Mogollon Chaparral	57	30
Mojave Mid-Elevation Mixed Desert Scrub	60	25
Rocky Mountain Subalpine-Montane Riparian Woodland	92	60
Mediterranean California Subalpine-Montane Fen	105	55
Madrean Upper Montane Conifer-Oak Forest and Woodland	111	45
Madrean Pinyon-Juniper Woodland	112	35

3. The resistance rasters were combined to adjust the hiking time for each pixel to create the cost surface (below). This equation reduces the optimum speed (0.0003 hours per meter is the same as 2 mph) by the vegetation and slope resistance factors.

$$COST = \frac{0.00031075 hours}{meter} * \frac{100}{100 - veg\_resist} * \frac{100}{100 - slope\_resist}$$

4. The Path Allocation tool in ArcGIS was used to generate distance, backlink, and allocation rasters for hiking routes. Starting points included trailheads, camping areas, and/or roads that can be used as starting points for hiking to plot locations.

5. The distance raster was reclassified based on hiking time to generate an access raster (floating point with values from 0 to 1):

Hiking access time (hr)	Score
0–0.5	1.0
0.51–1.0	0.9
1.01–1.5	0.8
1.51–2.0	0.5
>2.01	0.2

6. The access raster was multiplied by each stratum. This generated an inclusion probability raster for each stratum within a park, which was used as the inclusion probability for the spatially balanced sample (SBS) tool of the RRQRR algorithm (ArcGIS 9.0).

A.3 Plot allocation by park for the Sonoran Desert Network

For each park, the number of plots per stratum is proportional to the area in each stratum as a percentage of the sampling frame (non-excluded area of park). Unless otherwise indicated, strata representing less than 5% of the sampling frame were not allocated plots. (See Section 3.2.2 for detailed information on plot-allocation rules and exceptions.)

Initial plot allocation was based on preliminary estimates of variance but the total number of plots may change during the first five years of data collection. Within each stratum, the plots are sampled based on an ordered list output by RRQRR. Plots may be eliminated (not sampled) based on concerns for cultural resources, crew safety, or riparian resources.

A.3.1 Casa Grande Ruins National Monument

Initial plot allocation was based on six total plots. Because the Adamsville unit is very small (125 acres), RRQRR was not used and the unit was treated as one stratum within a separate sampling frame. Due to the park's small size and relatively uniform vegetation, only 3 plots per unit are required.

		Percentage of total		Plots per stratum	
Stratum	Total area (ac)	Park area	Frame area	Number	Number every 5 years
Main Unit					
Excluded	168	36	0	0	0
101	297	64	100	3	3
Adamsville Unit					
Adamsville	125	100	100	3	3

A.3.2 Chiricahua National Monument

Initial plot allocation was based on 46 total plots but the number of plots may change based on estimates of variance.

Stratum	Total area (ac)	Percentage of total		Plots per stratum	
		Park area	Frame area	Stratum	Number per year
Excluded	3,007	25	0	0	0
401	190	2	2	0	0
402	2,476	21	28	13	2 or 3
403	272	2	3	0	0
501	679	6	8	5	1
502	3,518	29	39	18	3 or 4
503	1,862	16	21	10	2

A.3.3 Coronado National Memorial

Initial plot allocation was based on 30 total plots based on initial estimates of variance. After two years of sampling, one plot was added to the 503 stratum to increase power. The total number of plots is 33 but may be adjusted as additional plots are sampled.

Stratum	Total area (ac)	Percentage of total		Plots per stratum	
		Park area	Frame area	Stratum	Number per year
Excluded	1,971	41	0	0	0
401	331	7	12	5	1
402	1,183	25	42	13	2 or 3
403	45	1	2	0	0
501	0.2	<1	<1	0	0
502	994	21	35	10	2
503	292	6	10	5	1

A.3.4 Fort Bowie National Historic Site

Initial plot was allocation was based on 10 total plots but the number of plots may change based on estimates of variance.

Stratum	Total area (ac)	Percentage of total		Plots per stratum	
		Park area	Frame area	Stratum	Number every 5 years
Excluded	543	56	0	0	0
402	426	44	100	10	10

A.3.5 Gila Cliff Dwellings National Monument

Initial plot allocation was based on 10 total plots but the number of plots may change based on estimates of variance. The main unit and the TJ Ruin unit were treated as separate strata.

Stratum	Total area (ac)	Percentage of total		Plots per stratum	
		Park area	Frame area	Stratum	Number every 5 years
Excluded	197	38	0	0	0
400	132	25	41	4	4
400_TJ	27	5	8	1	1
500	164	32	51	5	5

A.3.5 Montezuma Castle National Monument

The Montezuma Well unit was not included in the sampling frame. Within the main unit, Beaver Creek was buffered by 100 rather than 50 m. Initial plot allocation based on 10 total plots but the number of plots may change based on estimates of variance.

Stratum	Total area (ac)	Percentage of total		Plots per stratum	
		Park area	Frame area	Stratum	Number every 5 years
Excluded	333	46	0	0	0
201	249	34	63	5	5
202	148	20	37	5	5

A.3.6 Organ Pipe Cactus National Monument

Rather than sampling the entire park, uplands monitoring is focused within five land type associations (LTAs; areas with similar patterns of soil parent material, hydrology, vegetation, etc.) arranged along an east–west gradient across the north-central portion of the park. In 2010, park staff provided SODN with a shapefile delineating LTAs of interest. Overall, approximately 22% of the park (72,620 acres) was within a LTA of interest, while approximately 78% of the park (258,040 acres) was outside the LTAs of interest. As described above, areas near roads, trails, and washes were excluded within the LTAs of interest. Within the LTAs of interest within each stratum, plots were allocated using a probabilistic sampling design based on travel time (see cost surface discussion above). Initial plot allocation based on 60 total plots but the number of plots may change based on estimates of variance.

Stratum	Total area (acres)	Percentage of total		Plots per stratum	
		LTAs of interest area	Frame area	Number	Number per year
Outside LTAs of interest					
Excluded	258,040	---	---	0	0
Inside LTAs of interest					
Excluded	11,728	16	0	0	0
101	22,210	31	36	22	4 or 5
102	16,686	23	27	17	3 or 4
103	14,482	20	24	15	3
201	13	0.02	0.02	0	0
202	241	0.33	0.40	0	0
203	6,259	9	10	6	1 or 2
303	966	1	2	0	0
403	36	0.05	0.06	0	0

A.3.7 Saguaro National Park (East)

Within each stratum, plots were allocated using a probabilistic sampling design based on travel time (see cost-surface discussion above). While stratum 201 represents less than 5% of the district's sampling frame, many of the signature saguaro cacti are located within this stratum. Therefore, we included strata 201 in our sampling design. Initial plot allocation was based on 60 total plots based on initial estimates of variance. After two years of sampling, three plots were added to the 201 stratum to increase power. The total number of plots is 63 but may be adjusted as additional plots are sampled.

Stratum	Total area (acres)	Percentage of total		Plots per stratum	
		Park area	Frame area	Number	Number per year
Excluded	18,372	27	0	0	0
201	1,455	2	3	5	1
202	9,045	13	19	11	2 or 3
302	6,575	10	13	8	1 or 2
402	16,719	25	34	21	4 or 5
502	14,952	22	31	18	3 or 4

A.3.8 Saguaro National Park (West)

Within each stratum, plots were allocated using a probabilistic sampling design based on travel time (see cost-surface discussion above). Initial plot allocation was based on 26 total plots based on initial estimates of variance. After two years of sampling, one plot was added to the 302 stratum to increase power. The total number of plots is 31 but may be adjusted as additional plots are sampled.

Stratum	Total area (acres)	Percentage of total		Plots per stratum	
		Park area	Frame area	Number	Number per year
Excluded	6,618	27	0	0	0
101	2,193	9	12	5	1
102	3,351	14	19	5	1
201	224	0.9	1.2	0	0
202	11,205	45	62	16	3 or 4
302	1,036	4	6	5	1
402	7	0.03	0.04	0	0

A.3.9 Tonto National Monument

Initial plot allocation was based on 16 total plots based on initial estimates of variance. After the first round of sampling, three plots were added to the 302 stratum to increase power. The total number of plots is 19 but may be adjusted as additional plots are sampled.

Stratum	Total area (acres)	Percentage of total		Plots per stratum	
		Park area	Frame area	Number	Number per year
Excluded	435	39	0	0	0
101	14	1	2	0	0
102	117	11	17	3	3
201	1	0.1	0.2	0	0
202	485	44	72	11	11
302	53	5	8	5	5

A.4 Plot allocation by park for the Chihuahuan Desert Network

For each park, the number of plots per stratum is proportional to the area in each stratum as a percentage of the sampling frame (non-excluded area of park). Unless otherwise indicated, strata representing less than 5% of the sampling frame were not allocated plots. (See Section 3.2.2 for detailed information on plot-allocation rules and exceptions.)

Initial plot allocation was based on preliminary estimates of variance but the total number of plots may change during the first five years of data collection. Within each stratum, the plots are sampled based on an ordered list output by RRQRR. Plots may be eliminated (not sampled) based on concerns for cultural resources, crew safety, or riparian resources.

A.4.1 Big Bend National Park

Private land and developed areas within the park were excluded from the sampling frame. While the Chisos Mountains area would not have had plots allocated due to low percentage of the sampling frame (<5%), we allocated 10 plots to the Chisos Mountains at the park's request. A rough boundary of the Chisos Mountains was delineated and then divided into two strata representing the two elevation classes (5000–6000' and >6000'). The rock-fragment content of the soils was not included in the stratification of the Chisos Mountains. Five plots were allocated to each Chisos Mountains strata (Chisos_5000 and Chisos_600). Initial plot allocation was based on 100 total plots but the number of plots may change based on estimates of variance.

Stratum	Total area (acres)	Percentage of total		Plots per stratum	
		Park area	Frame area	Number	Number per year
Excluded	113,363	14	0	0	0
101	125,622	15	18	19	3 or 4
102	24,251	3	3	0	0
103	25,117	3	4	0	0
201	222,311	27	32	33	6 or 7
202	136,244	17	20	20	4
203	39,967	5	6	6	1 or 2
301	40,288	5	6	6	1 or 2
302	41,154	5	6	6	1 or 2
303	267	<1	<1	0	0
401 (non-Chisos)	10,631	1	2	0	0
402 (non-Chisos)	9,835	1	1	0	0
403 (non-Chisos)	952	<1	<1	0	0
500 (Chisos 5000–6000')	14,676	2	2	5	1
600 (Chisos >6000')	6,431	1	1	5	1

A.4.2 Carlsbad Caverns National Park

Initial plot allocation was based on 50 total plots but the number of plots may change based on estimates of variance.

Stratum	Total area (acres)	Percentage of total		Plots per stratum	
		Park area	Frame area	Number	Number per year
Excluded	13,453	29	0	0	0
201	552	1	2	0	0
202	0.4	<1	<1	0	0
203	0.1	<1	<1	0	0
301	2,316	5	7	5	1
302	2,325	5	7	5	1
303	5,157	11	16	7	1 or 2
401	418	1	1	0	0
402	5,094	11	15	7	1 or 2
403	14,695	31	44	21	4 or 5
502	968	2	3	0	0
503	1,731	4	5	5	1

A.4.3 Fort Davis National Historic Site

The interior of the park boundary was buffered by 20 m to avoid having plots directly on the boundary. Soils in the Mainstay-Brewster association, hilly map unit were assigned to the 401 strata. According to the NRCS Soil Survey Geographic (SSURGO) database, the Mainstay-Brewster association, hilly map unit consists of unnamed minor components (45% of map unit; unknown surface texture), Mainstay (30% of map unit; stony silt loam surface texture) and Brewster soils (25% of map unit, very gravelly loam surface texture). Because the texture of the dominant component of the Mainstay-Brewster association, hilly map unit is unknown, the map unit was assigned to the 401 strata (<35% rock fragments) based on the surface texture of the two known components using the all component aggregation method. Because the minimum number of plots per strata is five, ten plots are needed for the park. Initial plot allocation was based on 10 total plots but the number of plots may change based on estimates of variance.

Stratum	Total area (acres)	Percentage of total		Plots per stratum	
		Park area	Frame area	Number	Number every 5 years
Excluded	315	61	0	0	0
401	93	18	46	5	5
402	1	<1	<1	0	0
403	109	21	54	5	5

A.4.4 Guadalupe Mountains National Park

Initial plot allocation was based on 60 total plots but the number of plots may change based on estimates of variance.

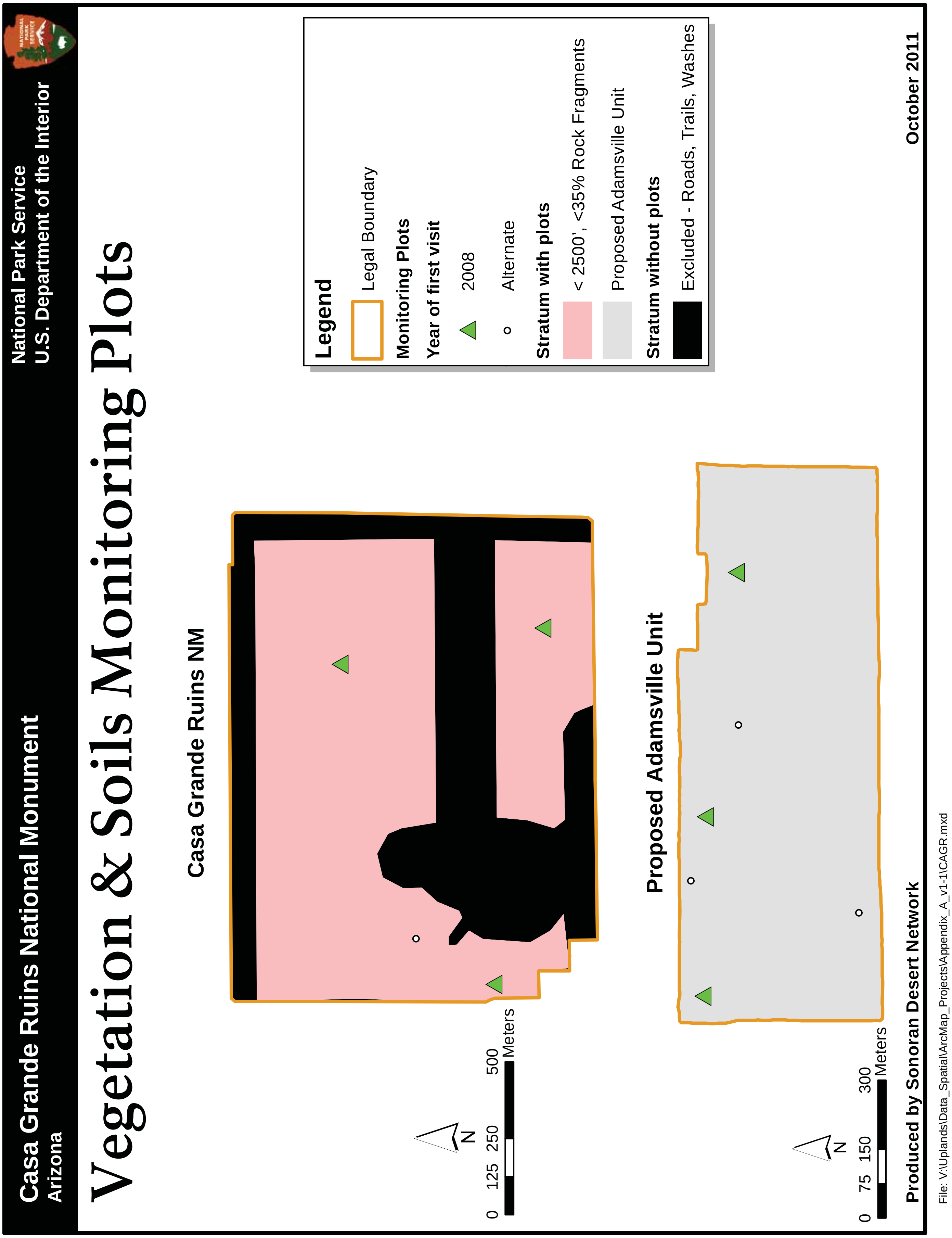
Stratum	Total area (acres)	Percentage of total		Plots per stratum	
		Park area	Frame area	Number	Number per year
Excluded	21,160	24	0	0	0
201	2,000	2	3	0	0
301	18,111	21	27	17	3 or 4
401	10,070	11	15	10	2
402	9,120	10	14	8	1 or 2
501	8,482	10	13	8	1 or 2
502	18,868	21	28	17	3 or 4

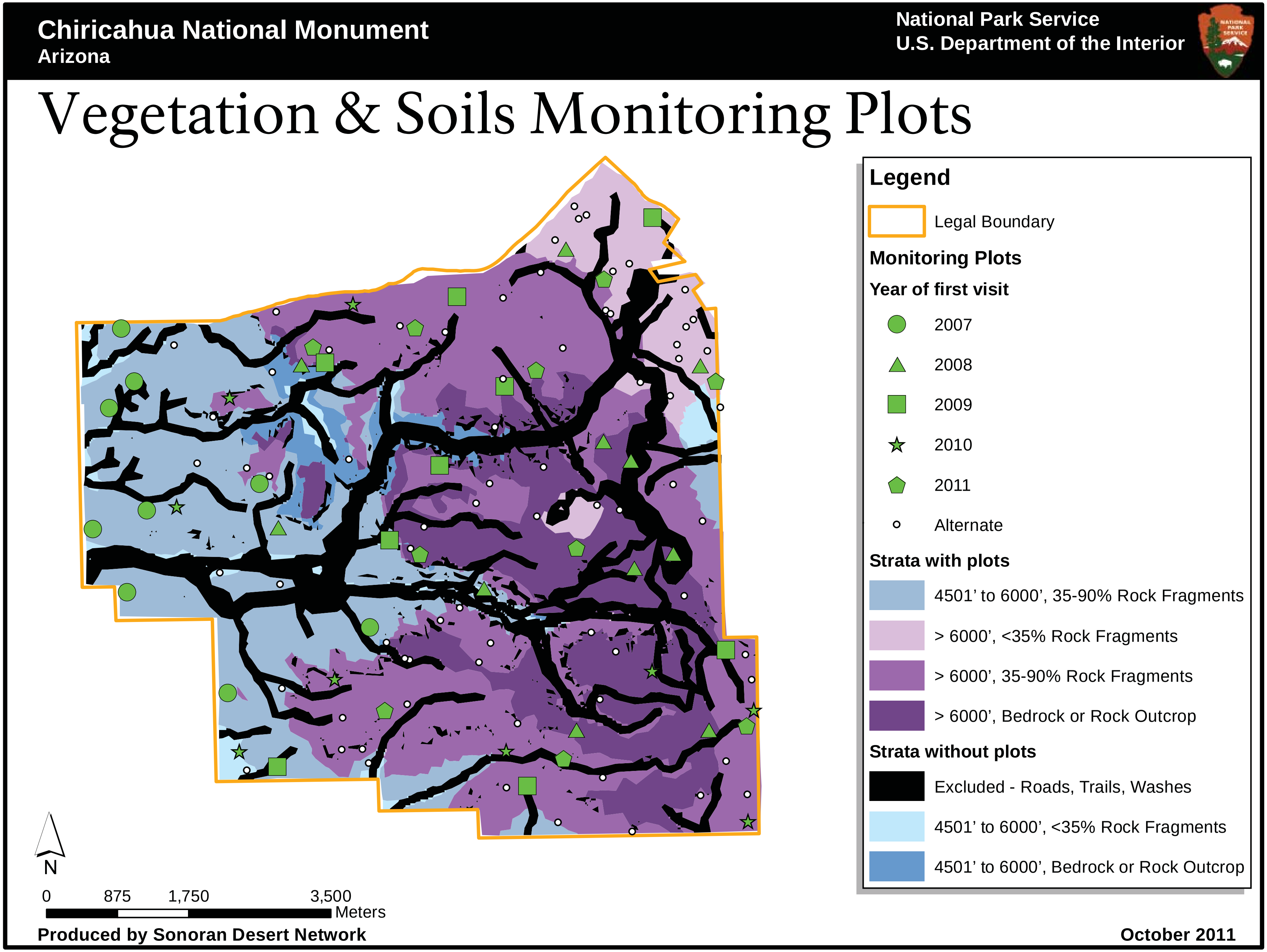
A.4.5 White Sands National Monument

Initial plot allocation was based on 60 total plots but the number of plots may change based on estimates of variance. In addition to the typically excluded areas, the Alkali flat, barren dunes, Lake Lucero, other intermittent lakes, and the salt flats were excluded from the sampling frame.

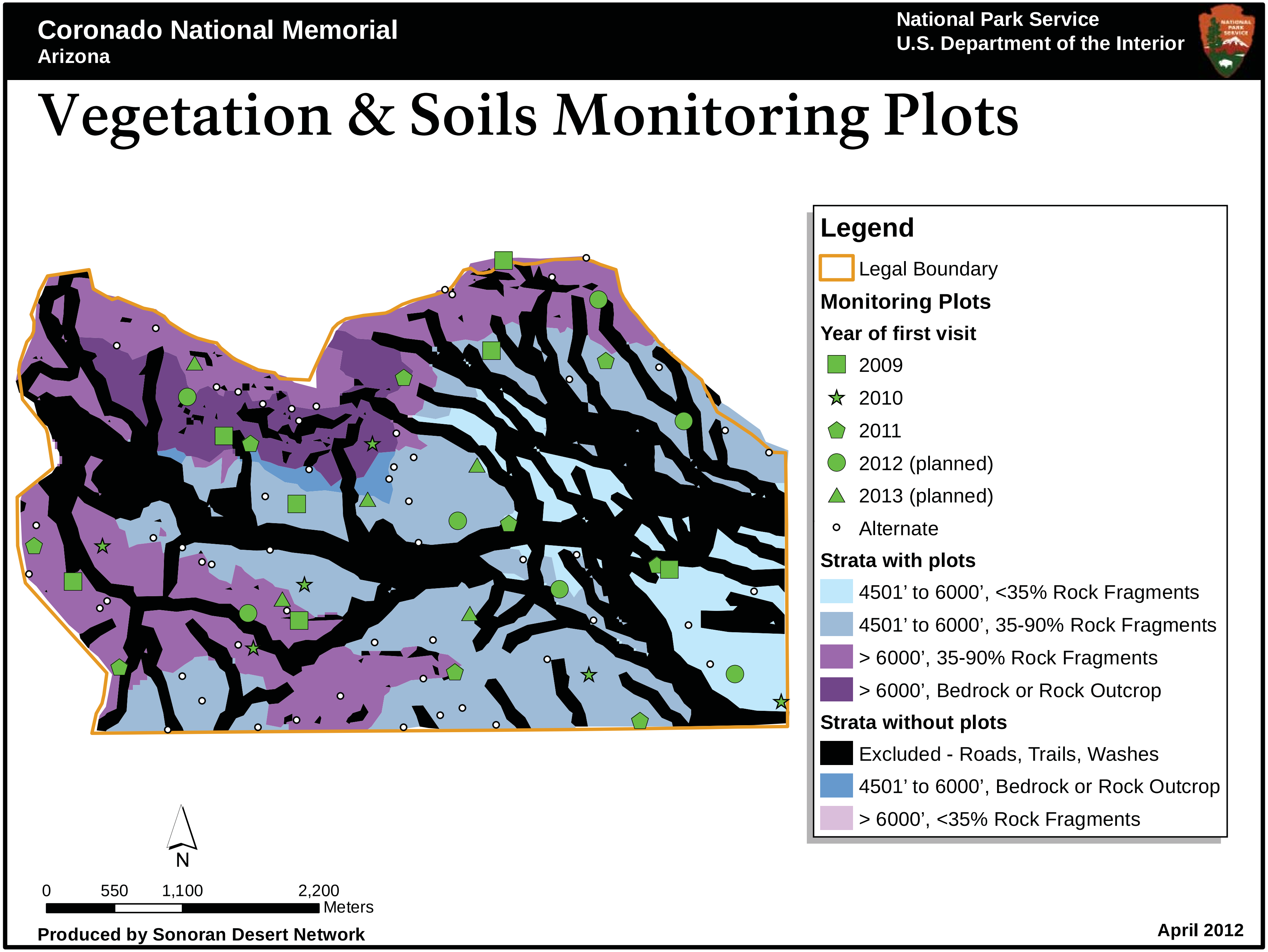
Stratum	Total area (acres)	Percentage of total		Plots per stratum	
		Park area	Frame area	Number	Number per year
Excluded	95,635	65	0	0	0
301	52,154	35	100	60	12

A.5 Sonoran Desert Network maps





File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_V1-1\CHIR.mxd

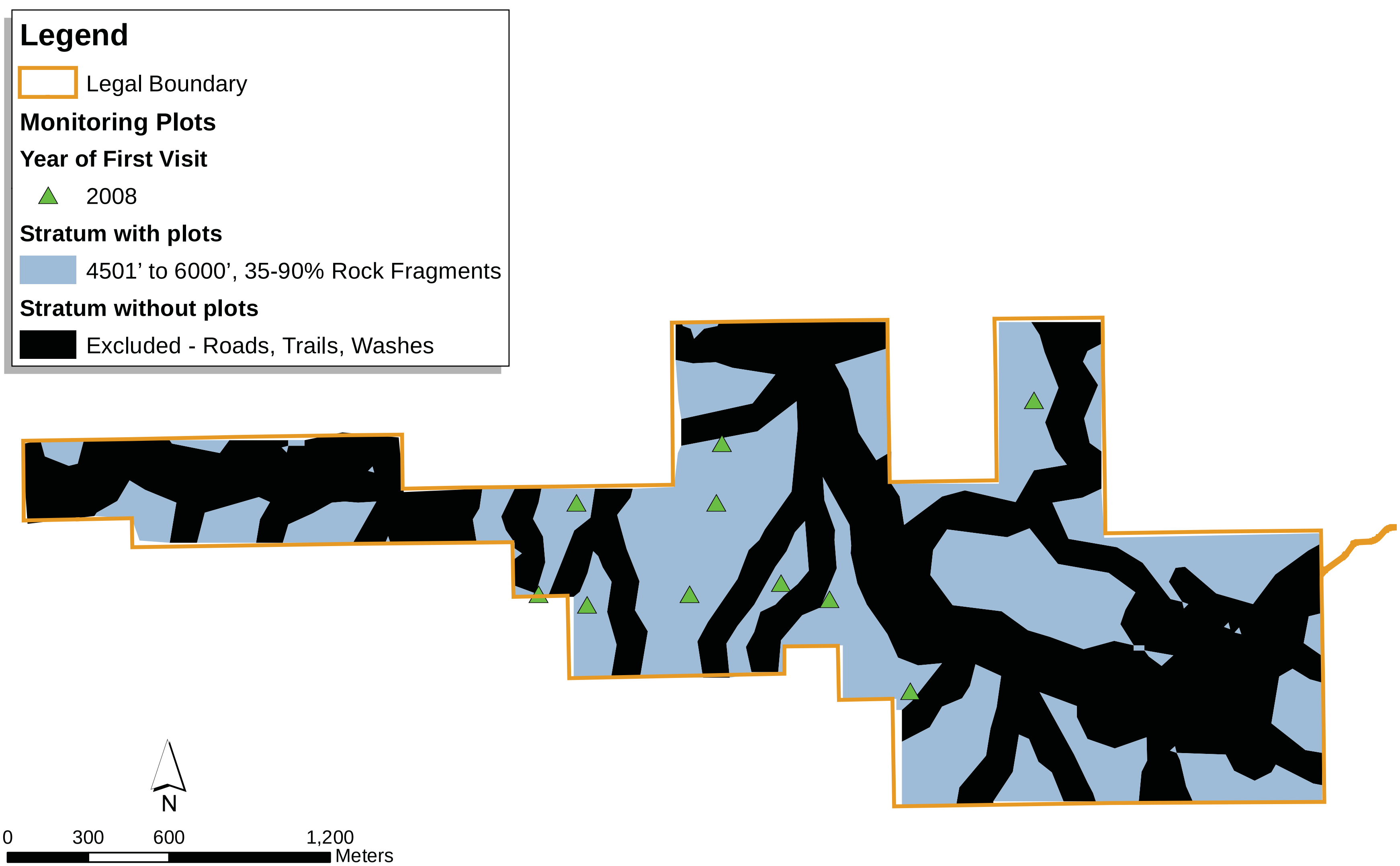


File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_v1-1\CORO.mxd

Fort Bowie National Historic Site
Arizona

National Park Service
U.S. Department of the Interior

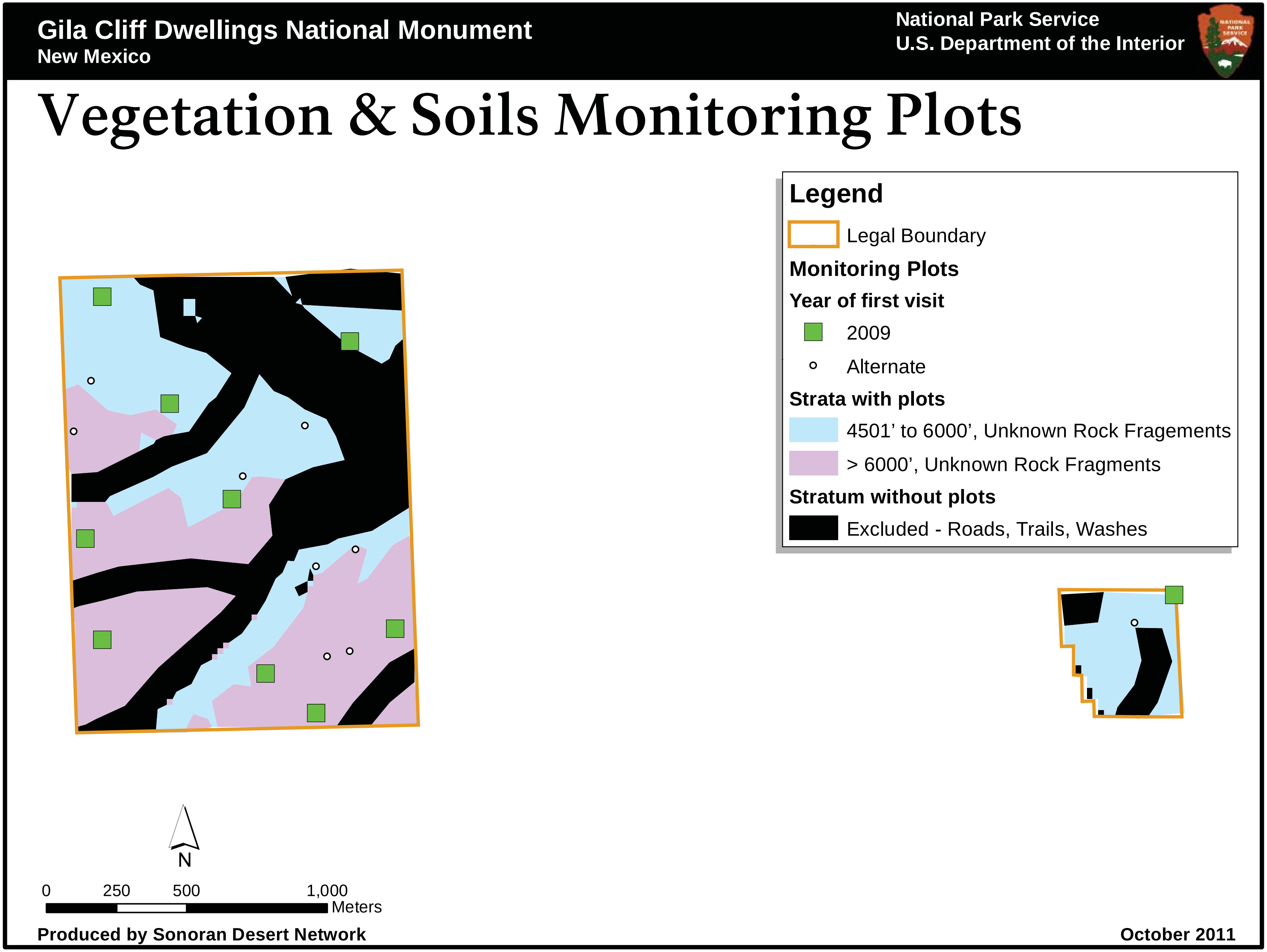
Vegetation & Soils Monitoring Plots



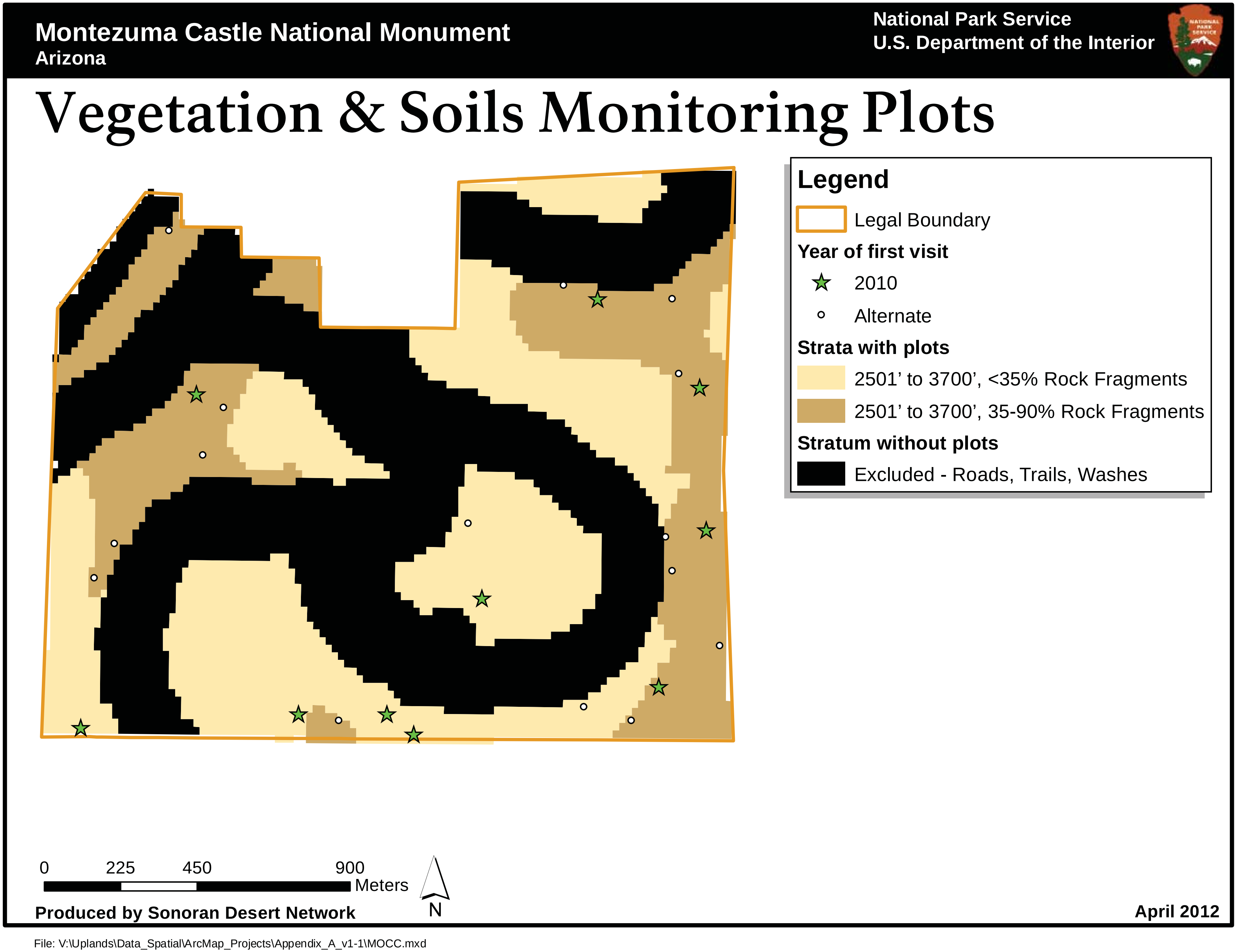
Produced by Sonoran Desert Network

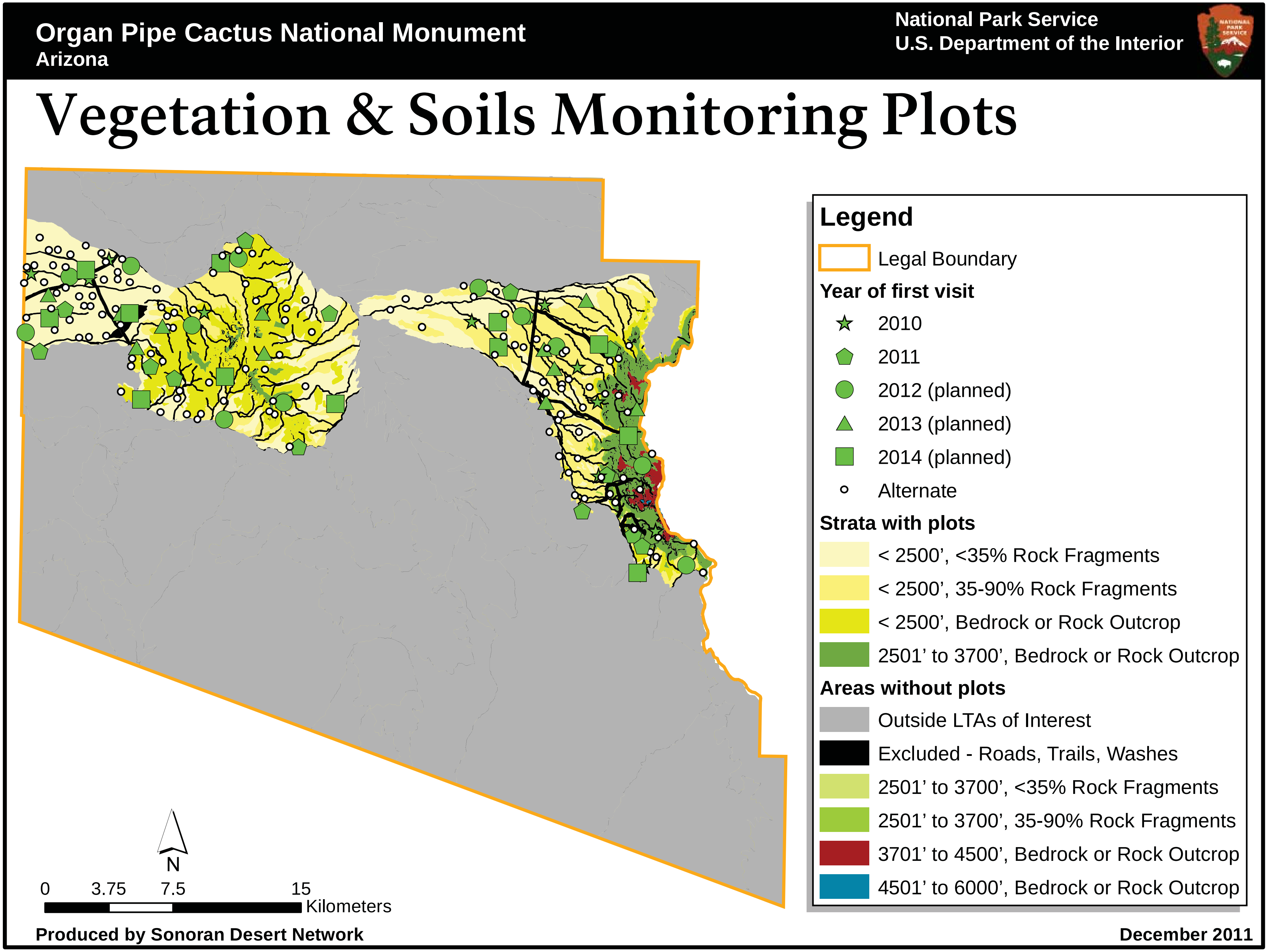
October 2011

File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_v1-1\FOBO.mxd



File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_V1-1\GICL.mxd


Montezuma Castle National Monument
Arizona
National Park Service
U.S. Department of the Interior
Vegetation & Soils Monitoring Plots
Legend
Legal Boundary
Year of first visit
2010
Alternate
Strata with plots
2501' to 3700', <35% Rock Fragments
2501' to 3700', 35-90% Rock Fragments
Stratum without plots
Excluded - Roads, Trails, Washes
0 225 450 900
Meters
N
Produced by Sonoran Desert Network
April 2012
File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_v1-1\MOCC.mxd

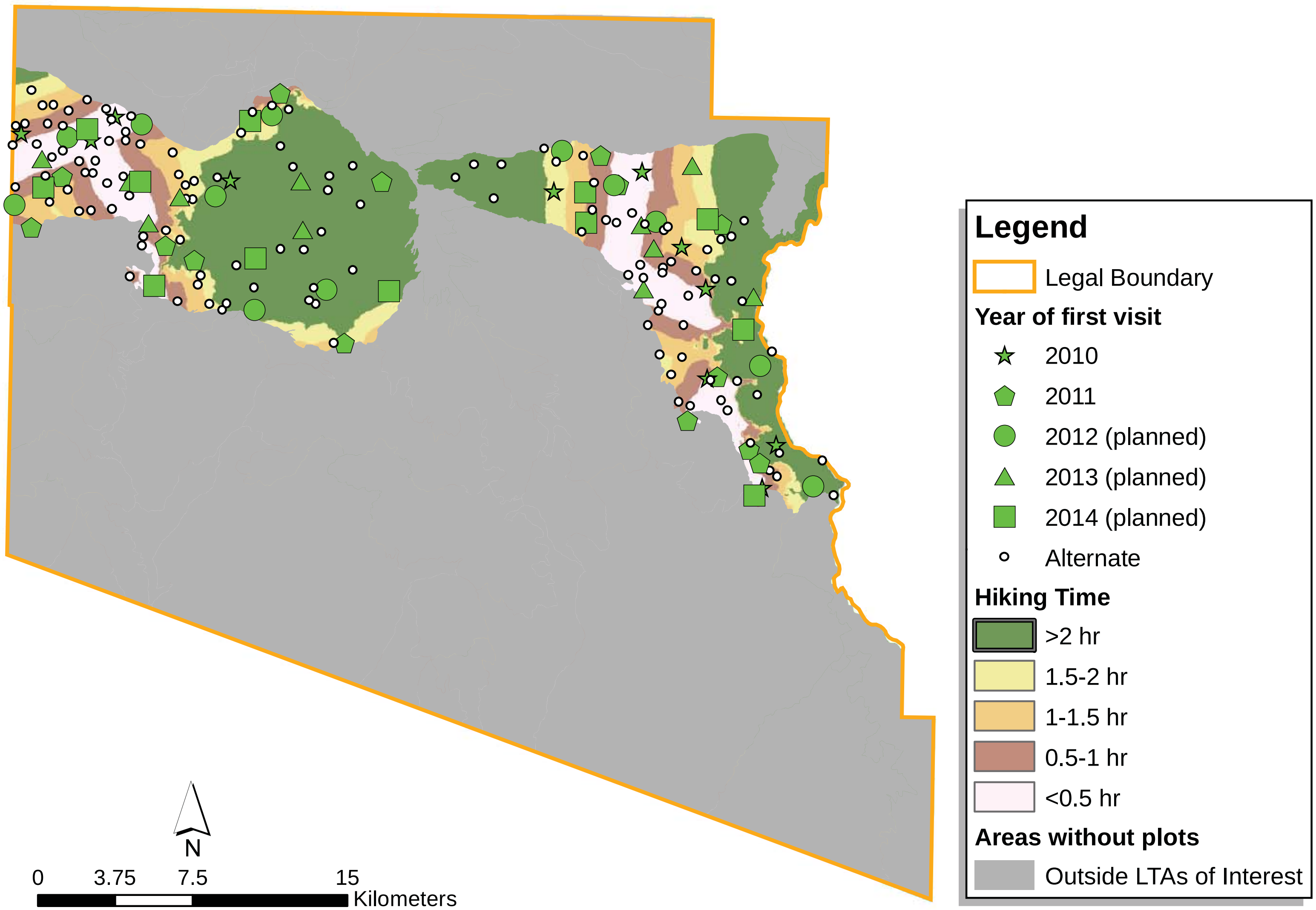


File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_v1-1\ORPI.mxd

Organ Pipe Cactus National Monument
Arizona

National Park Service
U.S. Department of the Interior

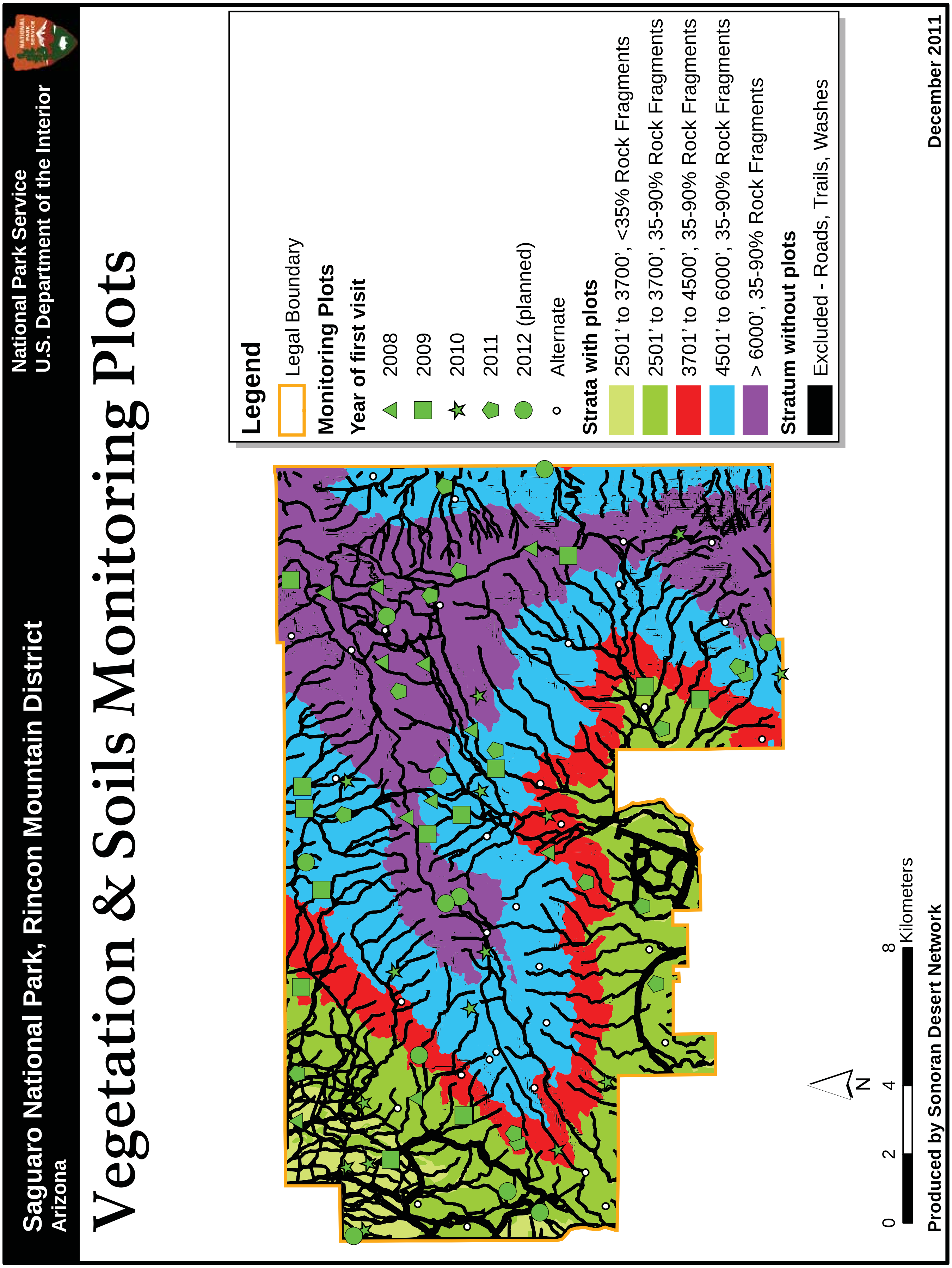
Vegetation & Soils Monitoring Plots



Produced by Sonoran Desert Network

December 2011

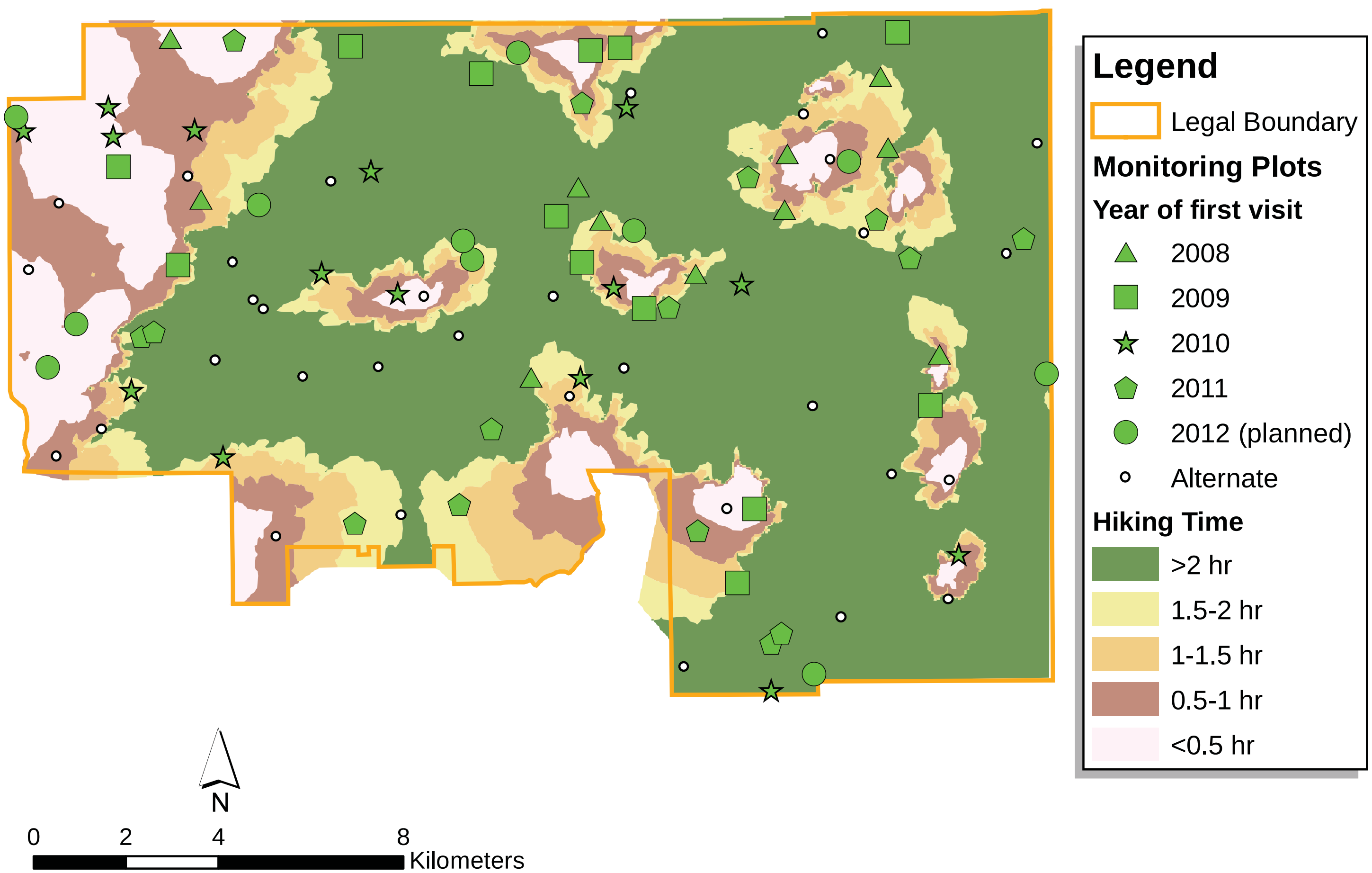
File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_v1-1\ORPI.mxd


Saguaro National Park, Rincon Mountain District
Arizona
National Park Service
U.S. Department of the Interior
Vegetation & Soils Monitoring Plots
Legend
Legal Boundary
Monitoring Plots
Year of first visit
2008
2009
2010
2011
2012 (planned)
Alternate
Strata with plots
2501' to 3700', <35% Rock Fragments
2501' to 3700', 35-90% Rock Fragments
3701' to 4500', 35-90% Rock Fragments
4501' to 6000', 35-90% Rock Fragments
> 6000', 35-90% Rock Fragments
Stratum without plots
Excluded - Roads, Trails, Washes
N
0 2 4 8
Kilometers
Produced by Sonoran Desert Network
December 2011
File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_v1-1\SAGE.mxd

Saguaro National Park, Rincon Mountain District
Arizona

National Park Service
U.S. Department of the Interior

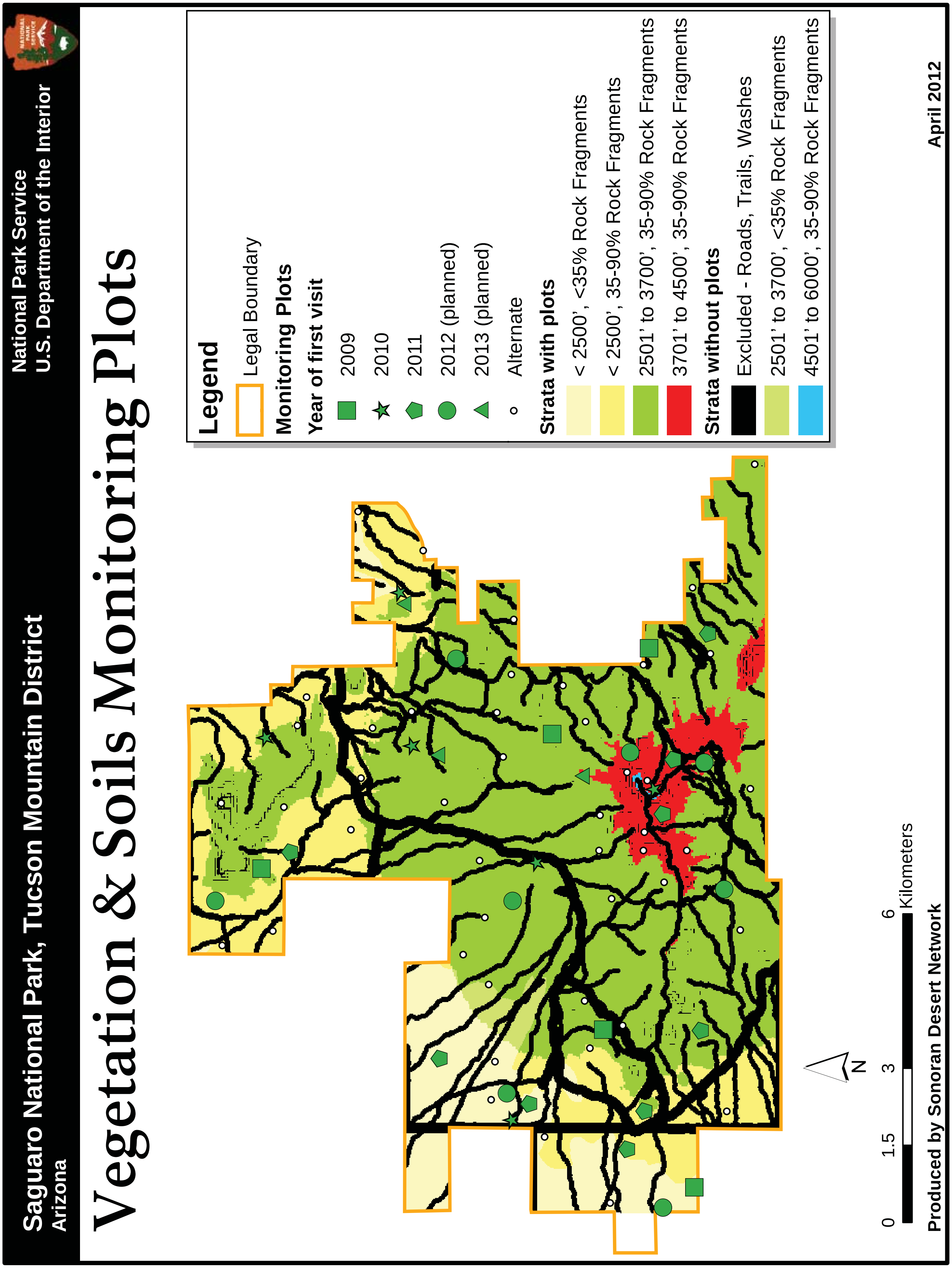
Vegetation & Soils Monitoring Plots



Produced by Sonoran Desert Network

December 2011

File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_v1-1\SAGE.mxd

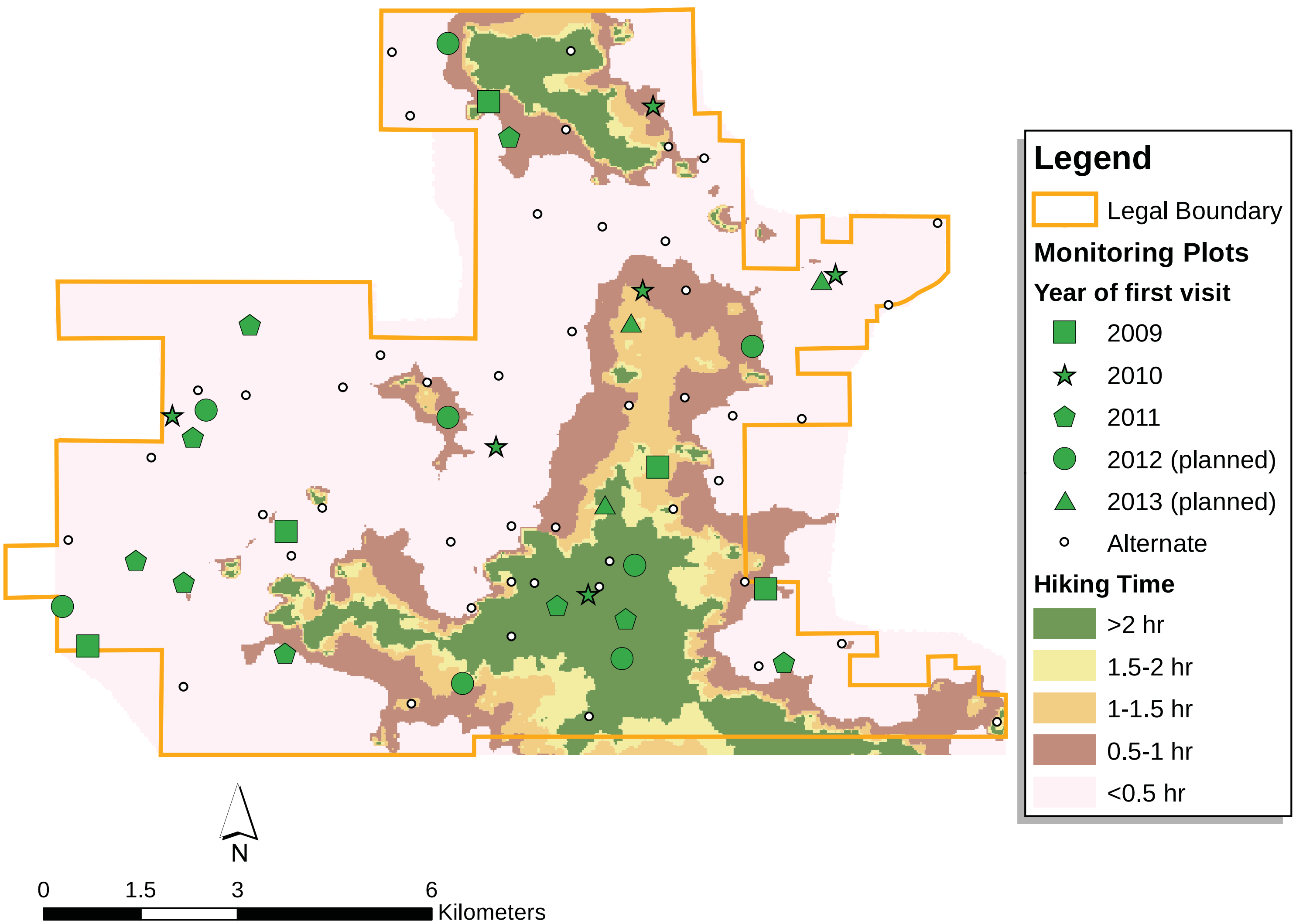


Saguaro National Park, Tucson Mountain District
Arizona
National Park Service
U.S. Department of the Interior
Vegetation & Soils Monitoring Plots
Legend
Legal Boundary
Monitoring Plots
Year of first visit
2009
2010
2011
2012 (planned)
2013 (planned)
Alternate
Strata with plots
< 2500', <35% Rock Fragments
< 2500', 35-90% Rock Fragments
2501' to 3700', 35-90% Rock Fragments
3701' to 4500', 35-90% Rock Fragments
Strata without plots
Excluded - Roads, Trails, Washes
2501' to 3700', <35% Rock Fragments
4501' to 6000', 35-90% Rock Fragments
N
0
1.5
3
6
Kilometers
Produced by Sonoran Desert Network
April 2012
File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_v1-1\SAGW.mxd

Saguaro National Park, Tucson Mountain District
Arizona

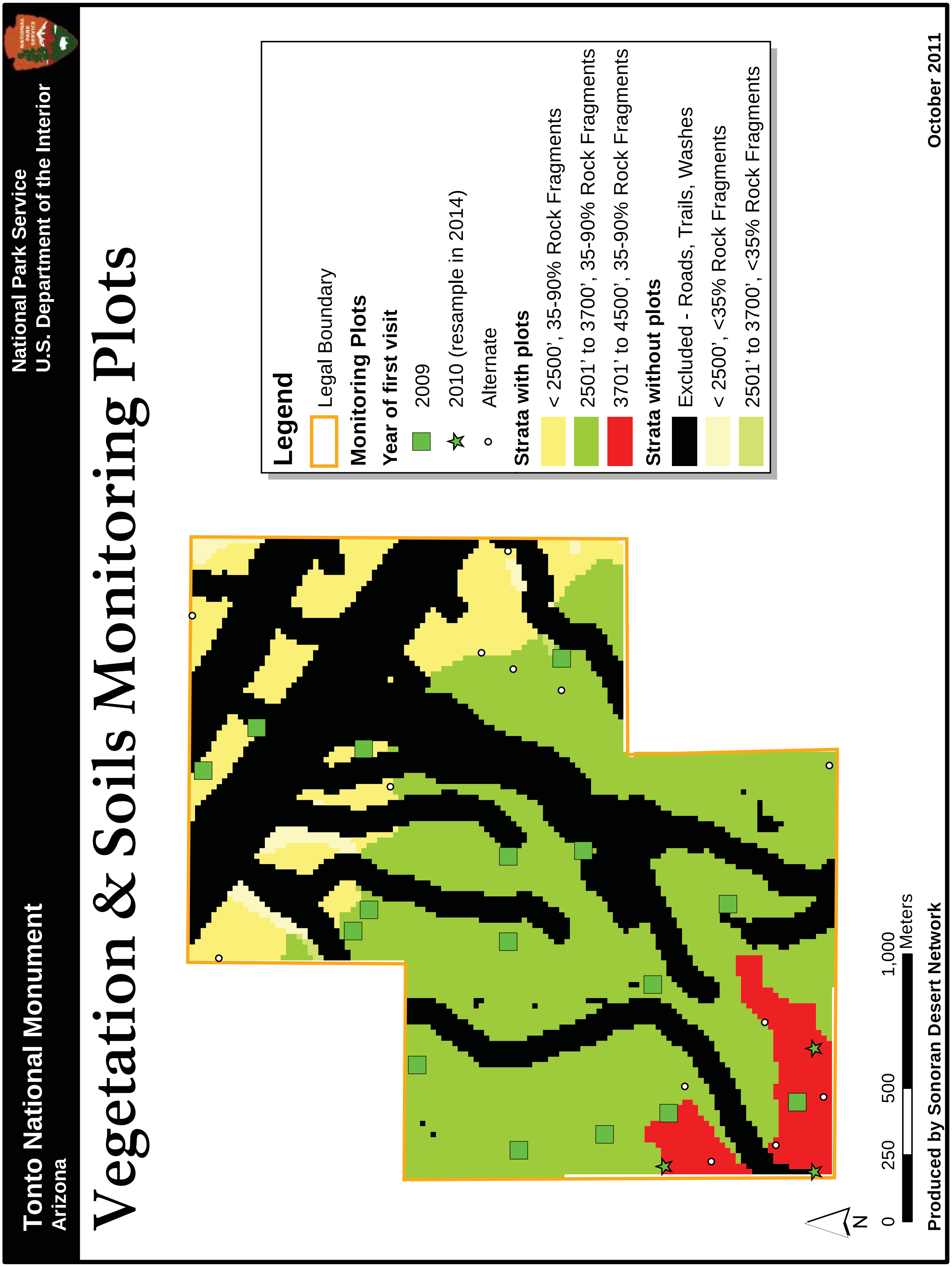
National Park Service
U.S. Department of the Interior

Vegetation & Soils Monitoring Plots

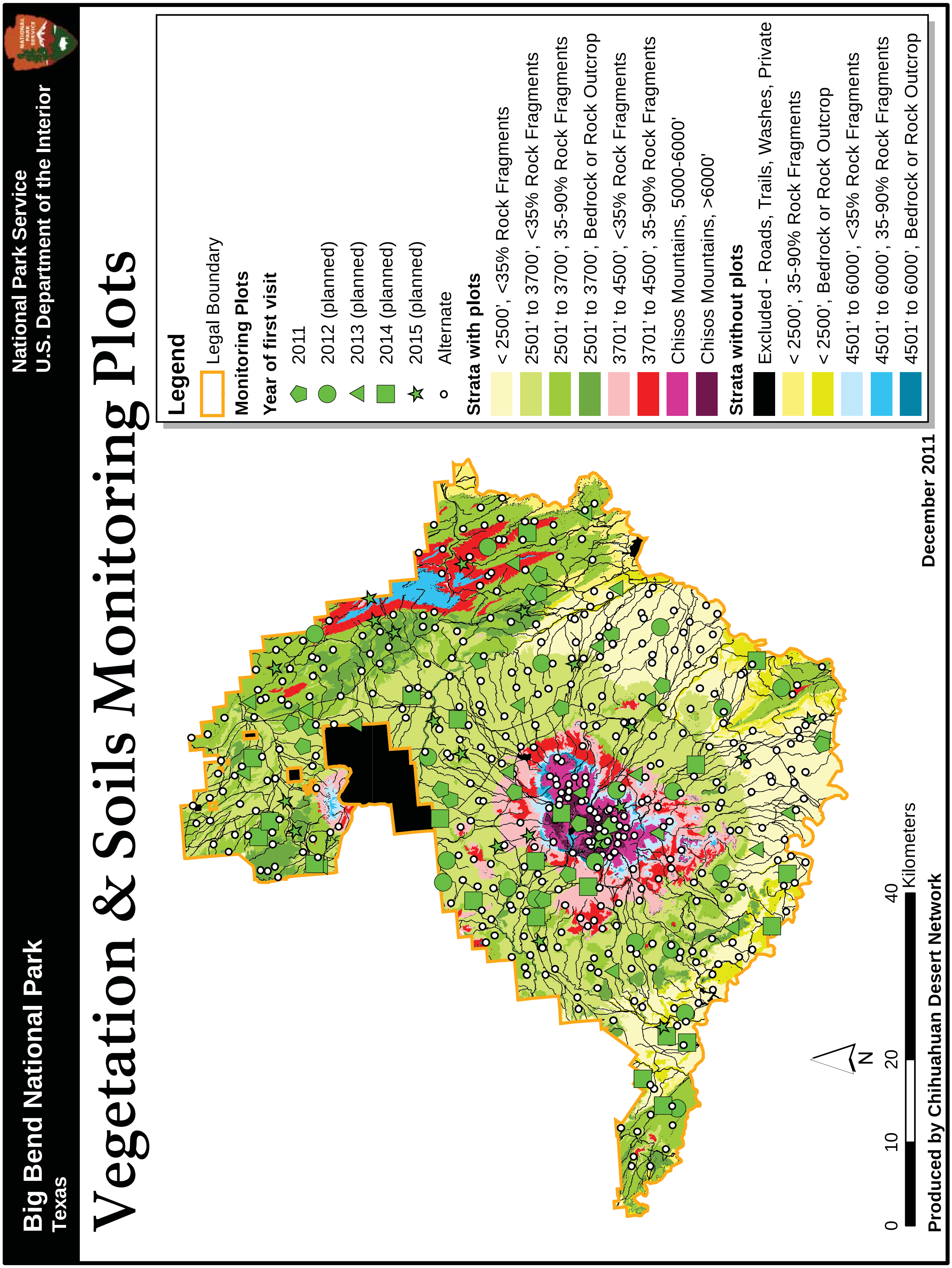


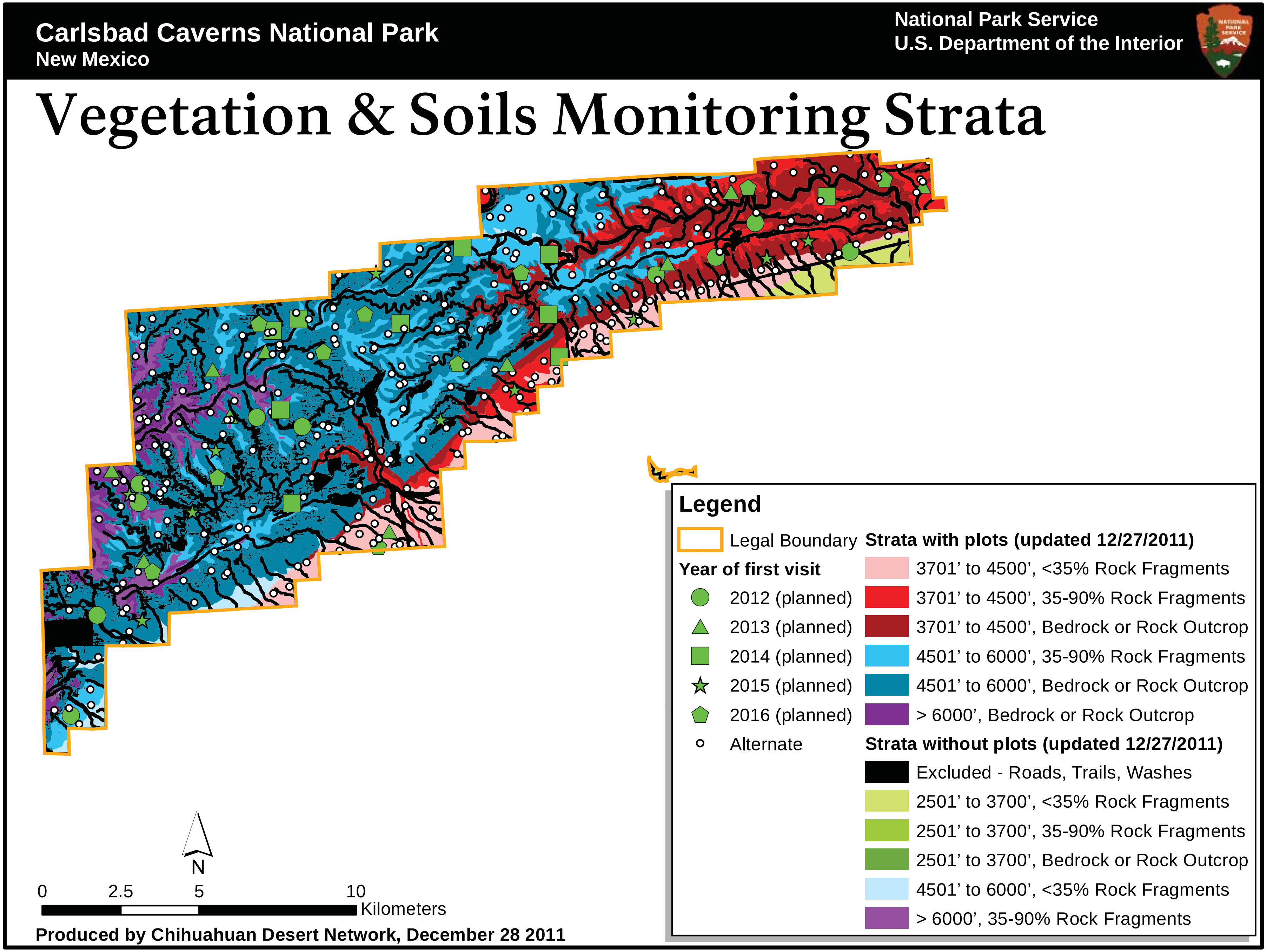
Produced by Sonoran Desert Network

April 2012

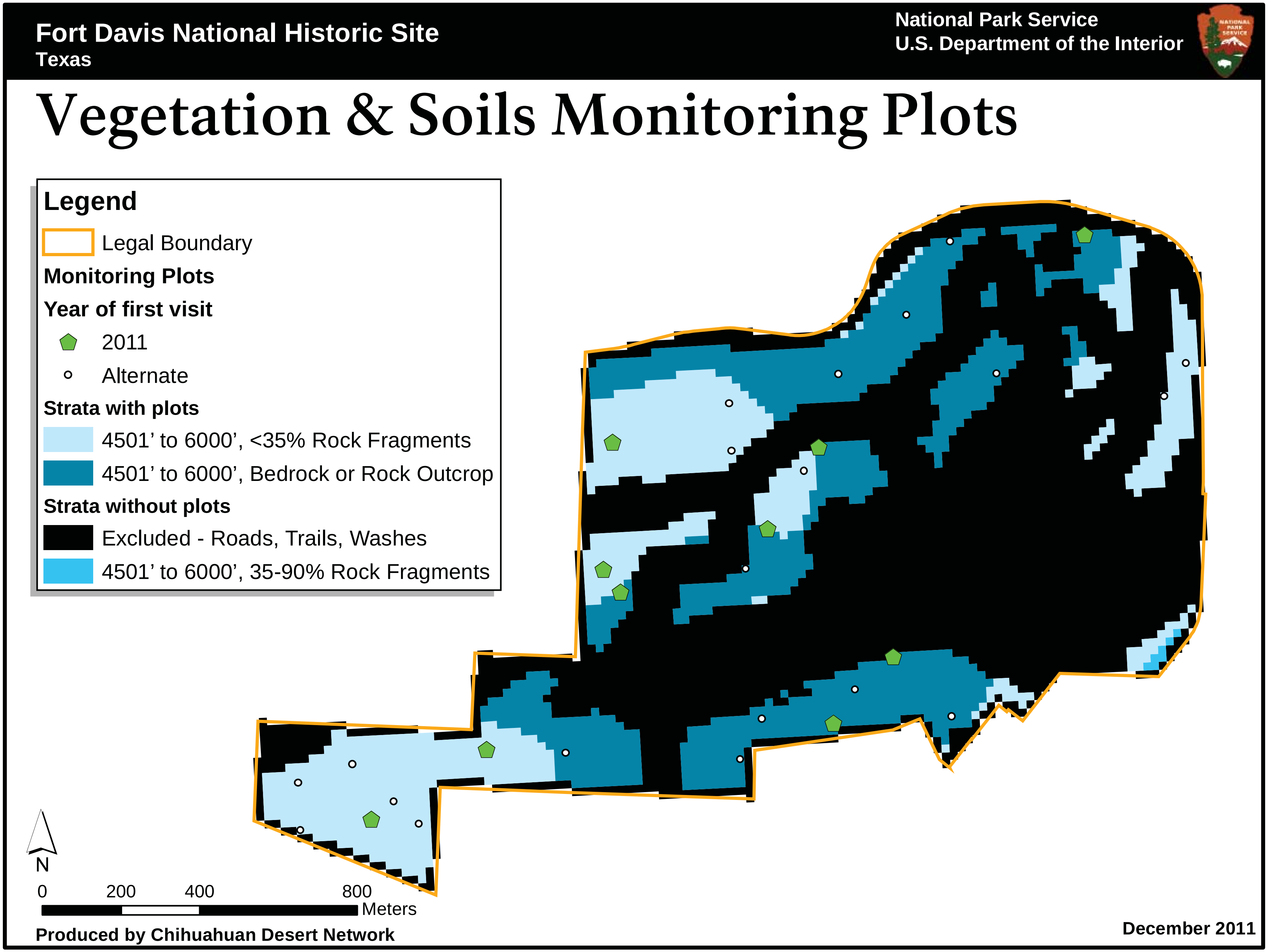

Tonto National Monument
Arizona
National Park Service
U.S. Department of the Interior
Vegetation & Soils Monitoring Plots
Legend
Legal Boundary
Monitoring Plots
Year of first visit
2009
2010 (resample in 2014)
Alternate
Strata with plots
< 2500', 35-90% Rock Fragments
2501' to 3700', 35-90% Rock Fragments
3701' to 4500', 35-90% Rock Fragments
Strata without plots
Excluded - Roads, Trails, Washes
< 2500', <35% Rock Fragments
2501' to 3700', <35% Rock Fragments
N
0 250 500 1,000
Meters
Produced by Sonoran Desert Network
October 2011
File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_v1-1\TONT.mxd

A.6 Chihuahuan Desert Network maps





File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_v1-1\CAVE.mxd



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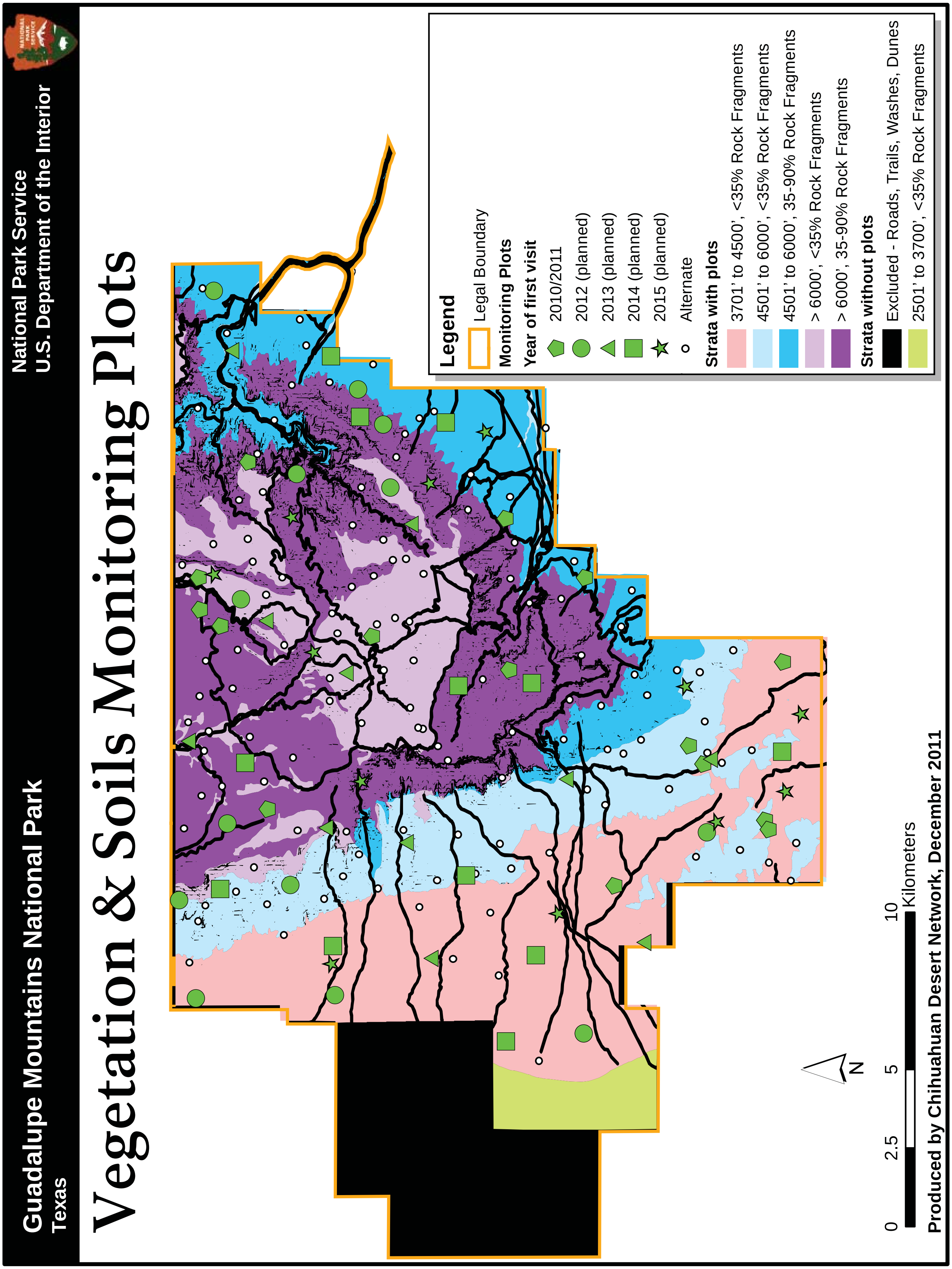
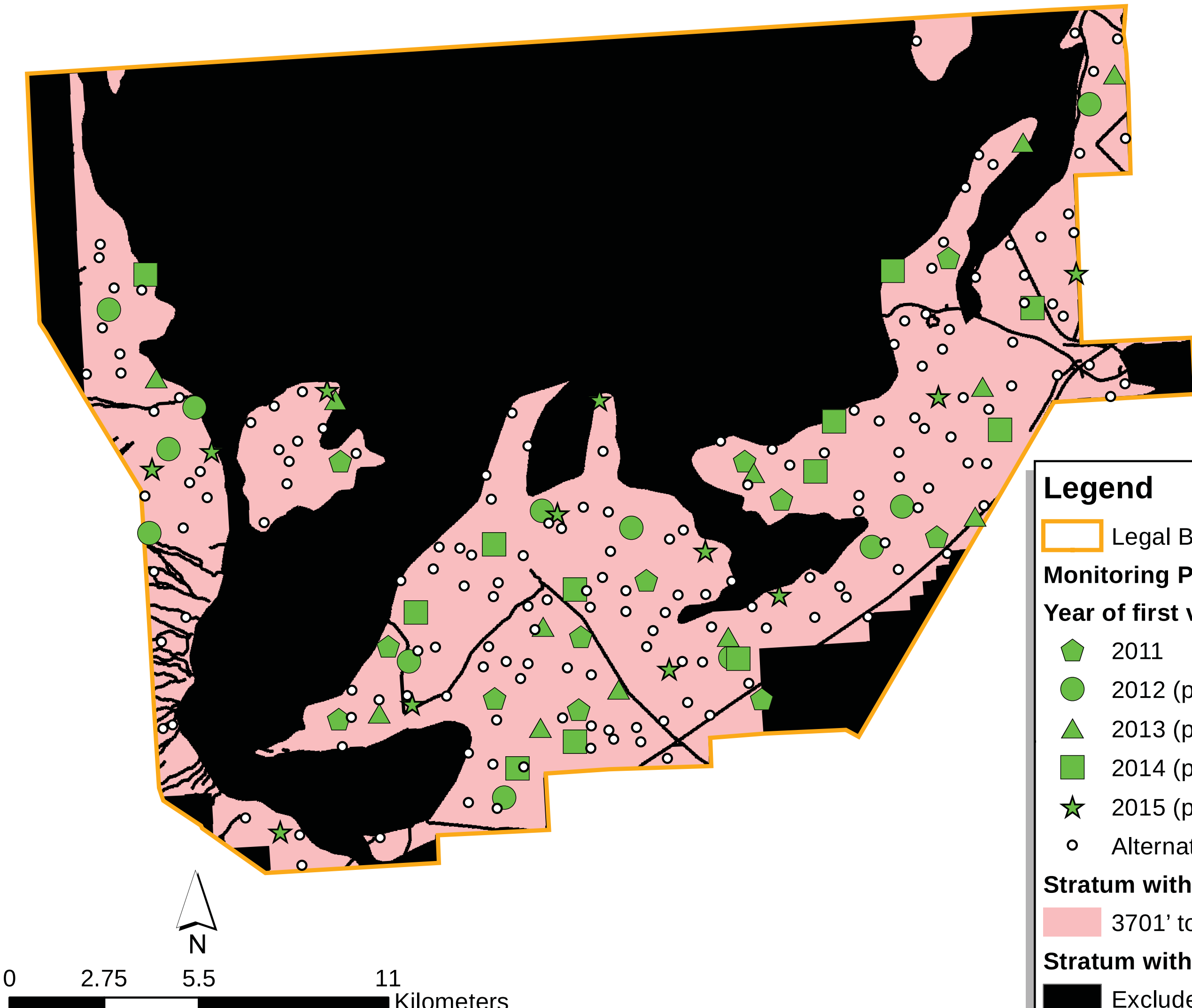


File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_v1-1\GUMO.mxd

White Sands National Monument
New Mexico

National Park Service
U.S. Department of the Interior

Vegetation & Soils Monitoring Plots



Legend

- Legal Boundary

Monitoring Plots

Year of first visit

- 2011
- 2012 (planned)
- 2013 (planned)
- 2014 (planned)
- 2015 (planned)
- Alternate

Stratum with plots

- 3701' to 4500', <35% Rock Fragments

Stratum without plots

- Excluded - Roads, Washes, Active Dune Areas

December 2011

Produced by Chihuahuan Desert Network

File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_v1-1\WHSA.mxd

Appendix B. Example Trip Summary

Chihuahuan Desert Network Upland Vegetation and Soils Protocol

Trip Summary Report
Guadalupe Mountains National Park
January 5, 2012

Purpose: To briefly summarize the 2011 field season of uplands vegetation and soils monitoring at Guadalupe Mountains NP.

Contacts: Please direct any questions about our vegetation monitoring program to project manager Sarah Studd, at (520) 343-8845 (sarah_studd@nps.gov), Cheryl McIntyre, at (575) 635-3659 (cheryl_mcintyre@nps.gov), or Kirsten Gallo, at (575) 575-646-5294 (kirsten_gallo@nps.gov).

Vital signs and other parameters sampled during this visit

- Vegetation cover
- Species/life form frequency
- Soil aggregate stability and bulk density
- Soil and biological soil crust cover
- *NEW* Fuels incorporated into soil cover measures

A brief description of each vital sign and parameter can be found in Appendix A.

Sampling highlights/notes

- Seven plots were established this field season bringing the total to 12 established since 2010. The 7 plots established in 2011 will be combined with the 5 plots established in 2010 into a single year of sampling (2010/2011) in our five-year rotating panel design. Therefore, we will revisit the 2010/2011 plots in 2016.
- We will sample 12 plots in 2012 and each year thereafter
- The sampling was conducted during August. Several plots that we intended to sample were not visited due to access constraints and/or steep slopes. We will try to visit some of plots with difficult accessibility in 2012.
- Plot photographs and scans of the paper datasheets are available on the Southwest Networks Collaborative (SWNC) SharePoint site under CHDN→Uplands: http://inpchdnms03/CHDN/Uplands/SitePages/Home.aspx
- Plot coordinates are available in Excel and GIS formats from CHDN and accompany this report for park staff.
- Figures 1–3 show the variety of vegetation that we sampled in 2011

How are plot names assigned?

The first three numbers, or prefix, of the plot name signify the stratum in which the plot is located. In this protocol, the strata are combinations of elevation and rock-fragment classes. The first number indicates the elevation band in which the plot is located. Guadalupe Mountains NP was divided into three strata representing its three elevation classes: 3,701–4,500', 4,501–6,000', and >6,000'.

Elevation (feet)	Stratum
<2,500'	10X
2,501–3,700'	20X
3,701–4,500'	**30X**
4,501–6,000'	**40X**
>6,000'	**50X**

The 1, 2 or 3 in the "ones place" of the strata is associated with the soil rock-fragment content. Soil rock-fragment classes were based on rock-fragment modifiers from the most recent soil survey. Rock-fragment content was not used to stratify the Chisos Mountains.

Rock-fragment percentage	Stratum
<35%	X01
35–90%	X02
>90% or BRO[1]	X03

[1]BRO = bedrock or rock outcrop

The last two or three digits in the plot name (following the underscore; e.g., _03) are determined by a randomization algorithm RRQRR. Plots are sampled roughly in in numerical order according to the RRQRR output. For example, for plot 501_02, the plot is greater than 6,000' in elevation (**5**01_02) and the soil rock fragment is less than 35% (50**1**_02) and was the second output form the RRQRR algorithm for the 101 stratum (501**_02**).

Seven plots were established this year (Appendix B). Plots were established in five elevation zones:

Stratum	Elevation	% rock fragments	Total area (acres)	Plots per stratum: 2011	Plots per stratum: Remaining (2012–2015)
301	2,501–3,700'	<35%	18,111	2	14
401	3,701–4,500'	<35%	10,070	1	8
402	3,701–4,500'	35–90%	9,120	1	6
501	>6,000'	<35%	8,482	1	6
502	>6,000'	35–90%	18,868	2	14

[1]BRO = bedrock or rock outcrop

What's ahead?

From 2012 to 2015, we will continue to establish monitoring plots in Guadalupe Mountains NP, adding another 12 plots each year for a total of 60 plots over a five-year period. Plots tentatively scheduled for monitoring in 2012 are shown in Appendix B.

By June 2013, data collected during the 2011 and 2012 field seasons will be analyzed and a data summary report will be published. Data summaries are generally not completed until at least two years of data have been collected two allow for evaluation of progress toward monitoring objectives and suggestion of any sampling modifications. The data summary reports will continue until five years of data have been collected.

Following the completion of five years of data collection (in 2015), a status and trends report will be published in the NPS Natural Resource Technical Report Series, summarizing the results from all 60 plots.

In 2016, we will return to resample plots established during the 2010–2011 field season.

Figure 1. Landscape view from plot 301_10.
Photo Metadata
Title: GUMO_V301-10
Subject: Looking at plot from 0, 20 corner (photo point 2)
Credit: NPS/Sam Robinson
Date: 8/19/2011

Figure 2. Landscape view from plot 402_03.
Photo Metadata
Title: GUMO_V402-03
Subject: Looking at plot from 50, 20 corner (photo point 3)
Credit: NPS/Sam Robinson
Date: 8/18/2011

Figure 3. Landscape view from plot 501_02.
Photo Metadata
Title: GUMO_V501-02
Subject: Looking at plot from 50, 0 corner (photo point 4)
Credit: NPS/Tyler Engle
Date: 8/24/2011

Appendix A: Descriptions of vital signs and associated parameters collected during this sampling trip.

Vegetation cover—Vegetation cover of common perennial species is an effective and traditional monitoring approach for plant populations. Cover is the percentage of ground surface covered by vegetation material, providing both an absolute and relative measure of species and lifeform abundance. This approach allows determination of status and detection of trend within a single species of interest, facilitating the use of “keystone” and “indicator” species, as well as providing focused information on species of management concern (e.g., established exotic invasive species, “flagship” species such as saguaro cacti). Determining the foliar cover of all common perennial species permits direct contrasts of species of interest and ensures that information is not lost if future research or management objectives focus on a species that is currently a lower priority.

Species/Life form frequency—Plant frequency is the number of times a plant species/lifeform is encountered in a given number of plots or sample points, providing a measure of the occurrence and distribution of species within a landscape or stratum of interest. Frequency provides an effective index of change over time and space and can efficiently provide information on species/lifeforms that are uncommon or that have highly variable year-to-year distributions, such as most desert annuals.

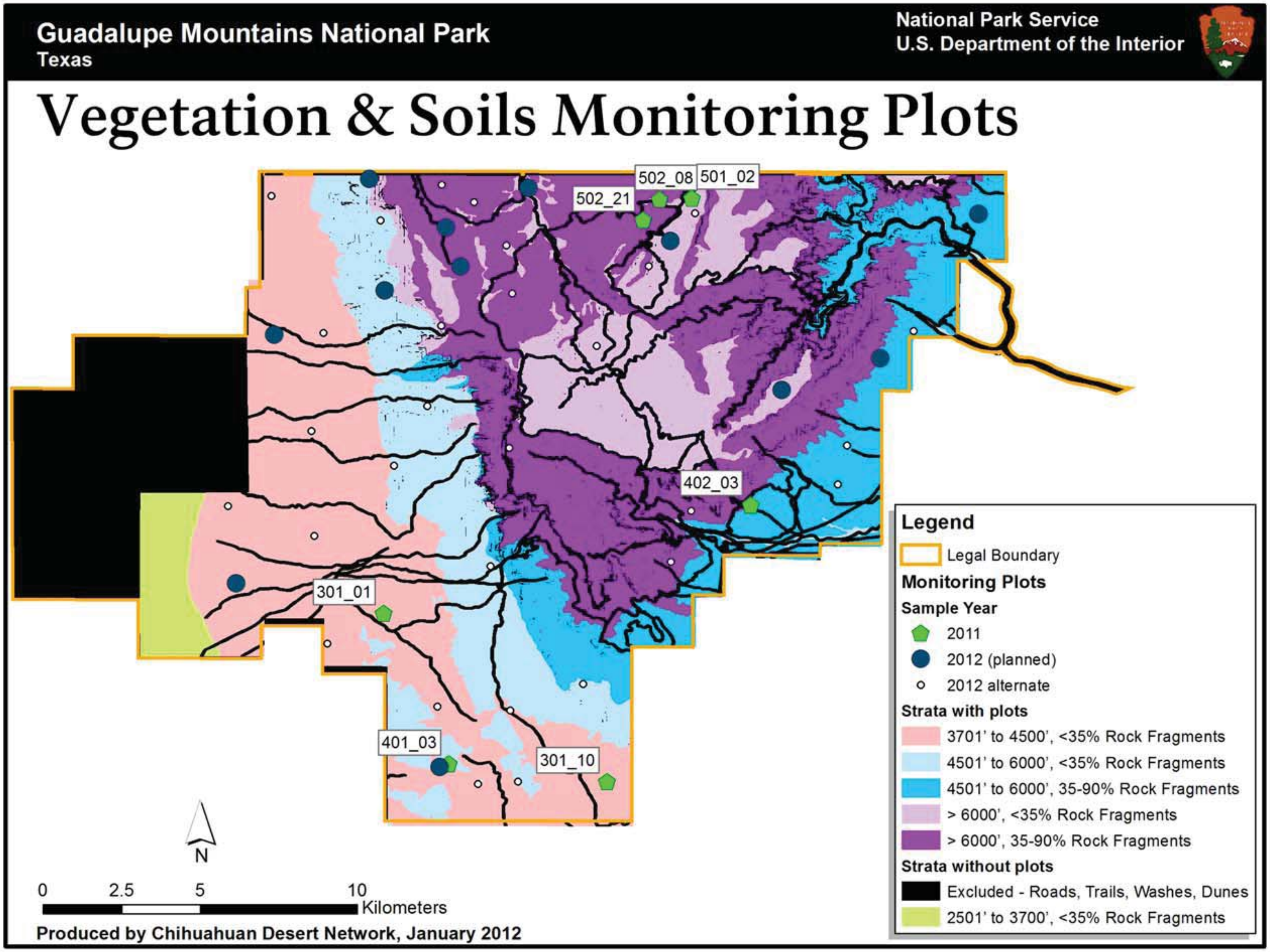
Density—Columnar cacti (saguaro, organ pipe, and senita) and ocotillo are tallied by height class within each of the five frequency subplots at each sampling location. Density will be given as number of individuals/hectare.

Fuels measures—Fuels measures have been incorporated into the monitoring design by replacing “Litter” as a basal cover category on the line-intercept with L0, L1, L2, L3 and L4. Each of these new categories represents different size classes of fuels, from leaves and needles up through 1,000-hour fuels over 3" in diameter. Fuels are recorded along each of the six transects.

Soil aggregate stability and bulk density—Surface soil aggregate stability is the resistance of soil aggregates on and near the soil surface to degradation. Soil aggregate stability provides both an indicator of site disturbance and site resistance to soil erosion and provides insights into soil water-holding capacity and infiltration rates. Soil bulk density is the mass per unit volume of the bulk soil matrix. Due to the destructive sampling techniques, bulk density will only be re-measured if observations indicate disturbances such as fire, landslide, or severe erosion. Bulk densities that are high or low for a given type of soil material can indicate stability and susceptibility of a site to erosion and other impacts like drought.

Soil and biological soil crust cover— Soil cover is the percentage of material (e.g., litter, duff, bedrock, gravel, rocks, vegetation, and biological soil crusts) covering the soil surface and provides an absolute and relative measure of these objects that influence erosion resistance. Biological soil crust cover is similar in concept, with the categories of interest being growth forms for all soil lichens. Bryophytes and cyanobacteria serve profoundly different ecological functions but are difficult to identify in the field. Therefore, they are identified to the morphological group level.

Appendix B: Map of plot sampling locations.



File: V:\Uplands\Data_Spatial\ArcMap_Projects\Appendix_A_v1-1\GUMO.mxd

Appendix C. List of Standard Operating Procedures and Datasheets Attached to this Document

C.1 Standard operating procedures

Copies of the SOPs found on this list can be found in a folder attached to the electronic version of this document.

Uplands_SOP01_Season_prep_and_equipment_v110
Uplands_SOP02_Hiring_and_training_v110
Uplands_SOP03_PlotDesign_and_SetUp_v101
Uplands_SOP04_Landscape_data_v120
Uplands_SOP05_Vegetation_sampling_v120
Uplands_SOP06_Bio_soil_crusts_v210
Uplands_SOP07_Soil_stability_v110
Uplands_SOP08_Revisit_methods_v101
Uplands_SOP09_After_field_season_v100
Uplands_SOP10_Daily_data_management_v100
Uplands_SOP11_Data_management_v100
Uplands_SOP12_Soil_analysis_v200
Uplands_SOP13_Documenting_fire_severity_v100
Uplands_SOP14_RevisingTheProtocol_v200

C.2 Data sheets

Copies of the data sheets found on this list can be found in a folder attached to the electronic version of this document.

1_Plot_Check_List_And_Description_v110
2_New_Location_Datasheet_v110
3_Vegetation_Transect_datasheet_v120
4_Soil_Stability_Datasheet_v110
5_Biological_Soil_Crust_Datasheet_v210
6_Landscape_Soil_Characterization_Datasheet_v120

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 960/113738, April 2012

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

www.nature.nps.gov

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