The Natural Communities and Ecological Condition
of the
Sonoran Desert National Monument and Adjacent Areas

Pacific Biodiversity Institute

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EXECUTIVE SUMMARY

The purpose of this project was to describe, map and assess the ecological condition of the natural communities and the extent of exotic plant invasion in the Sonoran Desert National Monument (SDNM) and adjacent areas. The study area consisted of the SDNM, a ¼ mile buffer around the SDNM and adjacent portions of the US Air Force Barry M. Goldwater Range (BMGR) and Tohono O'odham Nation (TON).

In Phase 1, the natural communities of the SDNM and adjacent areas were mapped and described. Limited reconnaissance fieldwork was conducted for use in the initial descriptions. We integrated multiple sources of data in mapping the natural communities including field data, satellite imagery, topography, soil maps, and prior vegetation maps, but relied most heavily on interpretation of digital color infrared orthophotos. We developed two GIS models using topographic information to aid in separating the *Creosotebush–Bursage Desert Scrub* community from the *Paloverde - Mixed Cacti - Mixed Scrub on Bajadas* community and to predict the distribution of the *Mountain Upland* community.

In Phase 2, we incorporated both coarse scale and fine scale approaches to condition assessment. In the coarse scale approach we used a chronosequence of aerial photography and multiple GIS layers to conduct a landscape-level assessment of disturbance features over the entire study area. The fine-scale approach involved a field-based assessment in which we collected detailed natural community data (320 plots) and more abbreviated exotic plant data (836 plots) at selected, representative sites. We conducted multiple analyses on these data (using hierarchical cluster analysis, detrended correspondence analysis (DECORANA), analysis of variance (ANOVA), and linear regression) to assess the natural variation and influence of stressors on natural community composition and distribution of exotic plants. The relative influence of stressors varied by community type. The factors that we determined to be most influential for each major community are summarized in Table A. There were insufficient examples occurring in the study area and/or plot sample sizes to evaluate the variation in composition and factors that might influence condition within four minor natural communities: rock outcrops, desert grasslands, desert springs and tinajas. These four communities are not included in Table A.

Table A. Primary factors influencing variation in species composition for each major natural community in the study area.

Primary Factors Influencing Variation in Composition within Each Natural Community	Creosotebush-Bursage Desert Scrub (87 plots)	Paloverde – Mixed Cacti - Mixed Scrub on Bajadas (34 plots)	Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes (64 plots)	Mesquite Woodland (13 plots)	Mountain Upland (36 plots)	Braided Channel Floodplain (21 plots)	Mountain Xeroriparian Scrub (16 plots)	Valley Xeroriparian Scrub (25 plots)
Elevation	X				X	X	X	X
Slope Steepness			X		X			
Aspect			X		X		X	
Soil Texture		X						
Geology			X				X	
Distance from Potential Livestock Congregation Area	X	X		X				
Distance from Roads				X				
Livestock Impact Index	X					X		

Our analysis of exotic plant distributions revealed significant differences in exotic plant cover by community type. Of the matrix communities, *Creosotebush–Bursage Desert Scrub* had the highest exotic plant cover, followed by *Paloverde - Mixed Cacti - Mixed Scrub on Bajadas* and *Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes.*

We looked at the relationship of percent cover of exotic species to multiple environmental and human-related disturbance factors, and found significant correlations with elevation, slope, aspect, and proximity to livestock congregation areas. Analysis of the five most common exotic species (*Schismus arabicus*, *Bromus rubens*, *Brassica tournefortii*, *Sisymbrium irio*, and *Erodium cicutarium*) showed differing strengths of relationships with the factors. We found that none of the species' distributions were significantly related to distance from roads. This finding reflected our field experience, where exotic plant cover was not predictably higher along unimproved roads, although it was quite high along the few major paved road corridors crossing the study area. We also created maps showing relative percent cover of 15 of the more common exotic species at all of our field plot locations.

In order to assess ecological condition, we first identified a number of field-based measurements that strongly influence condition and/or quantify levels of disturbance (species richness in native vs. exotic plants, ground cover of native vs. exotics plants, amount of bare ground, and diversity and abundance of native grass species). We used these to define and describe three levels of ecological condition, ranging from highly impaired areas (Condition Class 1) to relatively intact areas (Condition Class 3).

We developed condition models for each community based on results of our analysis of primary stressors for that community (see Table A), results of DECORANA and clustering analyses, and review of field data. For communities whose composition significantly varied according to degree of livestock impact, we based our models and maps on a distance from potential livestock congregation area GIS layer, applying varying thresholds of distance for the three condition classes, by community type. For communities with little variation in condition (as evidenced by analysis of plot data and based on field experience), a single condition class was applied to the entire natural community (e.g. *Rock Outcrops* are in good condition and were assigned Condition Class 3 and *Desert Springs*, which are in poor condition, were assigned to Condition Class 1). The *Desert Grasslands* community was a unique case. On SDNM lands this community is in poor shape and was assigned Condition Class 1, but adjacent grasslands on TON lands are in substantially better condition and were assigned Condition Class 2.

The maps of ecological condition for the individual communities were merged to create a single map. This map was then overlaid by disturbance data, created from the landscape-level disturbance assessment. Features in the disturbed layers were assigned appropriate levels of condition and were integrated with the community ecological condition map, such that sites assigned to lower condition classes (i.e. more impaired) in the disturbed layers overrode higher condition classes in the community map. Inputs to the community condition models and final map are shown in Table B.

Table B. Inputs to the community condition models and final condition map.

Factors Used in Modeling and Mapping Ecological Condition Class	Creosotebush-Bursage Desert Scrub	Paloverde - Mixed Cacti - Mixed Scrub on Bajada	Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slope	Mountain Upland	Mesquite Woodland	Braided Channel Floodplain	Valley Xeroriparian Scrub	Mountain Xeroriparian Scrub	Desert Grassland	Rock Outcrop	Desert Springs
Distance from potential livestock congregation area	X	X			X	X	X				
Natural community boundary (i.e. community was assigned to a single condition class)			X	X				X		X	X
Natural community boundary divided between SDNM and TON lands									X		
Roads	X	X	X	X	X	X	X	X	X	X	X
Linear disturbances	X	X	X	X	X	X	X	X	X	X	X
Developed/disturbed sites	X	X	X	X	X	X	X	X	X	X	X
Frequency of expended ordinance sweep operations (relevant only to communities occurring on the BMGR)	X	X	X				X	X		X	

Overall the ecological condition of the study area is moderately good. But the ecological condition of natural communities varies considerably from one location to another. Some communities appear to be experiencing high levels of human-related stress while other communities experience little stress. Of the three matrix communities that make up 97.5% of the study area, *Paloverde – Mixed Scrub – Mixed Cacti on Rocky Slopes* is in the best overall condition, followed by *Paloverde – Mixed Scrub – Mixed Cacti on Bajadas*, and finally *Creosotebush – Bursage Desert Scrub*, which contains a fair amount of highly disturbed areas. Figure A shows the proportion of each community that is in Condition Classes 1 through 3 (i.e. ranging from most impaired to most intact).

Based on our Phase 2 field data and analyses, we refined the natural community descriptions and map from Phase 1. We also extended the natural community map to include a one-quarter mile buffer outside the SDNM and significant parts of the BMGR and TON. We visually assessed the extended map to look for discontinuities of natural communities along the monument border and found that most communities continue their natural distribution patterns without artificial interruptions.

The refined natural community map is one of many data layers generated and/or improved during this study that may aid the BLM in resource management objective setting and decision-making. Tables C and D list new data created by Pacific Biodiversity Institute as part of this project that have been delivered to the BLM and TNC.

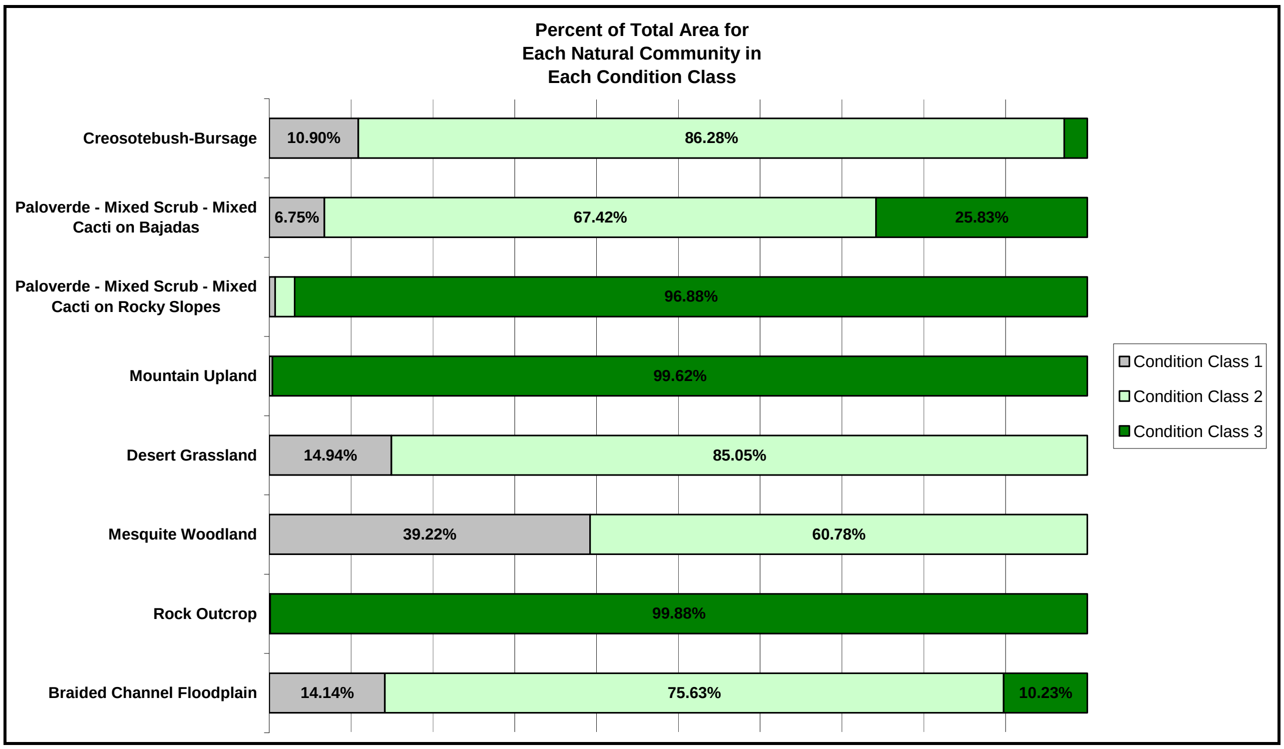


Figure A. Proportion of natural communities assigned to condition classes 1 through 3 (class 1 is most impaired, class 3 is most intact, and class 2 is intermediate).

Table C. GIS layers created by PBI for this project.

Data layer name	Description
SDNM_Natural_Communities	Polygon layer depicting the spatial distribution of the natural communities (excluding the valley and mountain xeroriparian scrub communities)
Ecological_Conditions	Polygon layer illustrating the geospatial layout of the three community condition classes
Xeroriparian_Scrub_Communities	Linear layer depicting the spatial distribution of the valley and mountain xeroriparian communities
Study_Area_Boundaries	Polygon layer illustrating the extent of the study area and the coarse scale ownership boundaries within the study area
Phase2_GPS_Waypoints	Point layer representing all the GPS waypoints taken during Phase 2 (includes all plots and miscellaneous observation points)
Developed-Disturbed_Sites	Polygon layer depicting small areas of land that have been substantially altered by human activity (including spreader dikes).
High_Density_Cow_Trail_Area	Polygon layer depicting areas of high cattle trail density
LinearDisturbances	Linear layer representing roads, trails, cattle trails, and other linear disturbance features that are visible in aerial imagery.

Table D. GIS layers improved by PBI for this project

GIS Layers Improved	Description of Improvement(s)
BLM Roads data	Our Linear Disturbance layer contains roads that are not on any of the existing road layers (but not all linear disturbances are roads). Our recommendation is that a reevaluation of the current road layer would result in a more complete inventory of roads in the study area.
Range Improvements Points	Our livestock congregation areas layer, which contains additional range improvement locations, represents an improvement to this layer.
Tinajas and Springs	We added a tinaja to a copy of this layer.
Initial natural community map of SDNM extrapolated from the BMGR (Hall et al 2001)	Our natural community map represents an improvement to this layer.

The information collected in this study and the analysis presented in the report will be useful in establishing a baseline of information on the condition of natural communities in the study area during the 2003 growing-season. The methods used in this study can be employed at a later date to collect similar data and then compare and contrast with data collected in this study. This will enable an assessment of changes and trends in the condition of the natural communities in this area.

We make several recommendations for further analysis and/or improvement of data. The ecological condition models and map could likely be substantially improved with more complete, accurate, and well-attributed roads and range improvement data. Formal accuracy assessments of the natural community and ecological condition maps could be useful in helping to guide applications of these data, and inform strategies for improving the data. Analysis of satellite imagery on an annual basis could be one cost-effective strategy for assessing landscape level changes in ecological condition over time. Finally, substantial field data were collected during this project that, if further analyzed, could provide additional insight into ecological condition of the natural communities.

Project Sponsorship

This report was prepared under CONTRACT AZFO-020821 (Natural Community Mapping, Characterization, and Condition Assessment for the Bureau of Land Management's Sonoran Desert National Monument) with The Nature Conservancy of Arizona. The goal of this report is to aid a partnership between the Conservancy, the Bureau of Land Management, the Department of Defense, and the Sonoran Institute, which is developing a biodiversity management framework for the Sonoran Desert National Monument.

Acknowledgements

During Phase 1 of the project, Aileen Jeffries assisted with fieldwork and logistical support, database design, data entry and analysis. George Wooten and Kim Romain assisted with mapping of the natural communities through photo-interpretation of color infrared digital orthophotos. Stephanie Weinstein and Barry Spicer assisted with fieldwork and provided valuable advice.

During Phase 2, Dr. Don Johnson assisted with fieldwork and checked the entire natural community database for data integrity. Lisa Hahn, Joyce Francis, Kathy Darrow, Greta Anderson and Elizabeth Makings all worked on the project as field botanists. Elizabeth Makings also verified plant specimens at the Arizona State University herbarium. Dr. Richard Felger spent many hours advising us and examining nearly all the plant specimens and verified identification of these specimens at the University of Arizona herbarium.

Throughout both phases of the project Dr. John Hall (TNC Arizona) provided considerable advice and assistance. John managed the project for TNC. John carefully reviewed the draft reports and provided extremely useful comments, which contributed to a greatly improved final document.

Mona Johnston and Heather Evans (interns at Pacific Biodiversity Institute) scanned and georeferenced historical aerial photographs. Heather Evans provided assistance with the revision and extension of natural community mapping. Juliet Rhodes, Carollee Spaulding, and Sarah Schrock conducted phase 2 data entry. Mona Johnston provided a graphic illustration of the braided channel floodplain community. Dr. Don Johnson, Mona Johnston and Aileen Jeffries assisted with editing of the final report. Paul Brown worked hard to keep our computer system healthy during the project and helped us deal with many technical challenges. Tracy Heffelfinger capably and efficiently handled the accounting on this project.

Jim Malusa and Dr. Roger Morrison consulted with us during the project and provided important advice that aided our mapping of some of the natural communities. Dr. Roger Morrison graciously provided us with his archive of 1968 and 1969 color infrared high altitude aerial images for use in the historical chronosequence. Anne Gondor (TNC Arizona), Stephanie Weinstein (TNC Arizona), and Karen Kelleher (BLM) all helped with providing us with geospatial data, references and assistance. The Luke Air Force Range (via Betsy Wirt) provided us crucial access to the East Tactical Area, Area A and other areas on the BMGR. The US Air Force also graciously provided us with temporary housing and office space at the Gila Bend Air Auxiliary Airfield. The project could not have been accomplished without the considerable software donations and support from Environmental Systems Research Institute and ERDAS. Some of the computer hardware used in the project was a generous donation by the Hewlett Packard Corporation and the Conservation Technology Support Program.

Table of Contents

List of Tables

List of Figures

Introduction

The purpose of this project is to describe, map and assess the ecological condition of the natural communities and the extent of exotic plant invasion in the Sonoran Desert National Monument (SDNM) and adjacent areas. The study area consisted of the SDNM, a ¼ mile buffer around the SDNM and adjacent portions of the US Air Force Barry M. Goldwater Range (BMGR) and Tohono O'odham Nation (TON) (Figure 1).

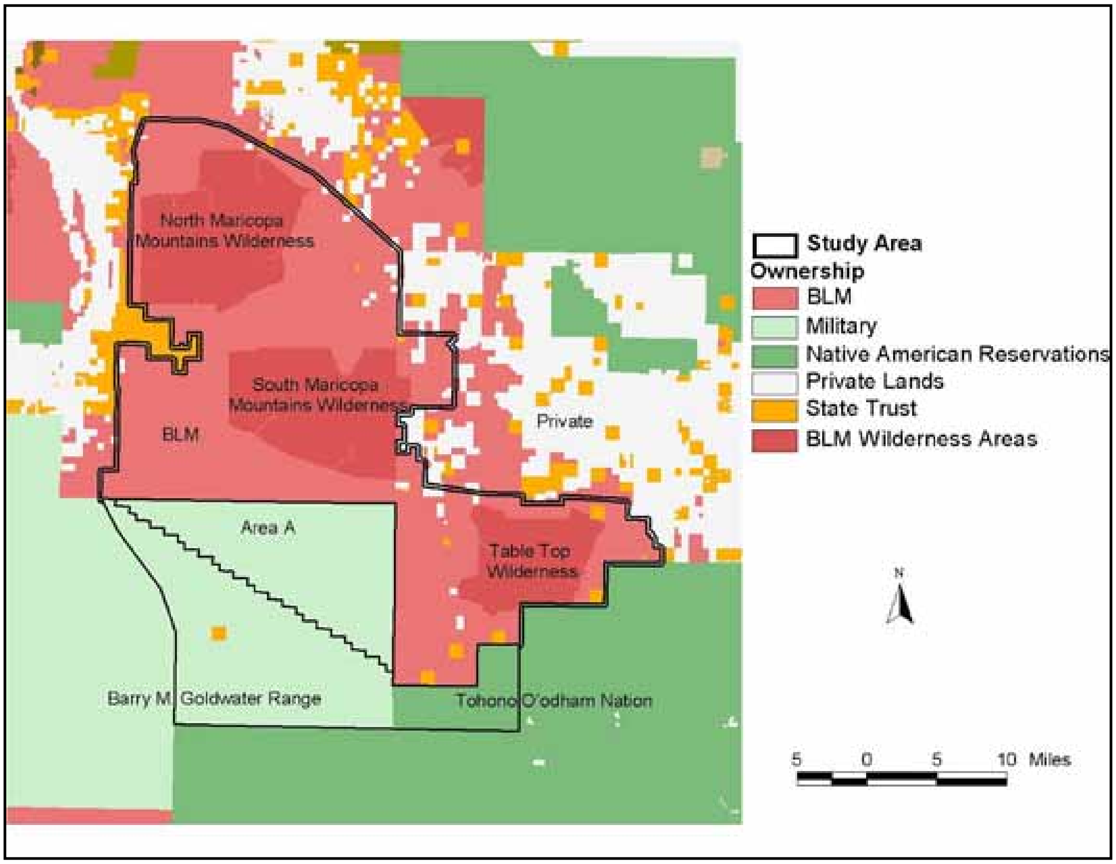


Figure 1. Ownership and management of the study area

This project was conducted in two phases. In Phase 1, the natural communities of the SDNM and adjacent areas were mapped and described. Limited reconnaissance fieldwork was conducted for use in the initial descriptions. The natural communities were mapped based on analysis of field data, satellite imagery, digital color infrared orthophotos and GIS modeling using topographic information.

In Phase 2, we incorporated both coarse scale and fine scale approaches to condition assessment. The coarse scale approach involved a landscape-level assessment and covered the entire study area. It was based on analysis of a chronosequence of aerial photography and GIS analysis of multiple data layers. The fine-scale approach involved a field-based assessment and was limited to representative sites selected throughout the study area. Natural community plot data and exotic plant plot data were analyzed to assess the natural variation and the influence of stressors on natural community composition as well as distribution of exotic plants. The outcome of combining and linking both approaches in one project yielded a more thorough and cost effective assessment of the ecological condition of the study area than would have been possible with either approach alone.

The information collected in this study and the analysis presented in this report will be useful in establishing a baseline of information on the condition of natural communities during the 2003 growing-season. The methods used in this study can be employed at a later date to collect similar data and then compare and contrast with data collected in this study. This will enable an assessment of changes and trends in the condition of the natural communities in this area.

Methods

Overall GIS Data and Aerial Imagery Methods

For use in both phases of the project, we acquired, processed, and reviewed existing imagery, including Landsat satellite data and digital orthophotos (Table 1). We acquired color infrared digital orthophoto quarter quads (CIR DOQQs) for almost the entire study area from the Arizona Regional Image Archive (ARIA). In addition, we examined panchromatic digital orthophotography provided by the BLM for the entire study area. This imagery had been merged at a 15-minute quad scale and was highly compressed with the ENVI compression algorithm. The image quality of the panchromatic orthophotography was not as good as the CIR DOQQs, so we used the CIR DOQQs in all areas of the study area except for a few areas where we could not obtain CIR DOQQ coverage.

Table 1. Imagery used in study.

Image Type	Image layer	Source	Date	Resolution
Digital Orthophotography	Color Infrared Digital Orthophoto Quarter Quads	ARIA	1996	1 meter
	Panchromatic Digital Orthophoto merged 15 minute quads (ENVI compressed format)	BLM	1996	1 meter
Landsat Satellite Imagery	TM7 image for path37 row37	ARIA	May 11, 2002	15 and 30 meter
	TM7 image for path37 row37	ARIA	March 17, 2002	15 and 30 meter
	TM7 image for path37 row37	ARIA	May 20, 2000	15 and 30 meter
	TM7 image for path37 row37	ARIA	Oct. 10, 1999	15 and 30 meter
	TM image for path37 row37	ARIA	July 22, 1985	30 meter

We acquired, processed and reviewed existing GIS data on vegetation, soils, geology, elevation, hydrography, disturbance and development, land ownership, and roads (Table 2). We used the elevation data (30-meter digital elevation model) to derive additional topographic layers (slope, aspect, shaded relief and 5-meter contours). The best available spatially explicit precipitation data (PRISM data) was also obtained and assessed, but its accuracy in the study area was questionable and it was not used. The PRISM data model is a statistical-topographic model for mapping climatological precipitation over mountainous terrain (Daly et al 1994) and is often the best precipitation data to use in a study of this nature. Our examination of the data for the study area revealed that PRISM significantly under-predicted precipitation in the Sand Tank Mountains. Some of the GIS layers are illustrated in Figure 2. All data were projected into a common map projection of UTM Zone 12, North American datum 1983, GRS1980 spheroid. It is one of the most robust map projections in use today.

Table 2. GIS Layers Used in Study.

Data Theme	Geospatial data layer description	Source	Date	Map Scale
Vegetation	Initial natural community map of SDNM extrapolated from the BMGR (Hall et al 2001)	TNC	2002	1:100,000 to 1:250,000
	Arizona GAP vegetation map	(AZ Land Information System (ALRIS)	1998	1:24,000
	Xeroriparian areas (same as streams)	TNC/BLM	2001	1:100,000
	Biotic Communities (Brown & Lowe (1980))	ALRIS	1993	1:100,000
Soils	NRCS soil layers	NRCS website	2002	1:24,000
	Arizona Soils	ALRIS	Digitized off map dated 1975	1:1,000,000
Geology	Geologic map of Arizona	ALRIS	1992	1:1,000,000
Topography	Digital elevation model data (DEM)	USGS/ARIA		30-meter
	Digital raster graphics (topographic maps)	USGS/ARIA		1:24,000
	Slope (derived from DEM)	PBI		30-meter
	Aspect (derived from DEM)	PBI		30-meter
	Shaded relief image (from DEM)	PBI		30-meter
	5-meter contours (from DEM)	PBI		1:24,000
Hydrography	Streams	USGS		1:100,000
	Tinajas and Springs	TNC	1997	1:24,000
Water developments	Wells and water development activities (ACTVREV, ACTVNON)	Arizona Dept. of Water Resources		
	Spreader Dikes	BLM		
Range Improvements	Range Improvements Points	BLM	1999	1:24,000
	Range Improvements Lines	BLM	2001	1:24,000
Land Ownership	Arizona GAP Ownership	Arizona GAP		
	AZLAND	ALRIS	1998	1:100,000
	SDNM Boundary	TNC/BLM	2002	
Transportation	BLM road layer	BLM	2000	1:100,000
	New draft BLM road layer	BLM	2003	1:24,000
	Roads for the BMGR	BMGR through TNC		
	TIGER road layer	US Census Dept.	2000	1:100,000
	Major Roads	ALRIS	1992	1:100,000

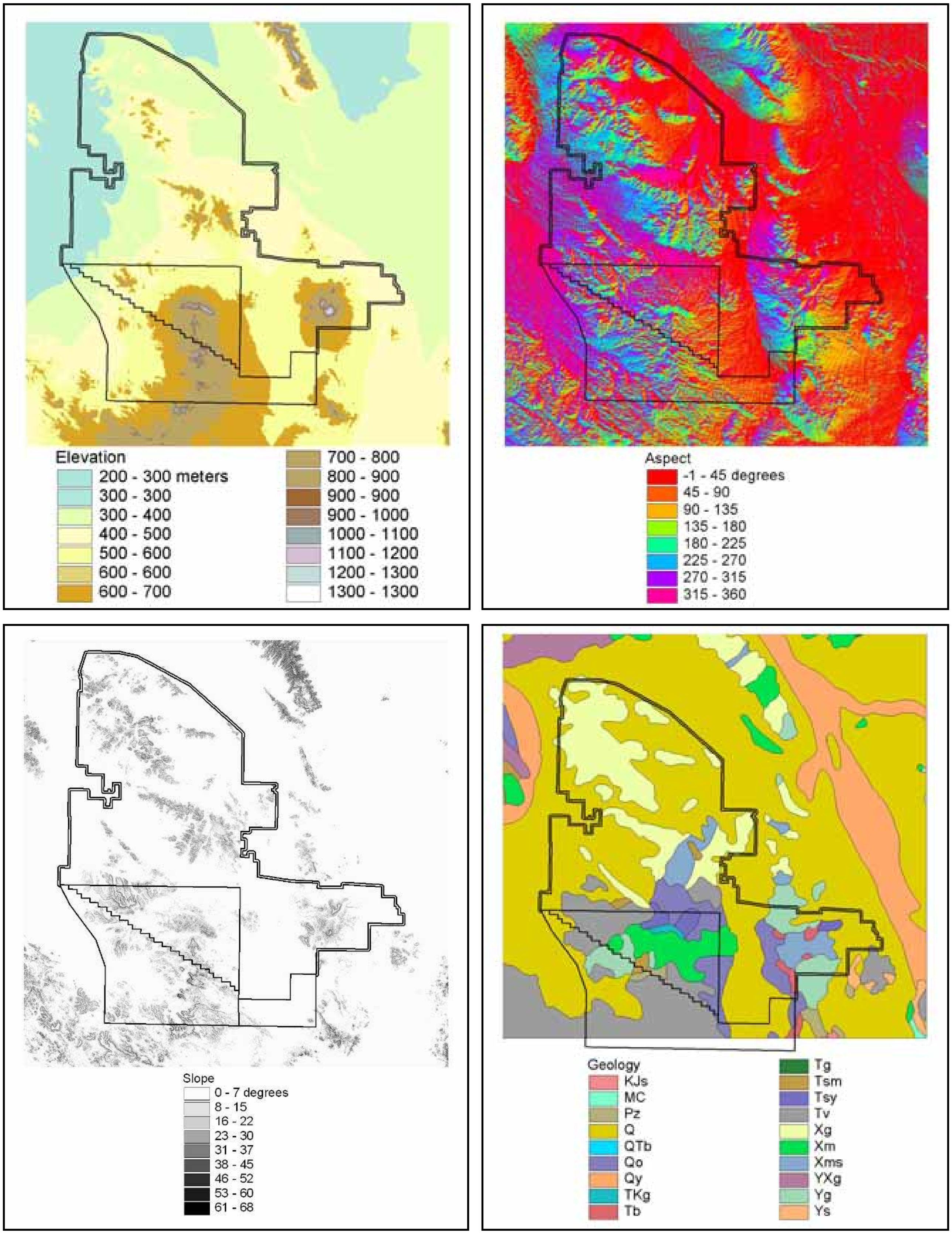


Figure 2. GIS layers of some of the abiotic factors examined in the study (refer to Table 2 for source information).

GIS layers were also created by the Pacific Biodiversity Institute and improved upon during this project, both to fulfill contractual obligations and to aid in the analyses of the study area. Tables 3 and 4 list and briefly describe the assortment of GIS layers that were created or improved upon.

Table 3. GIS layers created by PBI for this project.

Data layer name	Description
SDNM_Natural_Communities	Polygon Layer depicting the spatial distribution of the natural communities (excluding the valley and mountain xeroriparian scrub communities)
Ecological_Conditions	Polygon Layer illustrating the geospatial layout of the three community condition classes
Xeroriparian_Scrub_Communities	Linear Layer depicting the spatial distribution of the valley and mountain xeroriparian communities
Study_Area_Boundaries	Polygon Layer illustrating the extent of the study area and the coarse scale ownership boundaries within the study area
Phase2_GPS_Waypoints	Point Layer representing all the GPS waypoints taken during Phase 2 (includes all plots and miscellaneous observation points)
Developed-Disturbed_Sites	Polygon Layer depicting small areas of land that have been substantially altered by human activity (including spreader dikes).
High_Density_Cow_Trail_Area	Polygon Layer depicting areas of high cattle trail density
LinearDisturbances	Linear Layer representing roads, trails, cattle trails, and other linear disturbance features that are visible in aerial imagery.

Table 4. GIS layers improved by PBI for this project

GIS Layers Improved	Description of Improvement(s)
BLM Roads data	Our Linear Disturbance layer contains roads that are not on any of the existing road layers (but not all linear disturbances are roads). Our recommendation is that a reevaluation of the current road layer would result in a more complete inventory of roads in the study area.
Range Improvements Points	Our livestock congregation areas layer, which contains additional range improvement locations, represents an improvement to this layer.
Tinajas and Springs	We added a tinaja to a copy of this layer.
Initial natural community map of SDNM extrapolated from the BMGR (Hall et al 2001)	Our natural community map represents an improvement to this layer.

Phase One Methods

We developed an integrated approach to the preliminary mapping and description of natural communities. We used vegetation maps, a wide variety of GIS data, Landsat TM7 satellite imagery, digital orthophotography, review of literature on natural communities and reconnaissance-level fieldwork that focused on collection of ecological data on composition, structure and function of the natural communities.

Additional information on the methodology for mapping and describing individual communities is included in the natural community descriptions (Appendix A).

Preliminary Assessment of Available Data and Draft Natural Community Map

First, we reviewed the draft natural community map and GIS model developed by TNC for the BMGR and extrapolated to the SDNM. We used Landsat Enhanced Thematic Mapper 7 (TM7) satellite imagery from several dates (Table 1) to aid in this review. We performed an unsupervised spectral classification of the March 2002 image and examined normalized difference vegetation indices (NDVI) for several image dates. We examined the differences between the NDVI images to determine if vegetation changes were apparent that could aid in mapping the natural communities. The analysis of satellite imagery proved to be useful in determining some differences in vegetative composition between natural communities and ecological condition within communities. But we also found that significant variation in spectral response recorded in the satellite imagery was related to variation in soil and geology. Further use of satellite imagery for assessing ecological condition of communities on an annual basis is discussed in the recommendations section.

During our initial review and evaluation of the draft community map we examined other GIS data on vegetation, geology, soils, topography, hydrography, water developments, roads, and land ownership (Table 2). We assembled, read and reviewed pertinent literature on Sonoran Desert vegetation mapping and classification, and made contact with several relevant sources and experts. We briefly reviewed BLM's aerial photo-based vegetation/ecological-site mapping, their Ecological Site Inventory data, the Natural Resource Conservation Service (NRCS) Ecological Site Descriptions (ESDs) and associated soil maps and GIS data to determine how it might be of use in mapping the natural communities.

Based on our initial evaluation of all the above GIS data and imagery it became apparent that significant improvements in TNC's draft natural community map and GIS model for the SDNM were necessary to accurately depict the natural communities. We discussed our initial proposed modifications with TNC for this and subsequent tasks. At this stage, we determined that some of the NRCS soil mapping could be used in improving the natural community map.

We produced a series of maps to guide our fieldwork. The first map was of the entire study area and had a 1:85,000-scale Landsat TM7 satellite image background with the initial TNC natural community polygon boundaries, hydrography, and roads as overlays. The second set of maps was produced at a 1:12,830-scale with the CIR DOQQs as the background and hydrography, roads, and the NRCS soils layer as overlays.

Phase 1 Fieldwork

Our fieldwork was conducted from November 27 to December 23, 2002. The focus of this work was to closely examine the natural community boundaries depicted in the initial map provided by TNC, to examine the NRCS soil mapping, and to gather field ecology data and photographs that could be used to describe and depict the natural communities. We also recorded many field notes and map notations about the location of natural community boundaries and locations.

We collected information on the vegetation composition and structure in a representative sample of the natural communities as part of this reconnaissance fieldwork. The percent cover of all plant species within a 30-meter radius sample plot was recorded along with information on ground cover of bedrock, rock, gravel, sand and soil. Information on elevation, aspect, and slope was collected as well as pertinent information on landform, geology, and soil conditions. The location and description of each plot was recorded, including a GPS waypoint number. Each field plot was located to an accuracy of 5 to 8 meters using a Garmin eTrex GPS receiver. We also recorded GPS tracks to review the area examined during each day's fieldwork.

In addition to the field plots, many other observations of natural community locations and boundaries were noted in field notes and field maps. Often binoculars were used to examine areas that were not readily accessible by foot and notes about the vegetation composition and structure were recorded. Digital photographs were taken at each field plot (usually four photos per plot) and numerous additional photographs were taken of plant species, natural communities, and landscape perspectives on the natural communities.

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

We attempted to sample the significant ecological gradients within each community type, but were limited due to time and budget constraints. During the month of fieldwork, we collected plot data at 123 sites. We recorded natural community presence or boundaries at over 200 additional sites. Over 1000 photographs were taken, recording the composition, structure, and condition of the natural communities on the SDNM and adjacent lands.

Our fieldwork was conducted during the time of maximum plant dormancy. Most herbaceous plants and grasses were in senescence and annual plants were essentially non-existent. Grazing by livestock had reduced many grass species to short stubble, making identification nearly impossible. Because of these factors, many plants were difficult to identify. Some plant species were recorded as "unknown shrub" or only identified to the genus level. The extended drought experienced by this region accentuated the dormancy of many plants and often made it difficult to find remnants of leaves or seeds. Because of these factors the natural community composition and structure recorded in the reconnaissance field data should be considered as an initial and incomplete description of these natural communities.

During our Phase 1 fieldwork, we visited the only "tinajas" that are mapped on the SDNM. The two "tinajas" are mislabeled or misclassified on the existing maps and GIS data layers. They are "tanks" – or human constructed water developments. We mapped these as developed areas. There are no natural springs known to exist on the SDNM. Because of these factors, we did not include the *Desert Springs* or *Tinajas* natural communities in our initial Phase 1 map. However, our Phase 2 mapping included areas in the BMGR that contained *Desert Springs* and natural *Tinajas.* Therefore, we included *Desert Springs* and *Tinajas* in our Phase 2 maps.

Field Mapping

Some delineation of natural community boundaries was conducted during the 2002 fieldwork. This included field mapping of some of the *Mountain Upland* community boundaries and some of the boundaries between the *Creosotebush–Bursage Desert Scrub* and the *Paloverde - Mixed Cacti - Mixed Scrub on Bajadas* communities.

Analysis of Field Data

All natural community plot data were entered into a Microsoft Access database. Reports on each natural community were generated summarizing the average cover for each plant species and the percent of the plots in each community that each plant species occurred in (constancy). This enabled an evaluation of which species were most frequently encountered in each community and which species were dominant in each natural community.

The plot data were examined to determine which species were limited to specific communities and are likely to be indicator plants for those communities. Variations in tree cover and total vegetative cover were examined. Evidence of natural variation within natural communities was also examined. This analysis of plot data was used to help classify each plot into a single natural community type. In cases where plots were transitional between natural communities a secondary community type was also assigned to the plot.

The plot data and other observational data were then used as a guide for natural community mapping.

Interpretation of Digital Orthophotography

The CIR DOQQs proved to be extremely useful in the delineation of natural communities. Three people worked for nearly one month interpreting this imagery and on-screen digitizing or editing natural community boundaries. This work was checked for accuracy by the authors of this study. In addition to the DOQQs, the photo-interpreters used the plot data, other observation data, digital topographic data (elevation, aspect, slope, and contour lines), Landsat TM7 satellite imagery, NRCS soil data, hydrographic data, and geologic maps to aid in the interpretation of natural community boundaries.

Modeling of Natural Communities

Two GIS based models were developed for the project. The first model was developed to help separate the *Creosotebush–Bursage Desert Scrub* community from the *Paloverde - Mixed Cacti - Mixed Scrub on Bajadas* community. This distinction was perhaps the most difficult task encountered during the project, since the communities grade into each other. The model that was developed is described in the *Creosotebush–Bursage Desert Scrub* community description (Appendix A).

The second model was developed to predict the distribution of the *Mountain Upland* community. This model was based on analysis of the field plot data, other field observations, and limited field mapping. This model is described in detail in the *Mountain Upland* community description (Appendix A).

Integration

All the above data were integrated to compile the final map of natural communities. We first combined the three matrix communities (*Creosotebush–Bursage Desert Scrub*, *Paloverde - Mixed Cacti - Mixed Scrub on Bajadas,* and *Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes)* into a base map. Then the small patch communities (*Mountain Uplands, Desert Grasslands, Mesquite Woodlands,* and *Rock Outcrops)* were superimposed. In Phase 1, The riparian communities (*Braided Channel Floodplain*, *Valley Xeroriparian Scrub,* and *Mountain Xeroriparian Scrub)* were not superimposed, but are considered overlays to the matrix and small patch communities (but the *Braided Channel Floodplain* was imbedded in the natural community layer in Phase 2). Lastly, a *Developed/Disturbed Area* GIS layer was developed. This layer depicts small patches of land that have been substantially altered by human activity. Many of these areas retain some of the components of the original natural community present before development. Therefore these communities should be considered an additional overlay to the matrix, small patch and riparian communities.

Initial Community Descriptions

Initial community descriptions were developed based on literature review, field observations, and careful analysis of natural community plot data. These descriptions were revised during Phase 2 of this project (Appendix A).

Phase Two Methods

During Phase 2 we conducted a landscape-level assessment using digital imagery to look at areas of major disturbance and cover change. We collected extensive field data on community composition and structure, disturbance elements, and other environmental factors. These data were used to update the natural community descriptions and map from Phase 1. Information on exotic species distribution and abundance was also collected. We used these data to map and analyze distributions of exotic species. We conducted a variety of analyses to look at the relative influence of natural and human-related factors on the range of variation in community composition. Finally, we used the field data in combination with GIS layers to model and map relative ecological condition of the natural communities.

Review of Literature

All readily available information about historic and current condition of natural communities, rangeland conditions, and other environmental conditions from the BLM and US Air Force was obtained for this project. Literature searches and review of all readily available documents and photographs that are relevant to an assessment of the historical and current condition of natural communities in the SDNM were conducted. Review of prior information is helpful in evaluating how current conditions may have changed from past conditions and if current trends will result in desired future conditions on the SDNM.

Landscape-level Assessment

The landscape-level assessment incorporated current and historic aerial photography, satellite imagery, and map-based information to create a map with which to visually analyze the spatial relationships of disturbance features and the natural communities.

We used current and historical aerial photo chronosequencing to help us focus on areas within each natural community where native vegetation, soils, landforms or hydrology had been observably altered by human activities. Chronosequencing also helped us to decipher features visible in the current aerial imagery that were hard to interpret due to fuzziness, strange textures, or unique patterning. In this process we used a historical sequence of aerial photography from 1958 to 1996 (Table 5).

Table 5. Types of aerial photography used in landscape assessment.

Photo date	Source	Photo type	Scale
1958	BLM	Scanned panchromatic paper print	
1968	Roger Morrison, USGS/NASA	Scanned CIR color transparency	
1969	Roger Morrison, USGS/NASA	Scanned CIR color transparency	
1996	ARIA	CIR DOQQ	1 meter

Through interpretation of the aerial imagery and utilization of existing GIS data, we assembled many additional GIS layers for use in Phase 2. These are described in the section below.

Development of Disturbance GIS Layers

We developed five GIS layers representing various types and levels of disturbance. These layers are potential livestock congregation areas, roads, disturbed areas (polygon features, with disturbance type unspecified), linear disturbances, areas heavily disturbed from livestock, and areas of visibly lower vegetative cover than adjacent areas (associated with fence line boundaries). From the potential livestock congregation areas and roads data we created two additional gradient layers for use in the condition modeling and mapping. These are distance from potential livestock congregation areas and distance from roads (measured in meters) (Table 6 and Figure 3).

The potential livestock congregation area map was developed from the BLM's range improvement point GIS layer and represents sites potentially heavily used by, or attractive to livestock. Included are corrals and all water developments (tanks, wells, etc.) except wildlife catchments. In addition we included livestock water developments that we identified during fieldwork or from examination of digital orthophoto quads. The potential livestock congregation areas are a point coverage representing the center of the area of congregation. This point layer was used to develop the distance from livestock congregation grid, which was used in ecological condition modeling (Figure 3). Not all potential livestock congregation points have active livestock activity at any given time. As mentioned above, we derived this layer in large part from the BLM's range improvement point GIS layer. The BLM's range improvement layer does not contain information about past, present or potential future use. The level of use is not known for these points. We do know from our field examinations that the use level varies considerably from point to point and that some BLM range improvements may not have had much use for several years.

We created a road map by combining data from three GIS road layers. These layers were a BLM road layer acquired in April 2001, a draft BLM road layer from March 2003, and a road layer for the BMGR provided to us by TNC in March 2003.

"Developed/Disturbed Areas" are nonlinear disturbance features that are visible in the most recent aerial imagery we used during our analysis (CIR DOQQs from 1996) or in more recent Landsat TM7 satellite imagery. These areas can be anything from a parking area or gravel quarry to an industrial site. The SDNM's various berms and spreader dikes are included in this layer. From a spatial perspective, polygons rather than lines best represent the "Developed/Disturbed Areas". During development of this layer we examined the entire study area for signs of visible ground disturbance. We also examined existing GIS layers (like BLM range improvements, spreader dikes, etc.) to see how much disturbance existed at those sites.

"Linear Disturbances" are disturbance features like roads, dozer paths and scrapes, cattle trails, off-road vehicle paths, and hiking trails that are visible in the aerial imagery (not including roads already mapped in GIS data layers provided to us by the BLM, TNC, or BMGR). These features' spatial forms are best represented by lines rather than polygons because they have very narrow widths.

"High-Density Cow Trail Areas" or "Cow Circles" are roughly circular areas around a water source in which cattle trail density is high, resulting in a unique fan like pattern of cattle trails radiating out from the water source. We mapped areas within the outer edges of this fan like pattern of linear disturbances as a "High-Density Cow Trail Area". The amount of disturbed area is higher near the center of the cow "circle" than at the exterior since the distance between cow trails is greater in the outer part of the "circle".

Table 6. GIS data on disturbances developed during Phase 2.

GIS theme	Description
Potential Livestock Congregation Areas	Based largely on BLM's range improvement layer (livestock water sources, corrals) and additional livestock water sources identified by PBI
Roads	Road locations compiled from 2 BLM road layers, and a BMGR road layer
Developed/Disturbed Areas	Areas with development or fairly significant human disturbance visible on CIR DOQQs
Linear disturbances	Linear features with development or fairly significant human or cattle disturbance visible on CIR DOQQs
High-Density Cow Trail Areas	Areas around potential livestock congregation areas with visible disturbance (lack of vegetation, erosion) and a high density of cow trails that are observable in the field and/or on CIR DOQQs.
Areas of visibly lower vegetative cover than adjacent areas – associated with fence line boundary	Areas with lower vegetative cover than surrounding comparable areas separated only by fence lines. These areas are visible in both DOQQs and Landsat satellite imagery.
Distance from Potential Livestock Congregation Areas	Distance from potential livestock congregation areas, measured in meters.
Distance from Roads	Distance from roads, measured in meters.

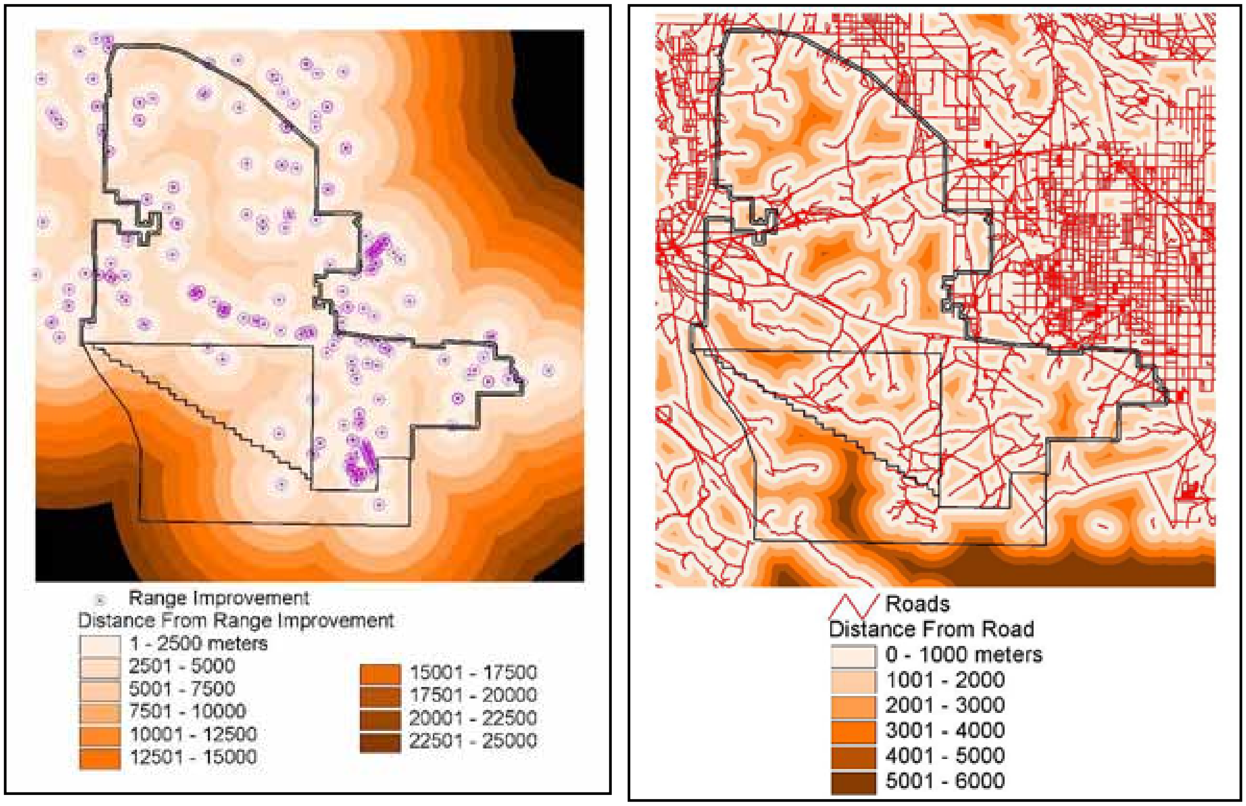


Figure 3. GIS layers showing disturbance gradients for distance from potential livestock congregation areas and distance from roads. (Refer to Table 2 for source information)

Phase 2 Field Data Collection

From March 27th, 2003 to May 21st, 2003, we conducted field sampling and other field-based studies to determine the presence of invasive exotic plants and the conditions of the natural communities. The fieldwork was designed to cover the natural diversity of the study area. More samples were placed in natural communities predicted to have higher levels of stress from human activities or where natural variation in community composition and structure were high.

A field crew composed of botanists and ecologists familiar with Sonoran Desert vegetation was responsible for data collection. A senior staff member was present throughout the fieldwork process, though the composition of the field crew varied depending on individual availability. The field crew was trained on site.

Plant Identification and Specimen Collection Methods

A significant amount of Phase 2 fieldwork consisted of collecting and identifying plants. In order to positively confirm the identification of species recorded in our plots and other areas of interest, field specimens were intensely scrutinized. In many cases voucher and unknown specimens were collected to be further analyzed at base camp where there was a dissecting microscope and reference library (Figure 4). All the collected specimens were further examined by either professional botanist Richard Felger at the University of Arizona, or Elizabeth Makings at Arizona State University. Once positive identifications were made, the field data forms were updated accordingly. The plant specimens are temporarily located at the PBI office, but we intend to pursue additional funding to order and label the specimens so that they may be deposited in the Arizona State University herbarium.

Figure 4. Elizabeth Makings uses a dissecting microscope at base-camp to identify a plant specimen.

Exotic Species Plots

The exotic species field-sampling method consisted of estimating percent cover of exotic species within 3-m radius plots on both sides of roads and travel corridors at half-mile intervals. In a selected sample of plots we also recorded the frequency of each exotic species (number of individuals). The plot centers were located at 3 and 10-meter distances from the road edge on each side of a road at the half-mile interval (unless one side was inaccessible due to ownership constraints or safety issues) (Figures 5 and 6). Information on road classification was recorded for each plot that occurred along a road. In addition to this sampling method, the presence and abundance of exotic plants were recorded in our natural community ecology plots. We also recorded information at other locations where exotics were abundant. The field data collection form that was used for exotic species sampling is included as Appendix Q. We sampled 836 exotic species plots throughout the study area. The data collected on exotic plants contains the information necessary for submittal to the Southwest Exotics Mapping Program (SWEMP).

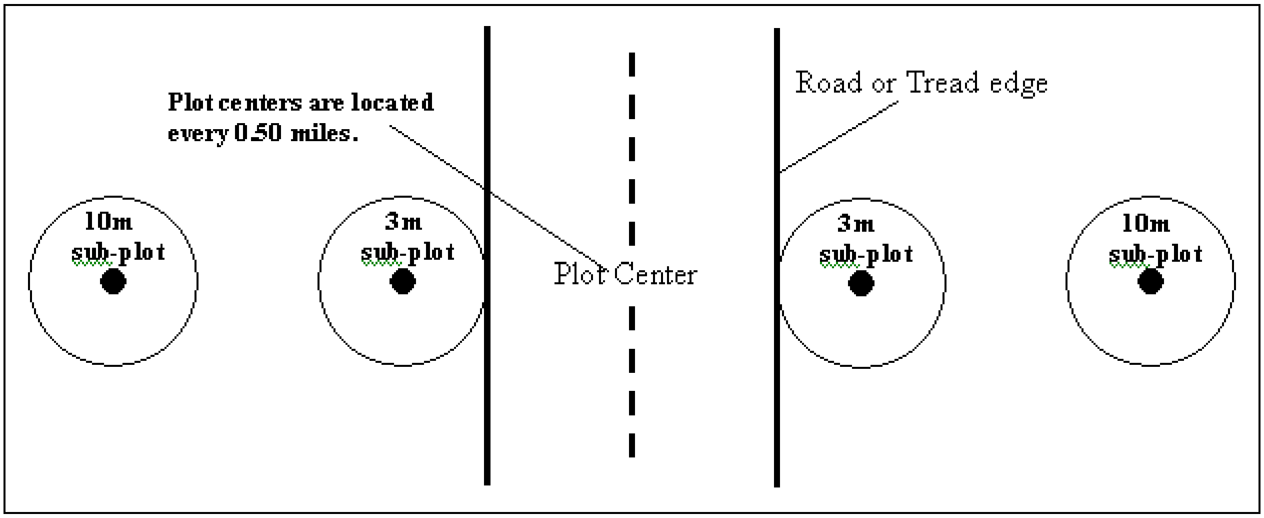


Figure 5. Illustration of the exotic species plot layout.

Figure 6. Locating exotic species plots at 3-m and 10-m from a road's edge was done using a painted nylon cord with an anchoring stake at one end.

Natural Community Condition Assessment Plots

Circular plots were used to collect data on the ecological condition of natural communities. Within a 12.5-meter radius plot, we made ocular estimates of the total percent canopy covers of all species.

At each plot center coordinates were taken with a GPS, and the elevation, slope, and aspect of the plot were found using an altimeter, clinometer, and compass. The percent cover of bedrock, rock, gravel, sand, and soil were individually recorded as cover estimates (not a cover class). Geologic substrate was also described (if it was readily discernable), along with landform and the micro-topography of the site. In addition to these data, any evidence of stressors or disturbance agents that occurred on the plot or in the vicinity of the plot were recorded. Information on soil surface condition, presence of biotic crusts, desert pavement, erosion, and plant pedestaling were also documented. The field data collection form for natural community sampling is included as Appendix P. Plant composition information was recorded in nine life form/structure categories: trees, cacti, shrubs, vines, grasses, ferns and club mosses, herbs, moss, and biotic crust. The number of individual saguaros occurring in a plot was also recorded. Each saguaro was listed as being in one of three size classes: below 1 meter in height, between 1 and 5 meters in height, or above 5 meters in height. We sampled 320 natural community condition plots within the study area.

Location of Plots

The exotic species plots and natural community plots were distributed so that all natural communities were sampled according to their extent and degree of natural variability (Figures 7 and 8). Additional sampling was done in areas where human stress factors may have influenced exotic species distributions and natural community composition and structure.

Natural community condition assessment field plots were specifically located by two methods. First, they were designated along disturbance-gradient transects that extended out from selected disturbed areas. The first plot was usually located in the heart of the disturbed area. The next plot's center was located along the previously determined disturbance-gradient transect line, 50-m from the first plot's center, or 50-m from the disturbed area's observed boundary (when the latter extended beyond 50-m from the center of the disturbance). The third plot's center was 100-m from the disturbed area. The 4th through 13th plots' centers were located at 500-m meter increments from the disturbed area, with the last plot's center located 5 km from the disturbed area (Figure 9). For many of the disturbance-gradient transects the final plots were not reached due to constraints imposed by landscape features or other disturbances. The orientation of the disturbance-gradient transect was determined by selection of a random azimuth (selected from a random number table) but the degree of randomness was constrained so that the transect lay largely within a similar environment along its extent, and so that it was not unduly influenced by other disturbance sources.

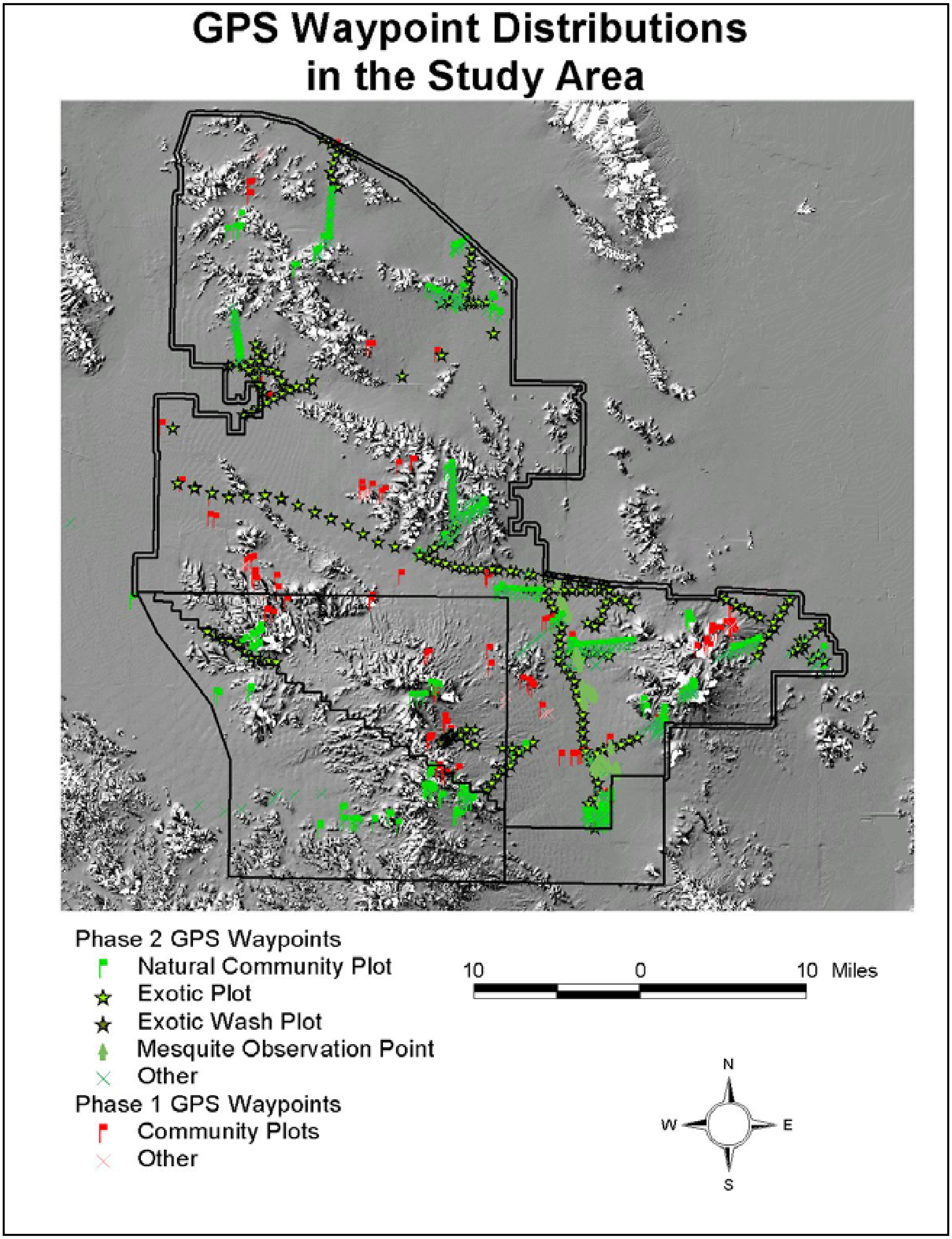


Figure 7. Distribution of all data collection locations.

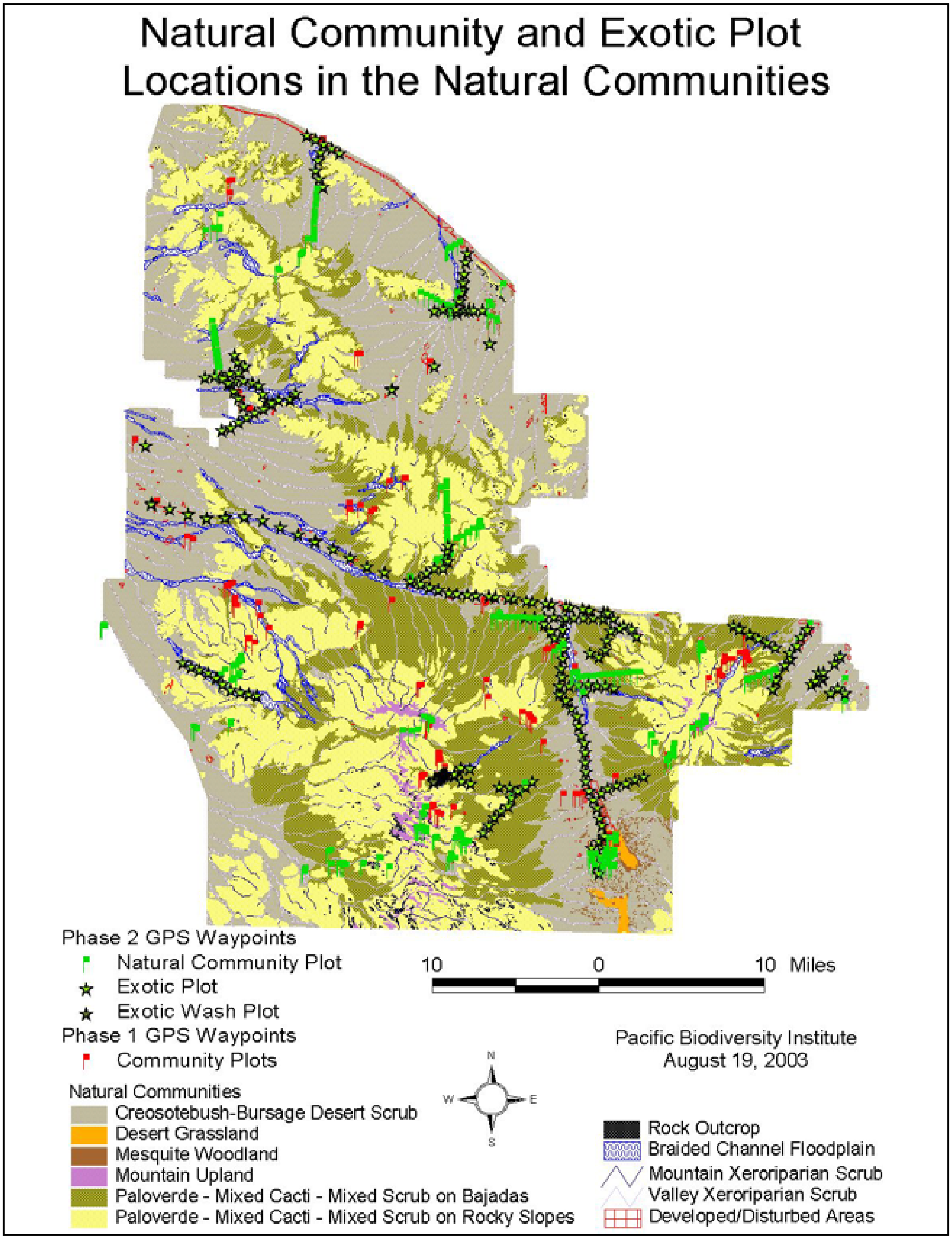


Figure 8. Distribution of natural community and exotic plots.

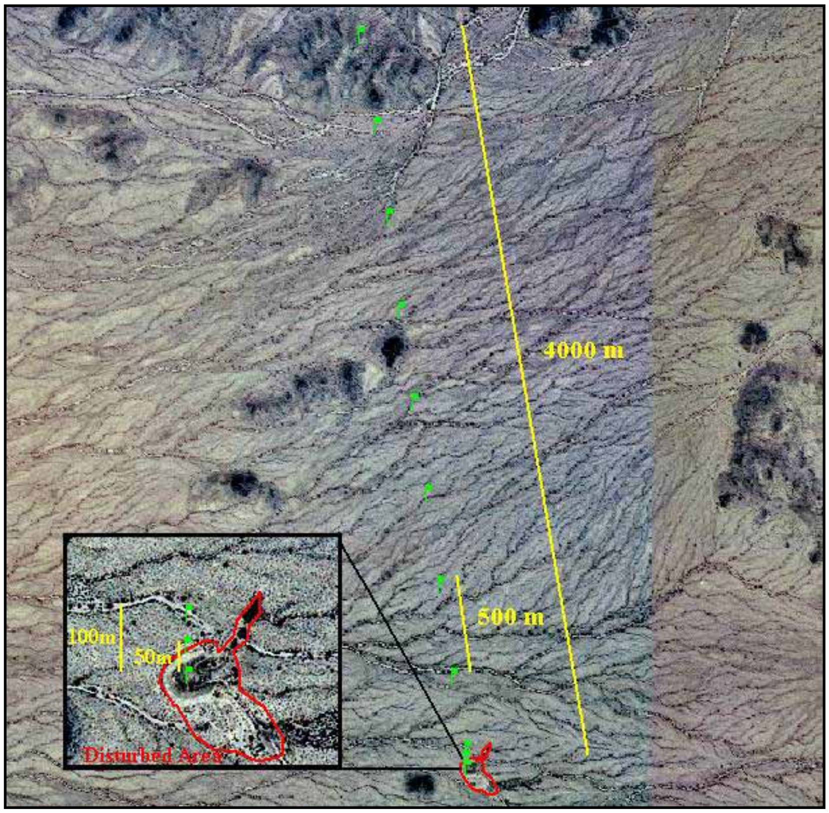


Figure 9. Example of a disturbance gradient transect (originating from Gap Tank).

Second-, some plots were strategically located to pick up the natural variation that occurs within natural communities. An effort was also made to locate plots in areas that may represent "baseline conditions", where little or no human-induced alteration appears to have occurred. The locations of these plots were selected using GIS analysis and image interpretation techniques prior to field sampling.

To assist in future natural communities monitoring, permanent plot markers (1.5 foot long, 3/8" diameter rebar stakes painted red) were placed at the natural community condition assessment sample sites (Figure 10). Some of these stakes were pounded so that their ends were flush or slightly below the ground surface. Precise relocation of these plots may require the use of metal detectors. The metal stakes in addition to GPS waypoints allow for precise relocation of all the natural community assessment plots. Exotic species plots were only marked by GPS waypoints.

 Locating and recording the center of a natural community condition assessment plot using a Garmin eTrex GPS receiver.	 Pounding in a rebar permanent plot marker to mark the center of a natural community assessment plot.
 Laying out the point intercept transect cable.	 Half meter points along the point intercept transect cable were marked with duct tape so as to be easily seen.

Figure 10. Examples of how the natural community condition assessment plots were established.

Point Intercept Transects

Point-intercept transects were used in selected natural community condition assessment plots to provide objective estimates of plant species cover. These transects were used repeatedly throughout the project to help calibrate field crew ocular cover estimates. Intercept information was taken at half meter intervals along four separate 12.5-meter transects, each starting from the center of the plot, forming a cross (Figure 11). The transects were laid out along the four cardinal directions, and plant species intercepting the transect at a half meter point (see Figure 10) were recorded. It was possible to have multiple species recorded at any given half meter point. This information was then used to calculate percent cover of each species in a given plot. At each intercept point, the presence of litter, soil, sand, gravel, rock, biotic crust or moss was also recorded, if one of these was present without vascular plant cover. The field data collection form used for point intercept sampling is included as Appendix R.

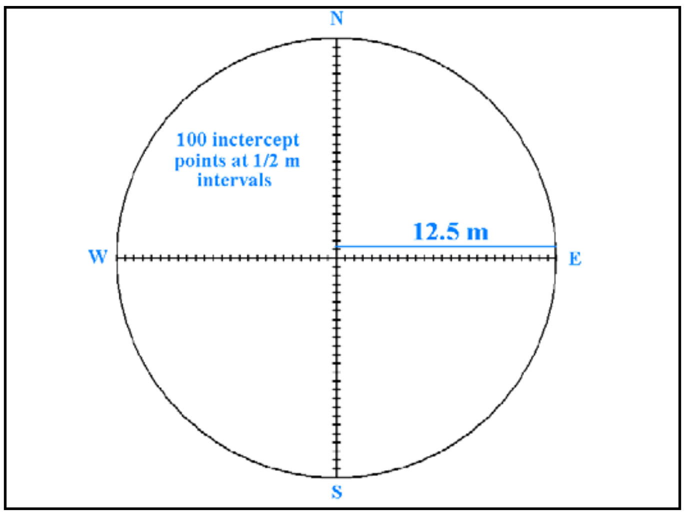


Figure 11. Illustration of the point intercept sampling layout.

While the point-intercept transects provided more objective data than ocular cover estimates, we found that they were inadequate in describing species diversity, since less abundant species were often not recorded by the point intercept method. We also found that they were inadequate in describing the relative cover of plants in communities where plants were often highly clumped (riparian areas, rocky slopes, mountain uplands). Because of these findings, the standard natural community assessment data methods (described above) were also used at the point intercept transect locations. Our final species composition and cover estimates recorded for these locations represented our synthesis of the two data collection methods.

Miscellaneous Field Observations

The fourth method of field data collection was the collection of field observations and notes taken while traversing natural communities between sampling locations and more intensive field study sites. Included in these observations were the presence of rare plants, exotic plants and unusual plant communities (Figure 12). The field data collection form used for collecting information between plots is included as Appendix T.

Figure 12. *Castela emoryi* in the Creosotebush-Bursage community in the Vekol Valley. This large specimen's location was recorded in our miscellaneous field observations data.

Field Collection of Disturbance Data

During field sampling, data on a variety of disturbance elements and stressors were collected. These data were useful in establishing an overall concept of baseline conditions. Only fine scale disturbances that had typically affected a natural community within the last 5 years were discernable. The development of disturbance data layers on a landscape level was previously described in the Phase 2 methods.

Each site was evaluated for the following disturbance elements and stressors.

a) Invasion of exotic species
b) Level of grazing pressure
c) Effects of vehicles on highways and roads
d) Off-road vehicle use
e) Recreational use
f) Hydrologic alteration
g) Mining

Grazing pressure and off-road vehicle use were quantified in a number of ways. Cow prints, cow dung, cow trails, horse prints, and horse dung were each individually tallied and recorded for each plot in which they occurred. Vehicle use was quantified by recording the number of individual vehicle tracks that occurred in each plot, and totals were sorted by the type of vehicle that made each track (car, motorcycle, ATV, etc.).

Quality Assurance

Quality assurance of field data was accomplished through a variety of means. These included:

- Inspection of plot data sheets by senior staff
- Independent sampling of selected plots by senior staff and comparison to data recorded by the field team.
- Duplicate (sometime triplicate) estimation of species occurrence and cover within many of the plots by multiple, independent observers. Once each observer had independently recorded species occurrence and estimated cover, then the results were compared and discussed, and a final estimate was entered for each species.
- Point-intercept transects in selected plots were used to calibrate observer cover estimates.

The above methods have proven to provide consistent and repeatable species cover estimates between trained observers.

Assessment of Unique Communities

Desert Grasslands

We conducted field surveys and natural community plots on the BLM side of the SDNM/TON boundary. An interesting trend we looked at for the *Desert Grasslands* community is the continuing mesquite invasion of the *Desert Grasslands.* We examined a series of historic aerial photos (chronosequencing) to help us understand the spatial dynamics of this trend in the past forty years.

Braided Channel Floodplain

The *Braided Channel Floodplain* community is a complex of various habitat types that occur on surfaces created and maintained by disturbances of varying magnitude and frequency. This community has some of the highest biodiversity in the study area due to the complex interspersion of habitat types. Sampling of the floodplain community was done by conducting transects across various floodplains, measuring the dimensions of the variety of surfaces encountered and conducting 12.5-m radius natural community plots on these surfaces. The result was detailed characterizations of the floodplain community at each transect location. Multiple transects across the study area provided a good assessment of the variation of condition and natural variability within this community.

Mesquite Woodlands

Data collection

The spatial distribution and ecological characteristics of *Mesquite Woodlands* were assessed using a combination of three different methods: analysis of aerial imagery, community ecology assessments, and **Mesquite Condition and Extent Plots**. Each method had its own strengths and weaknesses in accurately assessing mesquite community components, and combining the three methods provided the best overall understanding of mesquite communities.

The first method focused solely on mesquite patch distributions on a broad landscape level. We used Landsat TM7 satellite images, digital infrared orthophotos, and a reconnaissance field survey to digitize locations of suspected mesquite community patches and to gain a preliminary perspective about the range of variation of mesquite communities. The initial mapping was done as part of Phase 1 of this project. Further refinement of this landscape-level mapping was done during the initial stages of Phase 2, using GIS software and aerial photography from different time periods to distinguish probable mesquite community patches by their distinctive spectral qualities, texture, landscape location, and patch shapes. We mapped any changes of suspected mesquite communities through on-screen digitizing. This provided the Phase 2 field crew with geographically explicit areas of interest on which to focus the other two assessment methods. We updated the map as needed, based on the Phase 2 fieldwork.

The second method employed was the community ecology assessment, which was identical to the vegetation sampling done in the other natural communities, with the addition of tree height and diameter data. This method provided the most in depth data on differences in plant species diversity and composition between different mesquite patches. However, as this method was limited to an observational range of 12.5 m per plot, we found that an alternative sampling method would be necessary to adequately ground truth the extent of probable mesquite patches delineated by the aerial imagery mapping.

The third assessment method was designed during Phase 2 fieldwork to better provide mesquite community distributional data and some ecological data over many of the areas mapped during the aerial imagery work. This method consisted of traversing an area of interest and taking GPS waypoints along the way. At each waypoint an observer recorded spatial, structural, and compositional data, and also a subjective observational radius to which these components applied (Figure 13). Other important ecological dynamics, such as evidence of disturbance, were also recorded at each waypoint. The flexibility of the observational radius in this third method, as opposed to the vegetation sampling method, allowed for much more of the area of interest to be sampled while still providing important ecological data. The plot form used for this method is in Appendix S.

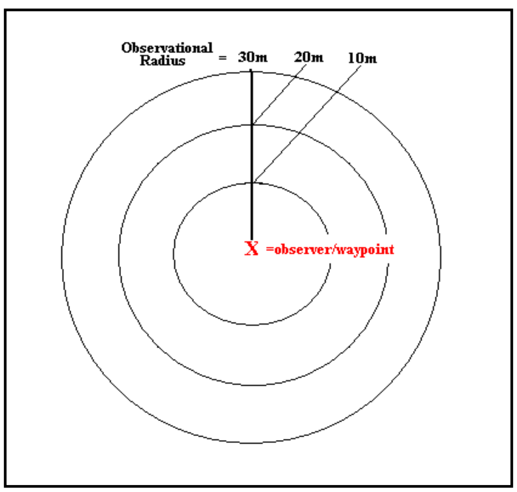


Figure 13. Illustration of the observation radius concept. The observational radius (OR) represents the amount of area an observer could see and to which the observations applied.

Data analysis

Mesquite community conditions were assessed using the data collected during Phase 2 fieldwork. Because of the substantial variation within the mesquite community, we divided the *Mesquite*

Woodlands into three sub-community types prior to analysis. These sub-community types are as follows:

1) Mesquite dominated woodlands established before the late 1960s
2) Mesquite stands found on or near spreader dikes or water tanks
3) Pure mesquite stands invading other natural communities after 1968

We describe the sub-communities by percent cover of growth form, and various condition factors such as average distance from water improvements and percent cover of exotic species. Table 7 shows the number of plots or spatial observation points taken within each sub-community type.

Table 7. Distribution of plots in various mesquite stand types.

Mesquite Stand Types	Number of Natural Community Plots	Number of Mesquite Condition and Extent Plots
Naturally Occurring/Persistent Stand	10	39
Stand in Tank/Disturbed Area	2	17
Young Stand in Area Previously Not Dominated by Mesquite (Invading Mesquite)	1	13
Total	13	69

Refinement and Extension of the Natural Community Map

While undertaking the fieldwork described above, substantially more was learned about the spatial distributions and characteristics of the natural communities. We used this information to modify the Phase 1 natural community map and community descriptions.

In order to detect whether any major cover type discontinuities occur along the monument boundary, we extended the natural community map to include a one-quarter mile buffer outside the SDNM and significant parts of the BMGR and TON. We mapped the additional area through on-screen digitizing, using a combination of digital aerial imagery cross-referenced with the Phase 2 field data, much in the same way the original natural communities map was produced in Phase 1.

We used the extended data to visually assess the degree and primary types of discontinuities in cover that occur along the monument boundary. We provide a qualitative description of these findings in the results.

Analysis of Exotic Plant Distributions

We examined the 5 most common exotic species on the monument (in terms of percent cover) in relation to human-based disturbance and environmental factors that might influence their distribution. We used linear regression to look at the distribution of *Brassica tournefortii*, *Bromus rubens*, *Erodium cicutarium*, *Schismus arabicus*, *Sisymbrium irio*, and the total number of exotic species in relation to elevation, slope, aspect, distance from potential livestock congregation areas, and distance from roads. We examined the relationships of these factors to exotic species distributions across and within community types. These analyses were based on a combined data set of the exotic plots and natural community plots. The exotic plot data, which were gathered using a quick, and less in-depth approach than the natural community data, did not include information on soil texture, geology, and vehicle and livestock impact indices and so these factors were not included in the analysis.

In order to use aspect in linear regressions, we converted this to two separate continuous variables as follows (Zar 1999):

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

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

Lastly, we used ANOVA to check for differences in percent cover of exotic species by community type. We limited this analysis to the natural community data, since the distribution of the exotic plots was heavily skewed to communities with higher exotic cover, and this would strongly influence the average cover of exotics calculated for each community. The regressions and ANOVA were run using SPSS 8.0 for Windows software.

Analysis of Variation within Natural Communities

We used two community analysis techniques to examine the variability of species composition within the natural communities. These were Detrended Correspondence Analysis (DECORANA or DCA) (Hill and Gauch 1980), an ordination technique, and hierarchical cluster analysis. Of the wide variety of ordination techniques available, we chose to use DECORANA for several reasons. First, we wanted to use an indirect gradient analysis approach, which, as opposed to direct gradient analysis, is most useful in representing the actual underlying gradients in community data, whether or not those gradients relate to secondary variables measured in the study (e.g. elevation, slope, etc.). The two most popular indirect gradient analysis programs are DECORANA and NMDS. Each have their own strengths and weaknesses and perform more or less satisfactorily depending on the type of data and applications. DECORANA is more commonly used in community ecology and is based on an underlying unimodal model of species distributions. NMDS is better suited to data that are non-normal or discontinuous (if species composition is determined less by a gradient than by other factors) (McCune and Mefford 1999; Palmer 2003). In addition, some of instability problems that were noted with previous versions of DECORANA had been addressed in the PC-ORD 4.1 software (McCune and Mefford 1999), which we used for conducting all of our analyses.

In order to get the most meaningful results, we eliminated extremely rare species from the analysis data sets (Gauch 1989). “Rare” species were those that occurred in less than 5 of the 320 natural community plots. We graphed and examined the ordination results, then looked at correlations of various environmental factors and human-related disturbance factors to that variation. Environmental factors were elevation, slope, aspect, soil, and geology. Human-related disturbance factors were distance from potential livestock congregation areas, distance from road, a livestock impact index, and a vehicle impact index (the two indices were previously described). To simplify and clarify analysis results for each community, we included only those factors that appeared influential in affecting variation for that community based on our field experience. Table 8 lists the primary factors influencing variation in species composition for each natural community.

Primary Factors Influencing Variation in Composition within Each Natural Community	Creosotebush-Bursage Desert Scrub (87 plots)	Paloverde - Mixed Cacti - Mixed Scrub on Bajadas (34 plots)	Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes (64 plots)	Mesquite Woodland (13 plots)	Mountain Upland (36 plots)	Braided Channel Floodplain (21 plots)	Mountain Xeroriparian Scrub (16 plots)	Valley Xeroriparian Scrub (25 plots)
Elevation	X				X	X	X	X
Slope Steepness			X		X			
Aspect			X		X		X	
Soil Texture		X						
Geology			X				X	
Distance from Potential Livestock Congregation Area	X	X		X				
Distance from Roads				X				
Livestock Impact Index	X					X		

Table 8. Primary factors influencing variation in species composition for each natural community

Ecological Condition of Natural Communities

In order to look at ecological condition we first identified a number of field-based measurements that strongly influence condition and/or quantify levels of disturbance. These were number and percent cover of native species, number and percent cover of exotic species, number and percent cover of native grasses, percent cover of sand and soil, a livestock index, and a vehicle use index. Based on these factors we defined and described three levels of ecological condition. Next, to test whether our GIS data could be used to model and map condition, we analyzed relationships of the plot-based measures of condition and disturbance to GIS-derived layers of distance from potential livestock congregation areas and distance from roads.

We used multiple sources of information (DECORANA graphs, cluster analysis results, and review of field data) to assign each natural community plot to one of the three condition classes. We used ANOVA to test how well the condition classes (as assigned to the field plots) were differentiated from each other in terms of the field-based measurements of condition and disturbance. The ANOVA was conducted only for the *Creosotebush – Bursage Desert Scrub* community, as an example.

Next we developed models for the 3 condition classes on a community-by-community basis. These models were developed based on examination of the previously assigned condition classes of the plots, distance from potential livestock congregation areas and distance from roads for those plots, the DECORANA results, cluster analysis results, and other field data. Finally we created a map portraying the modeled condition classes for all communities.

Relationship of Field-Based Condition and Disturbance Measures to GIS Layers of Disturbance

We used linear regression to look at relationships of field-based measurements of condition and disturbance to GIS-generated data layers that might contribute to a condition model. Specifically, we looked at field observations of number and percent cover of native species, number and percent cover of exotic species, number and percent cover of native grasses, percent cover of sand and soil, livestock impact, and vehicle impact in relation to distance from roads and distance from potential livestock congregation areas.

We ran regressions of each of the field-based variables against the GIS-derived distance from potential livestock congregation areas and distance from road variables for all natural community plot locations (n=320) using SPSS 8.0 software.

In order to quantify livestock impact, we incorporated 4 field-based measurements of livestock impact into a single livestock index. This index was calculated for each plot as:

Livestock Index = Number of cowprints + Number of horseprints + Number of cowtrails + Number of cow/horse dung piles

Similarly, we incorporated 3 field measurements of vehicle-related disturbance into a vehicle index for each plot. We gave heaviest weighting to the "number of roadways" measurement since the impact of this variable is proportionately greater and longer lasting than that of the other 2 variables. The vehicle index was calculated as:

*Vehicle Index = (100*Number of roadways) + Number of car tracks + Number of motorcycle/ATV tracks*

Segregation of Natural Community Plots into Condition Classes

We segregated the natural community plots into three condition classes. The three classes range from highly disturbed and altered sites (Condition Class 1) to relatively undisturbed sites (Condition Class 3), and are described in detail in the results. The condition class assignments were made primarily on the basis of professional judgment, and were informed by the integration of the DECORANA (ordination) results, cluster analysis results, our field data, field notes, and plot photographs.

As a starting point for working with each community's plot data, we looked at the ordination graphs and cluster analysis results for natural groupings of plots that we knew, based on our field experience, were of a similar condition level. In some cases the plots in our analyses divided nicely along these lines (e.g. *Creosotebush – Bursage Desert Scrub*). In other communities where there were less dramatic differences in ecological condition (e.g. *Rocky Outcrops*), the ordination and cluster analyses results were less useful in delineating groups of plots with similar condition. In these cases, we had to rely more heavily on review and interpretation of our field data to make decisions on condition class.

To test the integrity of the assigned condition classes, we used multivariate ANOVA to check for differences in field-based measures of condition and disturbance for plots assigned to the three condition classes. The field-based measures were number and percent cover of native species, number and percent cover of exotic species, number and percent cover of native grasses, percent cover of sand and soil, livestock impact index, and vehicle impact index. This analysis was done for the *Creosotebush-Bursage Desert Scrub* community only, as an example.

Modeling and Mapping of Ecological Condition

Once the natural community plots were assigned to a condition class, we examined the summary statistics for the plots of each community's condition classes and used these, in combination with professional judgment based on our field experience, to develop criteria for modeling condition for a given community. These criteria were then objectively applied to the entire community to create a map of condition class. Our models varied by community and were typically based on varying thresholds applied to the distance from roads and distance from potential livestock congregation areas GIS layers. We integrated the condition class maps for all communities in order to create the map of condition classes for the entire study area.

Next, we overlaid our roads layers, the developed/disturbed sites layer, and the linear disturbances layer and added these layers into our condition map as representing Condition Class 1 areas.

Lastly, we overlaid GIS data concerning the BMGR's East Tactical Area expended ordinance sweep program. This data layer depicts the extent and frequency of expended ordinance sweep activity and development in that region. We evaluated this layer with respect to the potential ecological impacts inherent with the different activity types. This layer was also evaluated in concert with our own field observations, resulting in a geo-spatially stratified condition class layer for the BMGR's East Tactical Area. This last layer was then added to the main condition map to produce the final ecological condition map.

The factors used in modeling and mapping the ecological condition classes in the study area are shown in Table 9.

Table 9. Inputs to the community condition models and final condition map.

Factors Used in Modeling and Mapping Ecological Condition Class	Creosotebush-Bursage Desert Scrub	Paloverde - Mixed Cacti - Mixed Scrub on Bajada	Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slope	Mountain Upland	Mesquite Woodland	Braided Channel Floodplain	Valley Xeroriparian Scrub	Mountain Xeroriparian Scrub	Desert Grassland	Rock Outcrop	Desert Springs
Distance from potential livestock congregation area	X	X			X	X	X				
Natural community boundary (i.e. community was assigned to a single condition class)			X	X				X		X	X
Natural community boundary divided along SDNM and TON lands									X		
Roads	X	X	X	X	X	X	X	X	X	X	X
Linear disturbances	X	X	X	X	X	X	X	X	X	X	X
Developed/disturbed sites	X	X	X	X	X	X	X	X	X	X	X
Munitions disturbance sites (relevant only to communities occurring on the BMGR)	X	X	X				X	X		X	

Results

Natural Communities of the Study Area

We mapped and described 12 natural communities in the study area (Table 10, Figure 14). These natural communities range from primary matrix communities to small patch communities. The communities are described in much more detail in Appendix A. This description includes information on composition, structure, function, disturbance processes, landscape context, examples of baseline conditions, mapping methods, biophysical modeling parameters, discussion of previous mapping efforts, and relationship to existing plant community classification systems.

Further natural community data is also presented in Appendices C and D. Appendices C and D contain in depth information on each community's composition and structure based upon our field data. All the plant species encountered in our Natural Community Condition Assessment Plots are expressed in these appendices, organized by the community in which they were found, and their growth form categories. The difference between Appendices C and D is that the species in Appendix C are sorted in an ascending order according to average percent cover, whereas the species in Appendix D are sorted in ascending order according to percent constancy.

Table 10. Upland Natural Community Descriptions.

Natural Community	Description
Creosotebush-Bursage Desert Scrub	Primary matrix community occupies the lowest elevations on the SDNM covering desert flats, valley bottoms and lower portions of bajadas. Community is dominated by *Larrea divaricata tridentata* and has a relatively low leguminous tree component compared to the *Paloverde - Mixed Cacti - Mixed Scrub on Bajadas* and *Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes* communities.
Paloverde - Mixed Cacti - Mixed Scrub on Bajadas	Secondary matrix community with greater leguminous tree and cacti cover than the *Creosotebush-Bursage Desert Scrub* community. This community is typically spatially "sandwiched" in between the *Creosotebush-Bursage Desert Scrub* and the *Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes* communities. This community occurs on the gentle slopes of desert bajadas. This is the community in which saguaro forests are found.
Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes	Tertiary matrix community occupying the mountainous slopes in the study area. A higher leguminous tree component, as well as a more frequent occurrence of *Encelia farinosa farinosa*, and *Lycium* species, distinguish this community from the *Paloverde - Mixed Cacti - Mixed Scrub on Bajadas* community.
Mountain Uplands	Patch community limited to the highest elevations (and mostly northern aspects) occurring in the study area. This botanically diverse community is primarily distinguished by the occurrence of *Canotia holacantha*, *Agave deserti simplex*, *Yucca baccata,* and other high elevation shrubs and trees.
Desert Grasslands	Patch community, limited to the upper Vekol Valley flats. This community is identifiable by its dominant bunch grass (*Pleuraphis mutica*) component and single canopy layer structure.
Mesquite Woodlands	Small patch community occurring in lowland flats, usually near a riparian or xeroriparian area. This community is characterized by its woodland structure and the dominance of *Prosopis velutina.*
Rock Outcrops	Small patch community typically occurring within a matrix of the *Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes* or *Mountain Upland* communities. This community has very low vegetative cover compared to the surrounding matrix communities, and the substrate is bedrock without soil accumulation.

Table 11. Riparian Natural Community Descriptions.

Natural Community	Description
Valley Xeroriparian Scrub	Linear patch community occurring around and encompassing the seasonal wash beds on the bajadas and lowland flats in the study area. This community has a high leguminous tree component, abundant vines, and a multi-layered canopy structure. It is distinguished from the *Mountain Xeroriparian Scrub* community by having a wash channel that is not confined to a bedrock substrate. This community's spatial occurrence is sensitive to peak flow events.
Mountain Xeroriparian Scrub	Linear patch community occurring around and encompassing the seasonal wash beds on the steeper mountain slopes of the study area. This community has a high leguminous tree component, and a multi-layered canopy structure. It is distinguished from the *Valley Xeroriparian Scrub* community by having a wash channel that is confined to a bedrock substrate. This community's spatial occurrence is not sensitive to peak flow events.
Braided Channel Floodplains	Patch community that has many similarities to the V*alley Xeroriparian Scrub* community but differs in regard to width, dominant geomorphic/hydrologic processes and vegetation composition. This community occupies relatively broad floodplain areas within the mountain valleys and along major washes on the bajadas. Multiple, cross-braiding channels characterize this community. Significant island areas and adjacent floodplain zones often exist that are inundated by floodwaters during high flow events. These areas are much wider than the typical xeroriparian communities and often bear some resemblance to river floodplains along major perennial rivers throughout the world.
Desert Springs	Small patch community that surrounds and encompasses a naturally occurring spring. This community is distinguished by having a unique plant species composition compared to the surrounding matrix community in which it occurs. The presence of plants typically sensitive to dry soil conditions are a good indicator of this community.
Tinajas	Small patch community that encompasses a naturally occurring tinaja. This community does not usually contain much terrestrial vegetation. It is found in a bedrock dominated substrate.

Refinement and Extension of the Natural Community Map

The natural community map, which was refined based on Phase 2 fieldwork, is shown in Figure 14. This map also includes natural community boundaries within a quarter mile buffer around the monument, and extensions into the BMGR and TON lands. Total areas covered by each natural community on the SDNM and extended areas are provided in Table 12. We did not subtract the area occupied by the riparian communities from the non-riparian communities in which they occur (*Braided Channel Floodplain* areas were subtracted). Xeroriparian communities are mapped with a 10-meter buffer on either side of the 1:100,000 GIS hydrography data upon which they are based.

Table 12. Area covered by major natural communities

	Natural Community	SDNM (hectares)	SDNM Buffer (hectares)	BMGR and TON Extension (hectares)	Total Study Area (hectares)
Non-Riparian Communities	*Creosotebush-Bursage Desert Scrub*	82,909	6,566	15,436	104,911
	Paloverde - Mixed Cacti – Mixed Scrub on Bajadas	50,895	1,215	7,787	59,897
	Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes	59,190	660	21,749	81,599
	Mountain Upland	1,283	0	1,019	2,302
	Desert Grassland	102	0	679	781
	Mesquite Woodlands	676	49	957	1,681
	Rock Outcrop	627	2	998	1,627
	Total Area of Non-Riparian Communities	**195,683**	**8,491**	**48,625**	**252,799**
Riparian Communities					
	Braided Channel Floodplain	5,186	157	176	5,519
	Valley Xeroriparian Scrub	2,790	158	544	3,492
	Mountain Xeroriparian Scrub	348	1	177	526
	Total Area of Riparian Communities				**9,537**

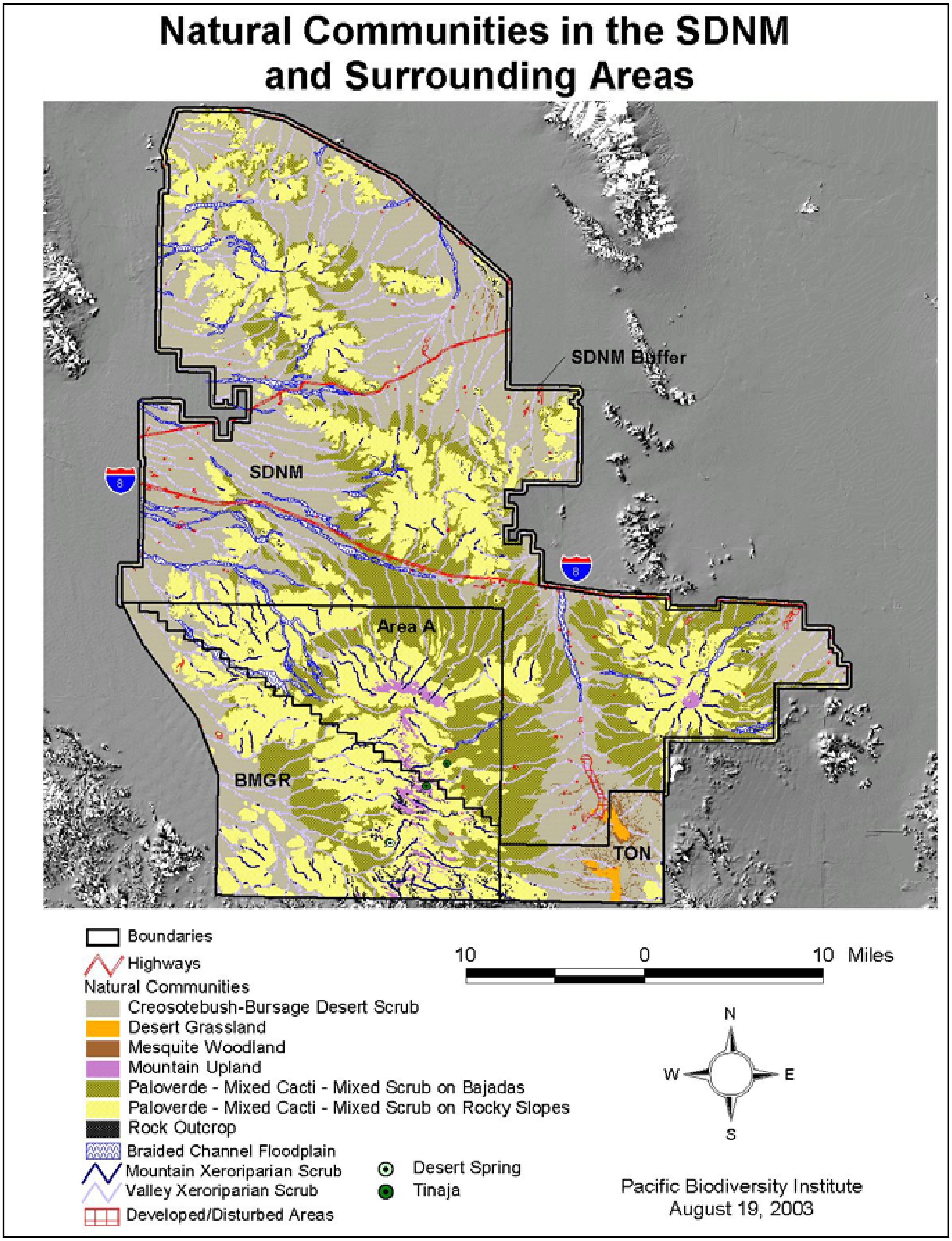


Figure 14. Natural communities in the SDNM and surrounding areas.

A visual inspection focusing on the continuity of the SDNM's major community types within the quarter mile SDNM buffer area showed that most communities continue their natural distribution patterns without artificial interruptions. However, on the northern boundary of the SDNM, along the El Paso Pipeline Road where it intersects with Prong Wash, the *Creosotebush-Bursage Desert Scrub* community is slightly interrupted within the SDNM buffer by agricultural fields.

Botanical Inventory of the SDNM and Adjacent Areas

During the Phase 1 and 2 fieldwork sessions, we identified 325 native plant species and 21 exotic plant species within the study area. A list of all the species encountered is presented in Appendix B.

Because the Phase 2 field season was delayed due to circumstances outside our control, our ability to positively identify every species we encountered was diminished. In many cases, phenology was not ideal for species identification due to the combination of several years of regional drought and the late timing of our spring fieldwork. At the time of our surveys, many plants had gone to seed and their leaves had already withered.

Specifically, certain species, such as *Caulanthus lasiophyllus and Sisymbrium irio,* became increasingly difficult to tell apart as field specimens dried up in late spring. Some cacti were difficult to accurately identify. Species from the genus *Opuntia* were too difficult for us to collect for expert assistance and sometimes proved to be beyond our realm of expertise to identify on site. We did not attempt to distinguish *Schismus arabicus* and *Schismus barbatus* (very similar exotic grasses). All specimens of the genus *Schismus* were recorded in our data as *Schismus arabicus*. All specimens that were examined by Dr. Richard Felger or Elizabeth Makings were *arabicus.* Other scientist working in this area have often just recorded this species at a genus level.

Analysis of Exotic Plant Distributions

Twenty-one species of exotic plants were found in the study area (Table 13). Many of these plants were found in only a few localities. The extreme drought conditions probably limited the visible occurrence of some species that are present in the study area. Surveys during wetter periods will likely reveal additional species.

Table 13. Exotic species found in the study area.

Scientific Name	Family	Growth Form	Common Name	Abbreviation
Avena fatua	Poaceae	grass	wild oat	AVEFAT
Brassica tournefortii	Brassicaceae	herb	Sahara mustard	BRATOU
Bromus carinatus	Poaceae	grass	California brome	BROCAR
Bromus rubens	Poaceae	grass	red brome	BRORUB
Chenopodium murale	Cheonopodiaceae	herb	nettleleaf goosefoot	CHEMUR
Conyza canadensis	Asteraceae	herb	Canadian horseweed	CONCAN
Cynodon dactylon	Poaceae	grass	Bermuda grass	CYNDAC
Eragrostis lehmanniana	Poaceae	grass	Lehmann lovegrass	ERALEH
Erodium cicutarium	Geraniaceae	herb	filaree	EROCIC
Hordeum murinum	Poaceae	grass	mouse barley	HORMUR
Hordeum pusillum	Poaceae	grass	little barley	HORPUS
Malva parviflora	Malvaceae	herb	cheeseweed	MALPAR
Pennisetum ciliare	Poaceae	grass	buffelgrass	PENCIL
Phalaris minor	Poaceae	grass	canary grass	PHAMIN
Salsola tragus	Chenopodiaceae	herb	russian thistle	SALTRA
Schismus arabicus	Poaceae	grass	mediterranean grass	SCHARA
Schismus barbatus	Poaceae	grass	mediterranean grass	SCHBAR
Sisymbrium irio	Brassicaceae	herb	London rocket	SISIRI
Sonchus oleraceus	Asteraceae	herb	cow thistle	SONOLE
Tamarix ramosissima	Tamaricaceae	shrub	salt cedar, tamarisk	TAMRAM
Triticum aestivum	Poaceae	grass	common wheat	TRIAES

Variation in Cover of Exotic Species Between Natural Communities

We examined the distribution of exotic species by community type (Figure 15). The highest average percent cover of exotics was found in *Mesquite Woodlands*, followed by *Braided Channel Floodplains,* and *Creosotebush - Bursage Desert Scrub*. The community with the lowest average percent cover of exotics was *Rock Outcrops*, followed by *Mountain Uplands*.

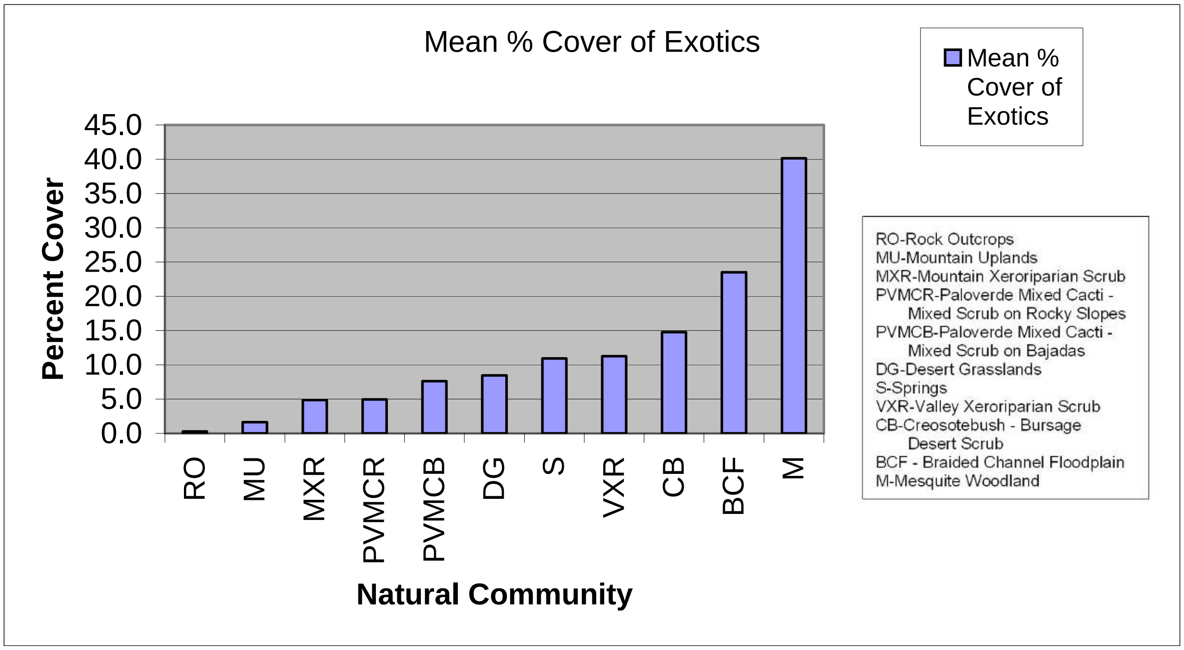


Figure 15. Mean cover of exotic species by community type.

We used ANOVA to check for statistically significant differences in percent cover of exotic species by community type and found significant differences among the communities (F 13.884, p-value <.001). To further clarify differences we used Tukey's HSD for multiple comparisons. Table 14 shows subsets of the natural communities based on significant differences from the multiple comparisons. The *Rock Outcrops*, *Mountain Upland*, *Mountain Xeroriparian Scrub*, and *Paloverde - Mixed Cacti-Mixed Scrub on Rocky Slopes* communities had the lowest percent cover of exotics (subset 1). The second subset with higher percent cover of exotics was composed of the *Paloverde - Mixed Cacti-Mixed Scrub on Bajadas, Desert Grasslands, Desert Springs, Valley Xeroriparian Scrub, Creosotebush-Bursage Desert Scrub,* and *Braided Channel Floodplains* communities. Some of these communities could not be significantly differentiated from other communities in subset 1, and these overlap communities are shown in both groups. The break between subgroup 1 and 2 is based on the significantly higher cover of exotics in *Paloverde - Mixed Cacti-Mixed Scrub on Bajadas* as compared to *Paloverde - Mixed Cacti-Mixed Scrub on Rocky Slopes*. Subgroup 3 consists solely of *Mesquite Woodlands*, which had by far the highest percent cover of exotics of all community types.

Table 14. Sample sizes and subsets (1-3) of natural communities based on differences (p < .05) in percent cover of exotic species.

Natural Community	Number of plots	1	2	3
Rock Outcrops	7	0.3		
Mountain Uplands	36	1.6		
Mountain Xeroriparian Scrub	16	4.8		
Paloverde-Mixed Cacti-Mixed-Scrub on Rocky Slopes	64	4.9		
Paloverde-Mixed Cacti-Mixed-Scrub on Bajadas	35	7.6	7.6	
Desert Grasslands	13	8.4	8.4	
Springs	3	10.9	10.9	
Valley Xeroriparian Scrub	25	11.3	11.3	
Creosote-Bursage Desert Scrub	87	14.8	14.8	
Braided Channel Floodplain	21		23.5	
Mesquite Woodlands	13			40.2

Analysis of Exotic Species Cover in Relation to Disturbance and Environmental Factors

Using linear regression to examine relationships of the 5 most common (i.e. highest percent cover) exotic species to human-related disturbance and environmental factors (elevation, slope, aspect, distance from potential livestock congregation areas, and distance from road), we found statistically significant relationships with 4 species - *Schismus arabicus*, *Bromus rubens*, *Brassica tournefortii*, and *Sisymbrium irio* (Table 15). *Erodium cicutarium* could not be significantly related to any of the factors. With the exception of *Schismus arabicus* in relation to elevation, however, all of the r-squared values (which represent the amount of variation in percent cover explained by the factor) were low. Distance from road did not significantly explain any of the variation in any of the species, and distance from potential livestock congregation areas was only weakly related to percent cover of *Schismus arabicus* and *Bromus rubens.* Elevation, with the highest r-squared values, explains 18.6% of the variation in percent cover of *Schismus arabicus* and 4.6% for *Bromus rubens.* Slope explains 4.5% of the variation in percent cover of *Schismus arabicus.*

When we ran regressions for each species-factor combination by community type, overall results were generally similar to those for all communities put together – statistically significant but rather weak relationships of a few exotic species with elevation, slope, aspect, and distance from potential livestock congregation areas. As with the overall analysis, when broken down by community type, *Schismus arabicus* and *Bromus rubens* generally showed the strongest relationships to any of the factors among the five exotic species. A notable exception was for the *Mesquite Woodlands* community, which had strong positive relationships of *Erodium cicutarium* with distance from potential livestock congregation areas and distance from road. *Mesquite Woodlands* did not show significant relationships with *Schismus arabicus, and Bromus rubens* was not present in our *Mesquite Woodlands* plots.

The regression results support observations in the field, that distribution of exotic species was not highly predictable except that some natural communities have higher concentrations than other communities and heavily disturbed areas have the highest concentrations of exotics. The relatively weak relationship of the exotic species with the GIS-derived human disturbance and environmental factors did not provide support for using these layers to model percent cover of exotic species as an additional input into our final condition model.

Table 15. Linear regression results showing relationship of human-related disturbance and environmental factors to percent cover of 5 exotic species.

All Communities (based on 752 plots, including Natural Community & Exotic plots) Cell values show (sign of regression slope), r-squared, (p-value). "-" represents non-significant findings, with p-value > .05						
	Brassica tournefortii	***Bromus rubens***	***Erodium cicutarium***	***Schismus arabicus***	***Sisymbrium irio***	**TOTAL EXOTICS**
# of plots with species present	46	39	225	695	108	
ELEVATION	(-) .011 (.004)	(+) .046 (.000)	-	(-) .186 (.000)	-	(-) .133 (.000)
SLOPE	-	(+) .026 (.000)	-	(-) .045 (.000)	-	(-) .046 (.000)
NORTHNESS	-	-	-	-	-	-
EASTNESS	-	(+) .009 (.021)	-	(-) .035 (.000)	-	(-) .020 (.000)
DISTANCE FROM LIVESTOCK CONGREGATION AREAS	-	(+) .005 (.050)	-	-	(-) .007 (.025)	(-) .007 (.018)
DISTANCE FROM ROADS	-	-	-	-	-	-

Exotic Species Distribution by Plot

We mapped the distribution of all exotic species based on their occurrence in natural community and exotic plots using a graduated symbol to illustrate the approximate amount of exotic plant cover at each location (Figure 16). We also created separate distribution maps for each of 15 exotic species based on their occurrence in natural community and exotic plots (Appendix E). Finally, we mapped the location and average percent cover of all exotic species in relationship to the natural communities (Figure 17). This was done by attributing the information presented in Table 14 to each natural community polygon. Also, the Developed/Disturbed Areas polygons were added to this map in the 25-50% exotic species cover category. The graduated symbol illustration in Figure 16 was also overlaid onto this map

These maps illustrate that most of the exotics were found within the *Creosotebush – Bursage Desert Scrub* matrix community or the small patch or riparian communities occurring with this matrix community. They also illustrate a high concentration of exotics along the I-8 road corridor, which runs east-west through the center of the monument. This is in contrast to many of the smaller roads and unpaved road corridors where we did not find noticeably higher concentrations of exotic species.

In the exotic species distribution maps, we also illustrated all the locations where exotic species were not present. We believe that this information on the absence of exotics will prove to be just as useful as the information on their presence. Areas without exotics may well represent refugia of native plants within a sea of exotic species and have considerable ecological significance. Many other locations only have common and widely dispersed exotics like *Schismus arabicus* and *Erodium cicutarium.* Monitoring the spread of exotics into un-infested areas, and studies on the population dynamics of exotic species are only possible with this kind of baseline information.

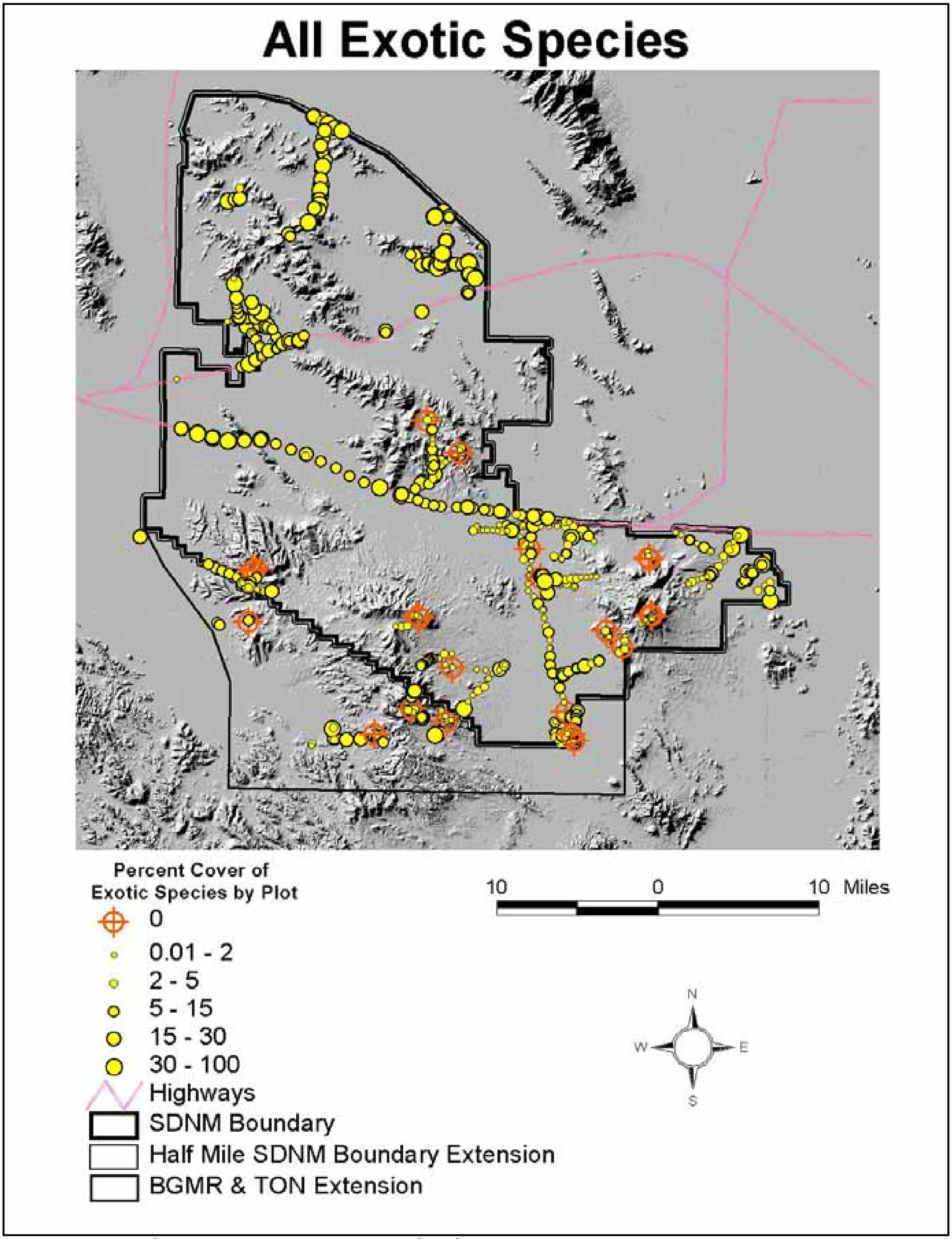


Figure 16. Total exotic species percent cover by plot

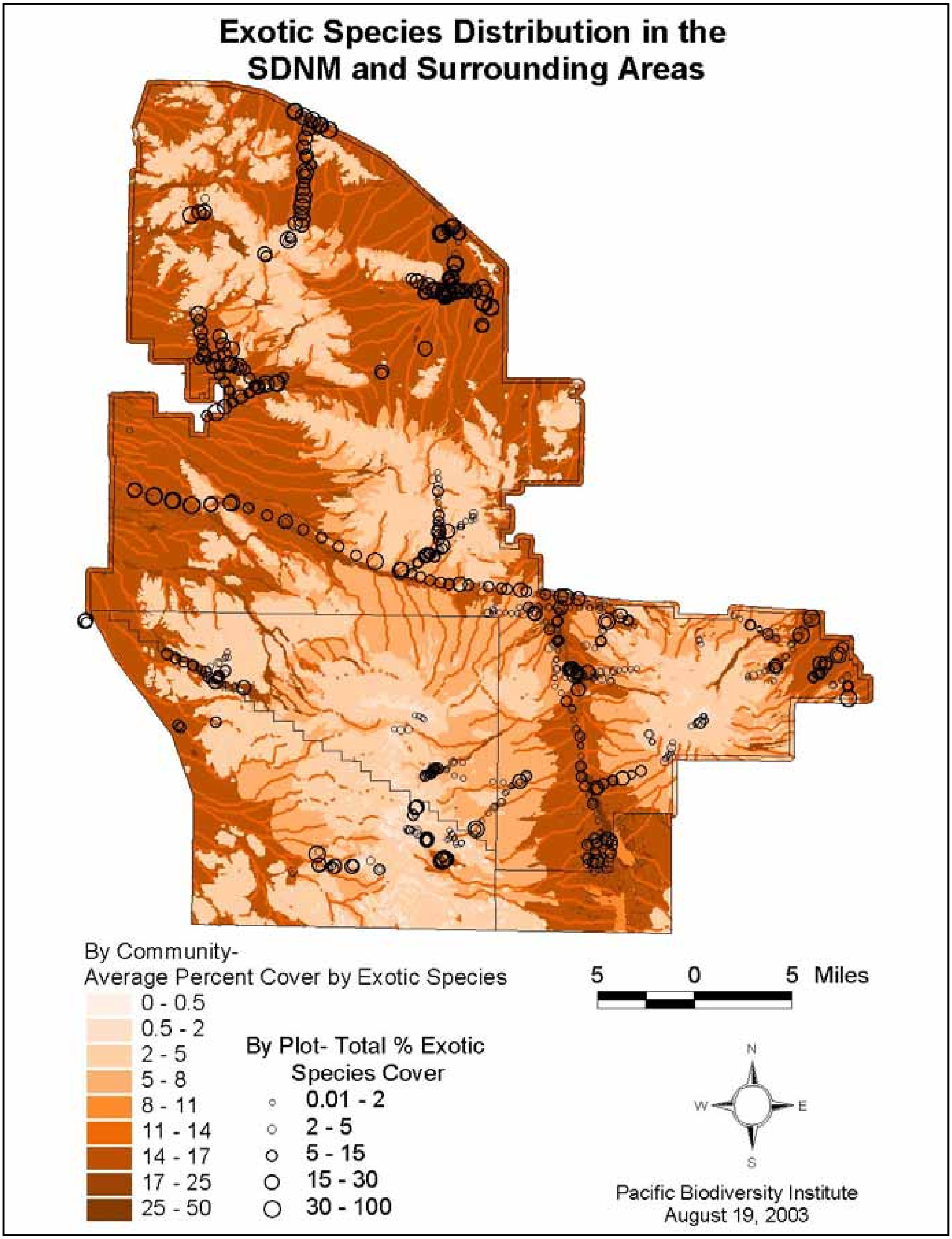


Figure 17. Average cover of exotic species by natural community.

Landscape-Level Assessment of Ecological Condition

The landscape condition was assessed using GIS data and aerial imagery. Figure 18 illustrates the distribution of the different types of visible disturbances that we mapped. Refer to the methods section for details about the creation and representation of the layers.

The total amount of "Developed/Disturbed Areas" according to our landscape assessment is 1,386 ha. The extent of impact on a given community's ecological condition from these disturbed sites is not necessarily contained completely within the mapped areas. Many of these developed areas function as exotic species distribution centers, allowing exotic species to become established and spread out in otherwise remote areas.

As with the "Developed/Disturbed Areas", the extent of impacts by the "Linear Disturbance" and "Roads" layers are not necessarily defined by the lines shown on the map. Because many of these lines represent established transportation routes, they often provide increased access to humans into areas that would otherwise be relatively inaccessible. Certain stress elements may be associated with this increased access. Taken together, the "Roads" and "Linear Disturbances" amount to over 250 kilometers of linear disturbance features.

There are over 1,900 hectares classified as "High-Density Cow Trail Areas". These types of areas proved to be highly disturbed sites (meriting Condition Class 1 or 2 status) according to our field survey results. The High-Density Cow Trail Areas are areas where there are radiating lines visible on aerial photography (cow trails) emanating out from a central area. As the distance from the central area increases, the degree of impact decreases. From examination of the field data it was apparent that the outer part of the "cow trail circles" would fit under Condition Class 2 and only the inner part within Condition Class 1. The difference between the inner and outer part of the High-Density Cow Trail Areas are adequately modeled in our livestock aggregation area distance modeling, where all areas within 500-m of a livestock aggregation area are mapped as Condition Class 1.

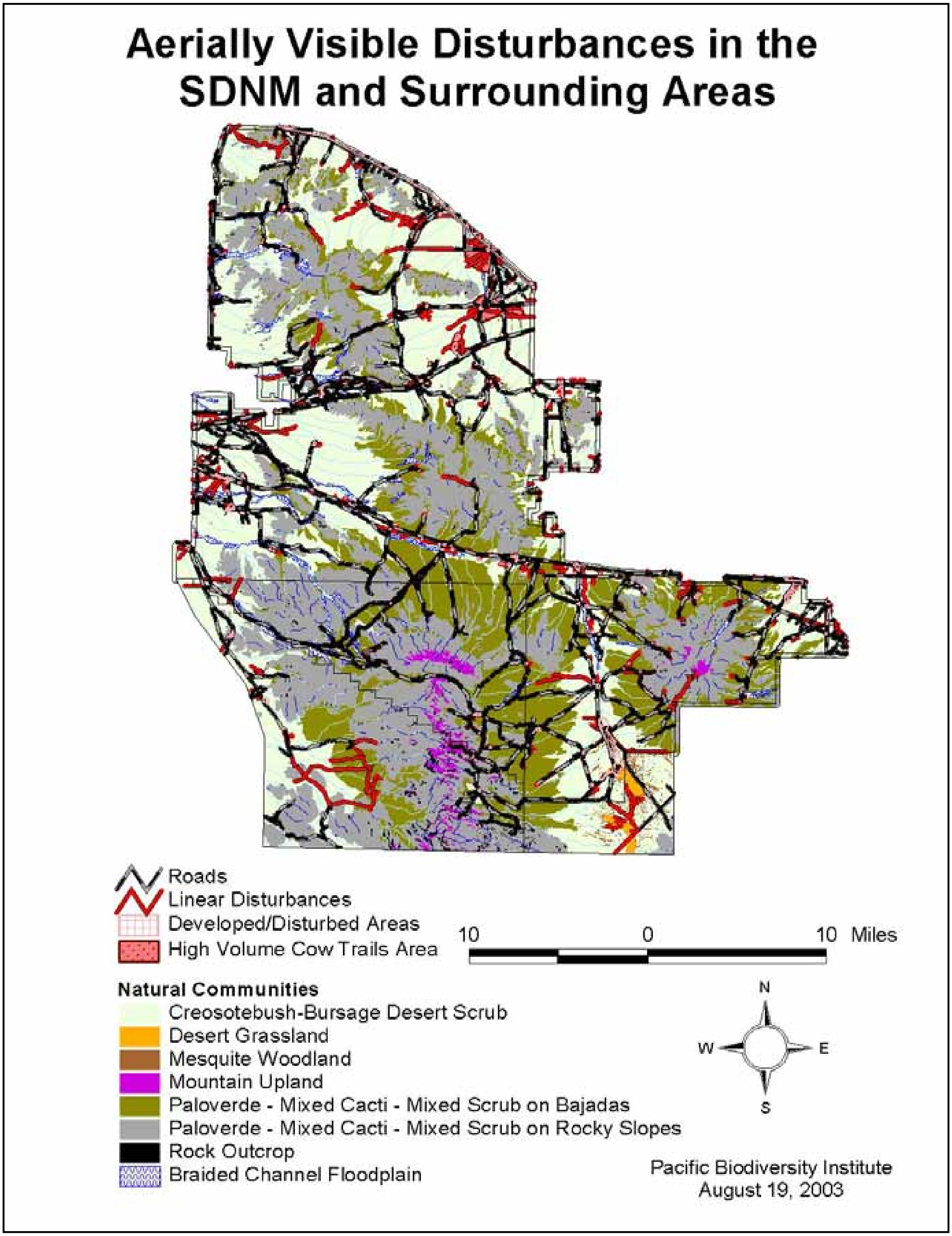


Figure 18. Coarse-scale disturbance map.

Taken together, it is apparent that the distribution and frequency of these disturbances are more typically located within certain natural community types, which in turn are correlated with certain large-scale topographic features. Low elevation areas with gentle slope (*Creosotebush-Bursage Desert Scrub, Paloverde - Mixed Cacti – Mixed Scrub on Bajadas, Braided Channel Floodplain, Valley Xeroriparian Scrub*, *Desert Grassland,* or *Mesquite Woodland* communities) contain the bulk of these coarse scale disturbances, probably because these types of areas are easier to develop and are the easiest to access. The natural communities in which these disturbance features were found have the highest mean cover of exotics, as was discussed previously.

Based on this information, the landscape-level ecological condition of the study area can be broken down into condition classes based upon the density of coarse scale disturbance features in a given area, or the distance of a given site from a coarse scale disturbance feature. In our final ecological condition map, we have classified all areas that are mapped as "developed/disturbed areas" and all areas within a 10-meter buffer of a linear disturbance or road in Condition Class 1. High-density cow trail areas were not included as an input layer in the final ecological condition map, because the level of impact and resulting ecological condition is better defined by our livestock aggregation area distance modeling.

Analysis of Variation within Natural Communities

We used ordination (DECORANA) and hierarchical cluster analysis to assess the variation in composition within natural communities and then examined the influence of a variety of environmental and human disturbance-related factors on that variation. For each community we provide graphs illustrating the clustering and ordination of the natural community assessment plots based on similarities in species composition. Similarity of species composition incorporates two measures: 1) how many of the same species occur in the plots and 2) similarity in percent cover of those species. Details on PC-ORD's clustering and DECORANA algorithms are described by Hill (1979) and McCune and Mefford (1999).

Cluster analysis and DECORANA are related tools in that both aid in visualizing the similarity of plots, however, we used them in slightly different ways. We used results of the cluster analysis and summary statistics created on the clusters to quantify and describe the variation within a community in terms of condition and disturbance-related variables (e.g. percent cover and number of native species, percent cover and number of exotics, etc.) (see Appendix F). Results of DECORANA were used primarily for evaluating the relationship of natural and human-related disturbance factors (e.g. elevation, slope, distance from road, etc.) on general patterns of compositional variation within a community. The two techniques are complementary, and integration of the results of these analyses helped reinforce the validity of our assessment of the variation within communities and the interpretation of that variation. The two analysis techniques and their corresponding graphs and figures are further described below.

Cluster analysis is a classification technique. It divides or classifies the data into as many groups as the data analyst specifies. We used our familiarity with the amount of variation present in the natural communities (from our fieldwork) and consideration of the number of plots in each community to determine the number of groups or clusters into which the data should be divided.

Once the data are grouped, it is up to the analyst to interpret the clusters and explain which factors (e.g. slope, distance from road, etc.) appear to be influencing division of the data. At any given level of clustering (e.g. five clusters vs. ten clusters), some clusters will be much more interpretable than others. We focus our discussion of the cluster analysis results on those groupings that are most interpretable.

An example of the hierarchical clustering results is Figure 19. The cluster analysis figures show the plot numbers on the left, color-coded by group number (the actual group numbers are meaningless except to identify separate clusters). By tracing back from the clusters on the dendrogram it is possible to see their relative distinctiveness. For example, clusters that separated from each other near the top of the hierarchical graph are more different from each other than those that are split closer to the bottom.

We also used DECORANA to examine variation in vegetative composition of plots. Rather than classifying the data into discrete groups, as in cluster analysis, DECORANA creates a continuous ordering of the plots based on their similarity. It reduces the dimensionality of the original data and creates 3 axes that relate to the strongest compositional patterns in the data. Typically the first 2 axes explain the bulk of the variation. The data can then be plotted on a 2-dimensional graph of the DECORANA axes, where plots that are located closer together are more similar in composition than those that are farther apart. DECORANA also orders species according to similarity in how they are distributed among the plots. Species, in addition to or instead of plots, can also be graphed against the DECORANA axes. As with the cluster analysis, it is then up to the analyst to look for meaningful explanations for patterns in these graphs.

An example of a DECORANA graph is Figure 20. The graph shows the locations of plots, identified by plot number (e.g. N23), in relation to the two primary DECORANA axes (i.e. the two axes which have the highest r-squared values and therefore explain the greatest amount of variation in species composition of the plots). The r-squared values for the individual axes and all axes combined (i.e. “cumulative r-squared”) are reported at the top of a table provided for each community (e.g. Table 16). The DECORANA graphs also incorporate results of the cluster analysis. Rather than showing each plot with the same symbol, we symbolized the plots according to the cluster analysis group number. (The actual group numbers for the clusters are meaningless – they just provide a way of referring to discrete clusters of plots). Plots that are grouped in the cluster analysis that are also in close proximity to each other on the DECORANA graphs likely represent some of the most distinct variation components within a given community.

An example of a DECORANA graph showing compositional similarity of plots for a particular species is Figure 26(a) (*Lesquerella gordonii* in plots of the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community). In these graphs, the size of the marker represents the relative percent cover of the species in a plot – the larger the marker the higher percent cover. We incorporated the results of the cluster analysis in these graphs as well, by choosing different symbols (color and shape) to mark different clusters. By integrating these results on a single graph it is possible to see the extent to which the clusters are correlated with certain species and how well both the DECORANA and cluster analysis capture that pattern. For example, in Figure 26(a), the DECORANA groups together plots with high percent covers of *Lesquerella gordonii*, as seen by the large symbols in close proximity to each other on the right side of the graph. The cluster analysis did the same, as seen by the fact that almost all the plots with large symbols are in a single group

(group 36). This suggests that the distribution of *Lesquerella gordonii* is quite an important component in describing the variation for the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community.

To aid in the interpretation of the DECORANA graphs, we looked at the relationship of environmental and human-related disturbance factors that we felt might, based on our field experience, be influential in affecting variation of vegetative composition in a given community. Continuous factors analyzed and their abbreviations (if applicable) in associated figures and tables are elevation (Elev), northness (Northnes), eastness (Eastnes), soil texture (Soiltext), distance from potential livestock congregation areas (Imprvdist), distance from road (Roaddist), a field-based livestock activity index (LI) and a field-based vehicle activity index (VI). Geology was also analyzed, but as discrete classes - granite, metamorphic (Metamrph), alluvium (Alluv) and volcanic.

We report the r-squared values for relationships of these factors with the 3 DECORANA axes in a table for each community (e.g. Table 16). We also illustrate these results by creating a vector overlay of the factors with the highest r-squared values on the DECORANA graphs (example in Figure 20). These types of combined graphs are often called "joint plots". In a joint plot, the lines (vectors) relating to the factors radiate from the centroid of the ordination scores. The angle of the line tells the direction of the relationship and the length of the line represents the relative strength of the relationship. For example, in Figure 20, elevation has the longest line and therefore has the strongest relationship of the factors with either of the axes (this can also be seen by looking at the r-squared values in Table 16). Since the elevation vector is angled to the right, plots on the left side of the graph will generally be lower in elevation. As you move right, at the angle of the vector, elevation of plots increases. Since the livestock index vector (LI) and potential livestock concentration vectors (Imprvdist) are at nearly opposite angles, this implies opposite gradients – as one value is increasing in the given direction, the other is decreasing. For some communities, we included additional DECORANA graphs that symbolize the plots according to their relative values for a particular factor. These plots can be interpreted in the same way as those that symbolize plots by relative percent cover for a given species (described above). For example, in Figure 27, markers with larger sizes symbolize plots with larger values for northness.

We did not test for statistical significance of the factor-Decorana axis correlations. Rather, we used the r-squared values in combination with r-squared values of the DECORANA axes (which quantify the amount of variation in the plots explained by each axis), as aids in interpreting the patterns of variation visible in the DECORANA graphs. We applied a general rule of thumb (the PC-ORD default) of including factors with r-squared values of 0.2 or higher on the joint plot (and highlighting these in the tables). However, this varied slightly by community. In some cases, we made adjustments to the 0.2 threshold to highlight those factors that, based on our field experience and analysis interpretations, seemed to best explain the variation. As the actual r-squared values are available in a table for each community, the reader can always refer back to those if he or she wishes to explore the influence of factors using different thresholds.

Variation within the *Creosotebush - Bursage Desert Scrub* Community

Eighty-seven natural community assessment plots were established in the study area, representing a range of environmental conditions within this community. The plots can be grouped by hierarchical cluster analysis into ten major groups. Detailed information on the composition of all the cluster groups is presented in Appendix G.

The primary group of plots (group 1, Figures 19 and 20) represents plots with low vegetative cover and low species diversity (Appendix G). *Larrea divaricata tridentata* is the dominant shrub (7.1% cover) and *Lesquerella gordonii* (1.85%) and *Lepidium lasiocarpum* (1.09%) are dominant herbs. As one progresses down the cluster diagram, the next group encountered is cluster group 24. Cluster group 24 has a little less *Larrea divaricata tridentata* (5.5% cover) and more *Ambrosia deltoidea* (2.14% cover) in the shrub strata. It has considerably more herbaceous and grass cover than group 1. *Schismus arabicus* is the dominant plant in this group (12.56%). *Pectocarya* spp. are the most abundant herbs (5.54% cover). *Plantago ovata* (3.58%) and *Lepidium lasiocarpum* (3.22%) are relatively abundant.

The next group encountered as one proceeds down the cluster diagram (cluster group 3) is characterized by very high abundance of *Larrea divaricata tridentata* (25.5% cover) and significant amounts of *Prosopis velutina* (7% cover). The exotic species, *Erodium cicutarium* (5.21% cover) and *Schismus arabicus* (5.5% cover) are the dominant herb and grass species in this group. This group is transitional to the *Mesquite Woodland* natural community.

Cluster group 2 is the next major group encountered in the cluster diagram. It has nearly as much *Larrea divaricata tridentata* (6.79% cover) as group 1, but it has 7 times more herbaceous and grass cover. *Schismus arabicus* is the dominant plant in this group (25.64%) but *Plantago ovata* (18.29%) and *Lepidium lasiocarpum* (12.36%) are also very abundant.

Cluster group 32 is the major group at the bottom of the cluster diagram. This group is similar to Cluster group 2 with nearly identical amounts of *Larrea divaricata tridentata* cover. It is characterized by very high abundance of *Lepidium lasiocarpum* (21.45%).

The minor groups (23, 37, 40, 54 and 56) are described in Appendix G.

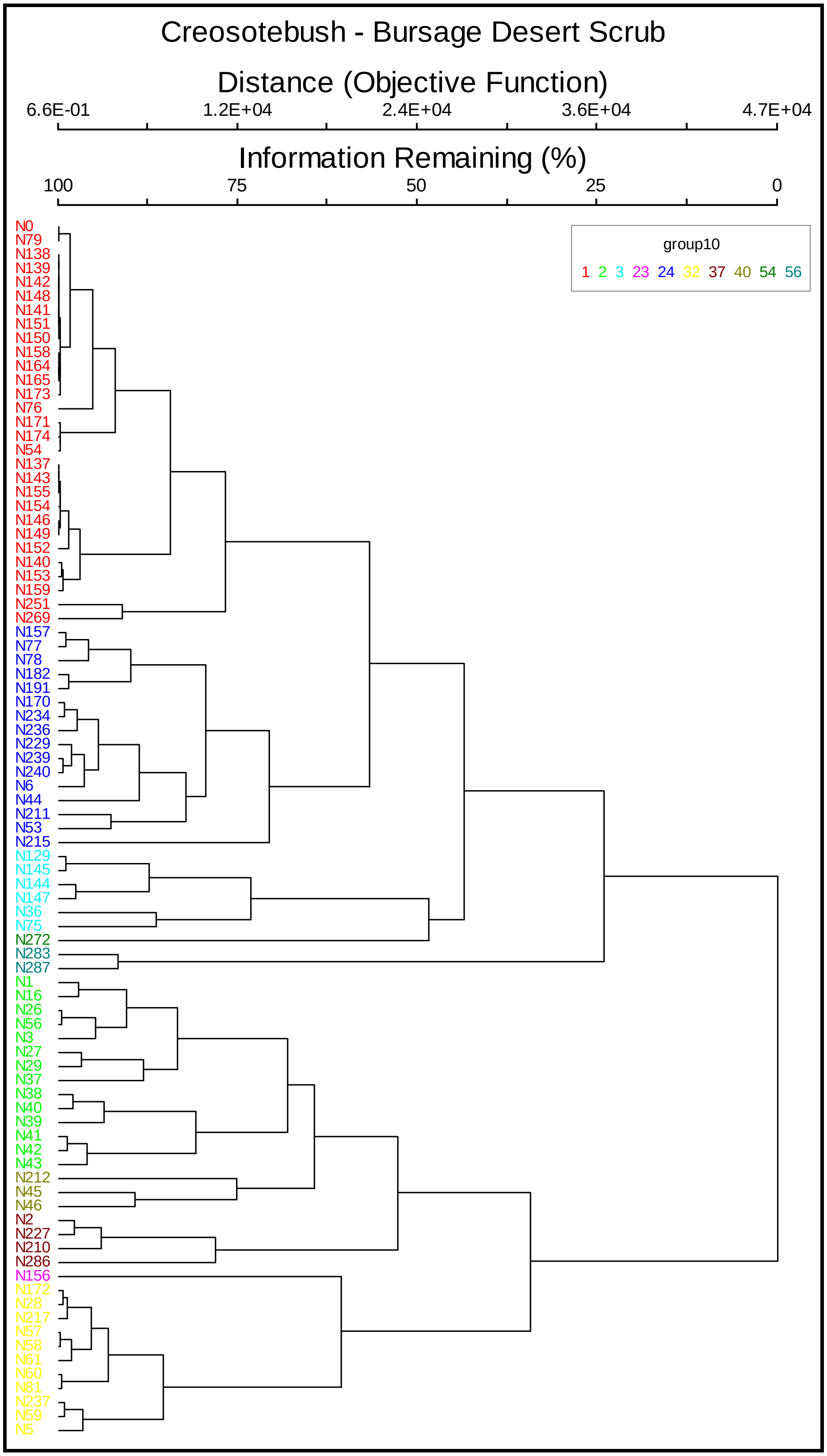


Figure 19. Hierarchical cluster analysis of *Creosotebush-Bursage Desert Scrub* natural community plots divided into ten major groups based on similarity of species composition.

Creosotebush - Bursage Desert Scrub occupies the greatest area of any of the natural communities and therefore has the potential for considerable natural variation in composition and structure. The relative uniformity of landform characteristics, however, limit this potential natural variation. This community only occurs in a narrow elevation range (most of the area is between 300 and 500 meters) on gentle slopes (0 to 2 degrees). Because of this, we did not consider aspect to be a significant factor in determining natural community composition and it was not included in the analysis.

Analysis of environmental factors in relation to DECORANA axes shows that elevation appears to be the primary factor driving natural variation (Table 16 and Figure 20). Although the elevation range of the community is rather small (about 250 to 685 meters), the upper elevations of this community and the lower elevations of the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* form an ecotone, meaning there is a gradual change in species composition as one community transitions into the other. In the higher elevations of the *Creosotebush - Bursage Desert Scrub* community, triangle-leaf bursage and tree covers increase. The relative cover of creosotebush decreases and total species diversity increases (as compared to the lower elevations).

Of the human-related disturbance factors examined, livestock use appears to be the greatest influence on community composition. DECORANA axis 2, which explains 15.6% of the variation in community composition, is most strongly related to the livestock index and distance from potential livestock congregation area factors (Table 16 and Figure 20).

Table 16. Coefficients of determination for DECORANA axes for plots within the *Creosotebush-Bursage Desert Scrub* community and correlation to environmental and disturbance gradients.

Creosotebush-Bursage Desert Scrub			
Cumulative r-squared for all 3 DCA axes = .399 (based on 87 plots)			
DECORANA Axis:	**1**	**2**	**3**
Axis r-squared	.176	.156	.067
	r-sq	**r-sq**	**r-sq**
Elevation	.516	.113	.177
Soil texture	*(Inadequate variation in the factor to calculate r-squared)*		
Livestock Index	.006	.258	.031
Vehicle Index	*(Inadequate variation in the factor to calculate r-squared)*		
Road distance	.062	.082	.024
Livestock congr. dist. (Imprvdist)	.000	.298	.004

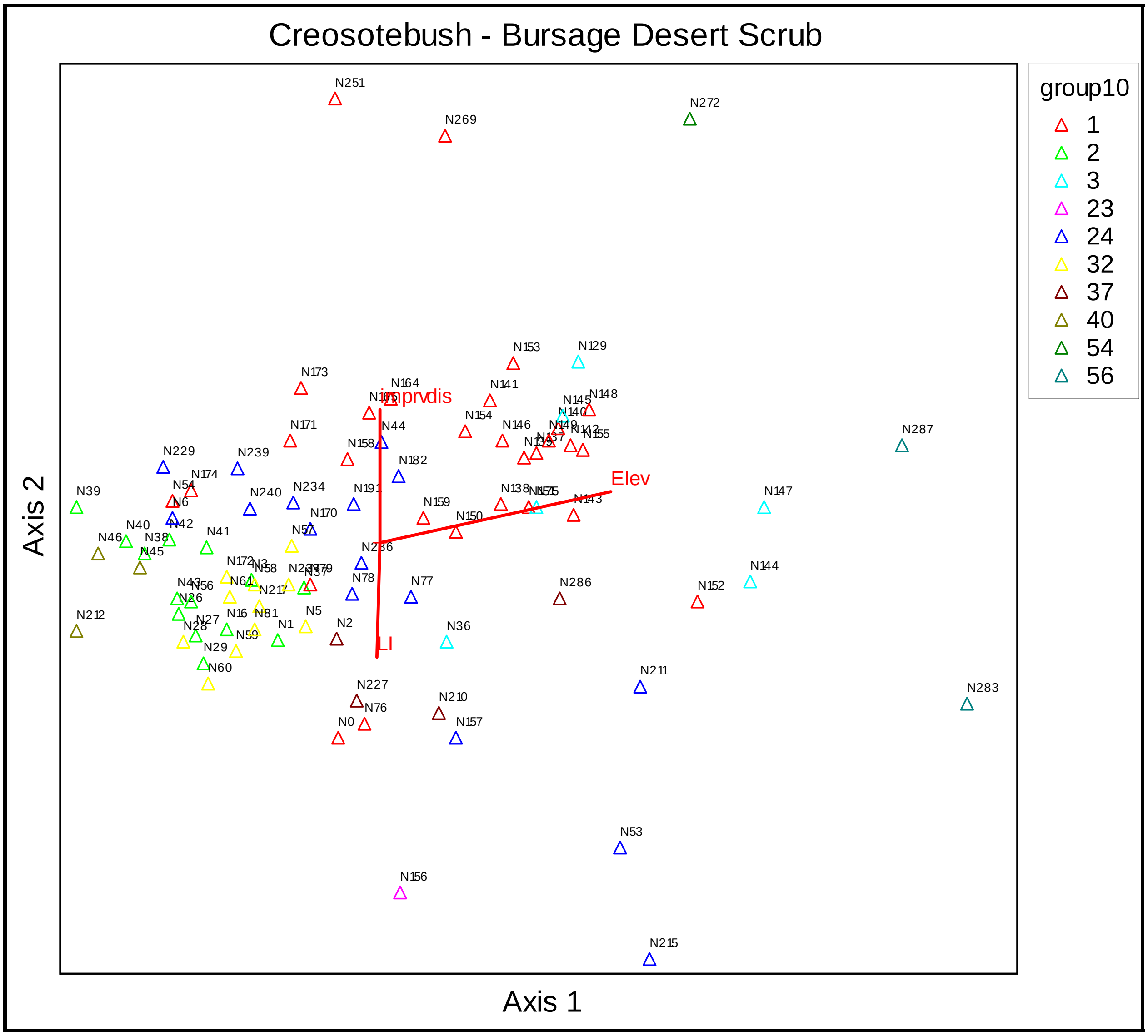


Figure 20. DECORANA graph of distribution of plots in Creosotebush-Bursage Desert Scrub in relationship to Axis 1 and 2 with plot clusters color-coded and relationship to significant secondary gradients illustrated by red line vectors.

Variation within the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* Community

Thirty-five field ecology plots were placed over a wide range of environmental conditions within this community. One outlier plot was removed from the dataset before conducting the DECORANA analysis because it was in a heavily disturbed area at the transition zone between the *Paloverde - Mixed Cacti-Mixed Scrub on Bajadas* community and the *Creosotebush-Bursage Desert Scrub* community. Although this plot was located in an area mapped as *Paloverde - Mixed Cacti-Mixed Scrub on Bajadas*, the location was so highly altered that it better represented highly disturbed *Creosotebush-Bursage Desert Scrub*. This plot was assigned to cluster group zero.

The remaining plots can be grouped by hierarchical cluster analysis into ten major groups (Figure 21). The first group of plots encountered in the cluster diagram (cluster group 1) contain *Parkinsonia microphylla* as the only tree species. There is also a moderate diversity of cacti, shrubs, herbs and grasses (Figures 21 and 22, Appendix H). This group has an overall low vegetative cover. The next group (cluster group 2) of plots represent areas without any tree or cacti cover, though they have a moderate cover of shrubs, herbs and exotic grasses. This group of plots' species composition matches better with the *Creosotebush-Bursage Desert Scrub* community, but because they occur as small inclusions within the *Paloverde - Mixed Cacti-Mixed Scrub on Bajadas* community, they should be included as a variation of this community.

Cluster group 3 has a more diverse tree canopy with *Olneya tesota* as the dominant tree species (2.57% cover). It has moderate shrub and herb cover with little grass or cacti. The next cluster group (group 14) is characterized by a low tree cover (1.5%) and a relatively high cover of cacti species (4.3%) – predominantly *Cylindropuntia acanthocarpa*. It has high herbaceous cover, with *Lepidium lasiocarpum* being the dominant plant in the community (13% cover).

The next major cluster group (group 8) in the cluster diagram is characterized by fairly low tree cover (2.5%), relatively high saguaro (*Carnegiea gigantea*) cover (0.88%), high shrub cover 18.38% and a high cover of herbs and grasses (27.69%). *Cryptantha maritima* (7.25% cover) is the dominant herb and *Schismus arabicus* is a common grass (10% cover).

The last major cluster group in the cluster diagram (group 12) is characterized by a much higher cover of *Parkinsonia microphylla* (10.74%) and a high cover of *Ambrosia deltoidea* (10.14%). It has a high herbaceous cover (19.86%), low grass cover (2.14%) and moderate cacti cover (2.04%). The native species diversity of this cluster group is exceptionally high and there is only one exotic plant species *Schismus arabicus* (1.89% cover) in this group of plots. This cluster group best represents typical baseline conditions for the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* community.

More information about the composition of the major and minor cluster groups is available in (Appendix H). The *Paloverde - Mixed Cacti – Mixed Scrub on Bajada* community is one of the most diverse natural community types with considerable variation in composition.

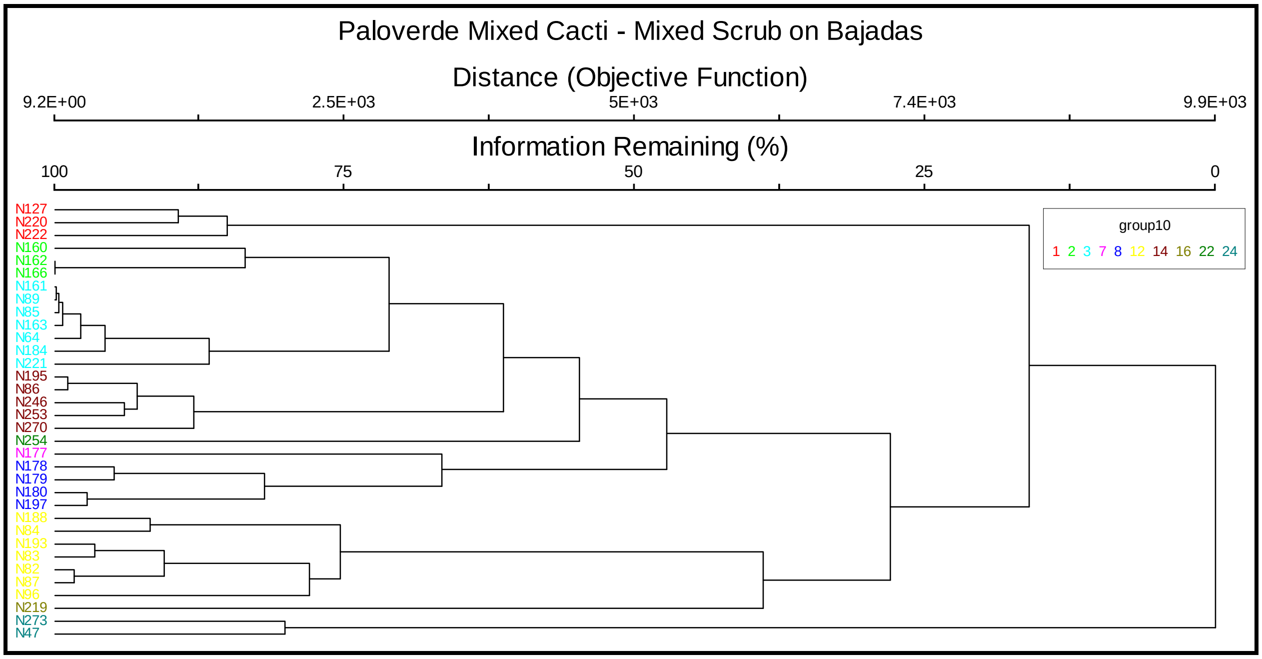


Figure 21. Hierarchical cluster analysis of the *Paloverde - Mixed Cacti-Mixed Scrub on Bajadas* natural community plots divided into ten major groups based on similarity of species composition.

The primary factors influencing the variation in composition within the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* community appear to be distance from potential livestock congregation areas (correlated with DECORANA Axis 1) and soil texture (correlated with DECORANA Axis 2) (Table 17, Figures 22 and 23). Although DECORANA axis 3 explains a higher percent of the variation than the other two axes (26.3% as compared to 18.4% and 11.6% for axes 1 and 2, respectively) it is not strongly correlated with any of our measured factors and therefore is not particularly interpretable. However, since it is significant in the overall ordination (i.e. in quantifying how similar plots are in terms of composition) we show the plots graphed against it and against axis 1, which has the second highest r-squared value (Figure 23).

Table 17. Coefficients of determination for DECORANA axes for plots within the *Paloverde - Mixed Cacti-Mixed Scrub on Bajadas* community and correlation to environmental and disturbance gradients.

Paloverde - Mixed Cacti-Mixed Scrub on Bajadas			
Cumulative r-squared for all 3 DCA axes = .563 (based on 34 plots) (one outlier removed)			
DECORANA Axis:	**1**	**2**	**3**
Axis r-squared	.184	.116	.263
	r-sq	**r-sq**	**r-sq**
Elevation	.169	.058	.006
Soil texture	.009	.201	.019
Livestock Index	.020	.079	.003
Vehicle Index	.031	.012	.017
Road distance	.032	.011	.069
Livestock congr. dist. (Imprvdist)	.353	.002	.055

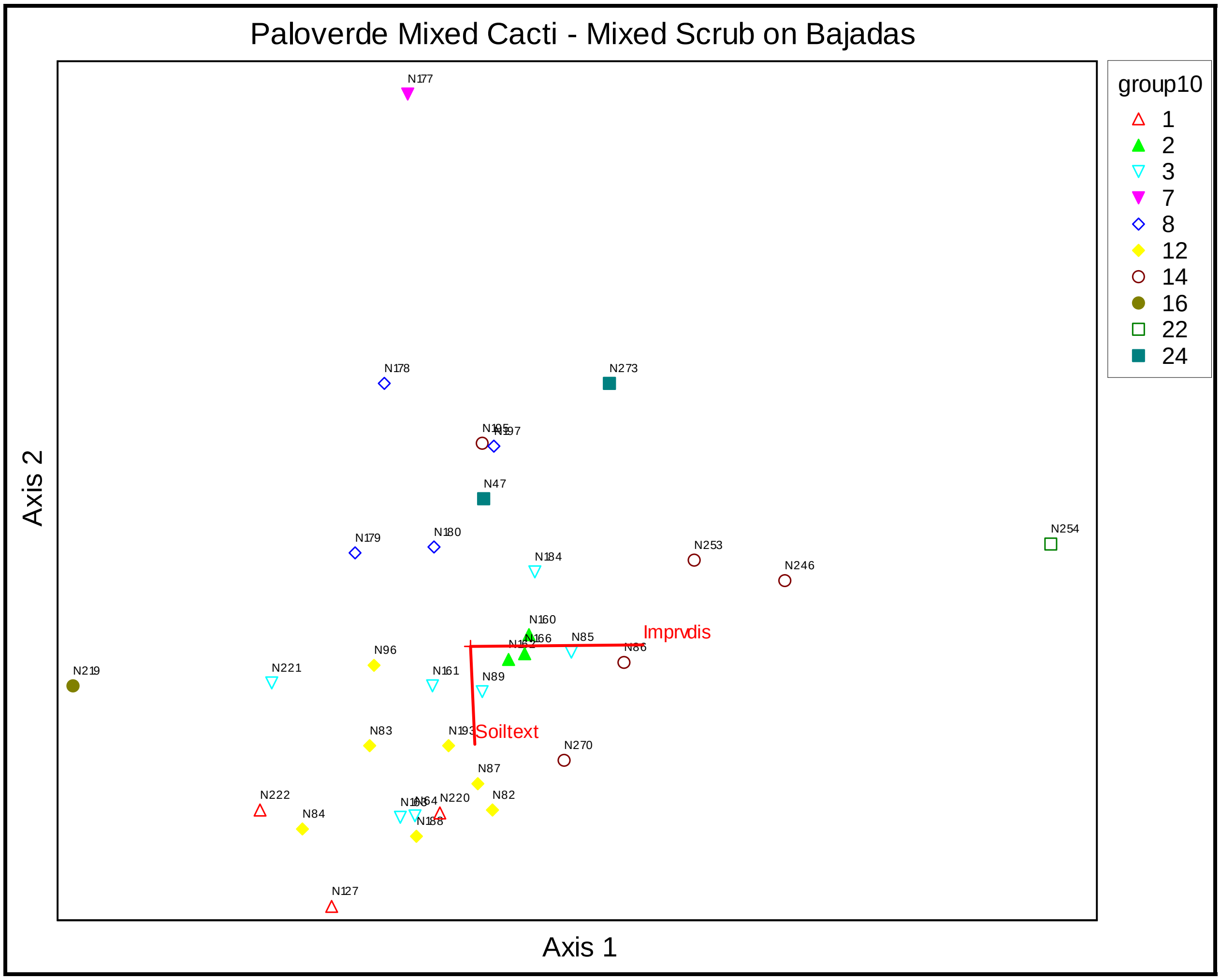


Figure 22. DECORANA graph of distribution of plots in the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* community in relationship to Axis 1 and 2 with plot clusters color-coded and relationship to significant secondary gradients illustrated by red line vectors.

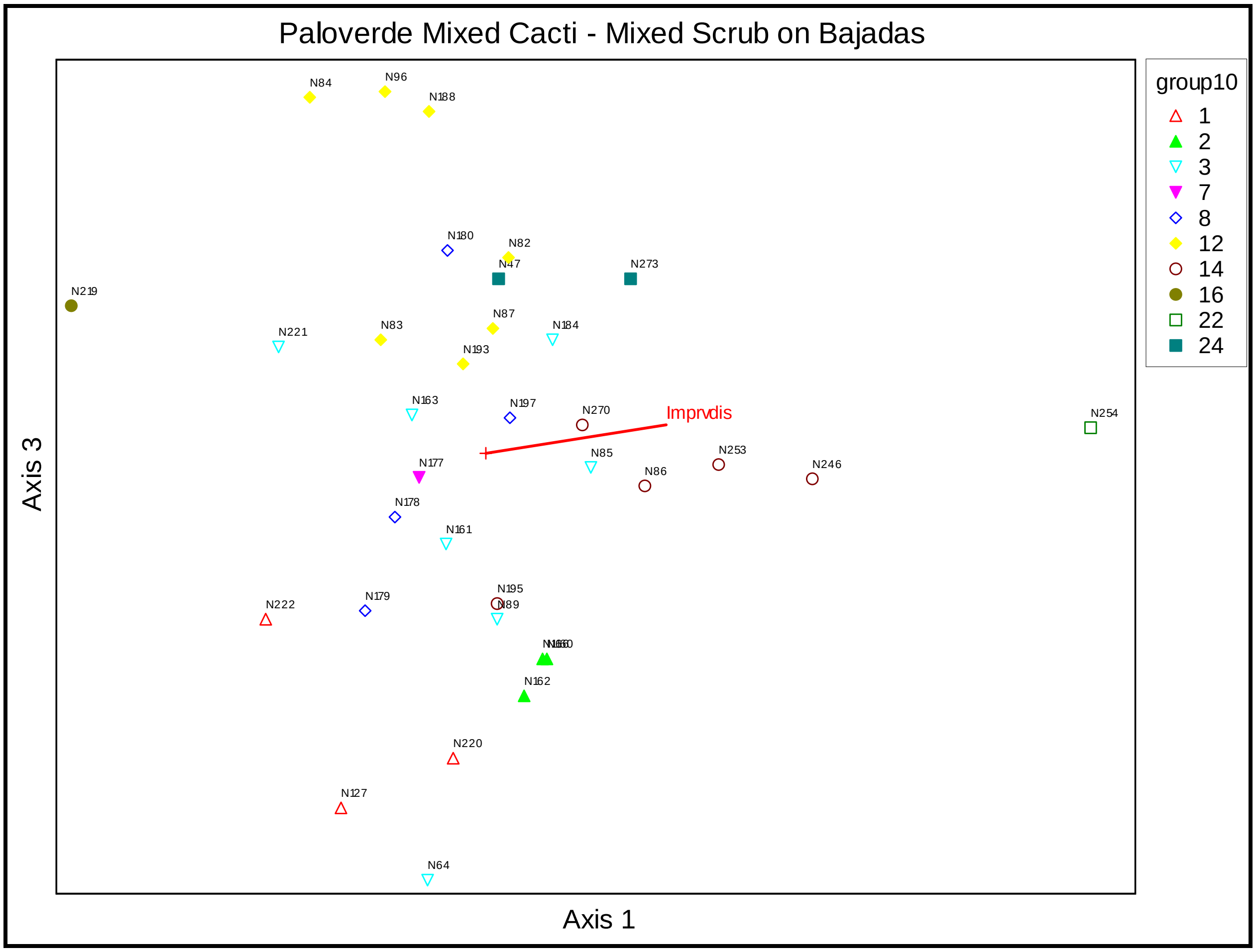


Figure 23. DECORANA graph of the distribution of plots in the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* community in relationship to Axis 1 and 3. Plot clusters are color-coded and relationships to significant secondary gradients are illustrated by red line vectors.

Variation within the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* Community

Sixty-four field ecology plots were taken within a wide range of environmental conditions within this community. These plots can be grouped by hierarchical cluster analysis into ten major groups. The first group of plots represents areas with moderate slope conditions on a variety of aspects and near average composition for this community (group 1, Figures 24 and 25). This group has only a low cover of *Schismus arabicus* and no *Erodium cicutarium* (Appendices I and J). *Encelia farinosa* is the dominant shrub and occurs in greatest abundance in this cluster group (Appendices I and J). The second cluster group of plots (group 4) represents areas with the highest cover of *Parkinsonia microphylla* (mean cover of 21.6%) of all the cluster groups (Appendices I and J).

Schismus arabicus is found in highest abundance in cluster group 15 (mean cover 28.25%) and *Erodium cicutarium* is found in highest abundance in cluster group 42 (mean cover 14.6%)

(Appendices K and L). Both of these cluster groups with high exotic cover are found primarily on more gentle slopes near the lower limits of the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community. These species are present in some other areas within this community, but only in low abundance. Other exotic species are found in low abundance in this community.

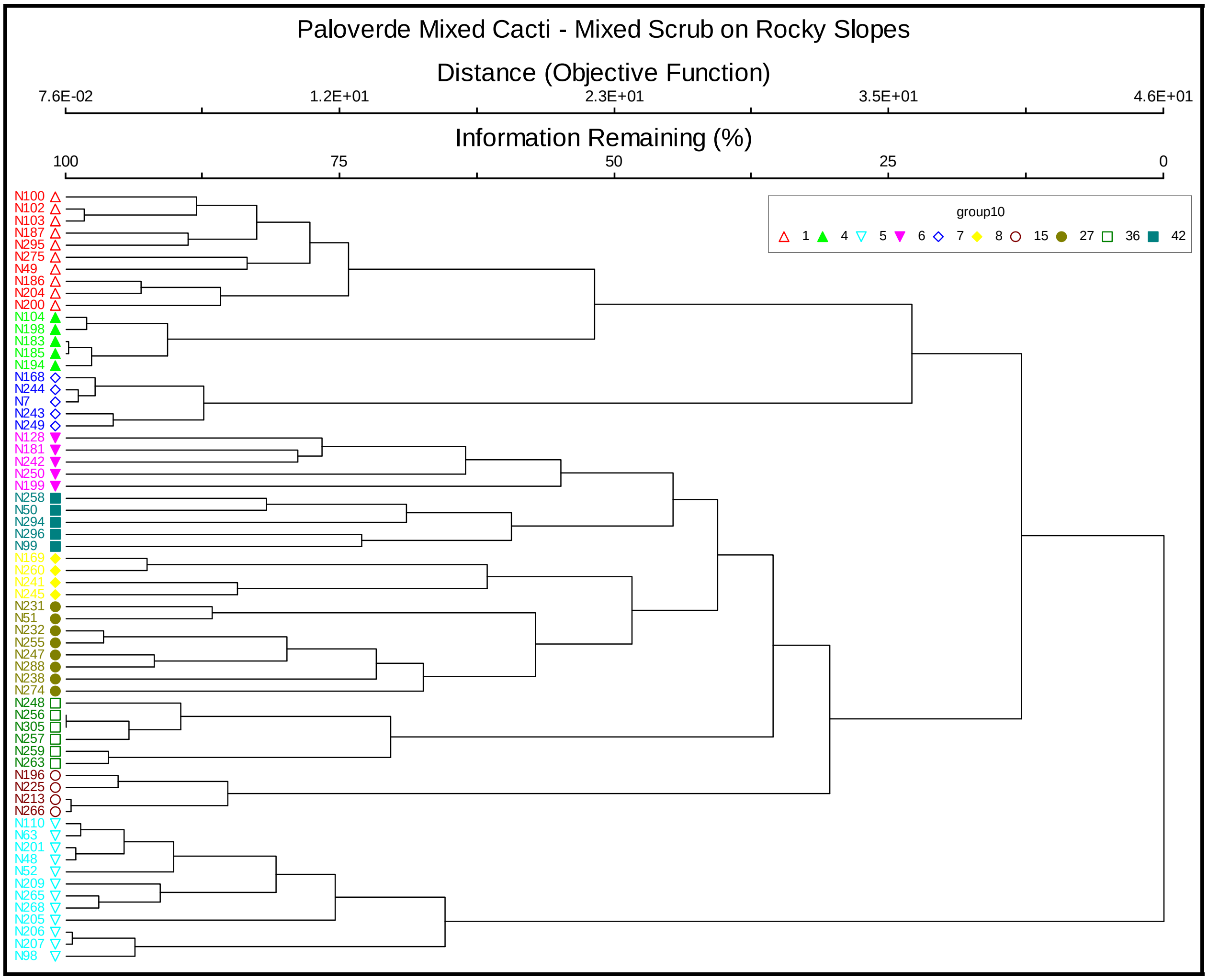


Figure 24. Hierarchical cluster analysis of the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* natural community plots divided into ten major groups based on similarity of species composition.

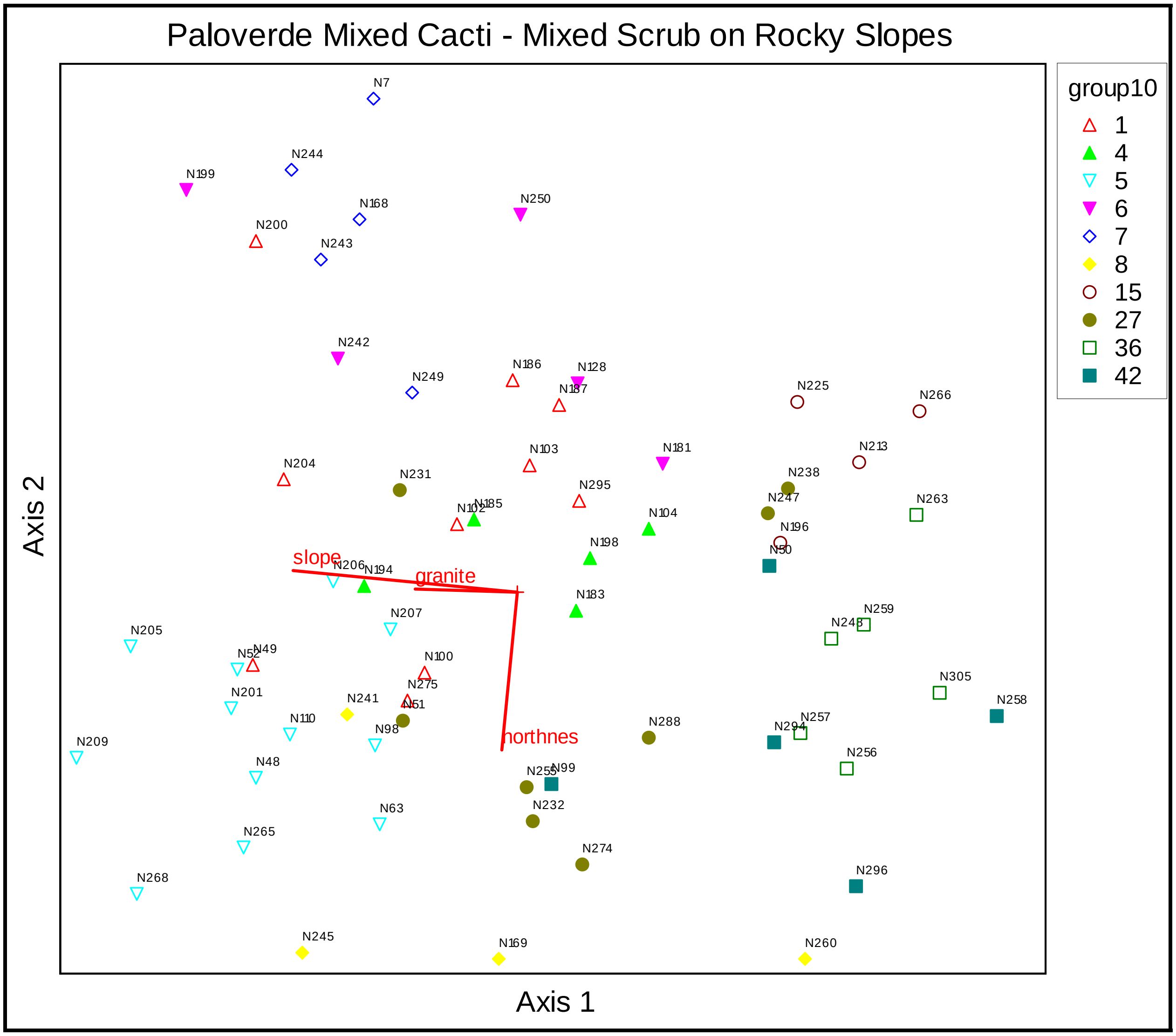


Figure 25. DECORANA graph of distribution of plots in the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community in relationship to Axis 1 and 2 with plot clusters color-coded and relationship to significant secondary gradients illustrated by red line vectors.

One of the extremes of the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community on DECORANA Axis 1 is represented by the last cluster group in the dendrogram (group 5), which is characterized by a high cover of *Selaginella arizonica* (Figure 26(b), Appendices K and L). This cluster group occurs primarily on north aspects (see Figure 27) of granitic mountains and has a mean *Selaginella* cover of 23.33%. Another extreme is represented by cluster group 36, which has a high cover of *Lesquerella gordonii* (16.17%) and *Lepidium lasiocarpum* (14.04%), diverse and abundant cacti species, low cover of *Parkinsonia microphylla* and low exotic species cover (Figure 26(a), Appendices K and L). This cluster group is found on more gentle slopes, generally without north-facing aspects.

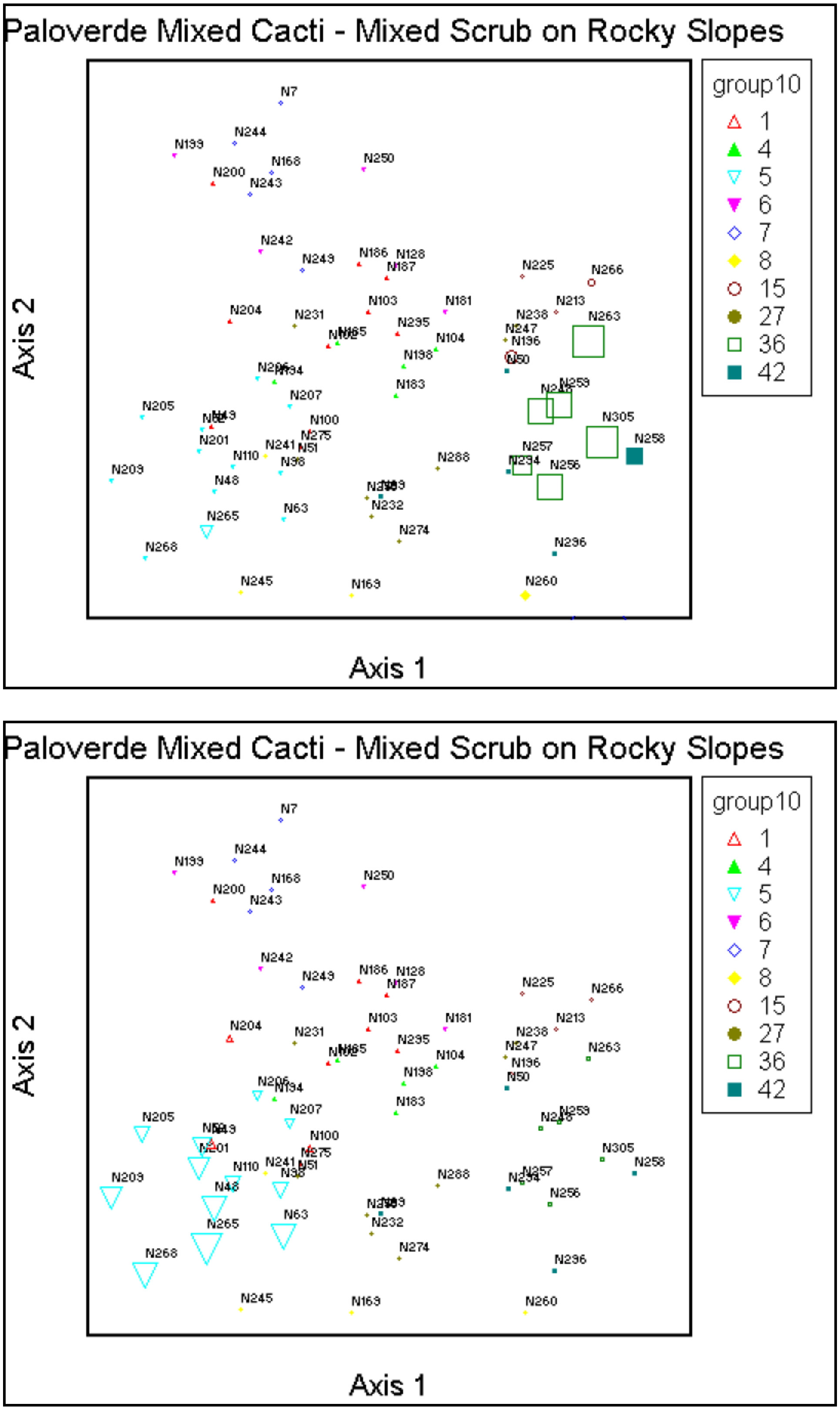


Figure 26. Distribution of plots illustrating cover of (a) (top) *Lesquerella gordonii* and (b) (bottom) *Selaginella arizonica*. Symbol size represents relative percent cover of each species. Plot symbol represents cluster group.

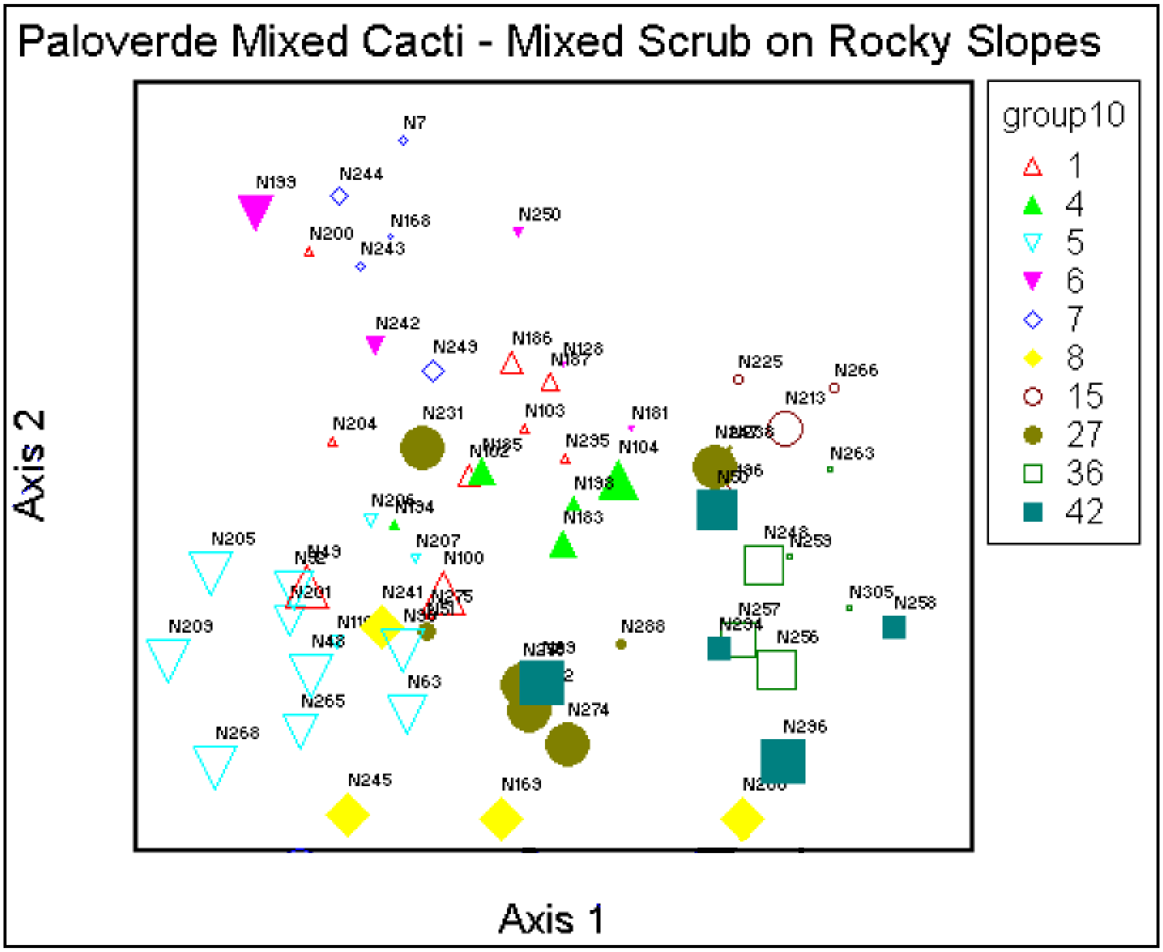


Figure 27. DECORANA graph of distribution of plots in the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community in relationship to Axis 1 and 2 with plot clusters color-coded and relationship to a "northness" gradient illustrated by proportional size of plot symbols.

One of the extremes of the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community on DECORANA Axis 2 is represented by cluster group 7, which is characterized by the highest cover of *Perityle emoryi* (mean cover 11.8%) (Figure 28(b), Appendices K and L). The other extreme is represented by cluster group 8, which contains the highest values of *Cryptantha pterocarya* (mean cover 15.5%) (Figure 28(a)).

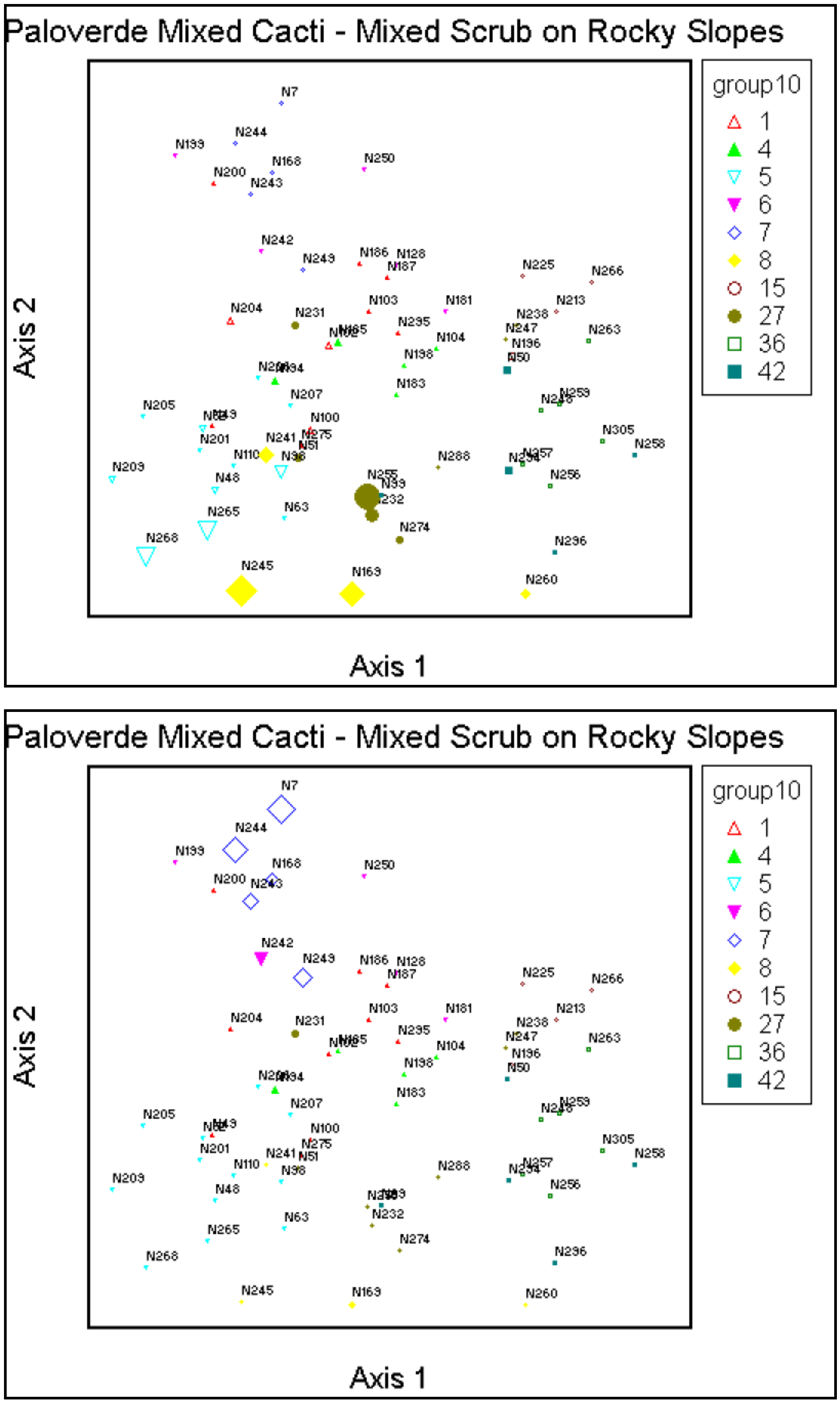


Figure 28. Distribution of plots illustrating cover of (a) (top)*Cryptantha pterocarya* and (b) (bottom) *Perityle emoryi* . Symbol size represents relative percent cover of each species. Plot symbol represents cluster group.

The *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community is the most diverse natural community in the study area with considerable variation in composition. Certain species are found in many areas within this community, but other species have strong preferences to certain sites with unique substrates, moisture and temperature characteristics (Appendices K and L). These sites can often be predicted based on aspect, slope, elevation and geology.

The primary factors influencing the variation in composition within the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community are slope steepness and presence of granitic substrate, correlated with DECORANA Axis 1, and "northness," correlated with DECORANA Axis 2 (Table 18, Figures 25 and 27). There are low correlations with human disturbance measures in this community. This finding matches our field observations that human disturbance is low and relatively uniform in this community.

Table 18. Coefficients of determination for DECORANA axes for plots within the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community and correlation to environmental and disturbance gradients.

Paloverde - Mixed Cacti-Mixed Scrub on Rocky Slopes			
Cumulative r-squared for all 3 DCA axes = .475 (based on 64 plots)			
DCA Axis:	**1**	**2**	**3**
Axis r-squared	.225	.202	.048
	r-sq	**r-sq**	**r-sq**
Elevation	.026	.029	.057
Soil texture	.177	.006	.036
Slope	.488	.046	.044
Northness	.033	.343	.047
Eastness	.020	.019	.012
Metamorphic	.002	.008	.020
Granite	.220	.005	.009
Volcanic	.112	.014	.001
Alluvium	.069	.000	.004
Livestock index	*(Inadequate variation in the factor to calculate r-squared)*		
Vehicle index	*(Inadequate variation in the factor to calculate r-squared)*		
Road distance	.026	.044	.012
Livestock congr. dist. (Imprvdist)	.079	.010	.030

Variation within the *Mountain Upland* Community

The *Mountain Upland* varies considerably in composition and structure but it is considerably less variable than the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community. This is largely due to its limited extent and fairly strict definition of community composition. The variation within this community is described in the cluster dendrogram (Figure 29) and corresponding cluster group descriptions (Appendix K).

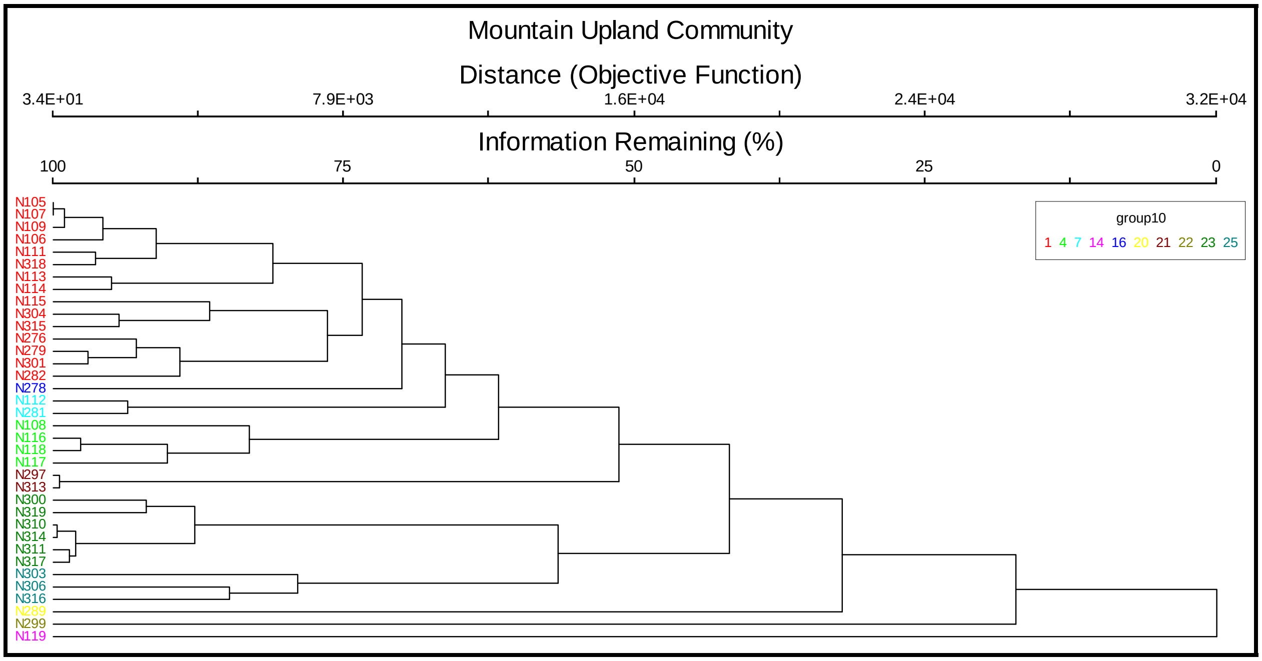


Figure 29. Hierarchical cluster analysis of the *Mountain Upland* natural community plots divided into ten major groups based on similarity of species composition.

The primary factors influencing the variation in composition within the *Mountain Upland* community are elevation, northness, and slope, all of which are correlated with DECORANA Axis 1 (Table 19 and Figure 30). Distance from road is also strongly correlated with DECORANA Axis 1, but based on our field experience; we think this finding is in error. Most of this community is at the tops of mountains and is relatively distant from roads. It is possible that errors in the roads data may be affecting this analysis. Since our field knowledge does not support this result, we have chosen not to highlight it as one of the significant factors for this community, despite its high r-squared value. Volcanic substrate and distance from potential livestock congregation areas are weakly correlated with DECORANA Axis 2 (Table 19, Figure 30). Elevation and distance from potential livestock congregation areas are highly correlated with DECORANA Axis 3 but since this axis only accounts for 6.7% of the variation in community composition, these correlations are not particularly significant.

Table 19. Coefficients of determination for DECORANA axes for plots within the Mountain Upland community and correlation to environmental and disturbance gradients.

Mountain Uplands			
Cumulative r-squared for all 3 DCA axes = .399 (based on 36 plots)			
DCA Axis:	**1**	**2**	**3**
Axis r-squared	.176	.156	.067
	r-sq	**r-sq**	**r-sq**
Elevation	.476	.001	.314
Soil texture	*(Inadequate variation in the factor to calculate r-squared)*		
Slope	.200	.000	.120
Northness	.424	.030	.010
Eastness	.014	.052	.073
Metamorphic	.042	.085	.059
Granite	*(Inadequate variation in the factor to calculate r-squared)*		
Volcanic	.067	.123	.080
Alluvium	*(Inadequate variation in the factor to calculate r-squared)*		
Livestock index	*(Inadequate variation in the factor to calculate r-squared)*		
Vehicle index	*(Inadequate variation in the factor to calculate r-squared)*		
Road distance	.612	.021	.161
Livestock congr. dist. (Imprvdist)	.168	.149	.415

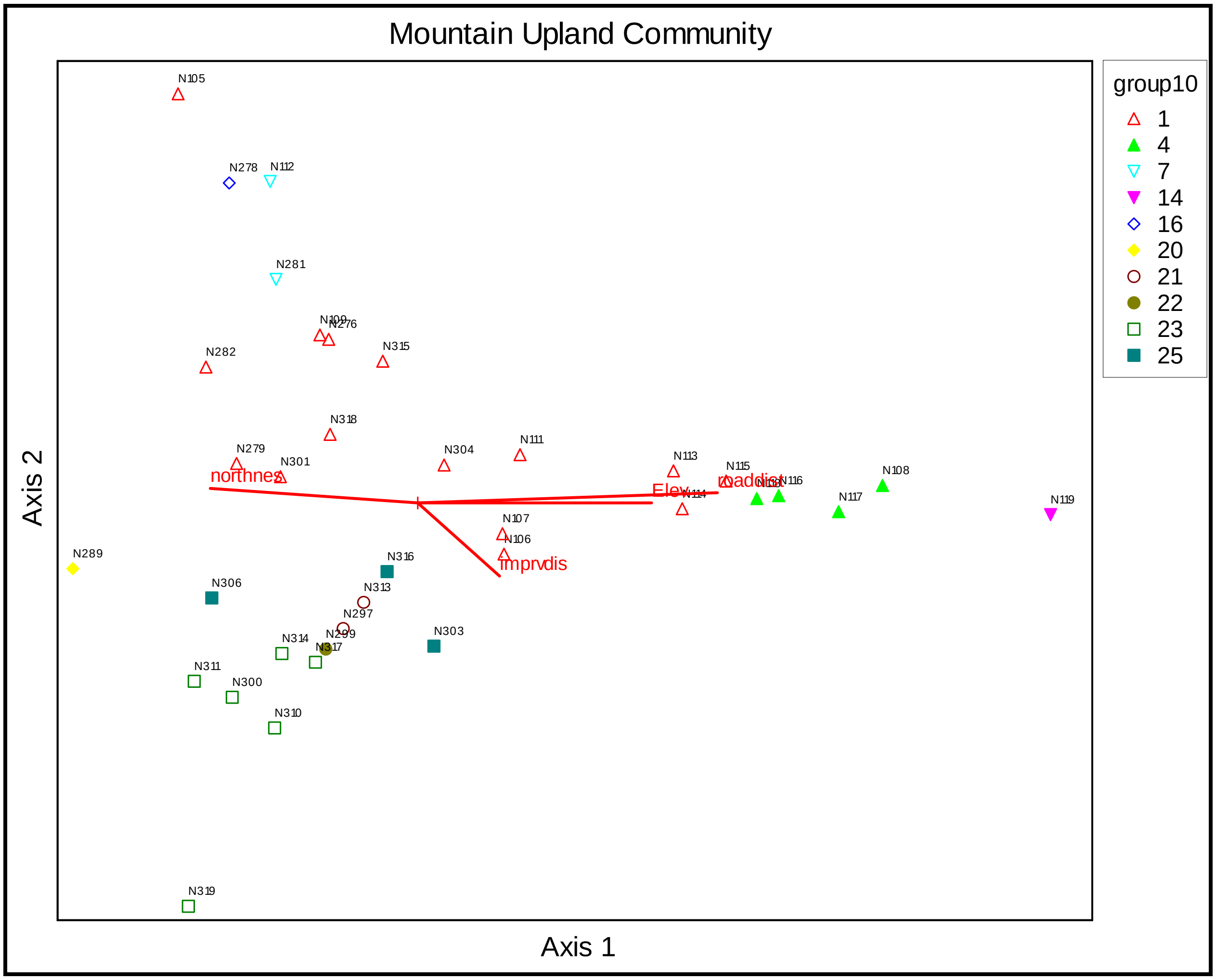


Figure 30. DECORANA graph of distribution of plots in the *Mountain Upland* community in relationship to Axis 1 and 2 with plot clusters color-coded and relationship to significant secondary gradients illustrated by red line vectors.

Variation within the *Desert Grasslands* Community

The *Desert Grassland* community as mapped and described in this project is limited to a relatively small area in the Vekol Valley and areas to the south on the TON. There is little variation within the small polygon of *Desert Grassland* that exists on the SDNM. We were not able to sample the grasslands on the TON because access permission was received well after the close of the spring field season. We will do further analysis of variation in the grassland community on both the TON and SDNM in late September or early October of this year.

Variation within the *Mesquite Woodland* Community

The *Mesquite Woodland* community varies somewhat in composition and structure but it is less variable than many of the communities in the study area. The variation in species composition within this community is represented in the cluster dendrogram (Figure 31 and Appendix L). Structural variation, perhaps the most significant factor influencing variation within this community, was not assessed in our DECORANA analysis.

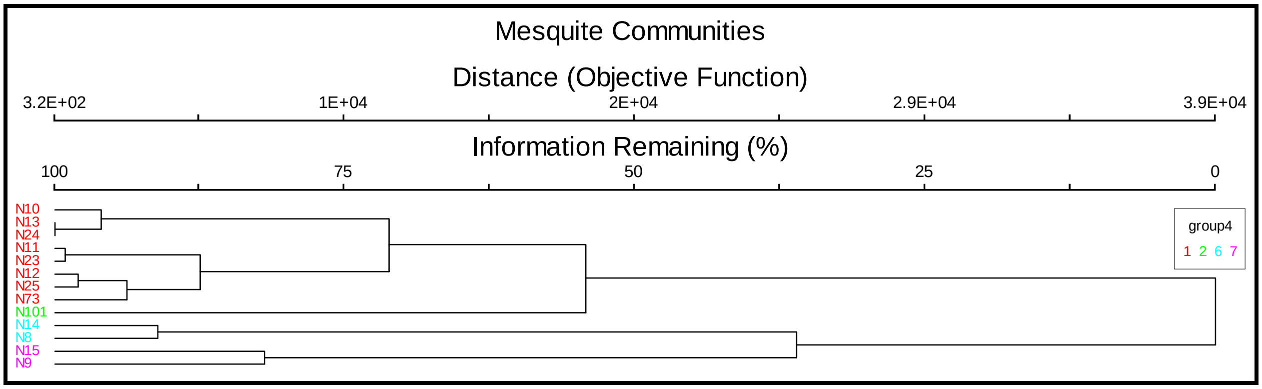


Figure 31. Hierarchical cluster analysis of *Mesquite Woodland* natural community plots divided into four major groups based on similarity of species composition.

The primary factors influencing the variation in composition within the *Mesquite Woodland* community are distance from potential livestock congregation areas and distance from roads, which are both correlated with DECORANA axis 1 (Table 20 and Figure 32). Although elevation appears to be correlated with axis 1, this is largely an artifact from the location of two plots at a different location and at notably higher elevations than the majority of the plots. Although elevation may play a part, we think that other factors related to the location of these plots explain much more of the variation in composition and therefore we have chosen not to highlight elevation as a factor.

Table 20. Coefficients of determination for DECORANA axes for plots within the Mesquite Woodland community and correlation to environmental and disturbance gradients.

Mesquite Woodlands			
Cumulative r-squared for all 3 DCA axes = .816 (based on 13 plots)			
DCA Axis:	**1**	**2**	**3**
Axis r-squared	.592	.149	.075
	r-sq	**r-sq**	**r-sq**
Elevation	.430	.050	.000
Soil texture	.084	.008	.088
Livestock index	.100	.051	.009
Vehicle index	*(Inadequate variation in the factor to calculate r-squared)*		
Road distance	.276	.017	.007
Livestock congr. dist. (Imprvdist)	.571	.126	.141

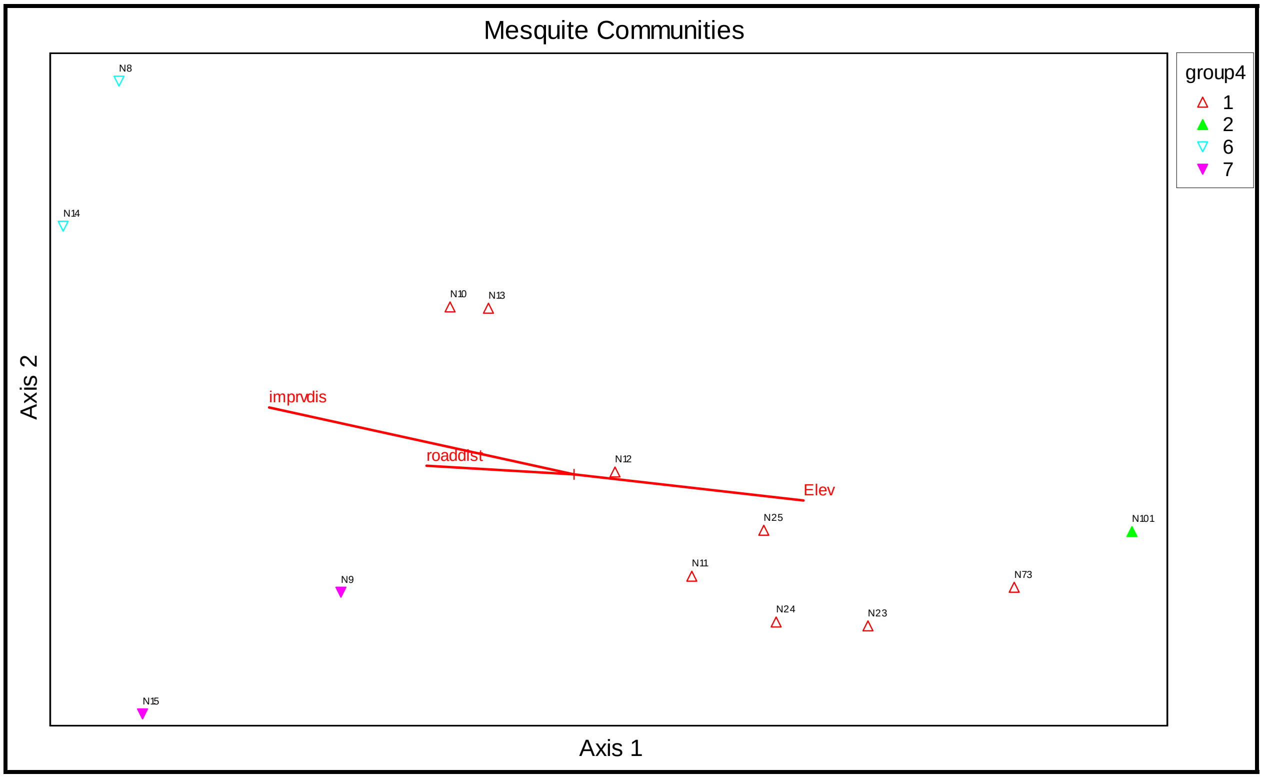


Figure 32. DECORANA graph of distribution of plots in *Mesquite Woodland* community in relationship to Axis 1 and 2 with plot clusters color-coded and relationship to significant secondary gradients illustrated by red line vectors.

Variation within the *Rock Outcrop* Community

The *Rock Outcrop* community covers the smallest spatial extent of any natural community in the study area. Because the rock outcrops are difficult and dangerous to sample due to extreme steepness and exposure, only limited sampling was done. The *Rock Outcrop* community is characterized by a low vegetative cover and presence of extensive surface rock. A description of the characteristics of this community is presented above, but no further analysis of variation was done due to the limited plot data available. Field observations revealed that variability due to human disturbance is low in this community.

Variation within the *Mountain Xeroriparian Scrub* Community

Mountain Xeroriparian Scrub communities are confined to narrow, relatively steep channels within the *Mountain Upland* and *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* communities. They are highly defined and limited in extent and therefore have less variation in composition than the surrounding communities. The cluster dendrogram for this community breaks the field plots into 6 clusters representing this variation (Figure 33). Variation in species composition within the cluster groups is presented in Appendix M.

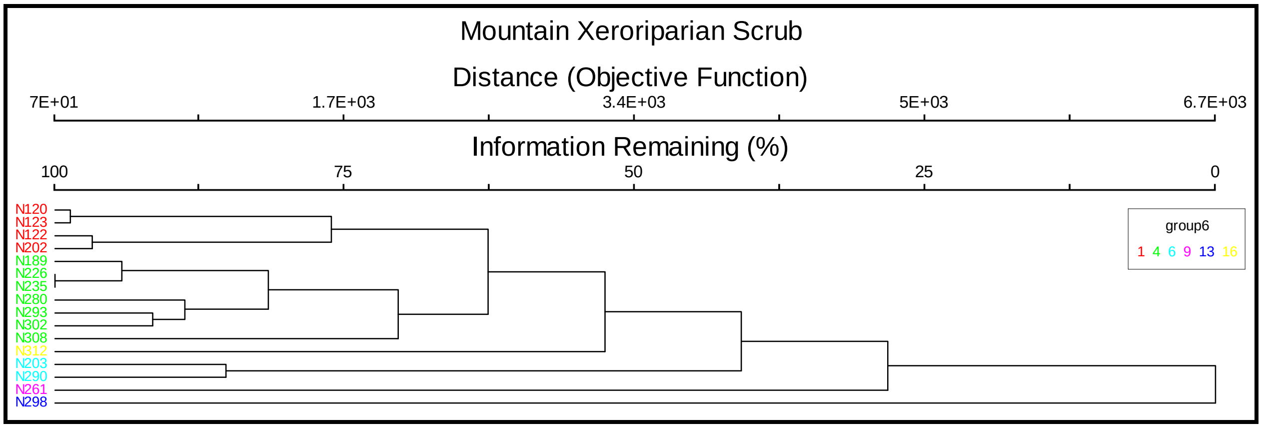


Figure 33. Hierarchical cluster analysis of the Mountain Xeroriparian Scrub community natural community plots divided into six groups based on similarity of species composition.

The primary factors influencing variation in composition within the *Mountain Xeroriparian Scrub* community are elevation, aspect (northness and eastness), and geologic substrate (volcanic and granite), all of which are correlated with DECORANA axis 1 (Table 21 and Figure 34). Although slope is weakly correlated with axis 3, this axis only accounts for 1.6% of the variation in composition, and therefore slope is not considered a strong factor. The vectors overlaying the ordination graph that represent geologic types show close to opposite directions for the influence of granite versus volcanic substrates on community composition (Figure 34). This implies that there are strong differences in vegetative composition between these two substrates.

Table 21. Coefficients of determination for DECORANA axes for plots within the Mountain Xeroriparian Scrub community and correlation to environmental and disturbance gradients.

Mountain Xeroriparian Scrub			
Cumulative r-squared for all 3 DCA axes = .367 (based on 16 plots)			
DCA Axis:	**1**	**2**	**3**
Axis r-squared	.367	-.016	.016
	r-sq	**r-sq**	**r-sq**
Alluvium	.083	.057	.012
Volcanic	.333	.001	.004
Granite	.268	.014	.184
Metamorphic	.019	.103	.046
Soil texture	.007	.088	.101
Eastness	.355	.021	.027
Northness	.284	.009	.048
Slope	.106	.020	.197
Elevation	.474	.117	.036
Livestock index	.002	.003	.168
Road distance	.042	.045	.002
Livestock congr. dist. (lmprvdist)	.005	.037	.098

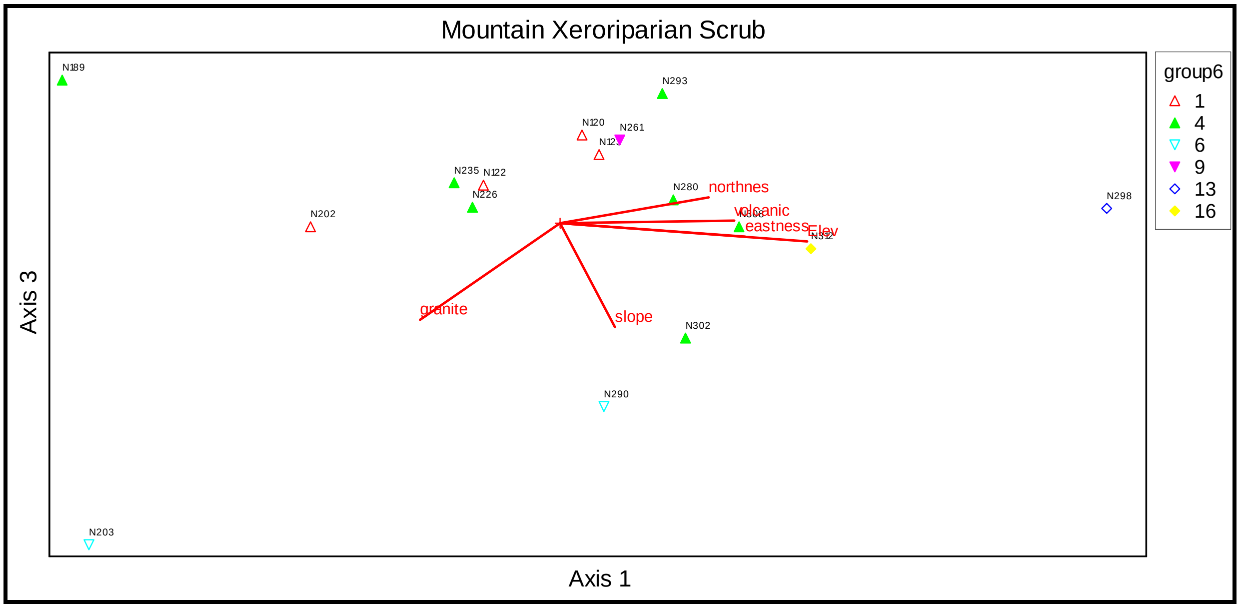


Figure 34. DECORANA graph of distribution of plots in the Mountain Xeroriparian Scrub community in relationship to Axis 1 and 3 with plot clusters color-coded and relationship to significant secondary gradients illustrated by red line vectors.

Variation within the *Valley Xeroriparian Scrub* Community

The *Valley Xeroriparian Scrub* community is confined to fairly narrow bands along stream courses that flow across the bajadas and desert flats, primarily within *the Creosotebush – Bursage Desert Scrub* and *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* communities. It occupies considerably more extent and has more variation in composition than the *Mountain Xeroriparian Scrub* community. The cluster dendrogram for this community breaks the field plots into 4 major clusters representing this variation (Figure 35). Variation in species composition within the cluster groups is presented in Appendix N.

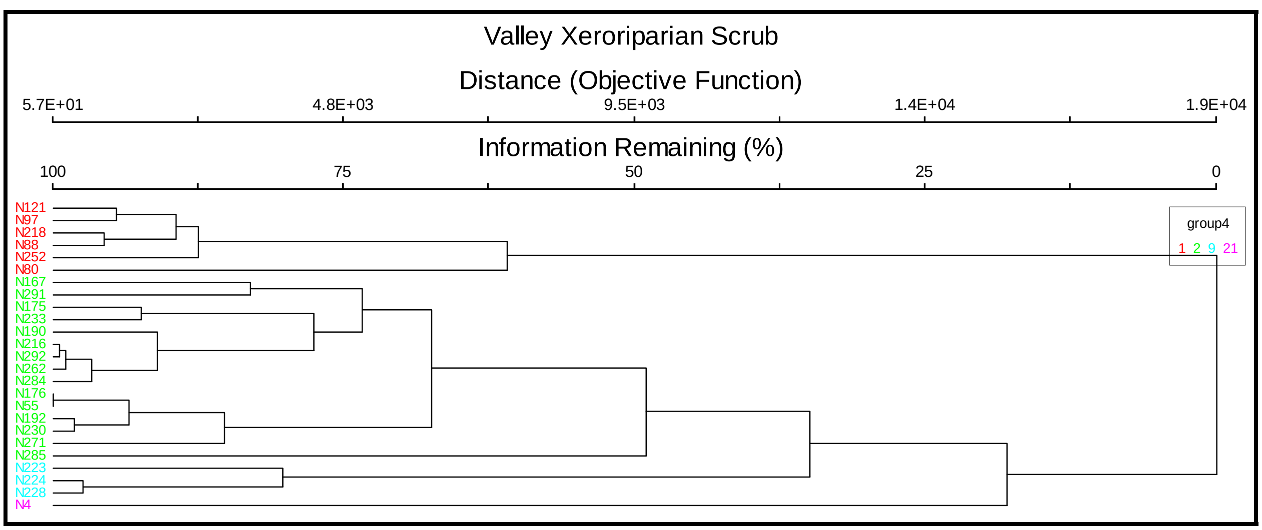


Figure 35. Hierarchical cluster analysis of the Valley Xeroriparian Scrub natural community plots divided into four major groups based on similarity of species composition.

The primary factor influencing the variation in composition within the *Valley Xeroriparian Scrub* community is elevation (Table 22 and Figure 36), which is correlated primarily with DECORANA axis 2 and to a lesser extent with axis 1. In the *Valley Xeroriparian Scrub* community the Vehicle Index values for all the plots was zero. Vehicle tracks often do not show in coarse gravel/ rock materials and are quickly erased by water in sandy washes. Since we didn't record any recent vehicle activity in the washes that we sampled, we did not include the Vehicle Index in the set of variables that we analyzed.

Table 22. Coefficients of determination for DECORANA axes for plots within the Valley Xeroriparian Scrub community and correlation to environmental and disturbance gradients.

Valley Xeroriparian Scrub			
Cumulative r-squared for all 3 DCA axes = .501 (based on 25 plots)			
DCA Axis:	**1**	**2**	**3**
Axis r-squared	.291	.172	.037
	r-sq	**r-sq**	**r-sq**
Elevation	.184	.315	.010
Livestock Index	.071	.008	.008
Road distance	.001	.129	.000
Livestock congr. dist. (Imprvdist)	.050	.045	.018

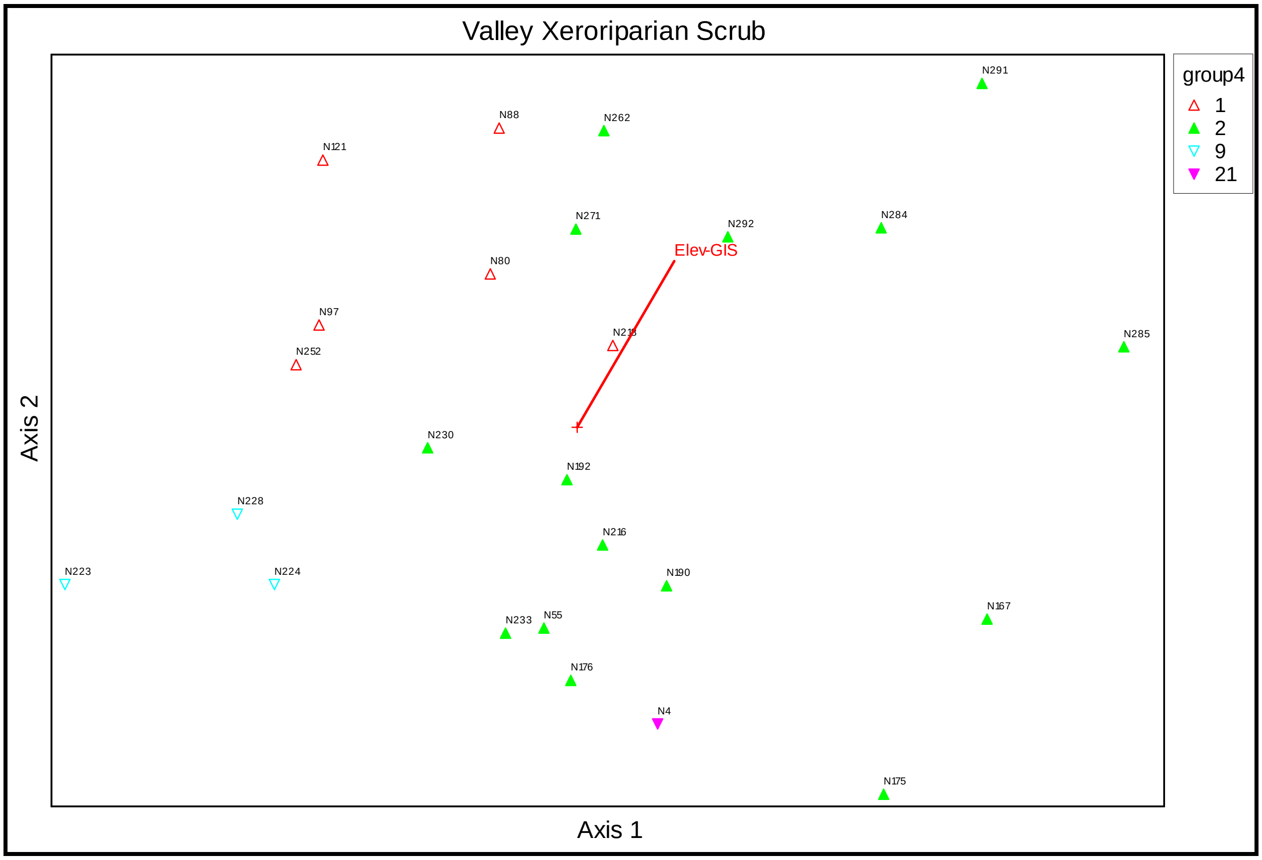


Figure 36. DECORANA graph of distribution of plots in the Valley Xeroriparian Scrub community in relationship to Axis 1 and 2 with plot clusters color-coded and relationship to significant secondary gradients illustrated by red line vectors.

Variation within the *Braided Channel Floodplain* Community

The *Braided Channel Floodplain* community is similar in many ways to the *Valley Xeroriparian Scrub* community. It occupies broad, braided channel drainage and floodplain areas that flow across the bajadas and desert flats, primarily within the *Creosotebush – Bursage Desert Scrub* and the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* communities. Because the floodplains are complexes of many sub-communities that occupy a variety of surfaces with varying disturbance histories (flooding, erosion, and deposition), variation within the *Braided Channel Floodplain* plots was high. The cluster dendrogram breaks the field plots into 5 major clusters that represent this variation (Figure 37). In all of the major cluster groups, the floodplain indicator plants *Baccharis sarothroides* and *Hymenoclea salsola* are present.

Cluster group 1 represents a single plot on a wash bank at the edge of the floodplain that is dominated by a dense shrub cover of *Lycium andersonii* (45% cover) and *Acacia greggii* (45% cover) (Appendix O). Cluster group 2 represents the wash beds that run through the floodplain area. They are largely covered by sand and gravel, but have a sparse cover of annual herbs and grasses. *Schismus arabicus* is the dominant plant in this group (5.5% cover) and *Pectocarya spp*. are also common (4.75% cover). There is a high diversity of other herbs with some shrubs and grasses in this group (Appendix N).

Cluster group 3 represents the tree dominated floodplain islands that are often part of the floodplain complex. This group is dominated by *Parkinsonia florida* (36.67% cover) along with *Olneya tesota* (18.33% cover). *Hymenoclea salsola* is the dominant shrub. *Schismus arabicus* is also abundant (43.33% cover). Overall species diversity is significantly lower than in cluster group 2.

Cluster group 5 represents floodplain border areas and islands that have a high similarity to the surrounding *Creosotebush-Bursage Desert Scrub* matrix community. *Schismus arabicus* is the dominant plant (42.83% cover). *Larrea divaricata tridentata* is the dominant shrub (2.25% cover). Cacti species are also present. There is a high diversity of herbs and high cover of herbs that are commonly associated with the *Creosotebush-Bursage Desert Scrub* community (*Pectocarya* spp., *Lepidium lasiocarpum*, and *Plantago ovata*) as well.

Cluster group 14 represents mesquite dominated (22.5% cover of *Prosopis velutina*) floodplain surfaces. This cluster group contains substantial amounts of *Larrea divaricata tridentata* (14.5% cover). *Pectocarya* spp. are also abundant (17.5% cover) as is *Schismus arabicus* (10% cover).

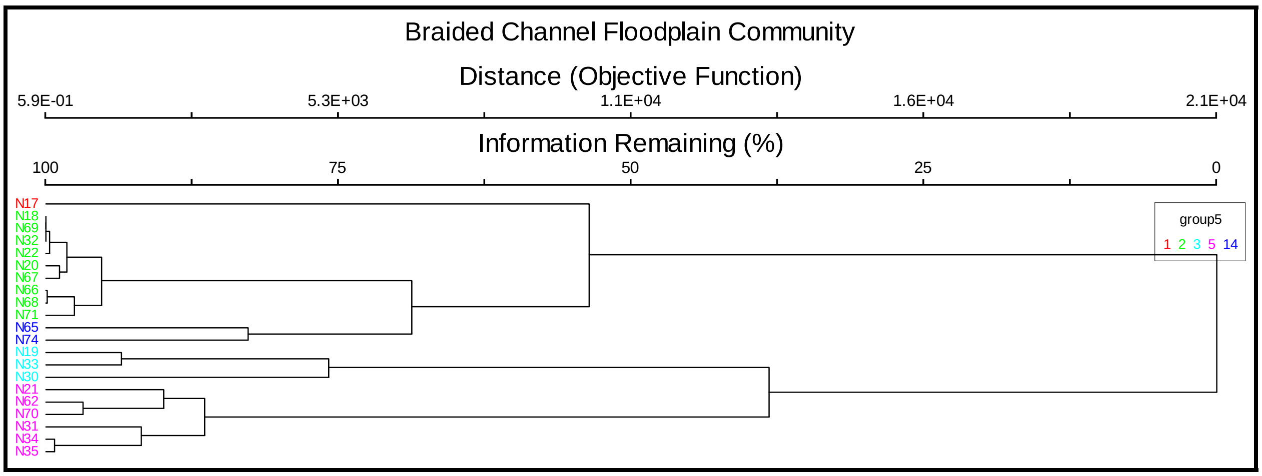


Figure 37. Hierarchical cluster analysis of the Braided Channel Floodplain natural community plots divided into five major groups based on similarity of species composition.

The primary factors influencing the variation in composition within the *Braided Channel Floodplain* community are our field survey-based livestock activity index and elevation (Table 23 and Figure 38), which are both correlated with DECORANA axis 2.

Table 23. Coefficients of determination for DECORANA axes for plots within the *Braided Channel Floodplain* community and correlation to environmental and disturbance gradients.

Braided Channel Floodplains			
Cumulative r-squared for all 3 DCA axes = .463 (based on 21 plots)			
DCA Axis:	**1**	**2**	**3**
Axis r-squared	.225	.202	.048
	r-sq	**r-sq**	**r-sq**

Elevation	.070	.420	.092
Livestock index	.070	.548	.001
Road distance	.007	.015	.013
Livestock congr. dist. (Imprvdist)	.002	.115	.039

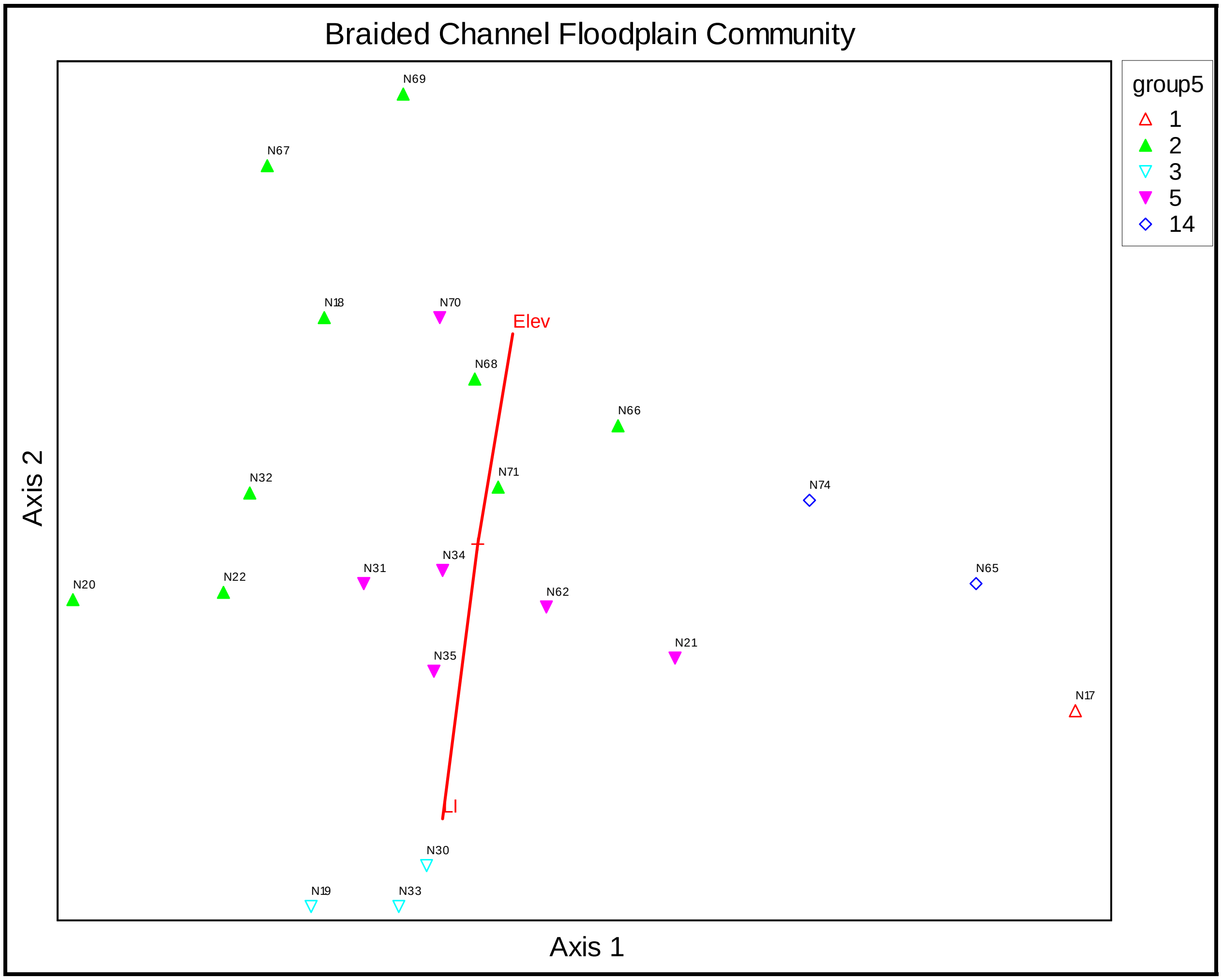


Figure 38. DECORANA graph of distribution of plots in the Braided Channel Floodplain community in relationship to Axis 1 and 2 with plot clusters color-coded and relationship to significant secondary gradients illustrated by red line vectors.

Variation within the *Desert Springs* and *Tinajas* Communities

Only two desert springs exist in the study area, both of which are of limited extent. While we sampled and described the natural community present at these two sites, the sample size was too small to analyze variation within this community. The mapped tinajas in the area were mostly man-made reservoirs or “tanks”, and vegetative analysis was not done.

Ecological Condition of Natural Communities

In order to look at ecological condition we first identified a number of field-based measurements that strongly influence condition and/or quantify levels of disturbance (e.g. percent cover of native and exotic species, etc.). We used these to define and describe three levels of ecological condition. We tested whether our GIS data could be used to model and map condition by analyzing relationships of the plot-based measures of condition and disturbance to GIS-derived layers.

We used multiple sources of information to assign each natural community plot to one of the three condition classes, then used ANOVA to test how well the condition classes (as assigned to the field plots) were differentiated from each other (this was done only for the *Creosotebush – Bursage Desert Scrub* community, as an example).

We developed models for the 3 condition classes on a community-by-community basis. Finally we created a map portraying the modeled condition classes for all communities.

Levels of Ecological Condition

We mapped three levels of ecological condition (Figure 42) based on the results of our landscape-level assessment and analysis of the natural community plot and exotic plant plot data. These three levels are described below:

> **Condition Class 1.** This condition class represents areas that have been altered to the point where the ecological condition often deviates dramatically from baseline conditions found in areas where stressors are much less prevalent. Areas characterized by Condition Class 1 often have high amounts of bare ground and/or exotic plant cover. The structure of the natural community present in Condition Class 1 areas is often significantly altered from baseline conditions. Often one or more of the structural layers may be significantly altered or even missing from the community. The composition of native vegetation is skewed toward species that can survive despite regular disturbance. Species diversity of native plants is usually low and native grass species are usually absent or in very low abundance (for a given community type). Evidence of accelerated erosion and soil compaction is often widespread and may represent a significant deviation from baseline conditions. Hydrologic alteration may often be present. Significant direct evidence of various stress factors is usually abundant. Rare plant species generally do not occur in this condition class.
>
> **Condition Class 2.** This condition class represents areas that show a fairly broad range of stress ranging from high to moderately low impact from a variety of stressors. Areas characterized by Condition Class 2 usually have moderate levels of exotic plant cover. The structure of the natural community present in Condition Class 2 areas is often relatively intact when compared to baseline conditions. Usually all structural layers are present, but form and stature may be altered from baseline conditions. Soil surface conditions are often intermediate between those in Condition Class 1 and Condition Class 3. Species diversity of native plants is often moderate for that community. Exotic species are usually present, but not as common or abundant as in Condition Class 1. Native grass species are often present, but usually in low abundance for that community type. Diversity of native grass species is relatively low when compared to baseline conditions. Evidence of accelerated erosion and

soil compaction may be present in certain areas, but is not dramatic and widespread. Hydrologic alteration is absent. Direct signs of stressors may be present, but not widespread or abundant. Rare plant species may be found in this condition class, but usually only at the upper end of the condition class. Rare plants that are found in this condition class are relatively tolerant of the stressors that are present.

Condition Class 3. This condition class represents areas that show the least stress within the study area and are the closest to representing baseline conditions. Areas characterized by Condition Class 3 usually have low levels of exotic plant cover, but certain sites may have localized infestations. The composition and structure of native vegetation correspond to the natural ranges of variation characteristic of the natural communities. Species diversity of native plants is often high relative to the community under consideration. Native grass species are usually present and often fairly abundant for the community type. Species diversity of native grass species is also often high. Soil compaction, accelerated erosion and hydrologic alteration are absent. Direct signs of stressors are usually absent. Certain rare plant species may only exist within this condition class.

Condition Class Modeling Assumptions

We found strong relationships between field-based measurements of condition and disturbance, and GIS-derived layers of distance from potential livestock congregation areas and distance from roads. Of 18 linear regressions of field data against GIS-derived data, 12 were highly significant [significance value of $p<.002$ (i.e. 0.05/18) was used to account for multiple regressions] (Table 24). Overall, the relationship between distance from road and the condition variables was weaker (5 of 9 regressions significant) than that of distance from potential livestock congregation areas (7 of 9 regressions significant). This difference reflects our impression from the field that, with the exception of a few major roads on the monument, the distribution of exotic species does not appear to be strongly tied to location of roads. Percent cover of native grasses and the vehicle impact index were not significantly related to either GIS-derived layer. We believe, however, that there actually is a significant correlation in the *Creosotebush-Bursage Desert Scrub* community between percent cover of native grasses and distance from potential livestock congregation areas, but we have too few plots in areas far removed from livestock influence to be able to test the statistical significance of this finding. This issue is discussed further below. Overall, the linear regression results of Table 24 provide strong support for using GIS-derived layers of distance from potential livestock congregation areas and distance from roads to model ecological condition on the SDNM.

Table 24. Linear regression results showing relationship of field-based measures of condition and disturbance to GIS-derived layers used to model condition on the SDNM.

		# of Native Species	% Cover of Native Species	# of Native Grasses	% Cover of Native Grasses	# of Exotic Species	% Cover of Exotic Species	% Cover of Sand & Soil	Livestock Impact Index	Vehicle Impact Index
Distance from Potential Livestock Congregation Areas	Regress. slope	(+)	(+)	(+)	Not Sign.	(-)	(-)	(-)	(-)	Not Sign.
	r-squared	.085	.031	.073		.037	.052	.117	.125	
	p-value	.000	.002	.000		.001	.000	.000	.000	
Distance from Road	Regress. slope	(+)	(+)	(+)	Not Sign.	Not Sign.	Not Sign.	(-)	(-)	Not Sign.
	r-squared	.07	.044	.096				.099	.071	
	p-value	.000	.000	.000				.000	.000	

Differentiation of Condition Classes

In order to test how well the condition classes were differentiated, we examined the condition classes assigned to the natural community plots in relation to the field-based factors we hypothesized were related to condition (livestock index, vehicle index, number and percent cover of native species, number and percent cover of exotic species, number and percent cover of native grasses, and percent cover of sand and soil). We did this analysis only for the *Creosotebush-Bursage Desert Scrub* community, to provide an example. Summary statistics of the condition factors for the *Creosotebush-Bursage Desert Scrub* community condition classes, based on 87 natural community plots, are provided in Table 25. The mean values for condition and disturbance factors by condition class generally reflect expected trends, with a few exceptions. Mean number of native species, percent cover of native species, and number of native grasses is higher for Condition Class 1 than Condition Class 2. In these cases, (and for most of the factors), it is worth noting the high standard deviations for Condition Class 1 versus Condition Class 2. Further detailed analysis and breakdown of plots by condition class might reveal "outlier" plots, which would strongly affect these means and might help explain the unexpected trends.

Table 25. Descriptive statistics concerning the relationship between condition and disturbance factors for the *Creosotebush-Bursage Desert Scrub* condition classes.

	Condition Class	Mean	Std. Deviation	Number of plots
Livestock Index	1	83.0	69.6	18
	2	11.0	29.0	66
	3	0.0	0.0	3
	All classes	25.5	49.7	87
Vehicle Index	1	28.9	75.4	18
	2	4.8	27.4	66
	3	0.0	0.0	3
	All classes	9.6	42.3	87
# of Native species	1	16.8	13.3	18
	2	11.4	5.9	66
	3	20.7	4.6	3
	All classes	12.9	8.3	87
# of Exotic species	1	3.3	2.4	18
	2	1.4	0.7	66
	3	1.3	0.6	3
	All classes	1.8	1.4	87
% Cover of Native species	1	48.3	28.1	18
	2	31.3	17.9	66
	3	63.3	11.7	3
	All classes	35.9	21.8	87
% Cover of Exotic species	1	26.3	19.7	18
	2	12.1	13.0	66
	3	4.1	3.6	3
	All classes	14.8	15.6	87
% Cover of Sand & Soil	1	37.7	24.7	18
	2	29.3	22.7	66
	3	6.8	2.0	3
	All classes	30.3	23.3	87
# of Native Grasses	1	0.6	0.9	18
	2	0.3	0.6	66
	3	1.7	1.5	3
	All classes	0.4	0.7	87
% Cover of Native Grasses	1	0.2	0.4	18
	2	0.6	2.2	66
	3	1.8	2.8	3
	All classes	0.5	2.00	87

Using multivariate ANOVA, we found 6 of the 9 condition/disturbance factors differed significantly ($p<..05$) among condition classes of the *Creosotebush-Bursage Desert Scrub* community (Table 26). The 6 factors differing among classes were livestock index, number of native species, number of exotic species, percent cover of native species, percent cover of exotic species, and number of native grasses. No differentiation could be made among the condition classes on vehicle index, percent cover sand/soil, and percent cover of native grasses.

Table 26. Multivariate ANOVA results for difference in condition classes assigned to *Creosotebush-Bursage Desert Scrub* natural community plots, by field-based measures of condition and disturbance.

Dependent Variable	Type III Sum of Squares	df	Mean Square	F	p-value	Significance at p=.05
Livestock Index	75310.693	2	37655.347	23.060	.000	Significant
Vehicle Index	8540.508	2	4270.254	2.467	.091	Not significant
# of Native species	595.158	2	297.579	4.711	.012	Significant
# of Exotic species	51.490	2	25.745	17.038	.000	Significant
% Cover Natives	6371.185	2	3185.593	7.771	.001	Significant
% Cover Exotics	3184.096	2	1592.048	7.576	.001	Significant
% Cover Sand/Soil	2703.682	2	1351.841	2.589	.081	Not significant
# of Native Grasses	6.498	2	3.249	6.868	.002	Significant
% Cover Native Grasses	6.861	2	3.431	0.862	.426	Not significant

Ecological Condition of Creosotebush - Bursage Desert Scrub

Our analysis of field data and field observations indicate that the *Creosotebush - Bursage Desert Scrub* community is one of the most disturbed communities in the study area. Significant parts of the *Creosotebush - Bursage Desert Scrub* community are in either Condition Class 1 or Condition Class 2, with only a limited portion (less than 3% of the area) in Condition Class 3. Nearly all of the developed/disturbed sites and linear disturbances mapped in our landscape-level assessment occur within this community. Most of the roads in the study area occur within this community. It has the highest level of exotic species of any matrix community (double the level in the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* community). The level of exotics was only exceeded by the *Braided Channel Floodplain* and *Mesquite Woodland* communities (which both lie within the *Creosotebush - Bursage Desert Scrub* matrix) (Appendix F).

The DECORANA analysis of stressors indicated that the field-based livestock activity index and distance from potential livestock congregation areas (GIS layer) had reasonably strong correlations with trends in community composition. Therefore, we used distance from potential livestock congregation areas as the basis for a GIS model to map ecological condition within the *Creosotebush - Bursage Desert Scrub* community (see Methods – Modeling and Mapping of Ecological Condition).

We assigned Condition Class 1 to areas within 500-meters of a potential livestock congregation area. We decided that the 500-meter distance limit represented a good balance between inclusion of most of the heavily disturbed sites and limitation of the presence of less disturbed sites. Over 76% of the plots in the *Creosotebush - Bursage Desert Scrub* community that we identified in the field as heavily disturbed sites fell within the 500-meter limit. Conversely, 53% percent of the field plots that were within 500-meters of a potential livestock concentration area were determined to be Condition Class 1 plots through analysis and interpretation of the plot data.

Likewise we determined from our analysis of the data and field observations that there were only limited areas in this community representing Condition Class 3. We used a distance of 6500-meters from a potential livestock congregation area for separating Condition Class 2 from Condition Class 3. This distance represents the average of the mean distances for plots assigned to Condition Class 2 and Condition Class 3. Based on our DECORANA analysis and field observations, we decided that we could only classify 3 of the 87 plots that we established in the *Creosotebush - Bursage Desert Scrub* community as Condition Class 3. All of our field plots that were over 6500-m from a potential livestock concentration area fell in Condition Class 3. Conversely, sixty percent of the field plots that were greater than 6500-meters from a potential livestock concentration area were determined to be Condition Class 3 plots.

In summary, the ecological condition of the *Creosotebush - Bursage Desert Scrub* community appears to be impaired by human-related stress factors. Overall, the condition appears to be most highly correlated to distance from potential livestock congregation areas. We determined that most of the *Creosotebush - Bursage Desert Scrub* community is in Condition Class 2 with lesser amounts in Condition Classes 1 and 3. Localized and often severe disturbance of the *Creosotebush - Bursage Desert Scrub* community resulting from ORV activity was observed during our fieldwork but we have not found an easy and scientifically supportable way to map or model this stress factor.

Ecological Condition of Paloverde - Mixed Cacti – Mixed Scrub on Bajadas

The ecological condition of the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* community is less impaired than the condition of the *Creosotebush - Bursage Desert Scrub* community. There is only half the level of exotic species in this community. Overall, there is more native vegetative cover, higher diversity of native plant species and more native grasses (Appendix F). We noticed much lower levels of accelerated erosion, less soil compaction and lower levels of recent livestock activity in this community. Our landscape level assessment indicated that the presence of developed/disturbed sites, linear disturbances, and roads was also much less in this community. Only very small portions of this community were mapped in Condition Class 1. Slightly over 25% of this community was mapped in Condition Class 3. Condition class 2 characterizes the dominant condition (67% of the area) of this community.

We used similar methods to those employed in the *Creosotebush - Bursage Desert Scrub* community to develop a predictive model for the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* community. Distance from potential livestock congregation areas was the primary factor that was correlated to variation in species composition within this community according to our DECORANA analysis. Therefore, we decided that this was our best spatial predictor of ecological condition within this community.

We determined that only one field plot represented a highly disturbed site within this community. Because of it's location near the boundary of this community with the *Creosotebush - Bursage Desert Scrub* community and it's highly altered vegetative composition, we excluded this plot from our DECORANA analysis as an outlier. Due to the lack of plots that represented Condition Class 1 in this community we chose to use the same model assumptions that we had used for the *Creosotebush - Bursage Desert Scrub* community to map Condition Class 1. All areas 500-meters from a potential livestock congregation area were considered Condition Class 1. Since there were few of these located within or near this community only a small portion of the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* community was mapped as Condition Class 1.

Most of our field plots were determined to represent Condition Class 2 (20 out of 35 plots). A lesser number (14) were determined to represent Condition Class 3. We determined that the best separation between Condition Classes 2 and 3 was at the average of the mean distances from potential livestock congregation areas for plots in these two classes, 3,925-meters. Ninety percent of our field plots that were assigned to Condition Class 2 fell within the mapped parameters for this class (500-m to 3,925-m). Conversely, seventy-five percent of the Condition Class 2 field plots were within these bounds. Fifty percent of our field plots that were assigned to Condition Class 3 were greater than 3,925-m and 100% of the field plots that fell within the area mapped as Condition Class 3 were classified correctly in that condition class.

In summary, the ecological condition of the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* community appears to be less impaired by human-related stress factors compared to the *Creosotebush - Bursage Desert Scrub* community. Like the *Creosotebush - Bursage Desert Scrub* community, the ecological condition appears to be most highly correlated to distance from potential livestock congregation areas. We determined that most of the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* community is in Condition Class 3 with lesser amounts in Condition Classes 2 and 1. Some disturbance resulting from ORV activity was observed during our fieldwork but this appears to be a fairly insignificant impact at this time.

Ecological Condition of Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes

The ecological condition of the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community is significantly less impaired than the condition of the *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* community. The level of exotic species cover is about 36% less in this community than on the bajadas. Overall, there is a higher diversity of native plants species on the rocky slopes, more native vegetative cover, nearly 10 times the cover of native grasses and 78% higher diversity in native grass species (Appendix F). In our field observations we did not encounter accelerated erosion, soil compaction, or much recent sign of livestock activity within this community. Our landscape level assessment indicated few developed/disturbed sites, linear disturbances, or roads in this community.

Our DECORANA analysis of variation in this community coincided with our field observations. This analysis revealed that measures of human-related stress factors were not significant in explaining variation in composition. A more complex analysis may indicate that the more gently sloping parts of this community that border bajadas or desert flats have an altered composition resulting from human-related stress factors. Our analysis of cluster groups indicated that plots within cluster group 15 and cluster group 42 had much higher levels of two exotic plants than the rest of the plots within this community. These plots appear to fall largely within the more gently sloping areas that border bajadas or desert flats.

Due to the lack of significant correlation between community composition and human-related stress factors, combined with our field observations, we decided that this entire community should be mapped as Condition Class 3 in our model, except for the presence of developed/disturbed areas, linear disturbances or roads. Therefore, essentially all of the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community is mapped as Condition Class 3.

Ecological Condition of the Mountain Upland Community

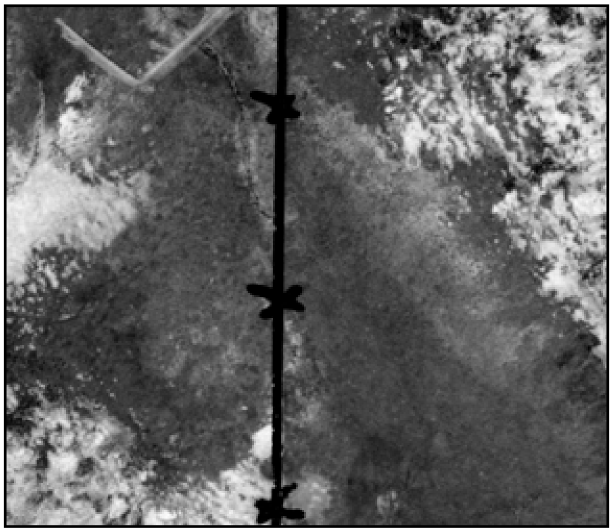
The ecological condition of the *Mountain Upland* Community is better than that of the *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community and significantly less impaired than the ecological condition of *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas* community. The level of exotic species cover is significantly less in this community than on the lower rocky slopes and bajadas. There is a significantly higher diversity of native plants species in this community as well as more native vegetative cover. The cover of native grasses is 370% higher than on the lower rocky slopes and there is a 70% higher diversity in native grass species here than on the lower rocky slopes (Appendix F). In our field observations we did not encounter accelerated erosion, soil compaction or recent sign of livestock activity. Our landscape level assessment indicated few developed/disturbed sites, linear disturbances, or roads.

Our DECORANA analysis of variation coincided in part with our field observations. While there appeared to be a high correlation between community composition and distance from roads and a weak correlation between community composition and distance from potential livestock congregation areas, we determined that these correlations are an artifact of the high degree of correlation between elevation and these disturbance measures. Elevation and "northness" explain most of the variation within this community. Our analysis of the *Mountain Upland* community indicated that measures of human-related stress factors were not significant in explaining variation within this community.

Due to the lack of a significant correlation between community composition and human-related stress factors combined with our field observations we decided that this entire community should be mapped as Condition Class 3 in our model, except for the presence of developed/disturbed areas, linear disturbances, or roads. For this reason, essentially all of the Mountain Upland community is mapped as Condition Class 3.

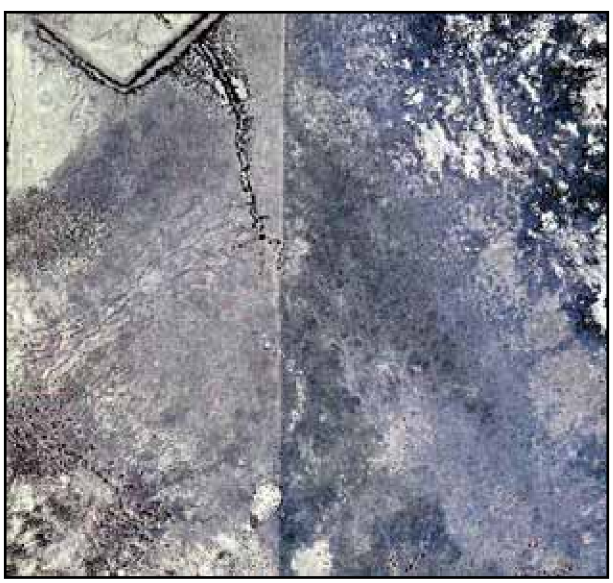
Ecological Condition of Desert Grassland Communities

The community condition assessment of the *Desert Grassland* community in the study area was greatly restricted due to sampling constraints on the TON, where a majority of the desert grassland community is located. Sampling done on the SDNM portion of the grassland community indicates that this community has been highly disturbed by hydrologic alterations and intensive grazing. Examination of historical aerial imagery shows that significant changes have taken place in this community in the last half-century. Figure 39 illustrates some of the landscape-level changes over time in this community. Inspection of a sequence of Landsat satellite images reveals similar findings. Assessment of all these images reveals a progressive distinction between the vegetative cover in the BLM portion of the grasslands compared to the TON portion of the grasslands. Over time, the BLM portion of the grasslands has less and less vegetative cover, while the TON portion of the grasslands appears to maintain its vegetative cover (Figure 39). Our field observations coincided with these findings (Figures 40 and 41).



1958 Scanned panchromatic paper print.
One color band image.
The thick black lines appearing on the image were on the paper original provided by the BLM. This line depicts the border between the SDNM and TON. Note the similar appearance of the grassland community in the center of the photograph on both sides of the border fence.

1968 Scanned CIR color transparency.
Three band color infrared image.
Notice that the main body of the grasslands through which the border fence cuts is somewhat similar on both sides of the fence, but the slightly darker color on the TON side of the fence and the clearly visible fence line from this high elevation spy plane photograph.



1996 CIR DOQQ (Little Table Top).
Three band color infrared image.
In this image there is a markedly different texture and color to the grasslands on the TON side of the fence compared to the SDNM side. The sequence of change seen in these aerial photos correlates with what was witnessed on the ground during field surveys. This is clear evidence that in 1996 there is much higher vegetative cover on the TON side of the fence.

Figure 39. Vekol Valley grassland aerial photographs covering a span of 38 years.

Figure 40. The border fences heading south between the TON (on left) and the SDNM (on right). Notice the differences in native grass cover between the two sides of the fence.

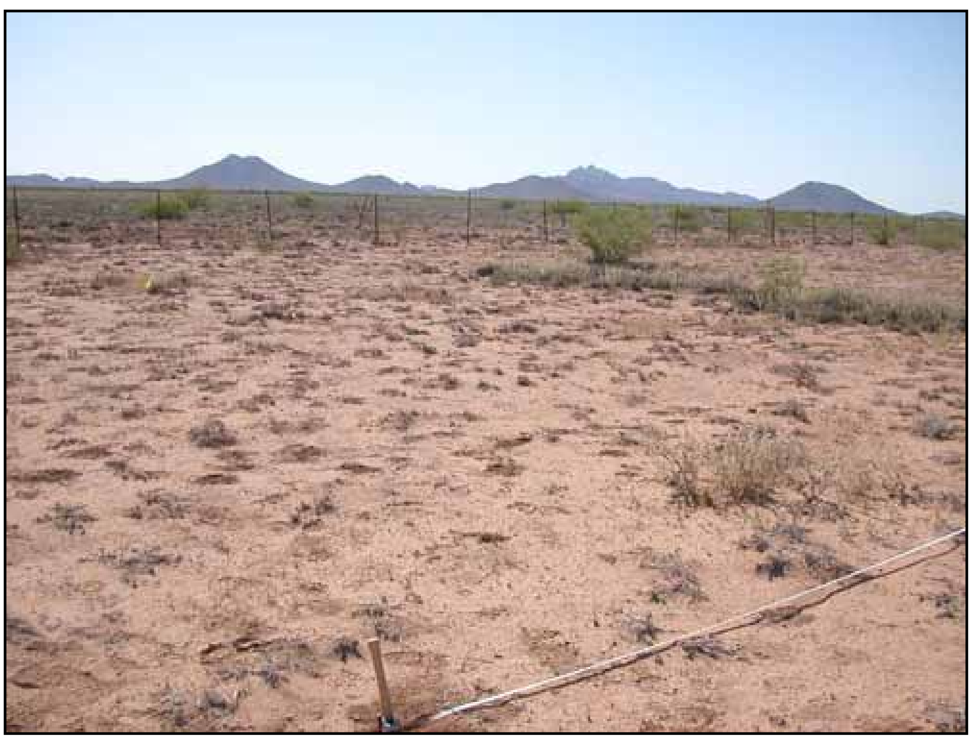


Figure 41. A field plot on the SDNM side of the grassland community. This is a highly disturbed site with low total vegetation cover. Notice the TON grassland in the background appears more vegetated with native grasses.

Due to the close proximity of the SDNM grasslands to significantly disturbed areas, the high rating of our desert grassland plots in the livestock disturbance index, and the landscape-level analysis presented above, the SDNM portion of this community was mapped as being in Condition Class 1. The portion of the grasslands on the TON side is mapped as Condition Class 2.

Ecological Condition of Mesquite Woodland Communities

Because the *Mesquite Woodland* community consists of small patches within the larger *Creosotebush – Bursage Desert Scrub* matrix community, conditions are heavily influenced by the conditions of the matrix. Most of the *Mesquite Woodland* community in the study area is in or near *Creosotebush-Bursage Desert Scrub* mapped as Condition Class 1.

Not only is the surrounding matrix community's condition indicative of a given *Mesquite Woodland* patch's condition, analysis of the natural community plot data suggests that condition characteristics meriting Condition Class 1 are accentuated in *Mesquite Woodlands* when compared to the surrounding matrix community's conditions. The mean cover of exotic species is 170% higher in the *Mesquite Woodland* community (40.2% mean cover) than the *Creosotebush-Bursage Desert Scrub* community (Appendix F).

Our DECORANA analysis of environmental factors and stressors indicated that distance from potential livestock congregation areas was strongly correlated with trends in community composition (road distance was correlated to a lesser degree). Therefore, we used distance from potential livestock congregation areas as the basis for a GIS model to map ecological condition within the mesquite community. We had previously determined that three plots were in Condition Class 2 while ten plots were in Condition Class 1. There was little overlap in distance from potential livestock congregation areas between the plots in Condition Classes 1 and 2. All the Condition Class 2 plots were at least 1,420-m from a potential livestock congregation area and this value was used to model the break between condition classes.

The mean distance from potential livestock congregation areas for all the *Mesquite Woodland* patches is low (Appendix F), and the mean distance from roads is even lower. Almost all of the *Mesquite Woodland* community in the study area is considered to be in Condition Class 1 or 2. We did not find any *Mesquite Woodland* patches that would qualify as Condition Class 3.

Ecological Condition of Rock Outcrops

The *Rock Outcrop* community has the lowest average percent cover of exotic species of any natural community occurring in the study area (0.3%) (Appendix F). This community also has some of the highest average elevations and average distances from potential livestock congregation areas within the study area. There were no indications of cattle or vehicle disturbances recorded in this community during Phase 2 fieldwork. Much of this community is inaccessible to humans without proper climbing equipment (due to the steepness and magnitude of the rock faces), therefore not much human disturbance has occurred in this community. In general rock climbing is not a common activity in the study area because of the friable nature of most of the rock. All of the *Rock Outcrop* community was determined to be in Condition Class 3.

Ecological Condition of Mountain Xeroriparian Scrub

Analysis of the factors that might affect the composition of the *Mountain Xeroriparian Scrub* community indicated that only topographic factors (elevation, eastness, northness) and geologic substrate were significant. This coincides with our field observations and the results from the matrix communities in which this community is situated. Little sign of human disturbance or livestock activity was recorded in this community. Low levels of exotic species, high cover and diversity of native species, and high cover and diversity of native grasses all indicate that this community is in relatively good condition (Appendix F). Therefore, all of this community was classified in Condition Class 3.

Ecological Condition of Valley Xeroriparian Scrub

Analysis of the factors that might affect the composition of the *Valley Xeroriparian Scrub* community indicated that only elevation was significant. In contrast to the *Mountain Xeroriparian Scrub* community, evidence of human-related stress factors was fairly abundant in this community. This community had a relatively high level of exotic plant cover and frequent signs of recent livestock activity and vehicle activity (Appendix F). We postulate that the lack of a strong correlation with human-related stress factors is due to the fact that livestock is attracted to the *Valley Xeroriparian Scrub* community and often travel fairly long distances to this community from livestock concentration centers. This was frequently observed during our fieldwork. Vehicles often use washes as travel routes, and like livestock are “attracted” to this community. This dispersal of human-related disturbance in this community results in a low correlation with our spatial disturbance distance measures.

We classified the condition of this community using the same methods as for the *Creosotebush – Bursage Desert Scrub* community - the matrix community in which most of this community lies. Most of this community is in Condition Class 2 with lesser amounts in Condition Classes 1 and 3.

Ecological Condition of Braided Channel Floodplains

The *Braided Channel Floodplain* communities are similar to the *Valley Xeroriparian Scrub* communities and the discussion above applies. We did find a high correlation with our field-based livestock activity index with axis 2 of our DECORANA analysis, but only a weak correlation with distance from potential livestock congregation areas. This community has the second highest level of exotic plants in our study (Appendix F).

We classified the condition of this community using the same methods as for the *Creosotebush – Bursage Desert Scrub* community - the matrix community in which most of this community lies. Most of this community is in Condition Class 2 with lesser amounts in Condition Classes 1 and 3.

Ecological Condition of Desert Springs and Tinajas

All of the *Desert Spring* communities in the study area have experienced high levels of development, therefore the *Desert Spring* community was determined to be in Condition Class 1. This classification is supported by the fact that according to our exotic species data, the *Desert Spring* community is listed as having the fifth highest average exotic species cover (10.4%) of all communities in the study area, and the highest average exotic species cover of any other community located in the upper elevations of the study area (Appendix F). Because we did not collect vegetation data for *Tinajas*, there is no information to describe the ecological condition.

Comparison of Ecological Condition Between Community Types

The ecological condition of the natural communities in the study area can be ranked from least altered condition to most altered condition. In the list below the least altered community is listed first and the most altered community is listed last. It is important to note that there is considerable variation in some of these communities and a simple comparison may not apply at any given site.

1. *Rock Outcrops*
2. *Mountain Uplands*
3. *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes*
4. *Mountain Xeroriparian Scrub*
5. *Tinajas*
6. *Paloverde - Mixed Cacti – Mixed Scrub on Bajadas*
7. *Valley Xeroriparian Scrub*
8. *Braided Channel Floodplains*
9. *Creosotebush – Bursage Desert Scrub*
10. *Desert Grassland*
11. *Desert Springs*
12. *Mesquite Woodlands*

This ranking is based on the analyses presented above. Abundance of exotic plants (Figure 15) was a primary factor used to determine the natural community condition. The proportion of the natural community in each condition class (Figure 43) was another factor that was used to determine rank. Field observations were also incorporated into this ranking.

Over 95% of the area concerning the first five natural communities in this list are mapped as Condition Class 3. Of these natural communities, *Rock Outcrops* are probably the least altered from baseline conditions, as few stressors were found to influence this community. *Rock Outcrops* also have the lowest level of exotic plant cover. The *Mountain Uplands* are isolated from most stress factors affecting the lowland communities, and community conditions are more pristine with few exotic plants. The *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* community is mapped as being slightly degraded on its lower margins by stressors that affect the lowlands. Likewise, the *Mountain Xeroriparian Scrub* and *Tinajas* communities are mapped as Condition Class 3, but may be slightly degraded along their lower margins.

The next four natural communities in the ranking list have significantly lower areas mapped as Condition Class 3 (and more exotic plants) than the first five communities, but these communities still retain over 10% of their areas in Condition Class 3. The last three natural communities in the list do not contain any area mapped Condition Class 3 and are considerably degraded from baseline conditions.

Map of the Ecological Condition of the Study Area

The ecological condition of the study area was mapped based on the parameters described above and in the methods section, and the results of our landscape-level analysis of condition. The GIS layers used and methods used in development of this map are described in detail in the Methods section of this report. Figure 42 was developed through integration of the results of the coarse-scale and fine-scale condition assessment work described above.

The charts in Figures 43 and 44 illustrate the amount of area in each condition class for the natural communities. These figures show the clear dominance of the matrix communities in terms of total area within the study area. They also show the contrast in overall condition between the lower elevation and upper elevation communities. Notice that the *Rock Outcrops, Mountain Uplands,* and *Paloverde - Mixed Cacti – Mixed Scrub on Rocky Slopes* communities are mostly in Condition Class 3 (dark green), while the other lower elevation (and gentler slope) communities are mostly in Condition Classes 1 and 2.

The Valley *Xeroriparian Scrub, Mountain Xeroriparian Scrub, Desert Spring*, and *Tinaja* communities were not included in figures 43 and 44 because we believe the current mapped extent of these communities significantly underestimates their extent. As noted in Appendix A and in the Recommendations section of this report, the two xeroriparian communities were mapped using 1:100,000-scale hydrography data produced by the USGS. The extent of these communities is much greater than delineated in the 1:100,000-scale data. Mapping of the *Desert Spring*, and *Tinaja* communities comes from GIS point data that doesn't contain or express any information related to spatial extent.

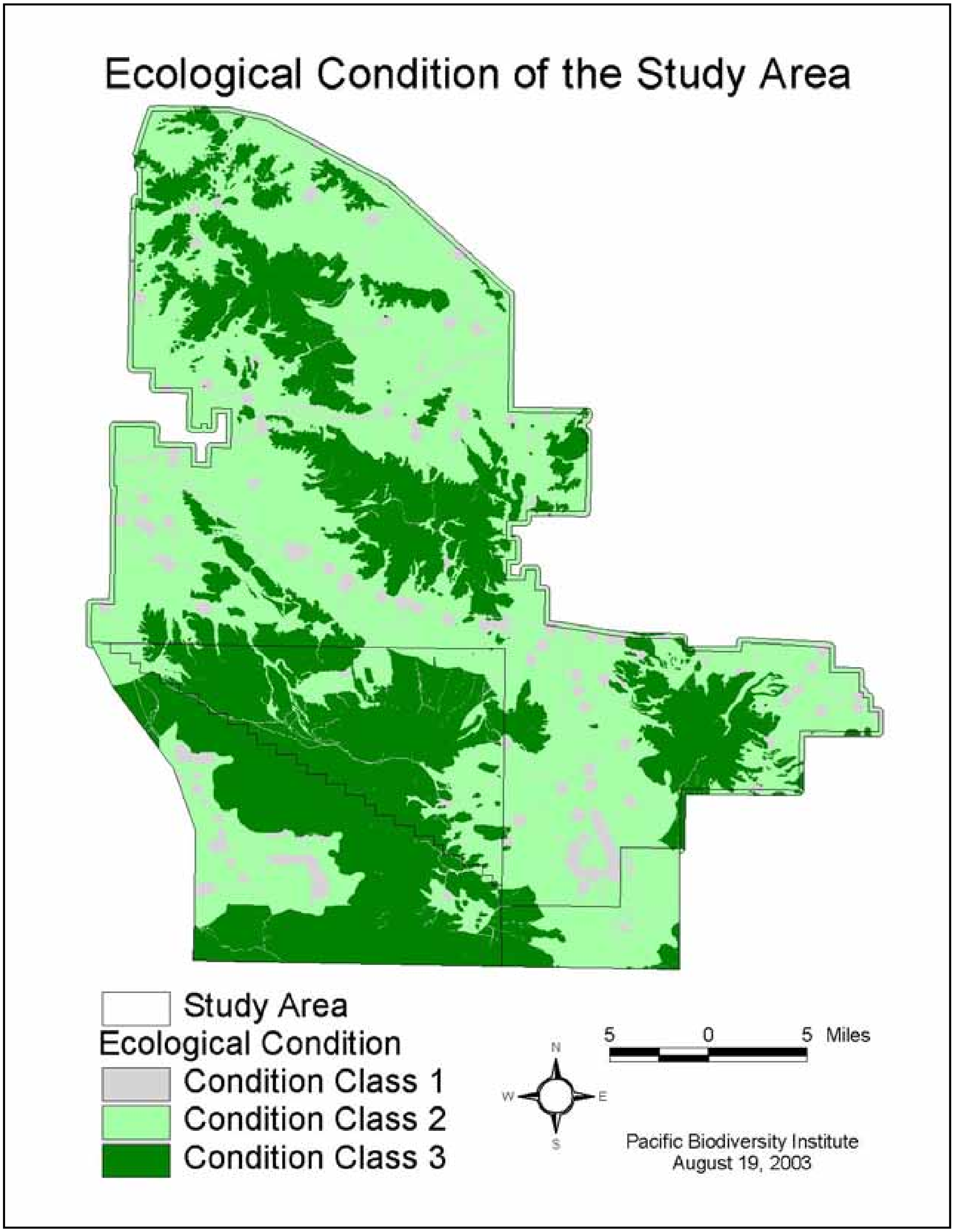


Figure 42. Map of ecological condition classes in the study area.

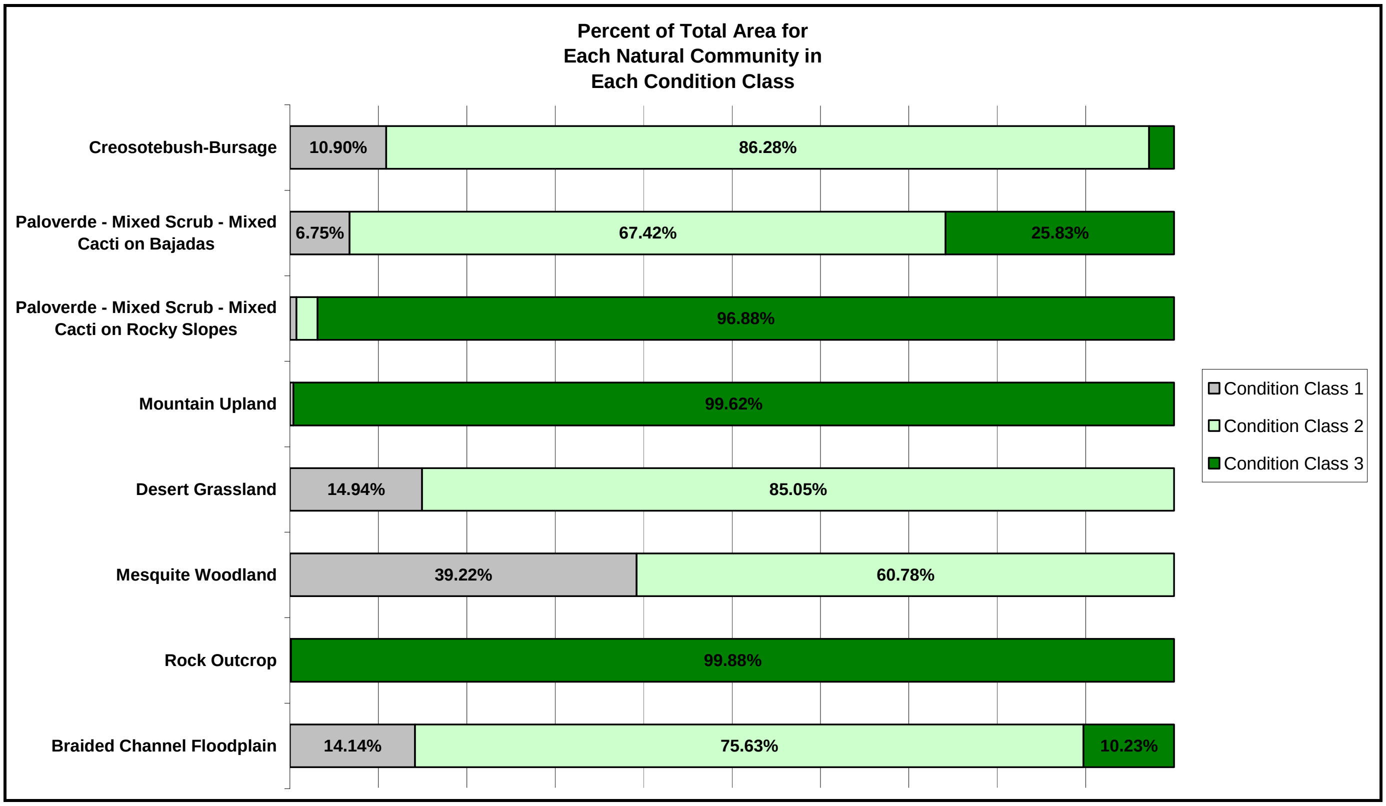


Figure 43. Proportion of natural communities assigned to each condition class.

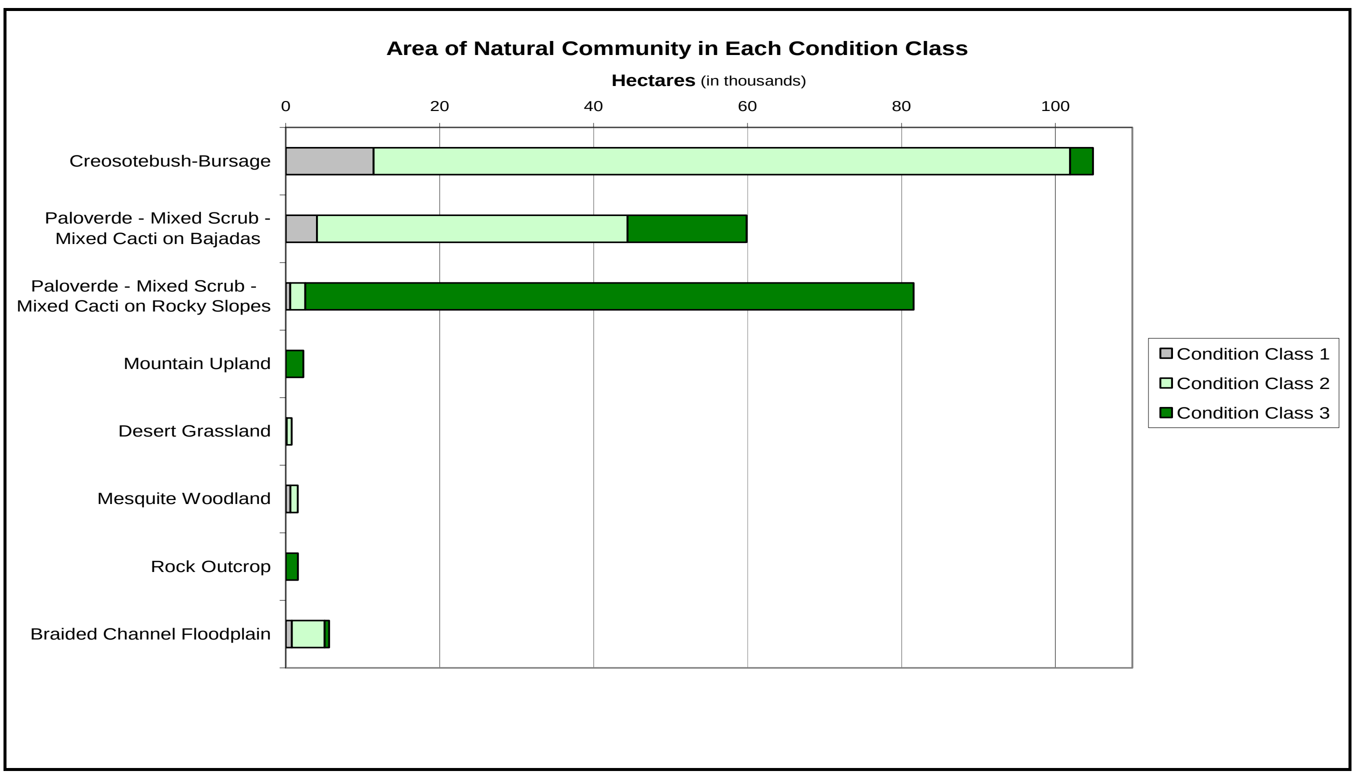


Figure 44. Area (in hectares) of the natural communities in each condition class.

Comparison of Natural Communities and Ecological Sites

We performed an analysis to describe the relationship of natural community classes to USDA NRCS ecological sites (this work was conducted during Phase 1 and is based on the Phase 1 Natural Community map). Ecological sites, which are used by the BLM in assessing and managing rangelands, are based primarily on soil differences. Natural communities are based on a combination of vegetation and physical factors, and are used by The Nature Conservancy to assess and manage ecosystems. Natural communities are a slightly coarser classification scheme than ecological sites, with eight natural communities mapped for the SDNM versus 15 ecological site classes. While the classification systems are based on slightly different criteria, they are complementary. Depending on the specific resource question at hand, one or the other system may prove more useful.

We used the NRCS Soil survey geographic database (SSURGO) GIS layers to map ecological sites. The SDNM falls within three state soil survey areas. The southwest portion of the monument, including much of the Sand Tanks and Javelina Mountain, is not mapped (Figure 45).

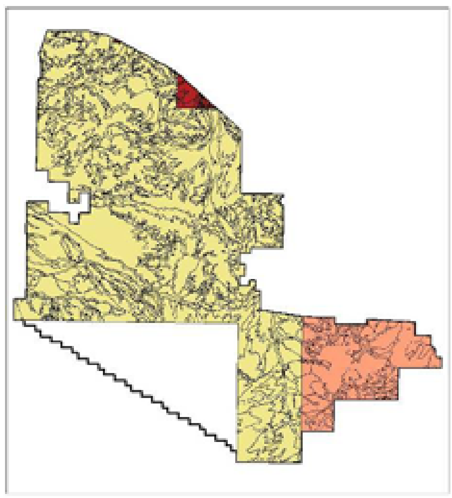


Figure 45. SDNM boundary with three soil survey areas and soil polygon outlines.

A complicating factor in our analysis is that the SSURGO data of the soil survey area covering most of the SDNM is based on a different data/coding structure than the other two areas. While the map line work generally appears continuous across the boundaries, the ecological site classifications often change abruptly (this can easily be seen in Figure 46).

We merged the SSURGO data from three soil areas into a single layer, and cross-walked data codings to arrive at a common list of 15 ecological site classes. Each mapped polygon represents a complex of these ecological site classes [e.g. Limy Fan (2-10" p.z.) 65% and Sandy Bottom (2-10" p.z.) 35%]. Thus, there are a large number of unique ecological site complexes. In order to limit the number of classes for analysis, we classified each complex type into one of 15 dominant classes and one of 29 subdominant classes. This reclassification is shown in Table 27. Once the data were reclassified, we intersected the ecological site map with the natural community map, floodplain and developed area overlays, and created summary tables.

Our analysis shows that most of the ecological site classes are comprised of multiple natural community types and vice versa. However, the ecological site classes do tend to be dominated by one or two natural community types, and five of the high elevation/more unique ecological site classes consisted primarily of only one natural community type. These types were basalt hills, granitic hills, and schist hills (mostly *Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes* communities), loamy bottom and saline loam (pure *Creosotebush–Bursage Desert Scrub* community). Limy fan, the most abundant ecological site class, is dominated by the *Creosotebush–Bursage Desert Scrub* community (85%), with *Paloverde - Mixed Cacti - Mixed Scrub on Bajadas* making up an additional 14%.

As natural communities are a coarser classification than ecological site classes, each community typically encompassed multiple ecological sites. However, the more unique types corresponded strongly with just one or two ecological site classes each. For example, the *Desert Grassland* community is dominated by limy upland, as well as deep, sandy loam upland. The *Mountain Upland* community is dominated by basalt hills, and the *Rock Outcrop* community corresponds strongly with granitic hills. In addition, the *Braided Channel Floodplain* community shows a strong correspondence with sandy bottom (77% of the floodplains were in the sandy bottom class).

The relationships among all of the classes can be seen in the tables and maps below (Tables 28 and 29 and Figures 46 and 47). The ecological site dominant and subdominant class codes correspond to those listed in Table 27. Floodplains and developed areas appear on the right side of the tables and do not contribute to totals. These classes were analyzed separately as they are overlays (during Phase 1) on the natural community map, rather than exclusive community types.

Given the differing purposes and criteria for classification of ecological sites and natural communities, it is not expected or desired that mapped units using the two systems should be the same. However, this analysis has shown a moderate to strong correspondence of the classifications as mapped on the SDNM, depending on community type.

Table 27. Reclassification of SDNM ecological site complexes into 15 dominant and 29 subdominant classes.

** Numbers in parentheses following each subdominant class are the number of complexes grouped to create that class. Many classes do not total 100% - this was a problem inherent in the original SSURGO data tables.*

1. Basalt Hills (2-10” p.z.)
    - 1.a. – Basalt Hills (2-10” p.z.) 55% (2)
2. Clay Loam Upland (7-10” p.z.)
    - 2.a. – Clay Loam Upland (7-10” p.z.) 90% (1)
3. Clayey Bottom (7-10” p.z.)
    - 3.a. – Clayey Bottom (7-10” p.z.) 90% (1)
4. Granitic Hills (2-10” p.z.)
    - 4.a. – Granitic Hills (2-10” p.z.) 50-60% (2)
5. Limy Fan (2-10 “ p.z.)
    - 5.a. – Limy Fan (2-10” p.z.) 65%-100% (13)
    - 5.b. - Limy Fan (2-10” p.z.) 45-60% and Sandy Bottom (2-10” p.z.) 20-25% (2)
    - 5.c. - Limy Fan (2-10” p.z.) 40%, Limy Upland (2-10” p.z.) 25%, and Sandy Bottom (2-10” p.z.) 15%
    - 5.d. - Limy Fan (2-10” p.z.) 60% and Loamy Bottom (2-10” p.z.) 30% (1)
6. Limy Hills (2-10 “ p.z.)
    - 6.a. - Limy Hills (2-10” pz) 35%, Shallow Upland (2-10” pz) 29%, and Limy Upland, Deep (2-10” pz) 15%
7. Limy Slopes (2-10 “ p.z.)
    - 7.a. - Limy Slopes (2-10” p.z.) 50% and Limy Upland (2-10” p.z.) 25% (1)
8. Limy Upland (2-10 “ p.z.)
    - 8.a. – Limy Upland (2-10” p.z.) 80-90% (4)
    - 8.b. – Limy Upland (2-10” p.z.) 60% and Limy Upland Deep (2-10” p.z.) 15% (1)
    - 8.c. – Limy Upland (2-10” p.z.) 50% and Limy Fan (2-10” p.z.) 30% (1)
9. Limy Upland, Deep (2-10 “ p.z.)
    - 9.a. - Limy Upland Deep (2-10” p.z.) 80% (1)
    - 9.b. - Limy Upland Deep (2-10” p.z.) 80% and Sandy Bottom (2-10” p.z.) 15% (1)
    - 9.c. - Limy Upland Deep (2-10” p.z.) 50% and Limy Upland (2-10” p.z.) 25% (2)
    - 9.d. - Limy Upland Deep (2-10” pz) 45%, Sandy Bottom (2-10” pz) 20%, and Limy Fan (2-10” pz) 20% (1)
    - 9.e. - Limy Upland Deep (2-10” p.z.) 40% (1)
10. Sandy Bottom (2-10” p.z.)
    - 10.a. - Sandy Bottom (2-10” p.z.) 75%-100% (3)
    - 10.b. - Sandy Bottom (2-10” p.z.) 65% and Limy Upland Deep (2-10” p.z.) 25% (1)
11. Sandy Loam, Upland (2-10” p.z.)
    - 11.a. - Sandy Loam, Upland (2-10” p.z.) 90% (1)
    - 11.b. - Sandy Loam, Upland (2-10” p.z.) 50-60% and Sandy Bottom (2-10” p.z.) 20-25% (2)
    - 11.c. - Sandy Loam, Upland (2-10” p.z.) 50% and Loamy Bottom (2-10” p.z.) 30% (1)
12. Loamy Bottom (2-10” p.z.)
    - 12.a. - Loamy Bottom (2-10” p.z.) 85% (1)
13. Schist Hills (2-10” p.z.)
    - 13.a. – Schist Hills (2-10” p.z.) 35% and Limy Hills (2-10” p.z.) 20% (1)
14. Saline Loam (7-10” p.z.)
    - 14.a. – Saline Loam (7-10” p.z.) 40% and Limy Fan (2-10” p.z.) 35% (1)
    - 14.b. – Saline Loam (7-10” p.z.) 40% and Limy Upland, Deep (2-10” p.z.) 35% (1)
15. Shallow Upland (2-10” p.z.)
    - 15.a. - Shallow Upland (2-10” p.z.) 55% (1)
    - 15.b. - Shallow Upland (2-10” pz.) 40%, Sandy Loam, Upland (2-10” p.z.) 20%, and Sandy Bottom (2-10” p.z.) 15% (1)

Table 28. Distribution of dominant ecological site class by natural community type.

Dominant Class	Creosotebush-Bursage Desertscrub (CB) (ha.)	% of Class in CB	Desert Grasslands (ha.)	% of Class in Desert Grasslands	Mesquite Woodlands (ha.)	% of Class in Mesquite Woodlands	Mountain Uplands (ha.)	% of Class in Mountain Uplands	Paloverde - Mixed Cacti-Mixed Scrub (PV MC_MS) on Bajadas (ha.)	% of Class in PV MC-MS on Bajadas	Paloverde - Mixed Cacti-Mixed Scrub (PV MC-MS) on Rocky Slopes (ha.)	% of Class in PV MC-MS on Rocky Slopes	Rock Outcrops (ha.)	% of Class in Rock Outcrops	TOTAL (ha.)	Braided Channel Floodplains (BCF) (ha.)	% of Class comprising all BCF	Developed Areas (ha.)	% of Class comprising all Developed
1	27	0	0	0	1	0	177	3	163	3	5791	93	66	1	6225	0	0	10	2
2	0	0	0	0	0	0	0	0	24	83	5	17	0	0	29	0	0	0	0
3	80	29	77	28	120	43	0	0	0	0	0	0	0	0	277	0	0	172	27
4	48	0	0	0	2	0	57	0	548	2	30915	97	425	1	31995	16	0	0	0
5	43052	85	0	0	274	1	0	0	7177	14	142	0	2	0	50647	801	19	146	23
6	0	0	0	0	0	0	0	0	80	49	83	51	0	0	163	0	0	0	0
7	82	6	0	0	0	0	0	0	995	78	193	15	0	0	1270	0	0	1	0
8	6622	33	0	0	18	0	19	0	12193	61	1264	6	4	0	20120	57	1	82	13
9	21955	66	163	0	86	0	0	0	10195	31	720	2	1	0	33120	73	2	108	17
10	3823	65	0	0	267	5	0	0	1781	30	31	1	0	0	5903	3322	77	19	3
11	7415	62	212	2	245	2	0	0	3957	33	177	1	0	0	12005	25	1	105	16
12	1	100	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	2977	100	5	0	2982	0	1	0	0
14	48	100	0	0	0	0	0	0	0	0	0	0	0	0	48	0	0	0	0
15	700	17	0	0	0	0	0	0	2609	62	891	21	0	0	4200	10	0	1	0
TOTAL	83852		452		1013		253		39720		43190		505		168984	4304	101	644	100

Table 29. Distribution of subdominant ecological site class by natural community type.

Sub Class	Creosotebush-Bursage Desertscrub (CB) (ha.)	% of Subclass in CB	Desert Grasslands (ha.)	% of Subclass in Desert Grassland	Mesquite Woodlands (ha.)	% of Subclass in Mesquite Woodlands	Mountain Uplands (ha.)	% of Subclass in Mountain Uplands	Paloverde - Mixed Cacti-Mixed Scrub (PV MC_MS) on Bajadas (ha.)	% of Subclass in PV MC-MS on Bajadas	Paloverde - Mixed Cacti-Mixed Scrub on Rocky Slopes (PV MC-MS on RS) (ha.)	% of Subclass in PV MC-MS on RS	Rock Outcrops (ha.)	% of Subclass in Rock Outcrops	TOTAL (ha.)	Braided Channel Floodplain (BCF) (ha.)	% of Subclass comprising all BCF	Developed Areas (ha.)	% of Subclass comprising all Developed
1a	27	0	0	0	1	0	177	3	163	3	5791	93	66	1	6225	0	0	10	2
2a	0	0	0	0	0	0	0	0	24	83	5	17	0	0	29	0	0	0	0
3a	80	29	77	28	120	43	0	0	0	0	0	0	0	0	277	0	0	172	27
4a	48	0	0	0	2	0	57	0	548	2	30915	97	425	1	31995	16	4	0	0
5a	5169	97	0	0	9	0	0	0	172	3	1	0	0	0	5351	2	0	39	6
5b	1040	39	0	0	21	1	0	0	1555	58	64	2	0	0	2679	342	8	15	2
5c	29399	84	0	0	36	0	0	0	5320	15	75	0	2	0	34833	399	9	56	9
5d	7445	96	0	0	207	3	0	0	130	2	2	0	0	0	7784	58	1	36	6
6a	0	0	0	0	0	0	0	0	80	49	83	51	0	0	163	0	0	0	0
7a	82	6	0	0	0	0	0	0	995	78	193	15	0	0	1270	0	0	1	0
8a	845	14	0	0	4	0	19	0	3925	67	1065	18	0	0	5859	17	0	3	0
8b	3752	40	0	0	9	0	0	0	5583	59	139	1	4	0	9486	21	0	3	0
8c	2026	42	0	0	5	0	0	0	2684	56	61	1	0	0	4775	19	0	75	12
9a	190	6	0	0	0	0	0	0	3071	94	15	0	0	0	3275	11	0	10	2
9b	6019	75	0	0	1	0	0	0	1922	24	37	0	0	0	7978	4	0	2	0
9c	3303	47	0	0	0	0	0	0	3035	43	640	9	1	0	6979	11	0	4	1
9d	3939	86	163	4	78	2	0	0	409	9	0	0	0	0	4588	16	0	48	7
9e	8505	83	0	0	7	0	0	0	1759	17	28	0	0	0	10300	30	1	44	7
10a	35	100	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	2	0
10b	3788	65	0	0	267	5	0	0	1781	30	31	1	0	0	5868	3323	77	18	3
11a	296	97	0	0	6	2	0	0	2	1	0	0	0	0	304	0	0	0	0
11b	4122	50	0	0	8	0	0	0	3955	48	177	2	0	0	8261	25	1	13	2
11c	2998	87	212	6	231	7	0	0	0	0	0	0	0	0	3440	0	0	92	14
12a	1	100	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
13a	0	0	0	0	0	0	0	0	0	0	2977	100	5	0	2982	0	0	0	0
14a	13	100	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0
14b	35	100	0	0	0	0	0	0	0	0	0	0	0	0	35	0	0	0	0
15a	32	2	0	0	0	0	0	0	789	52	691	46	0	0	1512	8	0	1	0
15b	668	25	0	0	0	0	0	0	1820	68	200	7	0	0	2688	2	0	0	0
TOTAL	83852		452		1013		253		39720		43190		505		168984	4304	101	644	100

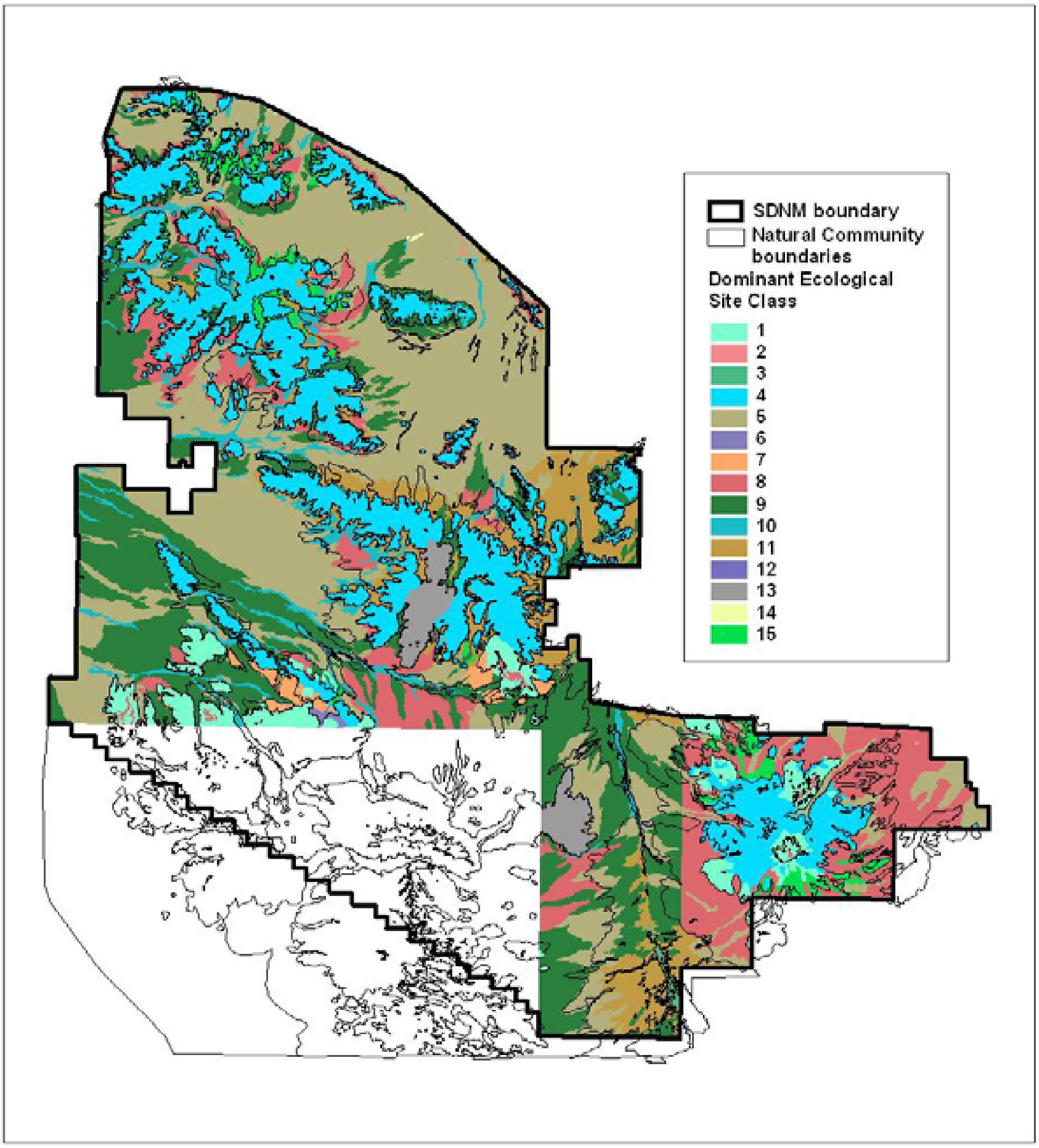


Figure 46. Dominant ecological site classes with natural community boundaries.
Map shows generally high correspondence of the higher elevation ecological site classes - granitic hills (class 4), basalt hills (class 1), and schist hills (class 13) - with natural community boundaries overlaid (black lines). Coding differences between soil survey areas can be seen by the strong vertical boundary line in the southeast portion of the map.

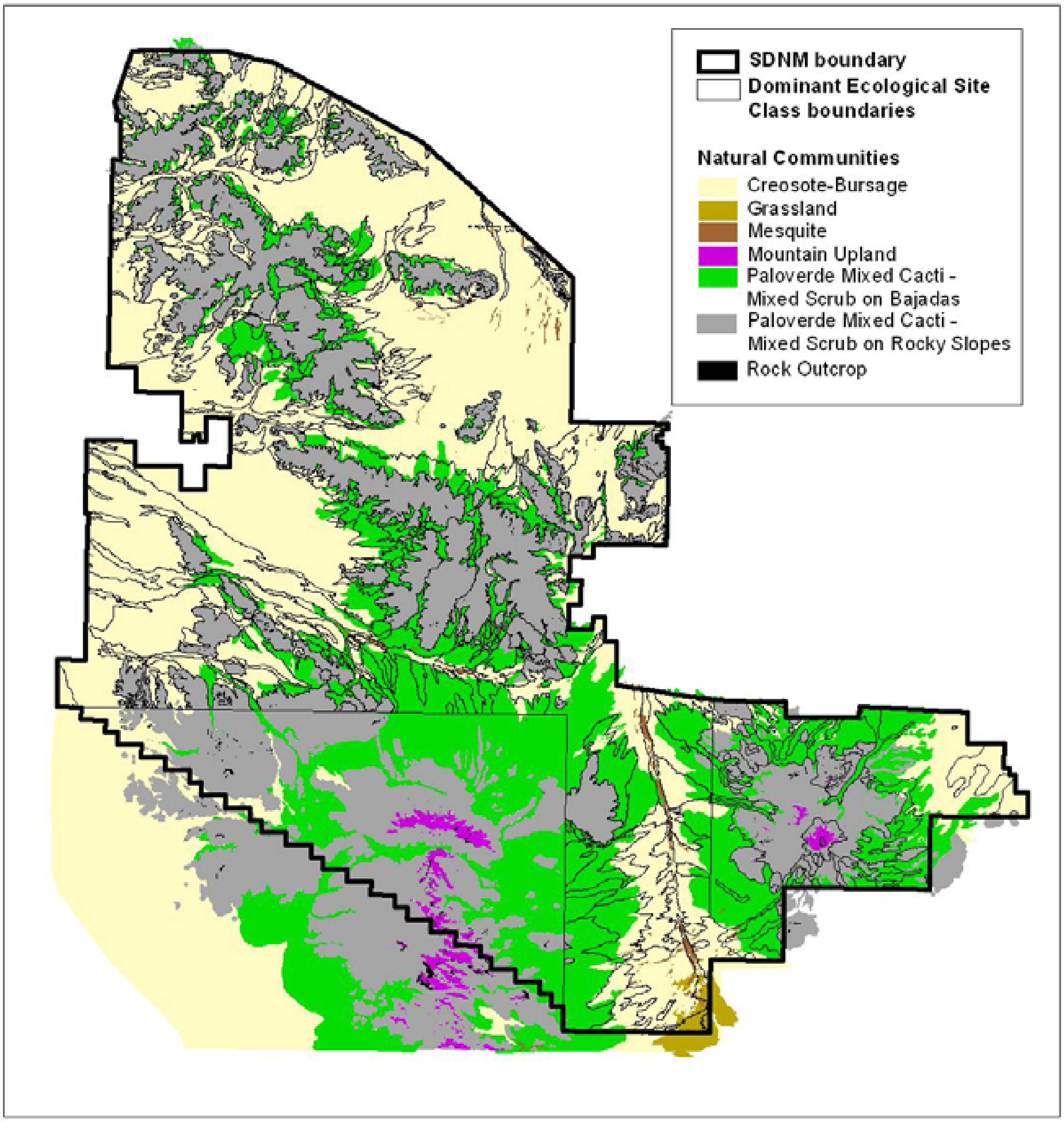


Figure 47. Natural communities with dominant ecological site class boundaries. Map shows generally high correspondence of mapped boundaries for the *Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes* community.

Discussion

Distribution of Exotic Plants

Exotic plants are more prevalent in some communities than in other communities. We found that the areas closest to disturbed areas had the highest exotic plant cover and the highest diversity of exotic plants. But some exotic plants (notably *Schismus arabicus, Erodium cicutarium*, and *Bromus rubens*) were found in all the natural communities, and they occurred in even the remotest locations far from disturbed areas.

We found that distance from roads was not a significant factor influencing the distribution of exotic plants. This contradicts our findings in the Pacific Northwest where we discovered a high correlation with distance from road (Morrison et. al 2003). However, we have preliminary indications that support the findings of Gelbard and Belnap (2003), who reported that exotic plant cover and exotic species richness is correlated with road type in a semi-arid environment. We often found that the few paved roads in the study area had relatively high levels of exotic plant cover and diversity immediately adjacent to the pavement. But we found that areas next to graded and unimproved dirt roads usually did not have significantly different exotic plant covers compared to the surrounding landscape. It is not yet clear whether the exotic species found along the paved roads will move out eventually into the surrounding landscape.

The presence of exotic plants in all of the natural communities indicates that the entire study area is somewhat altered from pre-settlement conditions, and no natural community is in pristine condition.

Ecological Condition of the Natural Communities

Overall, the ecological condition of the study area is moderately good. However, ecological conditions within the natural communities vary considerably from one location to another. Some communities appear to be experiencing high levels of human-related stresses, while other communities experience little. Tangible measures of stressors were observed in this study. These measures are: species richness in native vs. exotic plants, ground cover of native vs. exotics plants, amount of bare ground (sand and soil), diversity of native grass species, and abundance of native grass species. Evidence of accelerated soil erosion and soil compaction are also related to these stress factors. We found strong relationships between these field-based measurements of condition and disturbance and GIS-derived layers of distance from potential livestock congregation areas and distance from roads. These strong relationships provided support for using the GIS layers in developing the ecological condition map.

Analysis of data collected in the *Creosotebush – Bursage Desert Scrub* community, the primary matrix community of the Lower Colorado River subdivision of the Sonoran Desert, reveals that ecological condition is most strongly determined by gradients in distance from livestock water source, a livestock influence index, and an elevation gradient. Areas in close proximity to water sources or other substantial range improvements often have highly altered vegetative compositions and structures and altered soil surface conditions. The influence (stresses) of livestock extends throughout most of the community, as few of the regions we visited within the study area are without some indication of livestock influence. This stressor exhibits a predictable gradient of influence related to distance from water sources.

Stresses related to vehicle use were observed during fieldwork but were not as statistically significant as stresses related to livestock use. At the current time, stresses related to vehicle use are much more localized than stresses related to livestock use. We feel that a more detailed analysis of selected parts of the study area may help to clarify the extent of impact of vehicle stresses.

Stresses related to undocumented alien and drug traffic were observed to significantly impact the southern part of the study area. We did not collect data on these stressors but increases in these activities warrant further research on their ecological effects.

The ecological conditions of the natural communities within the study area have been affected by a long-term regional drought. Further study is needed during wetter periods to determine how natural communities will respond to more normal moisture levels.

Application of Results of this Study to BLM Standards for Rangeland Health

The Arizona BLM's *Standards For Rangeland Health And Guidelines For Grazing Administration* (1997) describes a set of rangeland health standards that are measurable and attainable, and that comply with various Federal and State statutes. These standards are a response to the Grazing Administration Regulations, at §4180.1 (43 Code of Federal Regulation [CFR] 4180.1), Federal Register Vol. 60, No. 35, pg. 9970, which directs that the authorized officer ensure that the following conditions of rangeland health exist:

> (a) Watersheds are in, or are making significant progress toward, properly functioning physical condition, including their upland, riparian-wetland, and aquatic components; soil and plant conditions support infiltration, soil moisture storage, and the release of water that are in balance with climate and landform and maintain or improve water quality, water quantity, and timing and duration of flow.
>
> (b) Ecological processes, including the hydrologic cycle, nutrient cycle, and energy flow, are maintained, or there is significant progress toward their attainment, in order to support healthy biotic populations and communities.
>
> (c) Water quality complies with State water quality standards and achieves, or is making significant progress toward achieving, established BLM management objectives such as meeting wildlife needs.
>
> (d) Habitats are, or are making significant progress toward being, restored or maintained for Federal threatened and endangered species, Federal Proposed, Category 1 and 2 Federal candidate and other special status species.

The Arizona BLM's standards then state, "These fundamentals focus on sustaining productivity of a rangeland rather than its uses. Emphasizing the physical and biological functioning of ecosystems to determine rangeland health is consistent with the definition of rangeland health as proposed by the Committee on Rangeland Classification, Board of Agriculture, National Research Council (Rangeland Health, 1994, pg. 4 and 5)."

Our ecological assessment of the condition of natural communities in the study area is designed to provide information relevant to "the physical and biological functioning of ecosystems" and to whether they are maintaining their productivity and diversity. The ecological assessment of natural communities and the exotic plant survey that we have conducted can be used to determine if conditions (b) and (d) above are met in the SDNM and adjacent areas. To a lesser extent the data we have collected can be used to assess the degree to which condition (a) above is met in the study area.

For example, rangeland health condition (b) involves the maintenance of ecological processes that result in healthy biotic populations and communities (or at least progress toward attainment of this condition). BLM can evaluate the condition classes that we have established in this study to determine which condition classes meet rangeland health condition (b). Ecological Condition Class 3 areas are likely the closest to meeting rangeland health condition (b). Condition Class 2 may or may not meet this condition depending on a variety of factors and interpretations. Condition Class 1, which represents areas with a substantially degraded ecological condition, where biotic populations and communities are highly altered, probably does not meet rangeland health condition (b).

Likewise, rangeland health condition (d) involves the maintenance of habitats for Federal threatened and endangered (T&E) species, Federal Proposed, Federal candidate and other special status species (or the making of significant progress toward being restored for these ends). The data we collected for this report can be used to help evaluate if adequate habitat conditions exist for T&E and associated species in the study area. Habitat conditions for each T&E species is unique and determination whether these habitat conditions have been maintained requires an intensive species-specific evaluation. However, it may prove useful to incorporate our condition-class assessment and mapping in the evaluation of habitat conditions for some of these rare species. It is possible that some of the areas mapped as Condition Class 3 have retained habitat conditions for T&E species similar to those present during presettlement times. Patch size of suitable habitat and connectivity are important factors that need to be evaluated for many species. Condition Class 2 areas may or may not retain adequate habitat for various rare species depending on a wide variety of factors and interpretations. For many rare species, areas in Condition Class 1 probably have a higher likelihood of failing to provide adequate habitat conditions. These areas are at a higher risk of not meeting rangeland health condition (d) for many species of concern due to the substantial habitat modification that is present in these areas.

The Arizona BLM's *Standards For Rangeland Health And Guidelines For Grazing Administration* (1997) set forth the following standards to be used in determining if the above rangeland health conditions area being met. The standards are:

> "Standard 1: Upland Sites. Upland soils exhibit infiltration, permeability, and erosion rates that are appropriate to soil type, climate and landform (ecological site).
>
> Standard 2: Riparian-Wetland Sites. Riparian-wetland areas are in properly functioning condition.
>
> Standard 3: Desired Resource Conditions. Productive and diverse upland and riparian-wetland plant communities of native species exist and are maintained."

The data we have collected and our analysis of these data can be used to gauge whether these standards are met. With regard to Standard 1, we have collected information on soil conditions and erosion where it was observed in our assessment plots. Plots where significant erosion or degraded soil conditions were observed may not be meeting this standard.

Our assessment of ecological condition of the natural communities of the SDNM and adjacent areas and our exotic plant survey is most applicable to assessment of whether ecological sites are meeting Standard 3, which calls for the maintenance of "productive and diverse upland and riparian-wetland plant communities of native species." BLM's rangeland health standards explain that the criteria for whether this standard is met or not is indicated by such factors as: composition, structure and distribution of vegetation. Extensive information on all of these factors for upland and riparian-wetland communities was collected in this study.

Areas in Condition Class 3 are very likely to meet Standard 3 since we determined that they currently have "productive and diverse upland and riparian-wetland plant communities of native species". Areas in Condition Class 2 may or may not meet this standard depending on a variety of factors and interpretations. Some Condition Class 2 areas may not meet rangeland health standards due to the abundance of exotic plants. Other Condition Class 2 areas may not meet the rangeland health standards due to the lack of native grasses or other important components of the natural community. Areas in Condition Class 1 are at a high risk of not meeting this standard because of the lack of native diversity present on these sites, the prevalence of exotic plants, and the relative low overall productivity of many sites because of their degraded condition.

Although, there are significant differences between the approach set forth in the BLM's rangeland health standards and guidelines compared to the ecological condition assessment that we have conducted, the two approaches are complementary. Our assessment can lend weight to conclusions derived using the traditional approach of assessing rangeland health. It can also be used directly to determine whether many of the rangeland health conditions and standards are met, or whether progress is being made toward their attainment.

Recommendations

Follow-up Workshop

We recommend a follow-up workshop with BLM, TON, BMGR, and TNC staff to facilitate the interpretation of the results and conclusions of this study. This workshop would include a demonstration and discussion of the field methods employed as well as a thorough explanation, demonstration and discussion of the analytical techniques used. The workshop would provide an excellent opportunity to discuss how the results of this study relate to more traditional measures of rangeland health.

Improvement of Base GIS Data

Several base data layers need substantial improvement. The road data sets that are currently available are all somewhat inadequate. The most current BLM road GIS layer is missing some significant roads in the BLM portion of the study area. Ironically, some of these roads are present in an earlier BLM road layer. We had to combine three road layers to get relatively complete coverage of the roads. However, during our creation of the linear disturbance layer we discovered that there are still many roads or significant vehicle routes that are not in any of the existing road layers. We recommend a complete reevaluation of the adequacy of the road GIS data for the study area.

The BLM range improvement GIS data also needs substantial improvement. The spatial location of range improvements is often only approximate. Many significant range improvements are not mapped and other range improvements that are shown are not apparent on the ground. The biggest improvement in this data set would be to attribute the range improvements, particularly the livestock water sources, with their current status and level of use. Some of the livestock water sources in this layer are defunct and no longer in use (or may have never been used). There are other livestock water sources (developed tanks) that exist but are not in this GIS layer. We could build better models of ecological condition of the natural communities if this data layer was improved.

Improvement in the Accuracy of the Ecological Condition Map and Model

The accuracy of the ecological condition map and model could be improved by the incorporation of better information about the location and status of range improvements and roads as discussed above. We could also modify the model so that it incorporates information on the levels of use of livestock water sources and the levels of use on roads. This model modification would probably result in a substantial improvement in the predictive accuracy of the model. Collection of additional field data in certain locations (e.g. areas near the boundary between condition classes) would also help to refine the input data and improve the predictive accuracy of the model.

Additional Analyses Based on Existing Data

A great wealth of data was collected during this study. Further analysis of these data would produce products that would be useful to BLM's management of the SDNM and to others that have interest in the management of the larger study area. Some of the possibilities for further study using existing data are listed below.

Improved Landscape-level Assessment

Further analysis of the information developed during the landscape-level assessment may yield useful information that can help guide land management within the study area. This analysis could include:

- Analysis of the amount of landscape-level disturbance occurring in each natural community type.
- Analysis of the amount of landscape-level disturbance in relation to human population centers, major transportation routes and other factors.
- Analysis of the fragmentation caused by landscape-level disturbances, including identification of the patch distribution in each community and the geographic factors controlling fragmentation. This analysis would lead to an additional measure of ecological condition. It could help identify the best management opportunities for the maintenance of unfragmented landscapes.
- Analysis of the effects of fragmentation on exotic species distributions, rare plant populations, and ecological condition of natural communities.

Exotic Plant Distribution and Dynamics

Further analysis of the exotic plant species distributions is possible and may yield information that is useful to land management opportunities and risks within the study area. This analysis could include:

- Ranking of exotic plant species by percent cover and constancy by natural community and within the study area as a whole. This will help determine exotic species management priorities within each natural community.
- Analysis of exotic species distributions in relationship to use-levels and surface types of the transportation routes within the study area.
- Development of a set of recommendations for exotic plant management within the study area.

Occurrence and Distribution of Rare Plant Species

During the field assessment phase of this project we recorded information on all vascular plant species that occurred in our field plots. We also noted the occasional occurrence of rare plants in our field notes. Voucher specimens were collected in many instances and have been identified by experts in Sonoran Desert flora. Further analysis and synthesis of our plant database and field notes could yield useful information on the distribution of rare plant species. It would be useful to compare the lengthy plant species list with Heritage Global Ranks and the current state and federal T&E plant list to determine if there are additional globally rare species on the SDNM. We recommend further data analysis, mapping, and reporting based on the information collected in this project. This would result in the following products that could help guide the management of rare species:

- A list of rare plants found in the study area and their state, federal and global status.
- Maps of the occurrences of each rare species encountered in this project.
- Analysis of factors that influence the distribution of rare species and development of predictive models for the distribution of rare species. This could result in a set of maps that indicate the probability of occurrence for each species throughout the study area.
- Development of a set of management recommendations for the maintenance of rare plant populations within the study area.

Preparation of Voucher Specimens for Herbarium Collections

Numerous voucher specimens were collected of vascular plants observed in the study area. Botanical experts have recognized many of these specimens as important collections that could add considerably to the knowledge base on the distribution of Sonoran Desert flora. They have recommended that work be undertaken to prepare these specimens and accompanied data about their occurrence, so that they can be added to a herbarium collection at either the University of Arizona or Arizona State University. Both herbariums have indicated interest in receiving these specimens.

Evaluation of Native Grass Conservation Elements

Native grasses were determined during a meeting about Conservation Elements of the Sonoran Desert National Monument in May 2003 to be an important conservation element. We identified that native grass diversity and abundance were an important indicators for natural community ecological conditions. Further analysis of the data collected in this project on native grass species is recommended. This would yield the following products that would help determine land management strategies within the study area:

- Maps of the occurrence and relative abundance of each native grass species.
- A map of the best representations of native grass aggregations.
- Further analysis of the factors that influence the distribution and abundance of native grass species.
- Ranking of the native grass species by rarity and sensitivity to disturbance factors
- Development of a set of management recommendations for maintenance of native grass diversity within the study area.

Further Analysis of Mesquite Woodlands

Due to time and budget constraints, not all of the *Mesquite Woodland* community data gathered during the fieldwork and landscape-level analysis phases of this project was analyzed. Information on tree diameters and heights was collected for some stands in the study area. Some of the information collected in Mesquite Woodland Condition and Extent Plots was also not analyzed. Along with such field-based data, some of the GIS attribute data created during the aerial imagery chronosequence analysis was not analyzed in this report. Further analysis of all these data sets along with our completed ecological condition analyses could help better our understanding of mesquite stand ages and growth patterns related to disturbances and natural conditions in the study area.

Comparison with Other Studies

Comparisons of the findings of this study with other Sonoran Desert vegetation studies would help put our findings into context relative to these other studies, both methodologically and with respect to our findings. A comparison with comparable studies could yield further insight into the broader distribution and characteristics of the natural communities described in this report. Likewise, a comparison with other attempts at ecological condition assessment would yield further insight into the trends we observed in this study.

Further Analysis and Comparison of Natural Variation Across All Communities

We recommend further analysis of variation in vegetation composition and structure across all communities. This should include a cluster analysis that spans all communities. This would yield useful insight into the delineation and characterization of the natural communities. It could be used to test whether the natural communities that we have identified are less variable across the plots that we used to characterize them than between each other (that is, are the natural communities, as we have defined them, logical natural groupings in and of themselves).

Further Characterization and Subdivision of Natural Communities

Further analysis of the substantial body of data collected during this project would likely yield additional insights into the ecological condition of the natural communities. These communities are defined rather broadly, and further characterization into variants would be illuminating. Our preliminary analysis of the data using cluster analysis and DECORANA indicated that many of the communities could be fruitfully subdivided into several variants. The ecological condition of each variant may be quite unique and this information could be useful in determining management directions for various parts of the SDNM and adjacent areas.

Study of Saguaro Demographics

Further analysis of the ecology data collected during our study may reveal significant trends in saguaro (*Carnegiea gigantea*) recruitment and demographics that may be related to ecological condition and other factors. This analysis was beyond the time and fiscal constraints of this project, but significant demographic data were collected on the number of saguaros in each natural community plot and their height. We recommend further analysis of the saguaro demographic data and the relationship of the saguaro population demographics to natural community cluster groups, environmental gradients, and disturbance gradients. Our hypothesis developed during our field observations is that the distribution of small saguaros is closely associated with certain cluster groups and is influenced by the level of livestock activity. This hypothesis needs to be tested through a rigorous examination of the demographic data in relationship to the other data collected in this project.

Cataloging and Labeling of Photo Collection

An extensive collection of photos was developed during this project. These photos include plot photos, photos of natural communities, photos of disturbance factors and stress elements, photos of exotic species occurrences, photos of rare species occurrences, and other events. Some of these photos have been incorporated into this report. But the photo collection may prove useful in many future circumstances. For example, photos exist of each field plot established during this study. These will be useful resources for future studies because they can aid in relocation of the plots as well as provide visual information that can aid in the comparison of conditions between sample dates. To be useful to the BLM or TNC, this extensive collection of over 7000 photos needs to be labeled, catalogued, and entered into a database.

Future Research Requiring Additional Data Collection

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

Further Assessment of Mesquite Woodlands

Analysis of aerial photos and satellite imagery revealed an extensive distribution of potential *Mesquite Woodland* patches in the Tohono O'odham Nation portion of the study area. Due to the differences of landscape management techniques already discussed in this paper, we recommend repeating the data collection methods used on the SDNM *Mesquite Woodlands* in the TON. Comparative analysis could provide useful insight into the status and trends within the mesquite woodlands on the SDNM. Specifically, further data gathering on both the SDNM and TON in mesquite patches around the Vekol Valley grassland should be considered a priority in order to better understand the community interactions and changes taking place there. Because a majority of both the mesquite and grassland communities are on the TON, it is important that more field information be gathered there. This will enable a much more comprehensive analysis to be done on the ecological conditions of these two communities.

Further Assessment of Desert Grasslands

Similarly, the greatest extent of the Desert Grassland community is located in the TON portion of the study area. Collection of additional data on both the TON and SDNM during different seasons would facilitate a better understanding of the factors influencing ecological conditions and variations in composition and structure in this natural community. The influence of disturbance factors and stressors needs further examination in this community, and an analysis that compares management practices and levels of disturbance across ownership and land management boundaries could be helpful in determining future land management strategies.

Exotic Plant Distribution and Dynamics

Exotic plant distributions may vary significantly from year to year, depending on moisture levels, other climatic factors, and management activities. We recommend repeat sampling and the expansion of the exotic plant plots established in this study into new areas. This would help create a more comprehensive view on the population dynamics of exotic plant species. We are midway through a multi-year evaluation in Washington State that has already shed significant light on the dynamics of exotic plants and relationships to other stress elements (Morrison et. al. 2003). We recommend a similar study in the Sonoran Desert.

Further Evaluation of Factors Causing Variation in Natural Community Composition and Structure

In many of the natural communities we found considerable inner-community variation in composition that was not readily explained by the factors that we analyzed. Some of the community variation may be explained by variation in age of the landform surface and composition of the substrate. Other variation may be explained by landscape history, environmental variables or disturbance factors not yet identified. Further collection of data on surface and substrate characteristics, landscape history and other factors combined with repeat sampling of natural community plots may shed light into the more elusive factors which affect natural community compositions.

Landscape-level Assessment

The landscape-level assessment could be improved through the use of an enhanced historical aerial photograph chronosequence, including photos from the National Archives. The landscape-level assessment conducted in this project was based on analysis of available aerial imagery that spanned the interval from 1958 to 1996. The imagery used varied considerably in scale, image type, and overall quality. The inclusion of both earlier and later imagery as well as more consistent imagery would improve the landscape level assessment. Ideally, this assessment would include imagery from the late 1940's, or any other period containing imagery of the study area before significant alterations were made (i.e. creation of Vekol spreader dikes).

Refined mapping and analysis of livestock congregation areas, livestock trails and the High-Density Cow Trail Areas would be possible if more current, higher resolution imagery was used. We were limited to the 1996, 1-meter resolution CIR DOQQs in this study. We recommend the use of color or CIR aerial photography at a scale of at least 1:15,000 for this enhancement.

Improvements to Mapping of Natural Communities

Xeroriparian Natural Community Mapping

As noted in Appendix A, the xeroriparian communities were mapped using 1:100,000-scale hydrography data, which was the only data available at the time this work was completed. The extent of the xeroriparian communities is seriously underestimated using this data layer. Our field sampling and analysis of the CIR DOQQs indicates that the actual number and extent of xeroriparian areas is more than 3 times that which was mapped using existing hydrography data. This results in a significant underestimation of the extent of these important natural communities.

We recommend that work be undertaken to rectify this deficiency. This could be accomplished through two approaches. The first approach would be to use 1:24,000 scale hydrography data, once this data is available from the USGS or other sources. The use of this data will rectify at least part of the problem, as it will more accurately delineate the intermittent streams and will include some of the smaller streams. The usefulness of 1:24,000 scale hydrography data depends in large part on the accuracy and currentness of the source data used in its development. The second approach would be based on a combination of automated and manual interpretation of CIR DOQQs using a new image processing approach we have developed to extract this information from the DOQQs. This new approach would probably yield more accurate and current delineation of the xeroriparian communities than the use of standard 1:24,000-scale hydrography data.

Improved Separation of *Creosotebush – Bursage Desert Scrub* from *Paloverde - Mixed Cacti - Mixed Scrub on Bajadas*

Defining the separation between these two matrix communities was the most complex mapping challenge presented in this study. While we found that satellite spectral characteristics and biophysical parameters could be used to approximate the two communities, the spectral/biophysical model we developed was not accurate enough to reliably map the two communities. Therefore, we relied on aerial photo interpretation and manual digitizing of the boundary between these two communities. But these two communities grade into each other through broad transition zones and it is difficult for photo-interpreters to draw the boundaries between the two communities in a consistent, repeatable fashion. Also, small patches of each community are contained within the other community, but it is difficult to map each inclusion through aerial photo interpretation and manual digitizing.

We have developed a new method to more reliably separate the two communities (along with the xeroriparian communities that overlay these matrix communities) through a combination of automated and manual interpretation of CIR DOQQs using an image processing approach created to extract this information from the DOQQs. We recommend applying this approach across the study area to more accurately distinguish *Creosotebush – Bursage Desert Scrub* from *Paloverde - Mixed Cacti - Mixed Scrub on Bajadas.*

Repeat Sampling for Exotic Plants and Changes in Ecological Condition of Natural Communities

Since field sampling occurred after a period of severe long-term local and regional drought, the condition of vegetation throughout the study area was substantially influenced by this phenomenon. We recommend that field sampling be repeated using similar methods after this drought has abated to determine the response of the natural communities and exotic plants to more moisture. Repeated sampling may be necessary to adequately determine which stressors have the most influence on the condition of the natural communities. During our field season, it was obvious that a long-term moisture deficit has been a major stressor that may have masked other factors. Precipitation can vary considerably from year to year, and some exotic plants (e.g. *Bromus rubens*) may be much more abundant during wetter periods. Likewise, many native grasses and forbs may be much more abundant during wetter periods.

Analysis of Satellite Imagery on an Annual Basis to Assess Changes in Ecological Condition

During both phases of this project we examined and analyzed a sequence of Landsat satellite imagery that covers the study area. Our initial analysis indicates that there is significant variation in spectral response that is visible between images from different times of the year and from different years. A surge in photosynthetically active vegetation can sometimes occur in the late spring, after vegetation has a chance to respond to winter rains. Comparison of images from one year to the next can reveal significant changes in abundance of photosynthetically active vegetation between years. Satellite image analysis could be used to gauge the relative level of actively growing vegetation between years and between seasons. This information could be useful in assessing improvement in range condition due to changes in livestock management or changes in precipitation levels. Assessment of the level of photosynthetically active vegetation from Landsat or ASTER satellite imagery could aid in rapid determination of the appropriate livestock stocking levels for specific sites or allotments.

Formal Accuracy Assessment

A formal accuracy assessment of the natural community map and the ecological condition map would be a valuable endeavor. This would entail the establishment of randomly located accuracy assessment plots in each natural community using a stratified, random sampling approach. Similar data to that collected during Phase 2 fieldwork would be collected at each accuracy assessment plot. These data would be analyzed and the results compared to the mapped natural community and ecological condition at that location. This information could then be used to determine errors of omission and commission or user's and producer's accuracies (Story and Congalton, 1986). A carefully designed and executed accuracy assessment will help validate the results of this study. It would also help to determine areas where additional data collection, mapping, and model improvement may be beneficial.

Conclusion

Twelve natural communities exist in the SDNM and adjacent areas. There is considerable natural ecological variation between each of these communities. There is also considerable natural variation within the communities and many communities grade into one another. The ecological variation within and between communities can be explained by gradients of moisture, temperature and substrates. Temperature and moisture are largely controlled by topographic factors (elevation, aspect and slope) and by regional precipitation gradients. Substrate conditions are a result of geology and soil conditions.

There are several stressors that influence the ecological condition of natural communities in the area. Some of these stressors affect only localized areas while other stressors influence the entire study area. Localized stressors include hydrologic alteration, undocumented alien and drug traffic, military training (BMGR), recreational sites and historical mineral and/or gravel extraction. Regional stressors include invasion by exotic plant and animal species, climate change and inadvertent weather modification, and air pollution from urbanized and agricultural areas. The influence of livestock and the influence of vehicles (both on roads and off roads) affect some natural communities (e.g. *Creosotebush – Bursage Desert Scrub*) more than other communities (e.g. *Rock Outcrops*). These last two stressors may have fairly extensive influence on condition within the natural communities where they occur.

There are many ways that the mapping of natural communities and the assessment of ecological condition can be improved. There are also many additional products that can be produced from the data collected in this study. We list a series of recommendations for further work that would greatly expand the usefulness of this study.

List of References

Bennett P.S., Kunzmann M.R., Graham L.A. 2000. Descriptions of Arizona vegetation represented on the GAP vegetation map. In: Halvorson W.L., Kunzmann M.R., editors. *Assessment, correction, and augmentation of the Arizona GAP vegetation data.* Tucson [AZ]: U.S. Geological Survey. Appendix B. p. 1-86.

Benson L. 1969. *The Cacti of Arizona*. University of Arizona Press. 218 p.

Benson, L. and R.A. Darrow. 1981. *Trees and Shrubs of the Southwestern Deserts*. 3rd. edition. University of Arizona Press, Tucson. 416 p.

Brown, D.E., editor. 1994. *Biotic Communities: Southwestern United States and Northwestern Mexico*. Salt Lake City [UT]: University of Utah Press. 342 p.

Brown D.E. and C.H. Lowe. 1980. *Biotic Communities of the Southwest* (map at scale 1:1,000,000). USDA Forest Service GTR RM-78.

Brown, D.B., Lowe C.H., Pase C.P. 1979. A digitized classification system for the biotic communities of North America, with community (series) and association examples for the Southwest. Arizona-Nevada Academy of Science 14(Suppl. 1):1-16.

Daly, C., Neilson, R.P., and Phillips, D.L. (1994) A statistical-topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology **33**: 140-158

Daniel, T.F., Butterwick M.L. 1992. Flora of the South Mountains of south-central Arizona. *Desert Plants* 10(3):99-119.

Douglas, E. 1938. Arizona's first irrigators. *Arizona Highways* Sept: 26.

Earle, W.H. 1980. *Cacti of the Southwest*. Rancho Arroyo Book Distributor. Tempe, AZ.

Epple, A.O. and L.E. Epple 1995. *A Field Guide to the Plants of Arizona*. LewAnn Publishing Co., Mesa, AZ.

Felger, R.S. & B. Broyles, eds. 1997. *Dry Borders: Binational Sonoran Desert Reserves*. Journal of the Southwest 39:303-860

Felger, R.S. 2000. *Flora of the Gran Desierto and Rio Colorado of Northwest Mexico.* University of Arizona Press. 673 p.

Gauch, H.G. 1989. Multivariate Analysis in Community Ecology. Cambridge University Press. New York. 298 pp.

Gavin T.A. 1973. *An Ecological Survey of a Mesquite Bosque*, MS thesis, University of Arizona, Department of Biological Sciences. Tucson, AZ.

Gelbard J.L. and J. Belnap. 2003. Roads as conduits for exotic plant invasions in a semiarid landscape. Conservation Biology 17(2):420-432.

Gerst, J.L. 1997. *Endangered and Threatened Wildlife and Plants; Determination of Endangered Status for the Cactus Ferruginous Pygmy-Owl in Arizona*. Federal Register, Vol. 63, No. 46, p. 10730

Grossman DH, Faber-Langendoen D, Weakley AS, Anderson M, Bourgeron P, Crawford R, Goodin K, Landaal S, Metzler K, Patterson KD, Pyne M, Reid M, and Sneddon L. 1998. *International classification of ecological communities: terrestrial vegetation of the United States*. Volume I, The National Vegetation Classification System: development, status, and applications. The Nature Conservancy: Arlington, VA

Hall, J.A., P. Comer, A. Gondor, R. Marshall, and S. Weinstein. 2001. *Conservation Elements of a Biodiversity Management Framework for the Barry M. Goldwater Range, Arizona*. The Nature Conservancy of Arizona, Tucson. 199 + ix p. +15 unpaginated figures.

Hendricks, D.M. 1985. *Arizona Soils*. Tucson [AZ]: College of Agriculture, University of Arizona. 244 p. + 1 map.

Hickman, J.C. 1993. *The Jepson Manual, Higher Plants of California*. Univ. of California Press, Berkeley.

Hill, M. O. 1979. *DECORANA--a FORTRAN program for detrended correspondence analysis and reciprocal averaging*. Ithaca, NY.: Ecology and Systematics, Cornell University.

Hill, M. O., and H. G. Gauch. 1980. Detrended correspondence analysis: an improved ordination technique. Vegetation 42: 47-58.

Jaeger, E.C. 1941. *Desert Wild Flowers.* Stanford Univ. Press, Stanford, CA.

Kearney T.H. and R.H. Peebles. 1960. *Arizona Flora*. Univ. of California Press, Berkeley. 1085 p.

Lacey, J.R., P.R. Ogden, and K.E. Foster. 1975. *Southern Arizona Riparian Habitat: Spatial Distribution and Analysis*. Bulletin 8. Office of Arid Lands, University of Arizona, 148 pages.

Marshall, R.M., S. Anderson, M. Batcher, P. Comer, S. Cornelius, R. Cox, A. Gondor, D. Gori, J. Humke, R. Paredes Aguilar, I.E. Parra, S. Schwartz. 2000. *An Ecological Analysis of Conservation Priorities in the Sonoran Desert Ecoregion.* Prepared by the Nature Conservancy of Arizona,
McCune B. and M. J. Mefford. 1999. PC-ORD. *Multivariate analysis of ecological data*, version 4. Gleneden Beach, OR. MjM Software Design

Sonoran Institute, and Instituto del Medio Ambiente y el Desarrollo Sustentable del Estado de Sonora with support from Department of Defense Legacy Program, Agency and Institutional Partners, 146 pp.

McAuliffe J.R. 1999. The Sonoran Desert: landscape complexity and ecological diversity. In: Robichaux R.H., editor. *Ecology of Sonoran Desert Plants and Plant Communities*. Tucson [AZ]: University of Arizona Press. p. 115-142.

Minckley, W.L. and T.O. Clark. 1981. Vegetation of the Gila River Resource Area, eastern Arizona. *Desert Plants* 3(3): 124-140.

Minckley, W.L., and T.O. Clark. 1984. Formation and destruction of a Gila River mesquite bosque community. *Desert Plants* 6(1):23-30.

Morrison P.H., G. Wooten, A. Workowski, A.H. Jeffries, R. Shultze, K. Besh, and K. Harma. 2003. *Demographics of Exotic Plants in the Chewuch Watershed, Washington.* Pacific Biodiversity Institute status report to Center For Invasive Plant Management. 46 p.

Nations D., Stump E. 1996. *Geology of Arizona*. Dubuque [IA]: Kendall/Hunt Publishing Company. 221 p.

Neff, J.A. 1940. Notes on nesting and other habitats of the White-winged Dove in Arizona. Journal of Wildlife Management 4:279-290.

Olson, C.E. 1940. *Forests in the Arizona Desert.* Journal of American Forestry 38(12):956-959.

Palmer, M. 2003. Ordination Methods for Ecologists webpage. http://www.okstate.edu/artsci/botany/ordinate/. Botany Department, Oklahoma State University, OK.

Rea, A.M. 1983. Once a river: bird life and habitat changes on the middle Gila. University of Arizona Press, Tucson. 346 pages.

Reynold S.J. 1988. *Geologic Map of Arizona*. Arizona Geologic Survey. Scale 1:1,000,000.

Szaro, R.C. 1989. Riparian scrubland and community types of Arizona and New Mexico. *Desert Plants* (Special issue) 9(3-4): 1-138.

Sellers, W.D., Hill R.H. 1974. *Arizona Climate 1931-1972*. Tucson [AZ]: University of Arizona Press. 616 pp.

Snetsinger, S. and R. Spicer. 2001. *Vegetation Classification and Mapping of the Florence Military Reservation, Pinal County, AZ*. Nongame and Endangered Wildlife Program Technical Report #176. Arizona Game and Fish Department, Phoenix, AZ. 129 pp.

Story, M. and R.G. Congalton. 1986. Accuracy assessment: A user's perspective. *Photogrammetric Engineering and Remote Sensing* 52(3): 397-399.

Stromberg, J.C. 2002. Ecological abstract on mesquite woodlands, TNC internal document.

Turner R.M., J.E. Bowers, T.L. Burgess. 1995. *Sonoran Desert Plants: An Ecological Atlas.* University of Arizona Press. 504 p.

Turner, D.S., R.S. Felger, K. Mauz, C.S. Funicelli, T. VanDevender, J. Malusa. 2000. *Biological Resources of the Proposed Sonoran Desert National Monument, Arizona*. The Drylands Institute, Tucson. 87 + ii p.

Vogelmann, J.E., S.M. Howard, L. Yang, C.R. Larson, B.K. Wylie, N. Van Driel, 2001. Completion of the 1990s National Land Cover Data Set for the Conterminous United States from Landsat Thematic Mapper Data and Ancillary Data Sources, Photogrammetric Engineering and Remote Sensing, 67:650-652.

Warren, P.L. and L.S. Anderson. 1985. Gradient analysis of a Sonoran Desert wash. Pages 150-155 in R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Folliott, and R.H. Hamre (tech. Cords.), *Riparian Ecosystems and their Management: Reconciling Conflicting Uses*. First North American Riparian Conference. April 16-18, Tucson, Arizona. General Technical Report RM-120. RMRS. USDA Forest Service, Fort Collins, Colorado.

Warren P.L., Mortenson K, Treadwell B.D., Bowers J.E., Reichhardt K.L. 1981. *Vegetation of Organ Pipe Cactus National Monument*. Technical Report No. 8. Tucson [AZ]: Cooperative National Park Resources Studies Unit, University of Arizona. 79 p. + map.

Weinstein, S., A. Gondor, J.A. Hall. 2002. Conservation Elements of the Sonoran Desert National Monument: A Preliminary Analysis. The Nature Conservancy of Arizona. Tucson. 42p.

Wetherwax M., B.G. Baldwin, S. Boyd, B.J. Ertter, R.W. Patterson, T.J. Rosatti, D.H. Wilken editors. 2002. *The Jepson Desert Manual: Vascular Plants of Southeastern California*. University of California Press. 627 p.

Yang T.W. and Lowe C.H. 1956. Correlation of major vegetation climaxes with soil characteristics in the Sonoran Desert. *Science* 12(3196): 542

Zar, J. H. 1999. *Biostatistical Analysis*. Prentice Hall, New Jersey. 663 pp.

APPENDICES – VOLUME 2

Appendix A – Natural Community Descriptions

Appendix B – List of Plants Identified During Study

Appendix C – Composition of Natural Communities (Sorted by Mean Percent Cover)

Appendix D – Composition of Natural Communities (Sorted by Constancy)

Appendix E – Maps of Exotic Plant Locations, for 15 Species

Appendix F – Summary of Condition Classes and Related Statistics by Community

Appendix G – Composition of Cluster Groups in the Creosotebush – Bursage Desert Scrub Community

Appendix H – Composition of Cluster Groups in the Paloverde - Mixed Cacti - Mixed Scrub on Bajadas Community

Appendix I – Composition of Cluster Groups in the Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes Community

Appendix J – DECORANA Graphs of Distribution of Major Plant Species in the Paloverde - Mixed Cacti - Mixed Scrub on Rocky Slopes Community

Appendix K –Composition of Cluster Groups in the Mountain Upland Community

Appendix L – Composition of Cluster Groups in the Mesquite Woodland Community

Appendix M – Composition of Cluster Groups in the Mountain Xeroriparian Community

Appendix N – Composition of Cluster Groups in the Valley Xeroriparian Community

Appendix O – Composition of Cluster Groups in the Braided Channel Floodplain Community

Appendix P – Natural Community Condition Assessment Plot Form

Appendix Q – Exotic Species Inventory Plot Form

Appendix R – Point Intercept Transect Form

Appendix S – Mesquite Condition and Extent Plot Form

Appendix T – Between Plots (Miscellaneous) Observation Form