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Mojave Desert Network Integrated Upland Monitoring

2012 Pilot Study for Grand Canyon-Parashant National Monument

Natural Resource Technical Report NPS/MOJN/NRTR—2014/902

ON THE COVER
Sagebrush shrub steppe community monitoring plot, Grand Canyon-Parashant National Monument
Photograph by: Mojave Desert Network Inventory & Monitoring Program, Integrated Upland field crew, NPS.

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Contents

Page

Figures v

Tables vii

Appendices ix

Executive Summary xi

Acknowledgments xiii

Acronyms xiv

1 Introduction 1

1.1 Vital Signs 1

2 Methods 3

2.1 Sampling Frames 3

2.2 Travel Cost Scenarios 5

2.3 Field Methods 6

2.4 Data Summary 8

3 Results 11

3.1 Travel Cost Scenarios 11

3.2 Office and Support Staff Costs 14

4 Issues and Implementation Recommendations 15

4.1 Travel and Field Time 15

4.1.1 Field Time 15

4.1.2 Travel Time to Field Sites 18

4.1.3 Field Crews 18

4.2 Field Procedures 18

4.2.1 Transect-related Procedures 18

4.2.2 Soil Sampling Point Procedure 19

Literature Cited 21

Figures

Page

Figure 1. Sagebrush (*Artemisia* spp.) shrub steppe community at Grand Canyon-Parashant National Monument. 2

Figure 2. The first 35 sites selected from the Generalized Random Tessellation Stratified (GRTS) survey design draw for Grand Canyon-Parashant National Monument. 4

Figure 3. Standard macroplot and transect layout for integrated upland monitoring. 7

Figure B1. Least cost travel paths to 35 Generalized Random Tessellation Stratified (GRTS) sites generated by the travel time cost surface model from the designated start point for Grand Canyon-Parashant National Monument. B-2

Figure C1. Locations of visited field sites and established macroplots within the sagebrush (*Artemisia* spp.) shrub steppe community at Grand Canyon-Parashant National Monument. C-2

Figure C2. Mean a) % cover and b) species richness of species for each life form by macroplot. C-3

Figure C3. Mean (+SE) total % cover by macroplot. C-5

Figure C4. Mean (+SE) % cover of live and dead species/life form by macroplot. C-6

Figure C5. Mean (+SE) proportion of quadrats infested by target invasive species by macroplot. C-7

Figure C6. Mean % cover for invasive and native species by macroplot. C-9

Figure C7. Mean (+SE) % cover of soil surface features per macroplot. C-10

Figure C8. Mean (+SE) a) % cover and b) proportion of quadrats of soil disturbance features per macroplot from the point-intercept and invasive species frequency quadrats procedures. C-11

Figure C9. Mean number of canopy gaps for a given size category per macroplot. C-12

Figure C10. Mean (+SE) gap size and total gap length per transect by macroplot for a) canopy and b) basal gaps. C-13

Figure C11. Mean number of basal gaps for a given size category per macroplot. C-14

Figure C12. Mean (+SE) values for pH and electrical conductivity (EC) by macroplot. C-15

Figure D1. Macroplot overview photo for macroplot 25. ..... D-1

Figure D2. Macroplot overview photo for macroplot 00C1. ..... D-2

Figure D3. Macroplot overview photo for macroplot 00C2. ..... D-3

Tables

Page

Table 1. Time and cost estimates for each field data collection procedure, field data management, and revisit set-up with a 2-person crew 12

Table 2. Time and cost estimates of field data collection by vital sign with a 2-person crew. 13

Table 3. Network staff cost estimates for the integrated upland protocol. 14

Table 4. Cost estimates, including hike times, to conduct different subsets of field procedures during a sampling event for the integrated upland (IU) monitoring protocol at Grand Canyon-Parashant National Monument. 17

Table B1. Travel time cost surface model estimates for one-way hiking, driving, and total travel time to 35 potential field sites selected in the Generalized Random Tessellation Stratified (GRTS) draw. B-3

Table B2. Cost estimates for round-trip hiking to 35 sites from the Grand Canyon-Parashant National Monument Generalized Random Tessellation Stratified (GRTS) draw for a 2-person crew. B-5

Table B3. Cost estimates for round-trip hiking to 35 sites from the Grand Canyon-Parashant National Monument Generalized Random Tessellation Stratified (GRTS) draw for a 3-4 person crew, consisting of one GS-5 field technician and 2-3 natural resource interns. B-5

Table B4. Time and cost estimates for conducting the soil measurements procedure in the field *vs*. in the office. B-5

Table B5. Cost estimates for initial macroplot set-up, including pre-reconnaissance of potential field sites. B-6

Table B6. Scenarios for crew schedules for a crew of two. B-6

Table C1. Mean % cover per macroplot of shrub and tree species found across three macroplots in 2012. ..... C-4

Table C2. Frequency of quadrats for dead *vs*. live, spatial location, and phenophase of the invasive species found across three macroplots in 2012. ..... C-8

Table C3. Dominant qualitative soil characteristics for two monitored macroplots in 2012. ..... C-17

Appendices

Page

Appendix A: Travel Time Cost Surface Model A-1

Appendix B: Travel Cost Scenarios Tables B-1

Appendix C: PARA Macroplot Data from the Pilot Study C-1

Appendix D: Macroplot Overview Photographs from the 2012 Pilot Study D-1

Executive Summary

The Integrated Upland (IU) Monitoring Protocol of the Mojave Desert Network Inventory and Monitoring Program (MOJN I&M) is one of the long-term monitoring protocols developed for the National Park Service "Vital Signs Monitoring Program," a long-term ecological monitoring program that will provide rigorous, scientifically-based information on the status and trends of park ecosystems. Data from this program are intended to help park managers evaluate complex and challenging resource issues and make sound decisions that result in long-term protection of park resources. Information on park resource conditions will also be useful for park planning, research, education, and public awareness.

Twenty priority park vital signs - indicators of ecosystem health - that represent a broad suite of ecological phenomena operating across multiple temporal and spatial scales were identified for MOJN I&M (Chung-MacCoubrey et al. 2008). The IU protocol (Pan et al. Unpublished Report [a]) addresses seven of these prioritized vital signs, including vegetation change, invasive plants, and soil-related vital signs. The focus of the IU protocol is upland shrub communities. Shrub communities were chosen because this physiognomic class collectively represents a large proportion of each park and captures several focal communities of interest (e.g., Joshua tree, creosote bush, and sagebrush), thus providing a common theme among parks (we use the term "park" for all units of MOJN). Each of the seven parks in the network, in collaboration with the MOJN I&M, selected a target upland community for monitoring. The sagebrush shrub steppe community was selected for monitoring at Grand Canyon-Parashant National Monument (PARA).

A pilot study for the IU protocol (Pan et al. Unpublished Report [a]) was conducted in the spring and summer of 2012 and included the establishment and measurement of 19 plots across six of the MOJN parks (MANZ was not included as part of the pilot study). The objectives of the pilot study were to: 1) to implement and fine-tune field methods and procedures (such as establishing macroplots, conducting field measurements, etc.) and 2) use information and time estimates from implementing field methods within target communities at parks to estimate protocol costs. In this report, findings based on the overall pilot study as well as park-specific field results for PARA are presented. Cost estimates were generated for conducting field procedures, travel to field sites, and different crew staffing scenarios. At PARA, one macroplot was successfully established and had field procedures implemented, while two macroplots that were selected for methods testing had more limited data collection. Using information based on macroplots from all parks, the time to implement various field procedures ranged from around 30 min (Site Assessment for Invasive Plants) to up to 360 min (Soil Measurements) for a two-person field crew. At PARA, the average estimated cost for each macroplot revisit (hiking time to field site plus field data collection, *not including driving time*) was $606, for a total of approximately $21,210 for 35 spatially randomly selected field sites. We found three shrub species across the macroplots, although only sagebrush (*Artemisia* spp.) was found on all macroplots, detected three of the four target status and trends invasive species on the macroplots, and compared qualitative and quantitative soil parameters across macroplots. We discuss issues and make recommendations regarding sampling return intervals, crew sizes and schedules, and sampling procedures. Our primary recommendations include:

- ✓ Increase the monitoring interval for soil procedures, including basal/canopy gaps.
    - Analyze one soil sample per sampling point.
- ✓ Increase the monitoring interval for repeat photographs to every 3-4 monitoring periods (9-12 year intervals).

Acknowledgments

We thank the Grand Canyon-Parashant National Monument staff for their support before, during, and after our field work. We appreciate their arranging and meeting with us to discuss monument and safety procedures. In particular, we thank Jennifer Fox, our point of contact, Brandon Boshell (BLM) for reviewing our site selection and offering advice on field conditions, Ray Klein for providing a safety briefing and general information on monument travel, David Van Alfen (BLM) for cultural compliance and guidance, Jeff Young (BLM) for facilitating our permit, and Dorie Miller for arranging housing.

The field work could not have been done without our dedicated field crew: Student Conservation Association (SCA) interns Ashley Popham, Craig Rowell, Petra Murdoch, Heather Benedict, and Karin Edwards (contract botanist). Janel Brackin (MOJN I&M Science Communicator) and Bob Truitt (MOJN I&M Data Manager) provided much time on data entry, clean-up, and QA/QC. Natasha Antonova, GIS specialist at the North Coast and Cascades Network Inventory and Monitoring Program, ran the travel time cost surface model. We are grateful for the guidance that Kirk Sherill, developer of the travel time cost surface model, provided. We thank Lise Grace, technical editor at the North Coast and Cascades Network Inventory and Monitoring Program, for formatting the report and guiding us through the publication process.

Acronyms

BSC	Biological soil crust
DEM	Digital Elevation Model
DEVA	Death Valley National Park
EC	Electrical conductivity
GAP	California Gap Analysis Program
GIS	Geographic Information Systems
GPS	Global positioning system
GRBA	Great Basin National Park
GRTS	Generalized Random Tessellation Stratified
I&M	NPS Inventory and Monitoring Program
IU	MOJN I&M Integrated Upland Monitoring Protocol
JOTR	Joshua Tree National Park
LAKE	Lake Mead National Recreation Area
MANZ	Manzanar National Historic Site
MOJA	Mojave National Preserve
MOJN	Mojave Desert Network
NHD	National Hydrography Dataset
NPS	National Park Service
PARA	Grand Canyon-Parashant National Monument
PMTS	Percent of Maximum Travel Speed
SOP	Standard operating procedure
TTCSM	Travel Time Cost Surface Model
USGS	United States Geological Survey

1 Introduction

The parks of the Mojave Desert Network Inventory and Monitoring Program (MOJN I&M) are faced with increasing pressures from air pollution, habitat loss, fragmentation, and altered disturbance regimes (e.g., fire, land development; Chung-MacCoubrey et al. 2008). Climate models also predict significant climatic changes, with increasing temperatures and decreasing precipitation, for the southwestern United States (Seager et al. 2007, Archer and Predick 2008). The presence and composition of vegetation depends on a multitude of abiotic and biotic factors including climate, resource availability, and soil microbial community. This makes vegetation and the soils associated with it good general indicators of environmental change across parks (Vasek and Lund 1980, Janssens et al. 1998, Klironomos 2002, Hereford et al. 2006).

The Integrated Upland (IU) monitoring protocol was designed to provide the status and trends of natural resources (vegetation, soil, and invasive plants; see *Section 1.1 Vital Signs*) in upland shrub communities at all seven MOJN parks: Death Valley National Park (DEVA), Great Basin National Park (GRBA), Joshua Tree National Park (JOTR), Lake Mead National Recreation Area (LAKE), Manzanar National Historic Site (MANZ), Mojave National Preserve (MOJA), and Grand Canyon-Parashant National Monument (PARA). Monitoring focuses on a target upland shrub community within each park. Data collected from IU monitoring plots will serve two very important purposes: 1) providing a quantifiable framework from which to build adaptive management policies, and 2) providing a baseline from which to establish additional scientific studies (e.g., those addressing cause and effect relationships). With a basic understanding of the park resources and processes affecting them, land managers can make more informed decisions about how to conserve these resources into the future.

We conducted a pilot study of the IU Monitoring Protocol at six of the MOJN parks (DEVA, GRBA, JOTR, LAKE, MOJA, PARA) and full implementation (where the planned number of macroplots were established and measured) of the protocol at the smallest park (MANZ). Nineteen macroplots were established and measured across the six pilot parks. We utilized findings from the six parks to estimate time and cost estimates for implementation of the IU Monitoring Protocol at each of the parks. This report describes the activities and findings of the 2012 pilot study for at Grand Canyon-Parashant National Monument (PARA), where we focused on the **sagebrush** (*Artemisia* spp.) **shrub steppe community** (Figure 1). The objectives of the pilot study were to: 1) implement and fine-tune field methods and procedures (such as establishing macroplots, conducting field measurements, etc.) and 2) use information and time estimates from implementing field methods at randomly selected field sites within target communities to estimate protocol costs. *We used the information collected during our pilot study to: 1) evaluate different travel cost scenarios to conduct IU monitoring (see Section 3 Results; Appendix B - Travel Cost Scenarios Tables), and 2) examine the field data collected using the SOPs (see Appendix C).*

1.1 Vital Signs

After a series of vital signs scoping workshops, 20 priority park vital signs - indicators of ecosystem health - that represent a broad suite of ecological phenomena operating across multiple temporal and

spatial scales were identified and ranked for MOJN I&M (Chung-MacCoubrey et al. 2008). The IU protocol directly addresses seven highly ranked vital signs out of the 20, which we broadly categorize as vegetation change, invasive plants, and soils (ranking out of 20):

- Vegetation change (2)
- Invasive/exotic plants (3)
- Soil-related:
  - Soil chemistry (9)
  - Soil hydrologic function (10)
  - Soil erosion and deposition (11)
  - Soil surface disturbance (12)
  - Biological soil crusts (13)

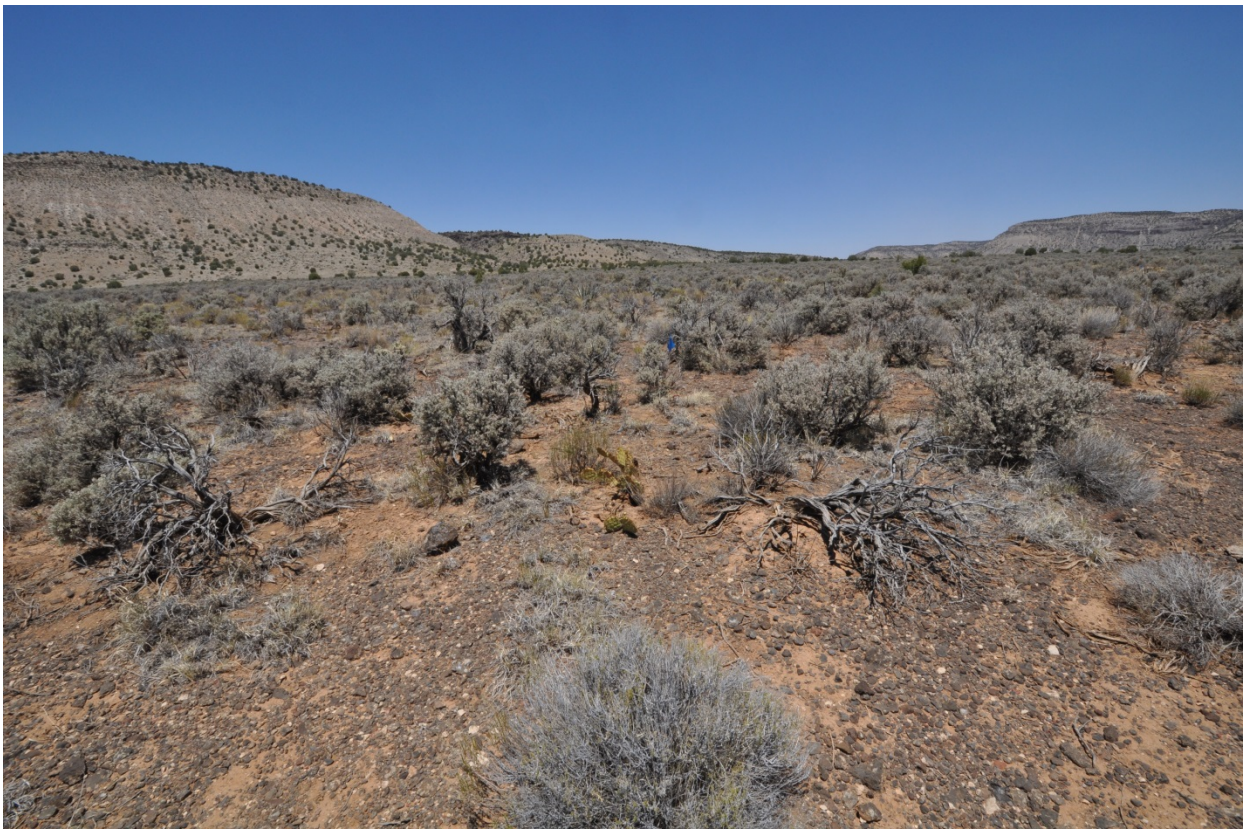

Figure 1. Sagebrush (*Artemisia* spp.) shrub steppe community at Grand Canyon-Parashant National Monument. Photo by Mojave Desert Network Inventory & Monitoring Program, Integrated Upland field crew, NPS.

2 Methods

Here, we describe how potential field sites were randomly selected using a Generalized Random Tessellation Stratified (GRTS; see *Section 2.1 Sampling Frames*) design or selected by field crews, how time and cost estimates were generated for travel cost scenarios (see *Section 2.2 Travel Cost Scenarios*), the field methods used for data collection (see *Section 2.3 Field Methods*), data quality assurance and control (QA/QC), data processing, and data analyses (see *Section 2.4 Data Summary*). These procedures are described in full in the MOJN IU protocol SOPs (Pan et al. Unpublished Report [b]).

2.1 Sampling Frames

At PARA, field sites for macroplot establishment were selected either from the GRTS survey design or by the field crew from appropriate community types close to roads; the latter were used only for methods testing and would not be included in future IU monitoring. The GRTS survey design (Stevens and Olsen 2004) produces a randomly selected set of sites that are spatially balanced across the monitored community and then takes into account the spatial distribution of field sites during data analysis. New GRTS survey designs may be used when IU monitoring is implemented at all parks.

In order to select potential field sites, we first determined the spatial distribution of the target upland community at PARA, the **sagebrush** (*Artemisia* spp.) **shrub steppe community**. This plant community was selected for monitoring because of its widespread spatial distribution and special management concern at PARA. Much of PARA is part of the Great Basin ecoregion and sagebrush (mostly *A. tridentata*) shrub steppe communities are the characteristic and dominant shrub community within a large extent of PARA. Similar to sagebrush communities in other areas of the Great Basin ecoregion, sagebrush communities at PARA are experiencing encroachment by pinyon-juniper trees and invasion by annual grasses. Monitoring changes in sagebrush shrub steppe communities is important for effectively managing these areas for grazing as part of the continued administration of grazing leases, which is specified in PARA's establishing Proclamation.

The spatial distribution of the sagebrush shrub steppe community was evaluated using a vegetation dataset provided by the Arizona Strip Field office (2007), the best available vegetation map for PARA. Using Geographic Information Systems (GIS), we created a 100 m buffer just inside the monument boundary, which was removed from the spatial distribution of the target community to ensure that any sites selected would be well-within the monument boundary. Where possible, we also eliminated target vegetation areas that were too small to support the 1 ha macroplot. The remaining area (190,806 ac) served as the sampling frame for the GRTS site selection (see Figure 2) and is considered the population of inference.

We used an equal probability GRTS survey design at PARA, so that all areas of the population of inference had an equal probability of being selected. We had an initial draw of 35 sites for the monument (Figure 2) based on power analyses across the different park units (see Pan et al. Unpublished Report [a] for details, report is available upon request), with an oversample of 300 sites, which allows for elimination of sites due to sampling frame errors arising from map inaccuracies (e.g., non-target vegetation type, site on private land; Pan et al. Unpublished Report [a]), as well as

the addition of sites in the future if it is determined from power analyses that more macroplots are needed.

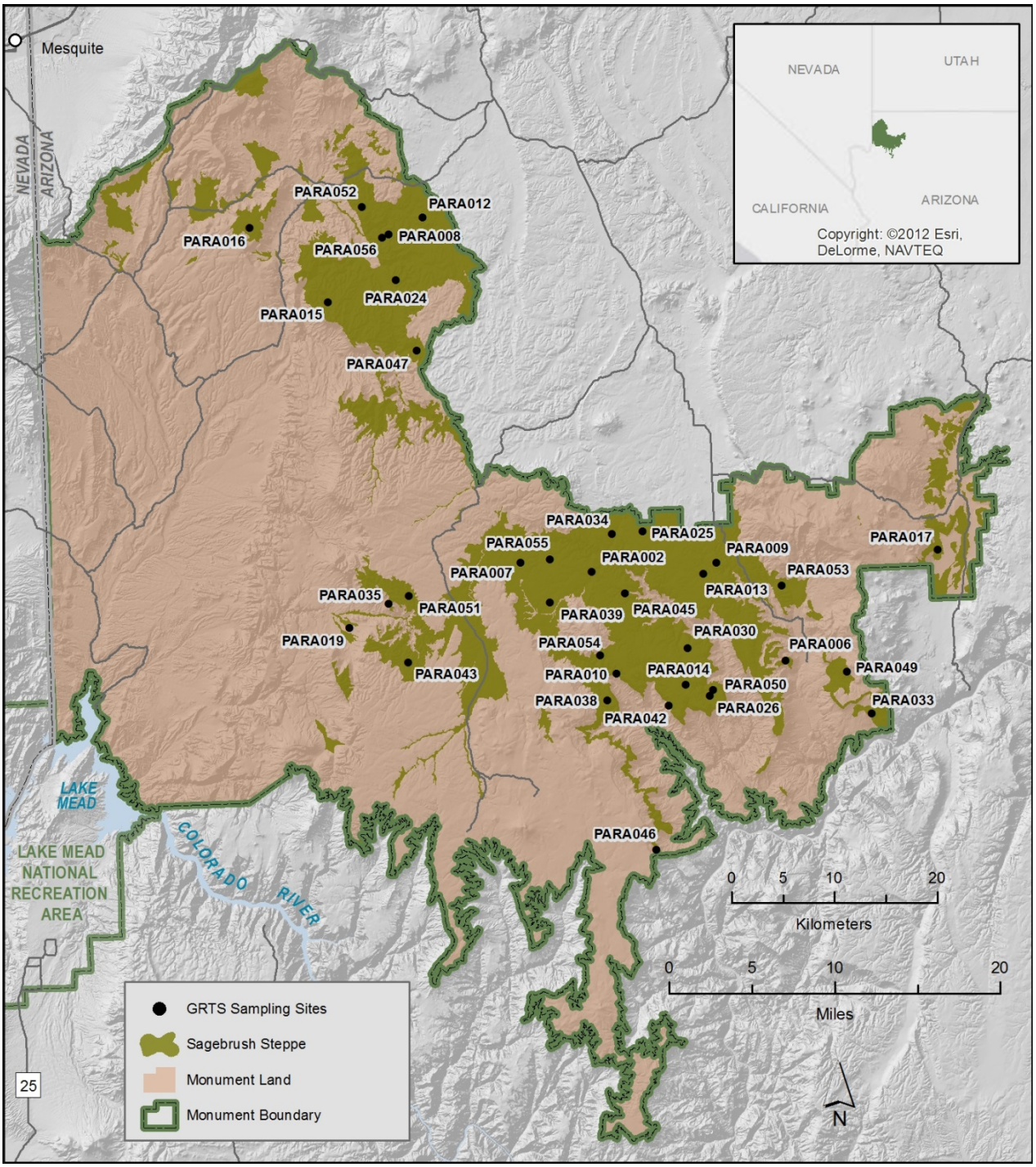

Figure 2. The first 35 sites selected from the Generalized Random Tessellation Stratified (GRTS) survey design draw for Grand Canyon-Parashant National Monument.

For the pilot season, we generated a list of 10 potential field sites by selecting a subset of field sites that were within 1 mile of a road from the initial draw of 35 sites at PARA. We then used a Digital

Elevation Model (DEM) and satellite imagery (available in Google Earth) to conduct office reconnaissance on the potential field sites at PARA, eliminating any sites that were unsuitable (e.g., unsafe, inaccessible). The remaining sites were then provided to PARA staff for further input. If monument staff deemed a site inappropriate for long-term monitoring (e.g., culturally-sensitive, unsafe), then the field site was rejected. If needed, a replacement site was added from either the remaining sites in the initial draw or from the oversample.

Potential field site visitation order was determined by MOJN I&M office staff. Field sites could also be rejected after field crews physically visited sites (Pan et al. Unpublished Report [b], *SOP 6 – Site Characterization*). If a field site was rejected by the crew, then they proceeded to the next site on the list of potential sites. If a site was acceptable, then a macroplot was established and data were collected.

After visiting the first site, we realized the significant time commitment required to visit sites on the GRTS list. We put a greater priority on testing our field methods and decided to have the field crew select sites in the sagebrush shrub community that were close to roads and to where the crew was staying. Thus, the full suite of data were collected on only one macroplot, and methods testing and limited data were collected at two sites close to a road (see Figure C1). However, only sites from the GRTS draw were used in the travel time cost surface model (see section *2.2 Travel Cost Scenarios*).

2.2 Travel Cost Scenarios

We evaluated travel to field sites (time and/or distance) using a travel time cost surface model (TTCSM; Appendix A), the number of field crew members, field crew schedule (e.g., 8 vs. 10 hour work days), and local vs. traveling crew in the travel cost scenarios. TTCSM and crew-related scenarios were conducted after the pilot study (and based loosely on field experience from the pilot study, such as estimates of travel time to different park units) to provide an overall cost estimate for IU establishment and monitoring of 35 macroplots at each park. In contrast, scenarios proposed for initial establishment of macroplots, field procedures, and subsequent revisits that consist primarily of field data collection, were based on pilot study time estimates for the six parks.

Estimates for initial establishment of macroplots included all costs associated with the establishment of macroplots, including office and field reconnaissance of potential field sites, and macroplot set-up. We assumed that 50 potential field sites would be evaluated through office reconnaissance and 40 sites through field reconnaissance.

We ran a TTCSM on the first 35 field sites from the PARA GRTS draw in ArcGIS (see *Section 2.1 Sampling Frames*). A TTCSM determines the shortest reasonable route to a field site and estimates the travel time to the site, given certain parameters (Sherrill et al. 2010). Six primary datasets were used in the model (source in parentheses): trails (LAKE), roads (PARA), boundary and NPS lands datasets (PARA), vegetation (USGS), digital elevation model (USGS), and streams (USGS). An impediment value (i.e., how much the impediment obstructs a person from walking the maximum speed) is given for parameters within each layer (see *Appendix A – Travel Time Cost Surface Model* for detailed specifications). Driving speeds were set to the type of road: primary (paved) roads were 30 mph, secondary (unpaved) were 25 mph, and tertiary (unpaved) and reclaimed roads (roads closed

or scheduled to be closed, so are no longer maintained) were 10 mph. Since hiking/walking speeds are likely to vary with field crew members, we ran the model using three maximum hiking speeds, 2, 2.5, and 3 mph. One start point toward the east side of the monument was designated as the travel start point to field sites (see Appendix B).

The costs for field crew travel time and field data collection/data management were estimated separately to show the cost of each component. Field data collection estimates were further separated by SOP and vital sign to allow for independent assessment under different monitoring scenarios (e.g., revisit periods). Field data collection times were estimated from field work conducted at all parks in the pilot study.

The scenarios that we examined for crew schedule were 8-hour days for 5 days a week, 10-hour days for 4 days a week, and 10-hour days for 8 days over a 2-week field tour. Crew travel time was estimated from the MOJN I&M office at LAKE, Boulder City, NV, to the park unit. Given the varying distances to the MOJN park units, travel was estimated to take 1-2 days of each week or 2-week field tour. Travel to PARA will likely be closer to 2 days per field tour. Estimates of per diem for NPS employees were not included in the hourly rates, but are presented separately as part of this scenario. Backcountry per diem was estimated at $20 per person per night.

Crews may be based at the park that they are working in for the field season, instead of returning to the MOJN I&M office at the end of each field tour. In this scenario, crews can either be temporarily based at the park unit that is being monitored and return to the MOJN I&M office after all field work is completed or be park-based; in both cases, minimal travel is anticipated.

The cost of field crew time was estimated for a GS-5 field technician and 1-3 volunteer natural resource interns (e.g., Student Conservation Association interns). We used an hourly wage estimate of $22 per hour for the GS-5 position and $14 per hour for interns. A GIS specialist would be needed to assist with office reconnaissance of potential field sites and to generate recommended travel routes to field sites. The hourly wage estimate for a GS-11 GIS specialist is $39. Wage estimates included benefits, when applicable.

2.3 Field Methods

A brief description of each field data collection procedure is presented in this section and SOPs referenced in this section are from Pan et al. (Unpublished Report [b]). The vegetation change vital sign is measured using the point-intercept procedure (SOP 8) and repeat photographs procedure (SOP 13). The invasive species vital sign is measured using the point-intercept procedure (SOP 8), invasive species frequency quadrats procedure (SOP 10), and the site assessment for invasives procedure (SOP 12). The soils vital signs are primarily measured using methods in the soil measurements procedure (SOP 11), with the exception of the soil erosion and deposition vital sign, which is measured with the basal/canopy gaps procedure (SOP 9). For specific details on the macroplot design and SOPs, see Pan et al. (Unpublished Report [b]).

Each macroplot was 100 m by 100 m (Figure 3). Within each macroplot, we established three parallel, 50-m transects spaced 25 m apart. The origin and end of each transect and the corner of the

macroplot closest to the origin of transect 1 were permanently marked with rebar, labeled with a tag, and the spatial location recorded using a GPS.

Three procedures were implemented on transects (referred to hereafter as transect-related procedures): the point-intercept, basal/canopy gaps, and invasive species frequency quadrats. The point-intercept procedure was used to measure vegetation, including target invasive plants, soil surface features, soil disturbance features, and biological soil crust (BSC) at points every 1 m along the transect. Identifiable vegetation was recorded to the species-level for shrubs and target invasive species; other identifiable vegetation was recorded by life form (i.e., grasses, forbs, or trees) or within a designated category (e.g., litter). Hereafter, species refers to both plant species and designations within life forms (e.g., annual grass, perennial grass) for plant cover. We used the basal/canopy gaps procedure to measure the potential for soil erosion by recording all gaps created by perennial plant bases and canopies along the transect that were ≥0.2 m.

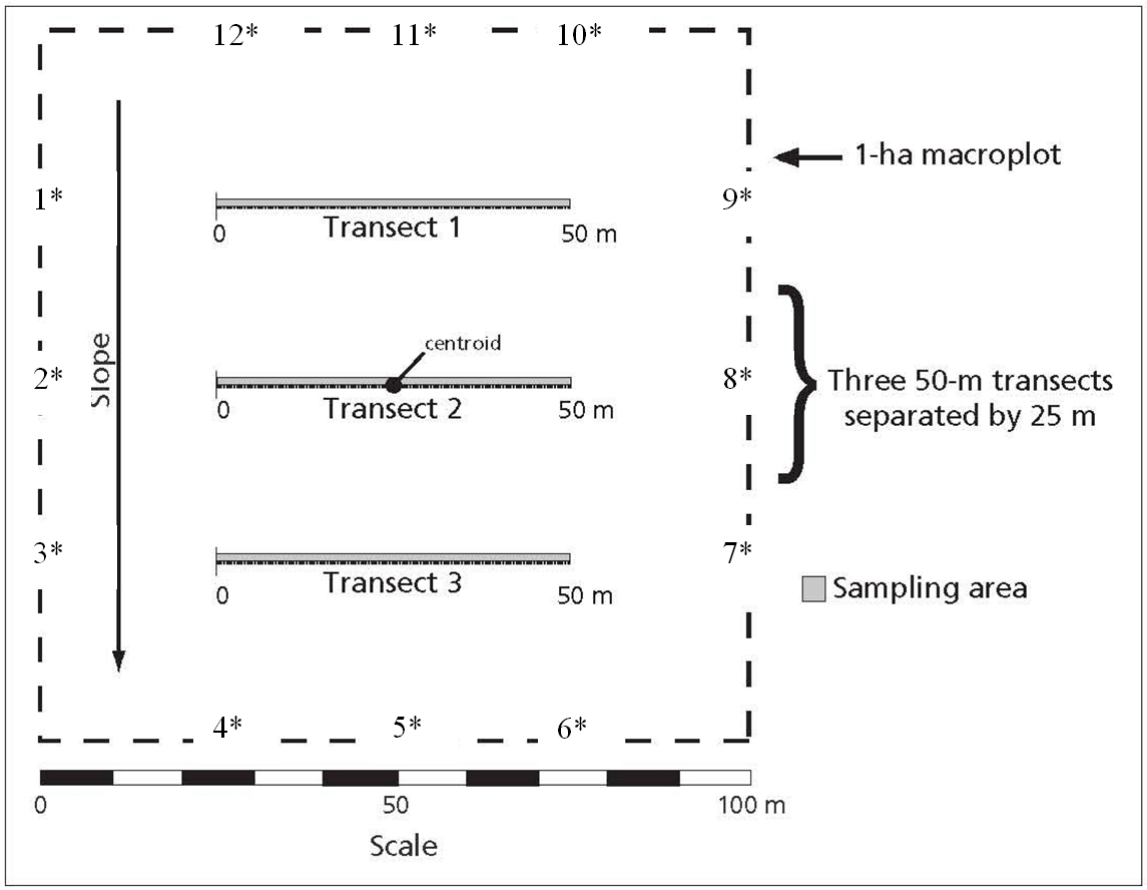

Figure 3. Standard macroplot and transect layout for integrated upland monitoring. Locations on the edge of the macroplot indicated by an "*" are sampling locations for soil parameters. The number next to the "*" is the sampling location number.

Four established upland invasive species, which we will refer to as status and trends (S&T) invasive species, were prioritized for monitoring at PARA: *Bromus rubens* (red brome), *Bromus tectorum* (cheatgrass), *Erodium cicutarium* (redstem filaree), and *Schismus* spp. (Mediterranean grass).

Frequency of target S&T invasive species and soil disturbance were assessed by placing 0.25 by 0.25 m quadrats every 1 m along transects. Presence of target S&T invasive species was further assessed using a patterned walk in the macroplot (SOP 12).

Soil parameters were sampled at 12 regularly spaced sampling points along the perimeter of each macroplot (Figure 3). At each soil sampling point, soil measures (except soil compaction readings) were taken for a vegetated (soil underneath vegetation) and barren (soil was not underneath vegetation) soil sample. Soil erosion will be assessed as direct and potential soil erosion (from the basal/canopy gaps procedure). We were not able to directly measure soil erosion during the pilot study because our assessment depends on the relative difference in soil height between monitoring periods at each of the rebar stakes ("soil erosion pin" method; Pan et al. Unpublished Report [b]). Canopy gap measurements can be used to assess the potential for wind erosion and basal gap measurements, the potential for water erosion.

One photograph was taken of each transect and one overview photograph was taken of the macroplot, all focusing on the vegetation, as described in the repeat photos procedure (SOP 13). Similarly, soil erosion specific photographs and an overview photograph of the macroplot focusing on the soil were taken and will, in future years, be used to assess soil erosion.

2.4 Data Summary

In this section, we describe the procedures used after data were collected in the field, starting with data entry, and continuing through QA/QC, data processing, and analysis. All measured variables were processed to provide macroplot-level estimates, making the macroplot the unit of replication and analysis.

QA/QC of data involved three main steps: verification, validation, and certification. During the pilot study, data were collected on hardcopy field forms. Data verification involved ensuring that data were accurately entered from the hardcopy field forms into the electronic database. To do this, each data field form was manually double-entered into the Infopath data entry system. Two different MOJN I&M staff entered each hardcopy field form into a SharePoint site using a Microsoft (MS) InfoPath front-end form. Digital files of the field forms were downloaded in a MS XML file format and converted to Excel and csv file formats in MS Excel 2010. Matching flat files for each field form were compared using the "Compare" procedure in SAS (SAS Institute, Inc.), which highlighted any differences in data entry between the two files. Differences between the files were manually checked against the paper field form and corrected in one flat file, which became the "official" digitized copy for the field form. Data validation involved checking the verified data files to ensure that the data values for each field were reasonable (e.g., pH values not >14, plant codes matched a species or group, recorded categories were valid for the field). We completed a 100% verification and manual validation check for data collected during the pilot study. Data certification procedures require that the MOJN I&M Program Manager certify the data, at which point, the data are ready for analysis and made available for distribution as appropriate.

Results are presented for individual macroplots or averaged across monitored macroplots. For transect-related procedures (i.e., point-intercept, basal/canopy gaps, invasive species frequency

quadrats), the data were first averaged across a transect and then averaged across all three transects to derive a macroplot-level measure. To determine absolute % cover of variables for a transect using the point-intercept procedure, we counted the number of times a species/category was recorded across the 50 points (every 1 m along the transect), divided the number by the total number of points (50), and then multiplied by 100. For invasive species frequency quadrats, we counted the number of quadrats per transect in which each target invasive species was found and divided that number by the total number of quadrats (50) to obtain a frequency per transect. Invasive species live/dead status, spatial distribution, and phenophase frequencies were calculated for only those quadrats that each invasive species was present on for a transect (e.g., frequency for presence under canopy was calculated by taking the number of quadrats where the species was found under canopy and dividing by the total number of quadrats on the transect in which the species was found).

Soil parameters collected along the 12 soil sample points were categorized as vegetated or barren and averaged across the 12 points to obtain a macroplot-level estimate. In certain instances (e.g., sample location on bedrock, no soil could be obtained, soil sample numbers were reduced due to time constraints), there were fewer than 12 soil sampling points, so data were averaged over all available points. For qualitative soil data, we determined the dominant category and present the range of categories observed across the sampling points.

3 Results

A summary of the travel cost scenarios for PARA is presented in this section. For more detailed information, including data collected during the pilot study, refer to *Appendix B – Travel Cost Scenario Tables* and *Appendix C – PARA Macroplot Data from the Pilot Study*. For ease of presentation, travel cost scenarios were estimated for a 2-person crew, the minimum number of people needed for most procedures. However, with a larger field crew, field procedures can be conducted simultaneously, resulting in less time spent at a particular field site.

3.1 Travel Cost Scenarios

Travel cost scenarios were broken into three non-overlapping components: travel (driving and hiking) to field sites, initial macroplot establishment, and field data collection costs. *Not including any driving travel* (see below for explanation), estimated total costs for the initial year of monitoring at PARA ranged from $560 to $898 per macroplot based on a 2-person crew for each procedure. For the randomly selected 35 sites from the GRTS draw, the average cost per macroplot was $704[1] during the initial establishment and the total cost was $24,640. Estimated cost for macroplot revisits (hiking time to field sites plus field data collection) averaged $606 per macroplot, and totaled $21,210 for the 35 macroplots. It is anticipated that five macroplots will be re-measured each field season to estimate crew measurement error. The estimated cost for the re-measurement of the five macroplots is $3,030. More detailed cost estimates, including a breakdown by vital signs, and scenarios for travel, field crew number, crew schedule, and local vs. traveling crew, are described below and in *Appendix B -Travel Cost Scenarios Tables*.

Travel costs are assumed recurring costs for monitoring and will not decrease with time or experience. We focused on hiking time in our travel scenario rather than total travel time (driving plus hiking) because the travel time cost surface model calculated travel time only from set starting locations (see Appendix B). Driving times for the 35 GRTS sites included in the TTCSM ranged from ~7 min to 147 min from the designated monument starting point (Appendix B). However, driving times will be highly dependent on the proximity of field sites (e.g., one drive may lead to multiple field sites), how sites are scheduled to be visited, and where the field crews are based. In some cases, the most substantial driving times may be from the MOJN I&M office to the park.

Hiking time and costs estimates are likely to be more consistent as they are measured from the nearest point off the road to the field site. Actual one-way hiking time estimates ranged from 10 to 893 min (hike distances are provided in Appendix B). When we categorized the 35 GRTS field sites by hiking times, we found that most (71%) of the field sites were accessible within a 60 min hike under the 2.5 mph model (Appendix B). Estimated costs for round-trip hiking to potential field sites at PARA ranged from $36 (<30 min hike one-way) to $200 (167 min hike one-way) for a 2-person

[1] Macroplot cost was calculated by taking the average hiking cost ($93, as determined from Table B2) and the midpoint of the cost range for establishment ($111) and field work ($500).

crew. With a crew of three or four people, which may be needed during macroplot establishment, estimated round-trip hiking costs ranged from $49-63 to $278-355 per site, respectively.

Estimates for all field data collection that was conducted during the pilot study, including field data management, ranged from $428-572 per macroplot for a 2-person crew. Individual estimates of time by field procedure showed that the basal/canopy gaps and soil measurements procedures were the most time consuming (Table 1).

Table 1. Time (minutes) and cost (dollars) estimates for each field data collection procedure, field data management, and revisit set-up with a 2-person crew (one GS-5 field technician and one natural resource intern). Estimates are based on average to high density vegetation communities. Total time for all field procedures ranged from 660-900 min. Less dense communities, like creosote shrublands, will take less time, particularly for the point-intercept and basal/canopy gaps procedures, where times may be less than half the current estimate.

SOP	Time Estimate	Time Estimate for 3 Transects/12 Points	Cost Estimate - Field Technician	Cost Estimate - Intern	Total Crew Cost per SOP
Point-intercept (8)	20-30 min/transect	60-90	22-33	14-20	36-53
Basal/Canopy Gaps (9)	60-75 min/transect	180-225	66-83	41-51	107-134
Invasive Species Frequency Quadrats (10)	30-45 min/transect	90-135	33-50	20-31	53-81
Soils Measurements (11)	20-30 min/point	240-360	88-132	54-82	142-214
Site Assessment for Invasive Species (12)	30 min	30	11	7	18
Repeat Photos (13)	60 min	60	22	14	36
Field Data Management (field QA/QC, data download)	60 min/day		22	14	36
Revisit set-up*		15-30	5-11	3-7	8-18

*Upper estimate includes soil revisit set-up.

When field data collection costs were calculated by vital sign, **we found that costs were greatest for the soil-related vital signs and lowest for the vegetation change vital sign** (Table 2). On average, the cost for each of the seven vital signs ranged from $56-76 per macroplot. The cost per soil vital sign varied greatly, with soil surface disturbance and biological soil crust being negligible (embedded into point-intercept and invasive species frequency quadrats) to soil erosion deposition ranging from $113-140 per macroplot. We also compared the cost of conducting soil procedures in the field *vs.* collecting soil and conducting procedures in the office. Estimated costs for soil procedures in the field ranged from $142-214, while soil collection in the field plus office measurements ranged from

$260-486 per macroplot (Appendix B). Despite issues with the electrical conductivity meter[2] in the field, data did not vary greatly between samples measured in the field *vs*. in the office (data not shown).

Table 2. Time (minutes) and cost (dollars) estimates of field data collection by vital sign with a 2-person crew (one GS-5 field technician and one natural resource intern). Travel and data management costs are not included. Soil surface disturbance and biological soil crust data collection are completely embedded in the point-intercept and invasive species frequency quadrats and are individually negligible.

Vital Sign (rank)	Estimate of Time for SOPs	Cost Estimate – Field Technician	Cost Estimate - Intern	Total Crew Costs per Macroplot
Vegetation change (2)	110-140	40-51	25-32	65-83
Invasive Plants (3)	120-165	44-61	27-37	71-98
Soil chemistry (9) Soil hydrologic function (10)	240-360	88-132	54-82	142-214
Soil erosion & deposition (11)	190-235	70-86	43-54	113-140
Soil surface disturbance (12)	Negligible	---	---	---
Biological soil crusts (13)	Negligible	---	---	---

Costs associated with initial establishment of a macroplot are non-recurring and only expected once. Estimates for initial macroplot establishment, which included pre-clearance of potential field sites and macroplot set-up but *not* travel (see above for travel estimates), ranged from $96-126 per macroplot for a 2-person crew (Appendix B). Macroplot revisit set-up costs are shown in Table 1.

We considered various crew scenarios for conducting the IU protocol field monitoring, specifically variation in crew number, crew schedule, and traveling *vs*. local (park-based) crew. Variation in crew number was examined in previous scenarios. Primarily, we considered a base crew of two people for most procedures. An additional one to two volunteer interns can be added to the base crew number, if needed, and procedures, such as the point-intercept and soil measurements, can be conducted simultaneously.

The primary impact of different crew schedule scenarios are the number of days spent traveling from the MOJN I&M office to parks, given the minimum number of field work days needed to collect data. It is expected that under long-term implementation of the IU protocol, all field data collection will take 1 day; thus, a minimum of 35 working field days are needed (or 40 working field days if 15% of monitored macroplots are revisited within the same season to estimate measurement errors). One-way travel time was estimated to be ~1 day for PARA (Appendix B).

We found that a crew schedule of 10-hour days, working 8 days out of 2 weeks, was the most economical, with 12-14 travel days, and the cost of travel time for a crew of two ranging from $4,272-4,984 to the more distant parks. Four-day work weeks, with 10-hour work days, were the least economical, with an estimated 36-40 travel days costing $12,816-14,240. Eight-hour days,

[2] It was difficult to get a stable reading on the electrical conductivity meter under windy or hot conditions. The meter seemed to overheat when temperatures were above 100º F.

working 5 days a week, fell in between the other scenarios, with an estimated 24-26 travel days costing $6,835-7,405. Per diem costs for two crew members ranged from $1,840-1,920 for the 10-hour days, working 8 days out of 2 weeks, to $2,240-2,400 for the 10-hour work days, working 4 days per week (Appendix B).

Field crews could also be either temporarily or permanently based at the monitored parks. In both cases, the amount of time that crews spent in travel to parks was drastically reduced. Crews that were temporarily based at parks for the field season would require at most 2 travel days, one day to and one day from the park, which would cost $576 ($288 times 2 days). If park-based crews are available, they would not require any travel days to the park and would likely have limited travel-related costs (e.g., per diem).

3.2 Office and Support Staff Costs

In addition to costs directly related to field data collection, costs are incurred by MOJN I&M network staff as they are needed to organize and plan the field season, provide logistical and data management support, and produce protocol reports. Network staff consist of the Logistics Technician, Data Management Team (Data Manager, GIS Specialist, and Data Technician), and Ecologist. The Logistics Technician is expected to spend 1/3 of his/her time on the IU protocol on a recurring basis. During the protocol initial establishment years, both the Data Management Team and the Ecologist are expected to spend more time on IU-related activities (e.g., 1/3 of the Ecologist's time). Once the protocol is established and monitoring consists primarily of revisits, it is anticipated that the Data Management Team and Ecologist effort will be reduced on IU-related activities (Table 3).

Table 3. Network staff cost (dollars) estimates for the integrated upland protocol.

Network Staff	Annual Cost - Initial Establishment	Annual Cost - Recurring
Logistics Technician (GS-7)	12,000	12,000
Data Management Team (GS-11, GS-11, GS-9)	27,000	15,000
Ecologist (GS-11)	31,000	24,000

4 Issues and Implementation Recommendations

We successfully established one macroplot from the GRTS draw that was within 1 mile of roads and tested methods at two macroplots not from the GRTS draw during our 2012 pilot season at PARA. Through the pilot study, we examined the effectiveness of our field procedures in the target community and some of the challenges of monitoring vegetation within parks. Below we highlight some of the issues that were elucidated (through the pilot study or outside discussions or meetings) and our recommendations to address them. Coordinates for potential field sites may be re-drawn using the GRTS survey design, depending on the recommendations that are adopted.

4.1 Travel and Field Time

During MOJN I&M's start-up review, it was recommended that monitoring of individual macroplots be limited to 1 day, including travel time to sites. The initial set-up of field sites is estimated to take approximately half a day, depending on vegetation type and field crew size (see *Section 2.2 Travel Cost Scenarios*). However, initial macroplot set-up is anticipated to be a one-time occurrence and not expected to affect field time in the long-term. Therefore, we focus on revisit-related field efforts and recurring travel below.

4.1.1 Field Time

The amount of time needed for monitoring and data collection varies depending on the community type and density of vegetation; the sagebrush shrub steppe community at PARA is on the medium to high density end of the vegetation spectrum. In general, denser vegetation will require more time, particularly for the basal/canopy gaps procedure. In years when there is a greater density of annuals, time needed for the point-intercept and invasive species frequency quadrats procedure will likely increase (SOP 9 considers only perennials). For all macroplots established during the pilot study (i.e., across all parks), it took ~360 to 480 min for a crew of three, working simultaneously on different procedures, to complete all vegetation, invasive plants, soil, and repeat photograph procedures; transect procedures were the time-limiting procedures.

<u>Recommendations:</u>

- ✓ Increase the time interval between sampling events for soil parameters, including basal/canopy gaps. For instance, transect-based basal/canopy gap measurements can be measured every other monitoring period (every 6 years), and point-based soil sampling procedures can be repeated every 5-6 monitoring periods (every 15-18 years). Under this proposed scenario, over a 20-year period, basal/canopy gaps would be monitored in years 1, 6, 12, 18, and soil sampling points in years 1 and 15. Direct monitoring of soil erosion with the soil erosion pin procedure can occur every monitoring period because the procedure is extremely quick (~15 min) and rates of soil erosion may be fairly rapid, depending on the local conditions.
- ✓ Increase the time interval between repeat photographs to every 3-4 monitoring periods (every 9-12 years); thus, repeat photographs would be taken in years 1, 9, and 18, or in years 1 and 12, over a 20-year period.

Cost estimates, including average hiking time, based on a 2-person crew for different combinations of field procedures at PARA are shown in Table 4; Table 4 cost estimates are based on the **recommended monitoring scenarios**[3]. The combination of procedures may vary from sampling period to sampling period, depending on the time between sampling events for each procedure, which may affect the estimated costs of monitoring for each sampling event. For example, conducting all procedures (scenario 5 in Table 4) every 3 years, IU monitoring at PARA would cost ~$78,750 to $101,640 over a 15-year period. On the other hand, following the recommendations above, such that the sequence of scenarios (Table 4) was 5, 1, 3, 2, 3, 4, over a 15 year period, monitoring costs would range from $57,400 to $71,960.

The drawback to increasing the monitoring intervals for the soil (including basal/canopy gap procedure) and repeat photographs procedures is that it will take much longer before enough data are collected for comparisons through time and an even longer period of time may be needed to detect whether trends exist. Previous power analysis results predicted that a 1% change can be detected with 80% power in 20 years, with monitoring occurring every 3 years, for vegetation cover (Pan et al., Unpublished Report [a]). Soils are likely to change more slowly than vegetation, so with monitoring occurring every 6 or 15 years, we may not be able to detect change in soils until ~50 to over 100 years, respectively.

[3] See *Section 4.2 Field Procedures* recommendation section below for description of recommendations. The average hiking cost per macroplot at PARA was the same as used in results ($93). The cost estimate for the soil measures ($49-95) and basal/canopy gaps procedure ($90-108) was based on the modifications recommended under *Section 4.2 Field Procedures*.

Table 4. Cost (dollars) estimates, including hike times, to conduct different subsets of field procedures during a sampling event for the integrated upland (IU) monitoring protocol at Grand Canyon-Parashant National Monument. *Cost estimates for the basal/canopy gap procedure (SOP 9) and soils measurements procedure (SOP 11) are based on the field procedure modifications recommended in section 4.2*. Cost estimates are provided per macroplot and for 35 macroplots. The IU protocol standard operating procedure number is shown in parentheses.

Scenario*	Point-intercept (8)	Basal/ Canopy Gap (9)	Invasive Species Frequency Quadrats (10)	Soils Measurements (11)	Site Assessment for Invasive Species (12)	Repeat Photos (13)	Cost per Macroplot	Total Cost for 35 Macroplots
1	X		X		X		200-245	7,000-8,575
2	X		X		X	X	236-281	8,260-9,835
3	X	X	X		X		290-353	10,150-12,355
4	X		X	X	X		249-340	8,715-11,900
5	X	X	X	X	X	X	375-484	13,125-16,940

*Scenario descriptions (all scenarios include scenario 1, so only additions to scenario 1 will be noted for all other scenarios): 1 – vegetation and invasive species procedures, 2 – plus repeat photos, 3 – plus basal/canopy gap, 4 – plus soil measurements, 5 – all SOPs (i.e., plus basal/canopy gap, soils measurements, and repeat photos).

4.1.2 Travel Time to Field Sites

Although the pilot study focused on field sites that were "close to roads," or <1 mile from a road, hiking times to field sites still ranged from 30-60 min each way. Ideally, field crews will either camp within a short hike to the field site or establish a base camp that is within a short drive of a cluster of field sites. Even with careful planning and efficient travel planning, realistic hiking times at PARA may average >60 min each way to sites.

Moreover, our current cost estimates will increase if field sites are to be a minimum distance from roads. Field sites that are close to roads are likely to experience greater disturbance (e.g., backcountry camping, high driving and walking traffic, road disturbances such as dust). Having field sites a minimum distance from roads could move many of the sites in the <30 min hike category into the 30-60 min category or greater, increasing the hike cost estimates by at least $36 per site for a crew of two.

4.1.3 Field Crews

Recommendations:

- ✓ Employ a minimum crew size of three during initial macroplot establishment for ease of carrying equipment and a minimum crew size of two during macroplot revisits. Use a crew size of 3-4 when soil parameters are measured, so that soil and transect procedures can be conducted simultaneously.
- ✓ Adopt a crew schedule of 10-hour days, working 8 days out of 2 weeks, to maximize the number of field data collection days.
- ✓ Use park field crews or temporarily park-based MOJN I&M field crews to reduce travel costs. However, park crews may not be available at all parks (e.g., MANZ, MOJA, or PARA).

4.2 Field Procedures

Through the pilot study, we were able to assess the effectiveness of the field procedures for gathering useful data to address the objectives for the IU protocol. Here, we focus on improving the vegetation and soil-related procedures, as we found the invasive species frequency quadrats procedure to be fairly efficient (Appendix C).

4.2.1 Transect-related Procedures

Point-intercept (SOP 8) – Implementing this procedure was fast and it was possible to read each transect in <60 min, depending on vegetation density. However, this procedure was not effective at detecting invasive plants or BSC.

Recommendations:

- ✓ Increase the number of points measured along transects. Currently, we read points at every 1 m (total = 50 points). *The number of points read could be increased to 100 per transect, or*

points read every 0.5 m. Half-meter intervals should provide a good balance between detecting more plants and not measuring the same individual plant multiple times.

- ✓ BSC was not detected using this procedure, although non-descript cyanobacterial crust was likely present. *We recommend that detection of BSC either be measured during the invasive species frequency quadrats procedure or be dropped altogether (i.e., the vital sign be dropped from the protocol).* More mature crust can be detected when more surface area is examined.

Basal/canopy gaps (SOP 9) – Originally, we had hoped this procedure would enable us to assess the life forms that created gaps on macroplots to understand how changes in vegetation may affect soil processes. However, given time constraints, *we will focus on measuring the potential for soil erosion with the gap data and not identify the species or life forms creating the gap*. This may reduce procedure time by 10-15 min per transect.

- ✓ Cost estimate of modified basal/canopy gaps procedure for a 2-person crew is $90-108 per macroplot.

4.2.2 Soil Sampling Point Procedure

The primary issue with the soil sampling procedure is the amount of time needed to measure the parameters. In the current procedure, 24 soil samples are analyzed, one vegetated and one barren sample at each of the 12 sampling points of the macroplot. Variation in most of the quantitative data parameters (i.e., penetration resistance, pH) was low both within samples at a point and between soil sampling points at each macroplot at PARA. While qualitative parameters varied within and between sampling points, macroplot-level assessments were fairly similar between vegetated and barren samples within a macroplot.

<u>Recommendations:</u>

- ✓ Analyze one soil sample per sampling point. Take a sample closest to the marked location, regardless of whether it is vegetated or barren.
- ✓ Reduce the number of soil sampling points to eight, two points on each side of the macroplot. Taken together, the total number of soil samples analyzed would be reduced from 24 to eight.
- ✓ Cost estimates for soil measurements would be reduced from $142-214 to $49-95.

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Appendix A: Travel Time Cost Surface Model

We used the travel time cost surface model (TTCSM) developed by Sherrill et al. (2010) to calculate point-to-point least-cost paths and travel times to potential field sites. Model input included six best-available spatial data sets for the monument, including trails, roads, monument boundary, vegetation, streams, and Digital Elevation Model (DEM). We estimated Percent of Maximum Travel Speed (PMTS) values for the vegetation and streams layers and travel speeds for roads and trails. Our model was estimated under the inverse linear vertical graph type, where it is assumed that it is harder to walk uphill than downhill (speed reduction uphill is greater than speed increase for downhill). Details for model inputs are described below.

Spatial Datasets

The PARA data used for the travel time cost model were acquired from PARA before 2009, at which point the data were best available. The original model was generated by Dana Robinson in April and May of 2011, at which point the data used were best available.

Trails Dataset

This shapefile was derived by MOJN I&M from "partrail_more.shp," which was created from the Lake Mead National Recreation Area roads layer. This layer was augmented to include road features that could be walked on from the "trans_routes" feature class that had "Administrative Use Only" and "Closed to All Motorized Use and Mechanized Use" designations in the "GROUP_DESC" field. In addition, segments in the road layer that had "ATV," "Motorcycle," "Stock," or "Trail Unknown Use" in the "GTLF_Use_C" field were also added to this layer.

Roads Dataset

The original data came from "trans_routes" feature class located in the Arizona_Strip_DO_Transportation feature dataset in Transportation.gdb. This dataset represents the transportation network for the BLM Arizona Strip District Office in a File Geodatabase Feature Class format. The original data set was clipped to the study area. The "GROUP_DESC" field was used to select features that were "Open to All Users," "Open to All Users with Seasonal Restrictions," "Open to All Users for Non-Motorized Uses; Mechanized Use Limits May Vary," and "Undesignated Routes." In addition, "GTLF_Use_C" field was used to select for "2wd" and "4wd-Touring" uses. The resulting layer was checked for logical consistency and road segments that were missing, but segments necessary for access to other road segments were added back to the layer. Road segments that were connected to trails and were not necessary to access other road segments were recoded as trails.

Boundary and NPS Lands Datasets

The PARA_Fed_Only feature class, obtained from a national dataset downloaded from the National Atlas website of federally owned or administered lands of the United States (2005, available from http://www.nationalatlas.gov/mld/fedlanp.html), was used to generate a non-Federal lands layer for the model by subtracting Federal lands from the monument boundary data set, producing the PARA_nonFeds.shp layer.

Vegetation Dataset

The vegetation layer used was the National GAP Landcover dataset, version 2.1, available from http://gapanalysis.usgs.gov/gaplandcover/.

Digital Elevation Model (DEM)

A 30-m DEM was used in the model. This is a standard USGS product available from: http://egsc.usgs.gov/isb/pubs/factsheets/fs04000.html.

Streams Dataset

Data were acquired from the National Hydrography Dataset (NHD; http://nhd.usgs.gov/) and converted to a stream order layer using the StreamOrder Tool for ArcGIS 9.3.

PMTS Values

Percent of Maximum Travel Speed (PMTS) is set for each pixel of each layer based on cover type. PMTS ranges from 0 to 100% with 0% representing a cell that is not passable and 100% representing a cell with no impediment to travel. The layers are then overlaid in order of priority. The PMTS settings that we used are indicated below.

Roads and Trails

- Roads = 100%
- Trails = 100%

Slope

- 0 to 10 degree = 90%
- 10-20 degree = 60%
- 20-30 degree = 30%
- 30-35 degree = 10%
- >35 degree = 0%

Streams

- 1st order = 70%
- 2nd order = 60%
- 3rd order = 50%
- 4th order = 30%
- 5th order = 20%

Land Types

Federal lands = 100%
Non-federal lands = 0%

Vegetation

- Open water = 0%
- Colorado Plateau Blackbrush-Mormon-tea Shrubland = 80%

- Colorado Plateau Mixed Bedrock Canyon and Tableland = 10%
- Colorado Plateau Pinyon-Juniper Shrubland = 80%
- Colorado Plateau Pinyon-Juniper Woodland = 80%
- Great Basin Pinyon-Juniper Woodland = 80%
- Inter-Mountain Basins Big Sagebrush Shrubland = 80%
- Inter-Mountain Basins Greasewood Flat = 80%
- Inter-Mountain Basins Juniper Savanna = 85%
- Inter-Mountain Basins Mixed Salt Desert Scrub = 80%
- Inter-Mountain Basins Semi-Desert Grassland = 90%
- Inter-Mountain Basins Semi-Desert Shrub Steppe = 80%
- Inter-Mountain Basins Volcanic Rock and Cinder Land = 60%
- Invasive Annual Grassland = 90%
- Invasive Annual and Biennial Forbland = 85%
- Invasive Southwest Riparian Woodland and Shrubland = 25%
- Mogollon Chaparral = 25%
- Mojave Mid-Elevation Mixed Desert Scrub = 80%
- North American Arid West Emergent Marsh = 0%
- North American Warm Desert Bedrock Cliff and Outcrop = 100%
- North American Warm Desert Badland = 50%
- North American Warm Desert Lower Montane Riparian Woodland and Shrubland = 65%
- North American Warm Desert Pavement = 100%
- North American Warm Desert Playa = 90%
- North American Warm Desert Riparian Mesquite Bosque = 20%
- North American Warm Desert Riparian Woodland and Shrubland = 25%
- North American Warm Desert Wash = 80%
- Rocky Mountain Gambel Oak-Mixed Montane Shrubland = 70%
- Rocky Mountain Lower Montane Riparian Woodland and Shrubland = 75%
- Rocky Mountain Montane Dry-Mesic Mixed Conifer Forest and Woodland = 60%
- Rocky Mountain Montane Mesic Mixed Conifer Forest and Woodland = 60%
- Rocky Mountain Ponderosa Pine Woodland = 70%
- Sonora-Mojave Creosotebush-White Bursage Desert Scrub = 85%
- Sonora-Mojave Mixed Salt Desert Scrub = 85%

Travel Speeds

Driving

- Primary, unpaved= 35 mph
- Secondary, unpaved = 25 mph
- Tertiary, unpaved = 10 mph
- Reclaimed (roads closed or scheduled to be closed that are no longer maintained) = 10 mph

Walking

- 2 mph
- 2.5 mph
- 3 mph

Layer Priorities

1. roads
2. trails
3. streams
4. non-federal lands
5. landcover (vegetation)

Literature Cited

Sherrill, K. R., B. Frakes, and S. Schupbach. 2010. Travel time cost surface model: standard operating procedure. Natural Resource Report NPS/NRPC/IMD/NRR—2010/238. National Park Service, Fort Collins, Colorado.

Appendix B: Travel Cost Scenarios Tables

The travel time cost surface model generated the least-cost travel paths to the first 35 sites generated from the GRTS draw for PARA (see *Section 2.1 Sampling Frames* in this report). Least-cost travel paths generally provided the fastest travel path (both driving and hiking) to the target location from a given start point (Figure B1). We ran three models, varying maximum hiking speeds from 2, 2.5, to 3 mph. Distances and travel times to the 35 sites are shown in Table B1.

Travel time and distance estimates from the TTCSM were made for one-way travel. Cost estimates based on hiking time for one-way travel were doubled to estimate round-trip cost estimates (Tables B2-B3). We used an hourly wage estimate of $22 per hour for the GS-5 position and $14 per hour for natural resource intern crew members. The hourly wage estimate for a GS-11 GIS specialist is $39. Wage estimates included benefits, when applicable. Estimates of per diem for NPS employees were not included in the hourly rates or field costs. Cost estimates were generated by multiplying the time to conduct the task by the hourly wage of the crew member. Most cost estimates were generated for a field crew of two; to get an estimate for additional field crew members, we add the appropriate rate for the additional field crew member to the estimate for the crew of two. For example, in Table B4, to estimate the cost for a 3-person crew to conduct field soil measurements, we would add the rate of the additional field crew member ($54-82) to the estimate for a 2-person field crew ($142-214) for a total of $196-296.

Cost estimates were also made for: soil procedures in the field *vs.* office (Table B4), site reconnaissance and initial macroplot set-up (Table B5), and different crew schedule scenarios (Table B6).

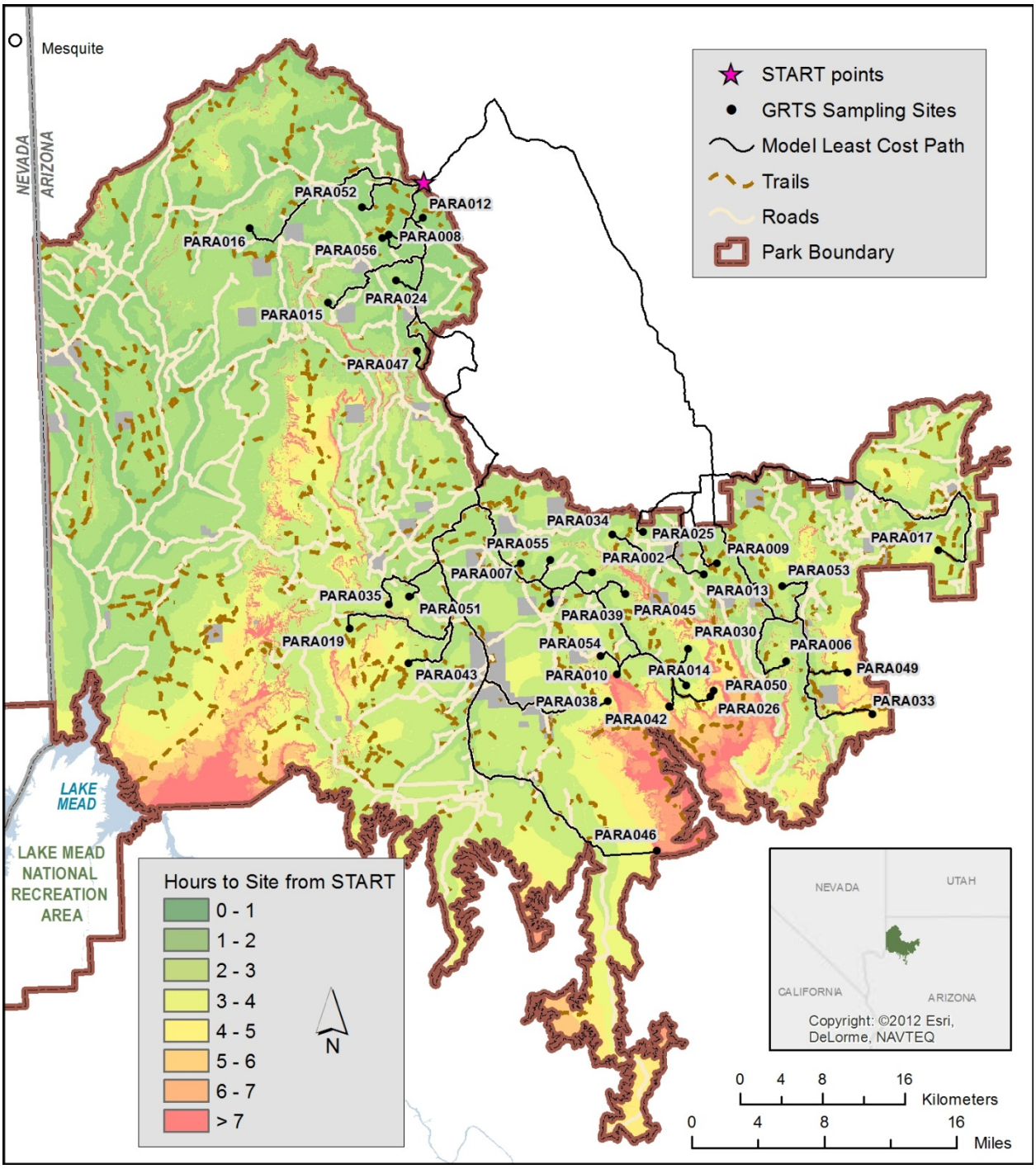

Figure B1. Least cost travel paths to 35 Generalized Random Tessellation Stratified (GRTS) sites generated by the travel time cost surface model from the designated start point for Grand Canyon-Parashant National Monument. Routes shown include driving and hiking paths. Trails on the map are closed or administration-only roads.

Table B1. Travel time cost surface model estimates for one-way hiking, driving, and total travel time to 35 potential field sites selected in the Generalized Random Tessellation Stratified (GRTS) draw. Drive times were estimated from the designated start point of the monument (see Figure B1). The site in bold was visited and established with a macroplot during the 2012 pilot field season. The estimated times shown are for a hiking speed of 2.5 mph. Under the estimated hiking time, the times in parentheses are for hiking speeds of 2 to 3 mph.

Macroplot ID	Distance From Nearest Road (mi)	Estimated Hiking Time (min)	Drive Time (min)	Estimated Total One-way Travel Time (min)
PARA002	0.856	29.42 (24.00-36.58)	96.00	125.42
PARA006	1.623	61.84 (51.00-77.03)	104.00	165.84
PARA007	0.626	20.14 (16.00-25.04)	80.00	100.14
PARA008	0.667	32.43 (32.43-43.00)	16.00	48.43
PARA009	0.632	33.28 (25.00-41.51)	98.73	131.28
PARA010	0.565	24.83 (20.00-30.82)	119.00	143.83
PARA012	0.610	31.52 (26.00-39.32)	7.00	38.52
PARA013	0.703	26.34 (22.00-32.77)	88.00	114.34
PARA014	1.315	46.66 (39.00-58.08)	118.00	164.66
PARA015	0.414	15.43 (12.00-19.11)	52.00	67.43
PARA016	0.724	27.57 (23.00-34.27)	34.00	61.57
PARA017	1.472	52.86 (44.00-66.06)	110.00	162.86
PARA019	0.863	31.20 (25.00-39.95)	109.00	140.20
PARA024	1.591	75.08 (62.00-93.78)	19.00	94.08
PARA025	**0.464**	**15.80 (13.00-19.64)**	**92.00**	**107.80**
PARA026	4.023	124.07 (103.00-155.11)	118.00	242.07
PARA030	1.221	46.81 (39.00-58.29)	122.00	168.81
PARA033	3.750	166.77 (138.00-208.35)	103.00	269.77
PARA034	0.545	28.30 (22.00-35.35)	107.00	135.30
PARA035	0.778	35.89 (29.00-44.81)	111.00	146.89
PARA038	2.265	85.00 (70.00-106.05)	139.00	224.00

Table B1. Travel time cost surface model estimates for one-way hiking, driving, and total travel time to 35 potential field sites selected in the Generalized Random Tessellation Stratified (GRTS) draw. Drive times were estimated from the designated start point of the monument (see Figure B1). The site in bold was visited and established with a macroplot during the 2012 pilot field season. The estimated times shown are for a hiking speed of 2.5 mph. Under the estimated hiking time, the times in parentheses are for hiking speeds of 2 to 3 mph (continued).

Macroplot ID	Distance From Nearest Road (mi)	Estimated Hiking Time (min)	Drive Time (min)	Estimated Total One-way Travel Time (min)
PARA039	0.506	19.36 (19.36-24.60)	98.00	117.36
PARA042	3.381	892.82 (744.00-1115.80)	117.00	1009.82
PARA043	1.287	61.02 (50.00-76.20)	109.00	170.02
PARA045	0.689	48.89 (40.00-60.89)	108.00	156.89
PARA046	3.215	121.19 (101.00-151.40)	147.00	268.19
PARA047	0.356	19.68 (15.00-24.35)	61.00	80.68
PARA049	2.794	148.72 (124.00-185.76)	94.00	242.72
PARA050	4.489	149.02 (124.00-186.30)	118.00	267.02
PARA051	0.789	32.76 (27.00-40.72)	98.00	130.76
PARA052	0.202*	9. 71 (8.00-12.08)	25.00	34.71
PARA053	0.360	20.23 (16.00-25.17)	113.00	133.23
PARA054	0.459	17.87 (15.00-22.27)	127.00	144.87
PARA055	0.459	14.75 (12.00-18.33)	92.00	106.75
PARA056	1.121	51.43 (42.00-64.23)	23.00	74.43

* Site that is within 0.25 mi of road. An additional six sites are within 0.5 mi of a road.

Table B2. Cost (dollars) estimates for round-trip hiking to 35 sites from the Grand Canyon-Parashant National Monument Generalized Random Tessellation Stratified (GRTS) draw for a 2-person crew. # of sites represents the number of field sites within each hiking time category from the 2.5 mph hiking speed travel time cost surface model (TTCSM).

One-Way Hiking Time (min)	Cost Estimate - Field Technician	Cost Estimate - Intern	Crew Cost per Site	# of Sites
<30	22	14	36	14
30-60	44	27	71	11
60-90	66	41	107	4
90-120	88	54	142	0
120+	122*	78*	200*	6

*Estimates were made based on the second highest approximate hiking times for the six sites in this category, which was ~167 min. The site with the longest hiking time estimate was an extreme outlier at 893 min and may not be accessible.

Table B3. Cost (dollars) estimates for round-trip hiking to 35 sites from the Grand Canyon-Parashant National Monument Generalized Random Tessellation Stratified (GRTS) draw for a 3-4 person crew, consisting of one GS-5 field technician and 2-3 natural resource interns. The first estimate in each range represents the estimate for a crew of three and the second for a crew of four. # of sites represents the number of field sites within each hiking time category from the 2.5 mph hiking speed travel time cost surface model (TTCSM).

One-Way Hiking Time (min)	Cost Estimate - Field Technician	Cost Estimate - Intern (2-3 interns)	Crew Cost per Site	# of Sites
<30	22	27-41	49-63	14
30-60	44	54-82	98-126	11
60-90	66	82-122	148-188	4
90-120	88	109-163	197-251	0
120+	122*	156-233*	278-355*	6

*Estimates were made based on the second highest approximate hiking times for the six sites in this category, which was ~167 min. The site with the longest hiking time estimate was an extreme outlier at 893 min and may not be accessible.

Table B4. Time (minutes) and cost (dollars) estimates for conducting the soil measurements procedure (SOP 11) in the field *vs*. in the office. Time estimates for office measurements was based on soil samples collected from Great Basin National Park and Manzanar National Historic Site. Total costs for office measurement of soils are $246-459.

Procedure	Time Estimate	Cost Estimate - Field Technician	Cost Estimate - Intern	Total Costs
Field	240-360	88-132	54-82	142-214
Office (collect soil)*	100	36	23	59
Office (measurements)	140-240	36-88	23-54	59-142
Office (travel to return soil or disposal procedure)	240-480	88-176	54-109	142-285

*Certain soil measurements still need to be made in the field (e.g., penetrometer).

Table B5. Cost (dollars) estimates for initial macroplot set-up, including pre-reconnaissance of potential field sites. Office reconnaissance conducted by GIS specialist (GS-11) and field reconnaissance by a field crew of two (GS-5 field technician and natural resources intern). SOP 6 is the site characterization procedure and SOP 7 is the macroplot establishment and revisit set-up procedure.

Procedure	Time Estimate (min) per Macroplot	Cost Estimate - Field Technician	Cost Estimate - Intern	Crew Cost per Macroplot	Total Cost for Macroplots
Office reconnaissance (assume 50 sites)	20-30	13-19	---	13-19	650-950
Field reconnaissance (*on-site only*; assume 40 sites plus completion of SOP 6)	20-30	7-11	5-7	12-18	480-720
Cultural clearance	?				
Macroplot set-up (includes SOP 7 for 35 macroplots)	120-150	44-55	27-34	71-89	2485-3115 (3430-4305; 4375-5495)*

*Estimate for 3- and 4-member crews, respectively, are shown in parentheses. Initial macroplot set-up will likely require a minimum 3-person field crew, given equipment and field weight requirements.

Table B6. Scenarios for crew schedules for a crew of two. Cost (dollar) estimates are the total for the field season. We assumed that one-way travel to parks would take either 1 day (Death Valley National Park, Great Basin National Park, Joshua Tree National Park, Manzanar National Historic Site, Grand-Canyon Parashant National Monument) or ½ day (Lake Mead National Recreation Area [LAKE], Mojave National Preserve [MOJA]). Per diem costs were estimated by taking the total number of travel days plus 40 field work days and subtracting the number of work weeks or field tours for the season (or ½ the number for LAKE, MOJA).

Procedure	# of Travel Days from LAKE (1/2 travel)	# of Field Work Days*	Cost Estimate for Travel - Field Technician	Cost Estimate for Travel - Intern	Per Diem Costs
8 hour days, 5 days/wk**	24-26 (12-13)	40	4224-4576 (2112-2288)	2611-2829 (1306-1414)	2040-2120 (1840-1880)
10 hour days, 4 days/wk	36-40 (18-20)	40	7920-8800 (3960-4400)	4896-5440 (2448-2720)	2240-2400 (1960-2000)
10 hour days, 8 days/2 wks	12-14 (6-7)	40	2640-3080 (1320-1540)	1632-1904 (816-952)	1840-1920 (1720-1760)

*Travel days were estimated for up to 40 field work days, as up to 15% of the macroplots may be revisited to estimate crew measurement error. With an additional 5 field days, 2 travel days were added to each scenario.

**Time would be tight to finish procedures, QA/QC, and daily travel to the more distant sites.

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Appendix C: PARA Macroplot Data from the Pilot Study

We established three macroplots at PARA, one location from the GRTS draw and two locations in sagebrush (*Artemisia* spp.) shrub steppe communities near roads. The latter sites were primarily chosen to assess field methods and may not be representative of the plant community to be measured because they were selected for certain traits (e.g., dominated by sagebrush and with little to no pinyon-juniper tree encroachment). Nonetheless, we present summaries of the vegetation, invasive plant, and soils data collected on all three macroplots. The data presented in this section pertain only to the monitored macroplots and cannot be extrapolated to the sagebrush (*Artemisia* spp.) shrub steppe community at PARA.

From the vegetation measurements, we found three shrub species and one tree species across the three monitored macroplots; only sagebrush (*Artemisia sp.*) was found on all macroplots (Table C1). From all of the invasive plant procedures, we detected three of the four target invasive species in the macroplots, with the number of invasive species found on each macroplot ranging from one to three. For most soil parameters, the range of values detected overlapped between macroplots (Table C3). We examined the potential for soil erosion with the basal/canopy gaps procedure.

We initially planned to establish five macroplots at PARA and were able to establish three macroplots and collected limited data after visiting three field sites in approximately eight days (this included travel time to the monument from Boulder City, NV; Figure C1). One macroplot was established on a site from the PARA GRTS draw, while the other two sites were established on non-GRTS sites and selected by the field crew in sagebrush steppe areas close to the road. The macroplot established on the GRTS site (macroplot 25) was located in the largest extent of the sagebrush steppe community at PARA and the two non-GRTS sites were located on the far eastern side of the monument (Figure C1).

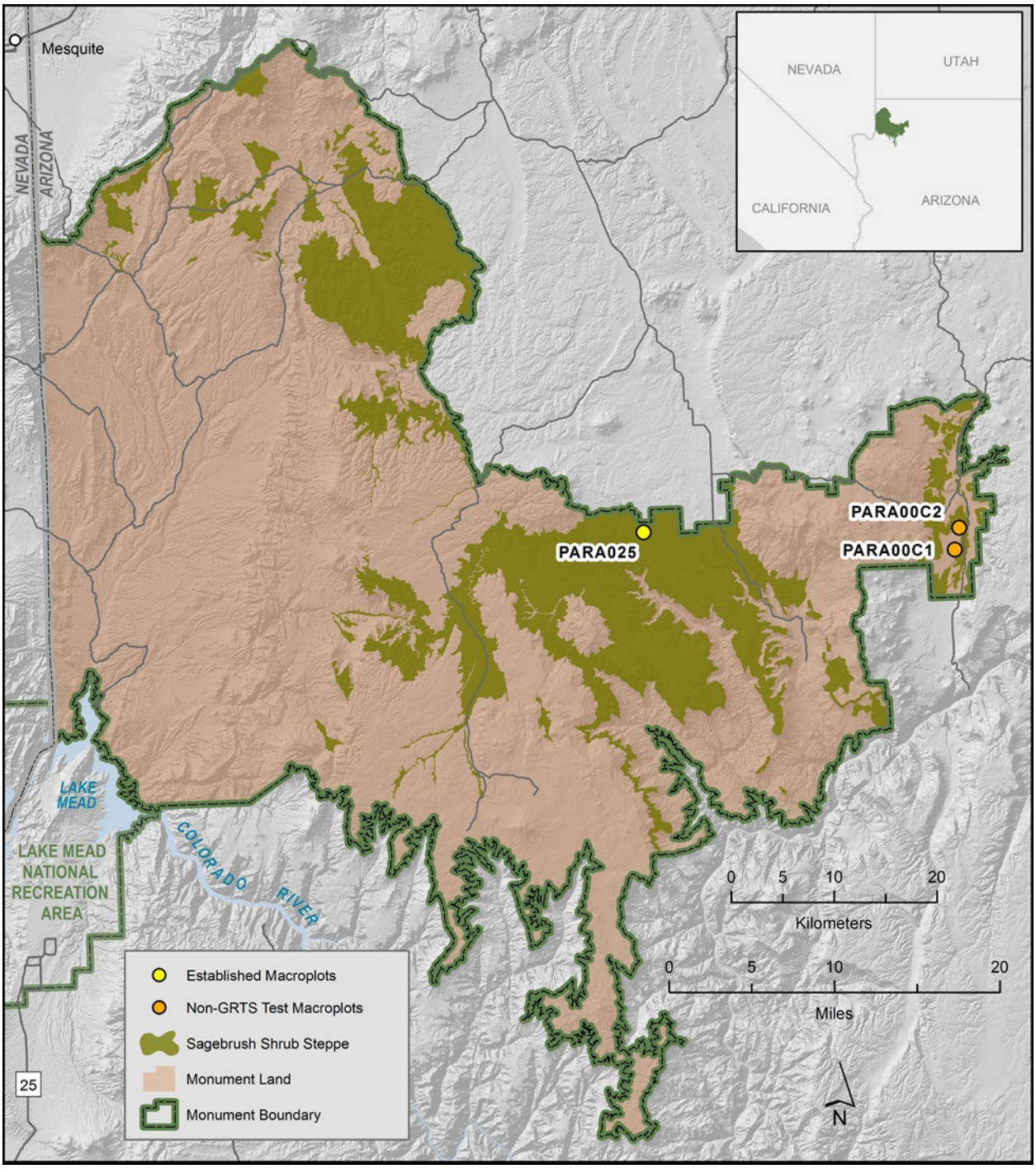


Figure C1. Locations of visited field sites and established macroplots within the sagebrush (*Artemisia* spp.) shrub steppe community at Grand Canyon-Parashant National Monument.

Vegetation

Across the three macroplots, we found a total of three shrub and one tree species (Table C1). The shrub species were found on multiple macroplots, with the species characteristic of the community, sagebrush (*Artemisia sp.*), found on all three macroplots. On the other hand, the tree species was

found on only on macroplot 25. The mean number of shrub species on macroplots ranged from 2-3 and the mean % cover of those species was <9% per species (Figure C2; Table C1).

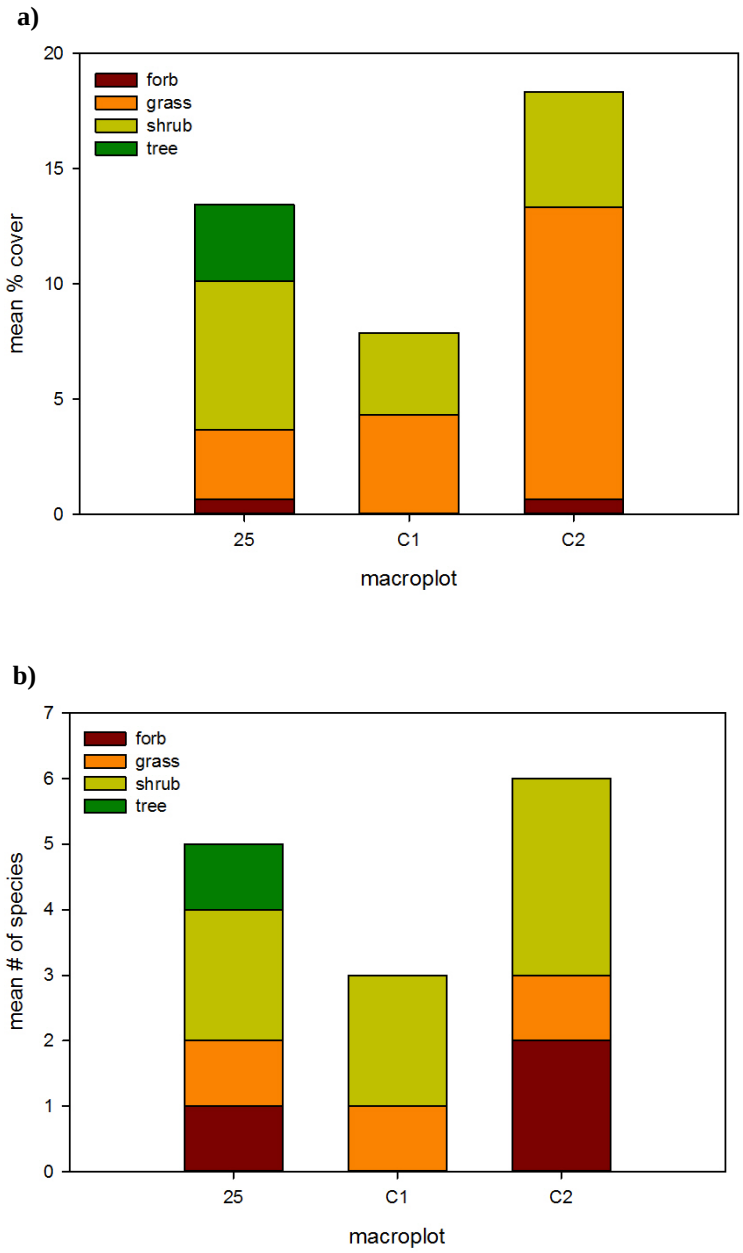


Figure C2. Mean a) % cover and b) species richness of species for each life form by macroplot. Species richness for all life forms except shrubs could include target invasive species and/or life form categories. For example, species richness for grasses would include target invasive grass species and vegetation recorded as annual grass, perennial grass, etc.

Table C1. Mean % cover per macroplot of shrub and tree species found across three macroplots in 2012.

Shrub Species	Common Name	Live (L) or Dead (D)	No. Plots Where Found	Mean % Cover (range)*
Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	L	3	8.667 (6-13.333)
		D	1	1.333 (0-4)
Chrysothamnus viscidiflorus	Sticky rabbitbrush	L	2	4.889 (0-9.333)
		D	1	0.222 (0-0.667)
Gutierrezia sarothrae	Snakeweed	L	2	1.333 (0-3.333)
		D	1	0.222 (0-0.666)
Juniperus osteosperma	Utah juniper	L	1	1.111 (0-3.333)

*Mean % cover over the three plots.

Total % cover on macroplots at PARA, determined by whether any vegetation was detected during the point-intercept procedure, ranged from 28 to nearly 60% (Figure C3). For each species or life form that was encountered, we recorded whether it was live or dead (senesced) in order to understand the composition of the vegetation in the community and as a possible early indicator of vegetation mortality. Unidentified or loose senesced vegetation was categorized as either litter or woody debris. Examining the components of cover, we found that the mean % cover for dead species/life form was higher than for live species/life form when we included litter/woody debris as a "life form" (Figure C4). When we excluded litter/woody debris, then the mean % cover for live cover was much higher than for the dead species/life form (Figure C4). There was great variation in % cover by life form (forbs, grasses, shrubs, and trees), especially with the two life forms that occur on all three macroplots (Figure C2a). Forbs were generally not very common, despite have species numbers that were similar to other life forms, as they had low % cover on two macroplots and were absent from the third macroplot (Figure C2).

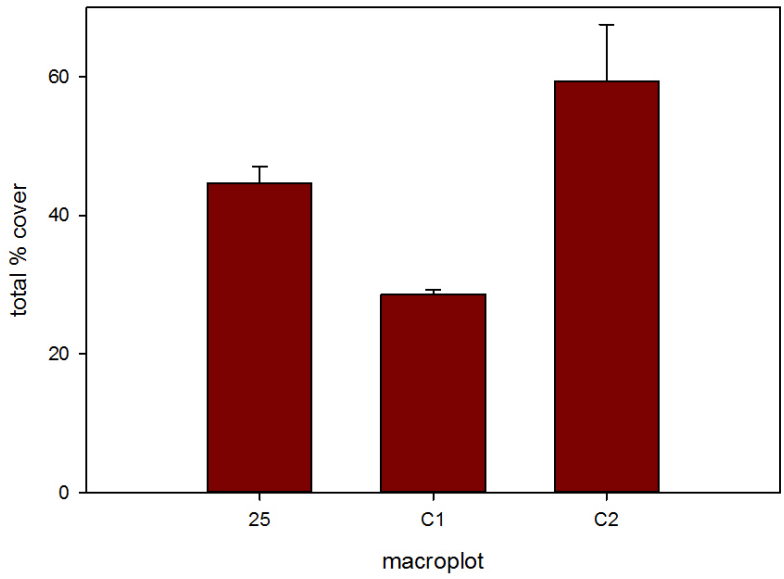


Figure C3. Mean (+SE) total % cover by macroplot.

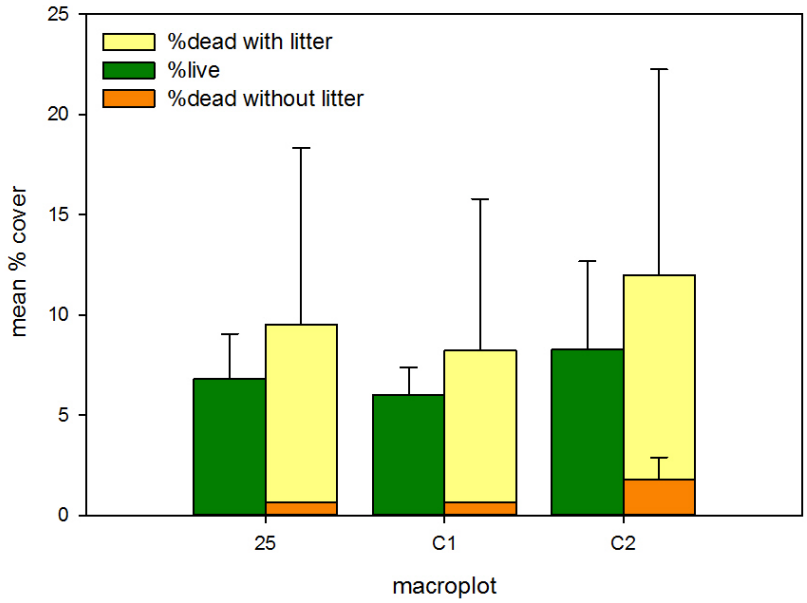


Figure C4. Mean (+SE) % cover of live and dead species/life form by macroplot. Dead species/life form cover included or excluded litter/woody debris as a dead species/life form category.

Status and Trends Invasive Plant Species

Using the point-intercept (SOP 8), invasive species frequency quadrats (SOP 10), and site assessment for invasive species (SOP 12) procedures, we detected three of the four target invasive species in the macroplots at PARA. No target invasive species was detected using the point-intercept procedure. One species was detected using the invasive species frequency quadrats, *Bromus rubens* (red brome). Two additional invasive species were detected using the site assessment for invasive species procedure, *B. tectorum* (cheatgrass) and *E. circutarium* (redstem filaree). Only *B. tectorum* was detected on all three macroplots and only through the site assessment for invasive species procedure.

Bromus rubens was found only on the two methods testing macroplots, 00C1 and 00C2, and was found on less than 10% of the quadrats that were examined (Figure C5). When *B. rubens* was found, it was predominantly in the interspace (space between plants) and dead (Table C2). We also detected *B. rubens* on macroplot 00C1 using the site assessment for invasives procedure (we did not search for *B. rubens* on macroplot 00C2 because it was found on all three transects, refer to Pan et al., Unpublished Report [b] for further information) and found that it consisted of scattered plants around the macroplot, had <2% cover, and was primarily in the mature seed/seed scatter phenophase.

Bromus tectorum was detected on all three macroplots with the site assessment for invasive species procedure. It generally ranged from a single plant to scattered plants, had <2% cover, and was dead. On the other hand, *Erodium cicutarium* was detected only on macroplot 00C1 as scattered plants, with <2% cover and in the mature fruit/seed scatter phenophase.

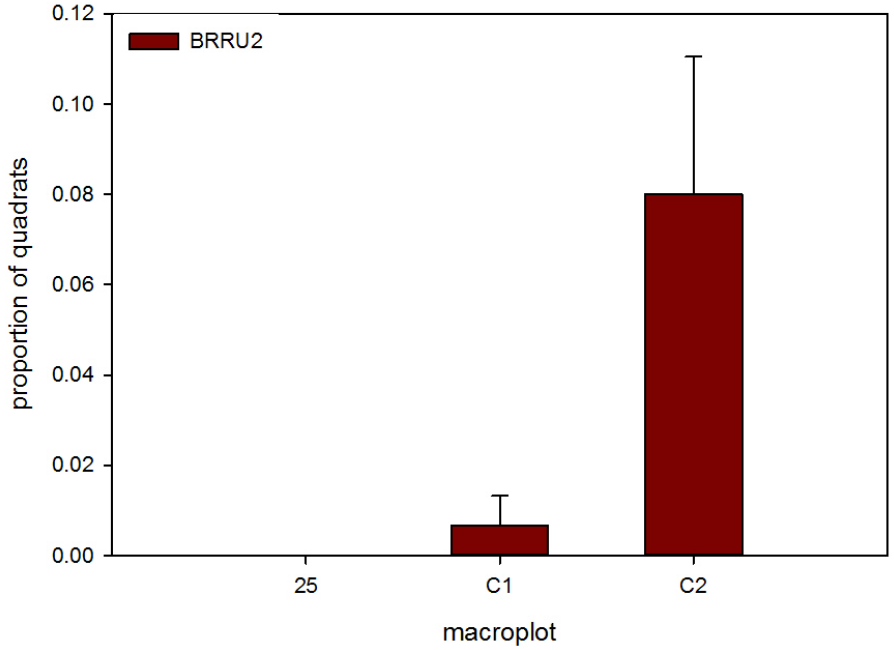


Figure C5. Mean (+SE) proportion of quadrats infested by target invasive species by macroplot. BRRU2 = *Bromus rubens* (red brome).

Table C2. Frequency of quadrats for dead *vs*. live, spatial location, and phenophase of the invasive species found across three macroplots in 2012. Ranges of data are in parentheses. Invasive plants in quadrats were categorized into one of nine phenophase stages and only phenophases found in the macroplots are shown here. No target S&T invasive plant species were detected on macroplot 25 using the invasive species frequency quadrats procedure.

Shrub Species	**Common Name**	**Dead vs. Live**		**Location***			**Phenophase*****
		Dead	**Live**	**C**	**CI**	**I**	**9**
Bromus rubens	Red brome	1	0	0.322 (0-0.644)	0.061 (0- 0.122)	0.617 (0.233- 1)	1

*Location: C=canopy, CI=canopy and interspaces, I=interspace.

**Only found on one macroplot.

***Phenophase: 1=seedling/early vegetative, 2=vegetative/ basal rosette or multiple tillers, 3=flower bud forming or boot stage, 4=early flowering (<25% flowers open per plant or inflorescence), 5=flowering, 6=late flowering (>75% flowers open per plant or inflorescence), 7=fruit/seed formation or ripening, 8=mature fruit/seed scatter, 9=dead/senescent.

Since no invasive species were detected with the point-intercept procedure, the estimate of mean % cover for invasive species with this procedure was 0% for all macroplots. On the other hand, the mean % cover of native species on macroplots ranged from ~4-6% (Figure C6).

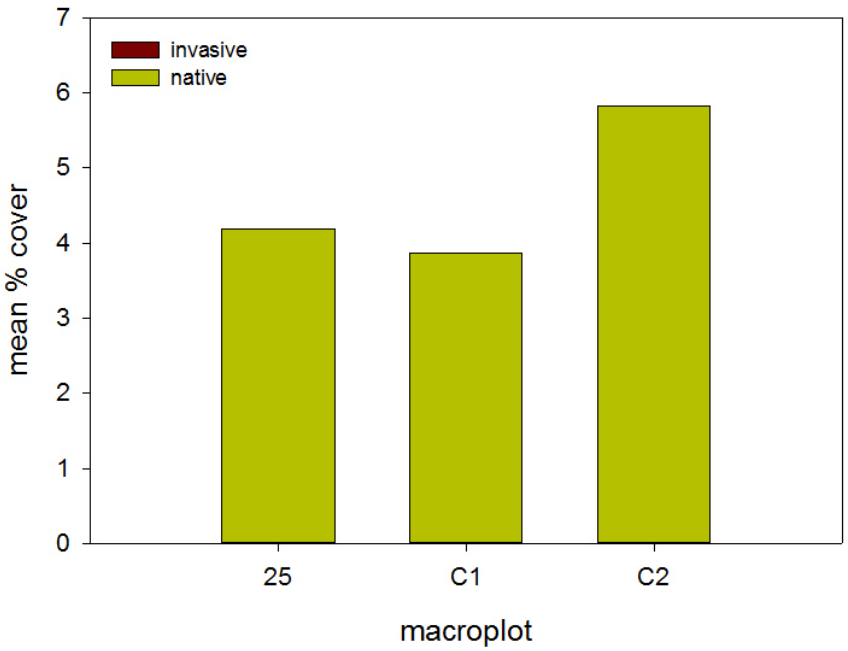


Figure C6. Mean % cover for invasive and native species by macroplot.

At PARA, the site assessment for invasive species procedure was the most effective for detecting invasive species, as we detected invasive species on each macroplot and three of the four target species. The site assessment for invasive species would be most useful to understand the early invasion process, as we would be more likely to detect species in the earlier phases of macroplot invasion. This assertion is supported by what we found at PARA, with the relatively low abundance of most invasive species on the measured macroplots. On the other hand, the point-intercept and invasive species frequency quadrats procedures would be more effective at detecting species that are of higher abundance and more widespread, given the limited area of the macroplot that is sampled. Taken together, the three procedures provide a more comprehensive understanding of the invasion process and invasive species population growth.

Soil Measurement Parameters

Soil measurement data (SOP 11) was incomplete on the three macroplots at PARA because of the focus on methods testing. Complete soil measurement data were collected only on macroplot 025, only four points were measured on macroplot 00C2, and no points were measured on macroplot 00C1. Although soil measurement data from macroplots 025 and 00C2 are presented, data from the two macroplots are difficult to compare with such large sample size differences.

For most of the soil parameters, the range of values detected overlapped across macroplots (but see soil carbonates; Table C3) and variation in quantitative soil parameters was low. Soil compaction

(penetration resistance) was “extremely low” for all points on both macroplots. pH ranged from ~7.6 to slightly above 8 and did not differ greatly between vegetated and barren soil samples. Soil salinity was fairly low on all macroplots, such that soils on all macroplots were considered non-saline. The potential for soil erosion was estimated using the basal/canopy gaps procedure.

We recorded seven soil surface features on macroplots using the point-intercept procedure, with mean % cover per macroplot ranging <1% to >81% (Figure C7) and bare soil and small rocks having the greatest % cover.

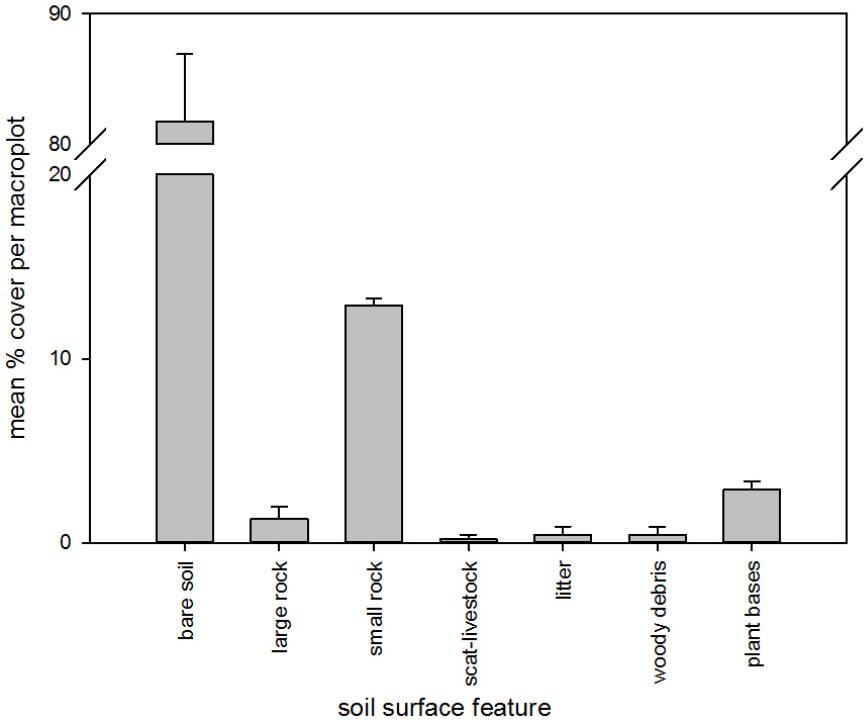


Figure C7. Mean (+SE) % cover of soil surface features per macroplot.

Soil disturbance features were detected using both the point-intercept and invasive species quadrats procedures. Three disturbance categories were detected with the point-intercept procedure, but all of the disturbances were not very common; human track/trails had the highest % cover at just <3% (Figure C8a). An additional four disturbance categories were detected with the invasive species quadrats procedure (Figure C8b). Human track/trail, livestock track/trail, and wildlife tracks were the most prevalent disturbances detected using the invasive species quadrats procedure.

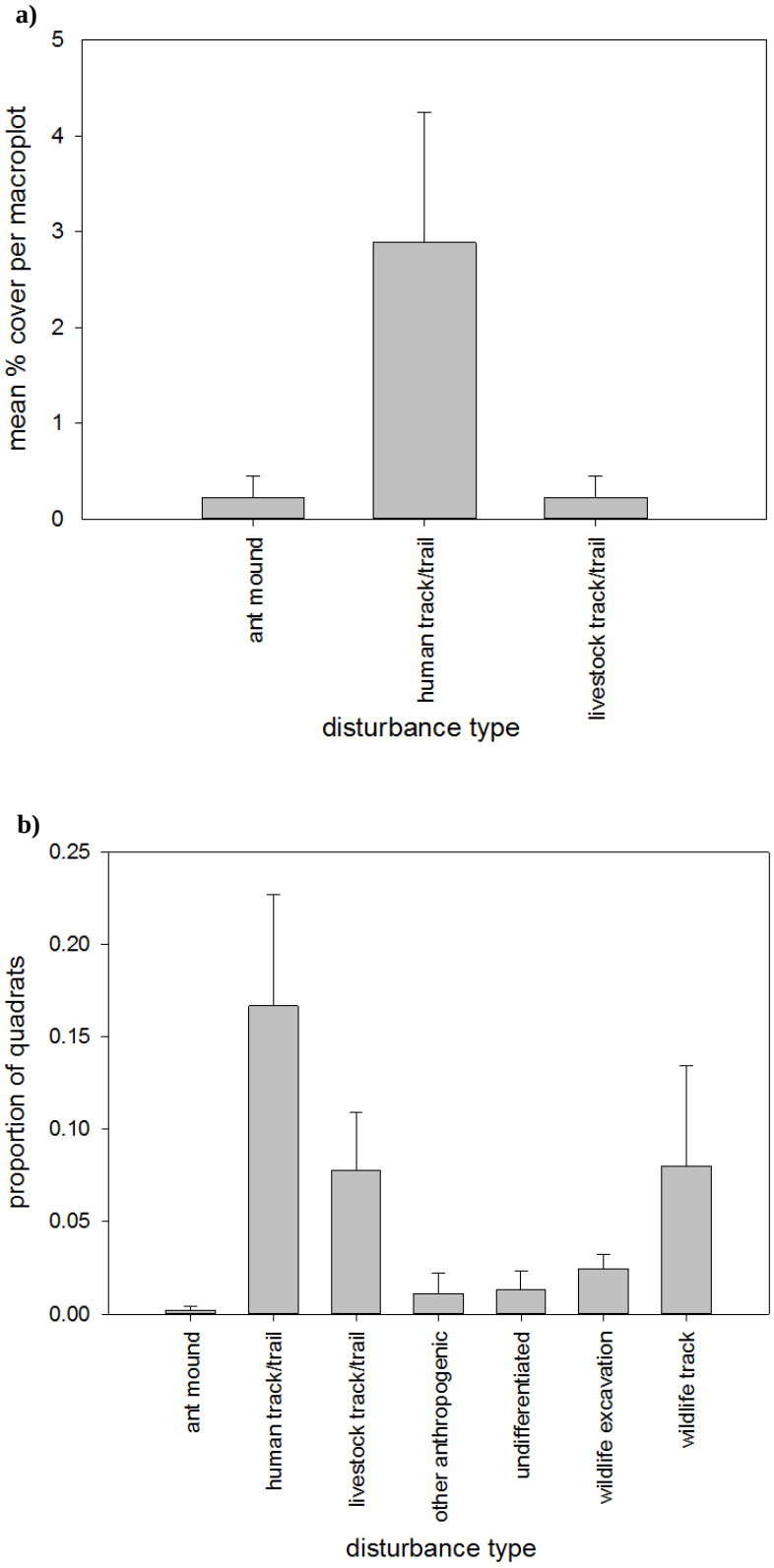


Figure C8. Mean (+SE) a) % cover and b) proportion of quadrats of soil disturbance features per macroplot from the point-intercept (SOP 8) and invasive species frequency quadrats (SOP 10) procedures, respectively.

The basal/canopy gaps procedure is designed to measure the potential for soil erosion by recording all gaps ≥0.2 m created by perennial plant bases and canopies along the transect. Canopy gaps can be used to assess the potential for wind erosion. The total number of canopy gaps ≥0.2 m ranged from 27-32 gaps per macroplot. The distribution of canopy gaps varied across macroplots and, interestingly, macroplots 00C1 and 00C2 did not have more similar gap distributions, even though they were closer to each spatially and were both selected by the crew as methods testing plots. Macroplots 00C1 and 25 had more similar gap distributions and gap numbers, each with a relatively even distribution of gaps across the four categories (Figure C9). On the other hand, half of the gaps found on macroplot 00C2 fell into the smallest gap size category. Gap distributions were reflected in the mean canopy gap size, with macroplot 00C2 having the smallest mean gap size at <0.9 m and macroplots 00C1 and 25 having a mean gap size >1.2 m (Figure C10a). The mean total length of all canopy gaps ranged from ~ 58-74%of transects for all macroplots (Figure C10a), reflecting the relatively dense vegetation of the sagebrush steppe community.

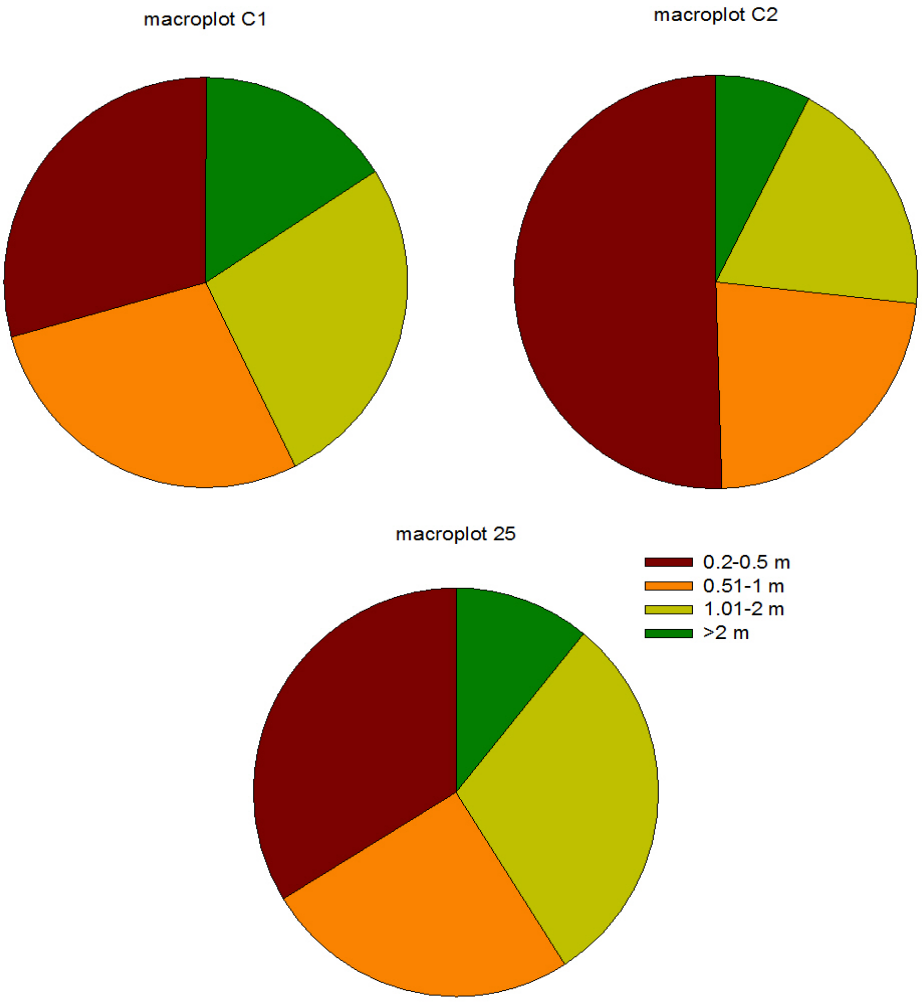


Figure C9. Mean number of canopy gaps for a given size category per macroplot. Macroplot 00C1 had a total of 27 gaps, macroplot 00C2, 35 gaps, and macroplot 25, 28 gaps.

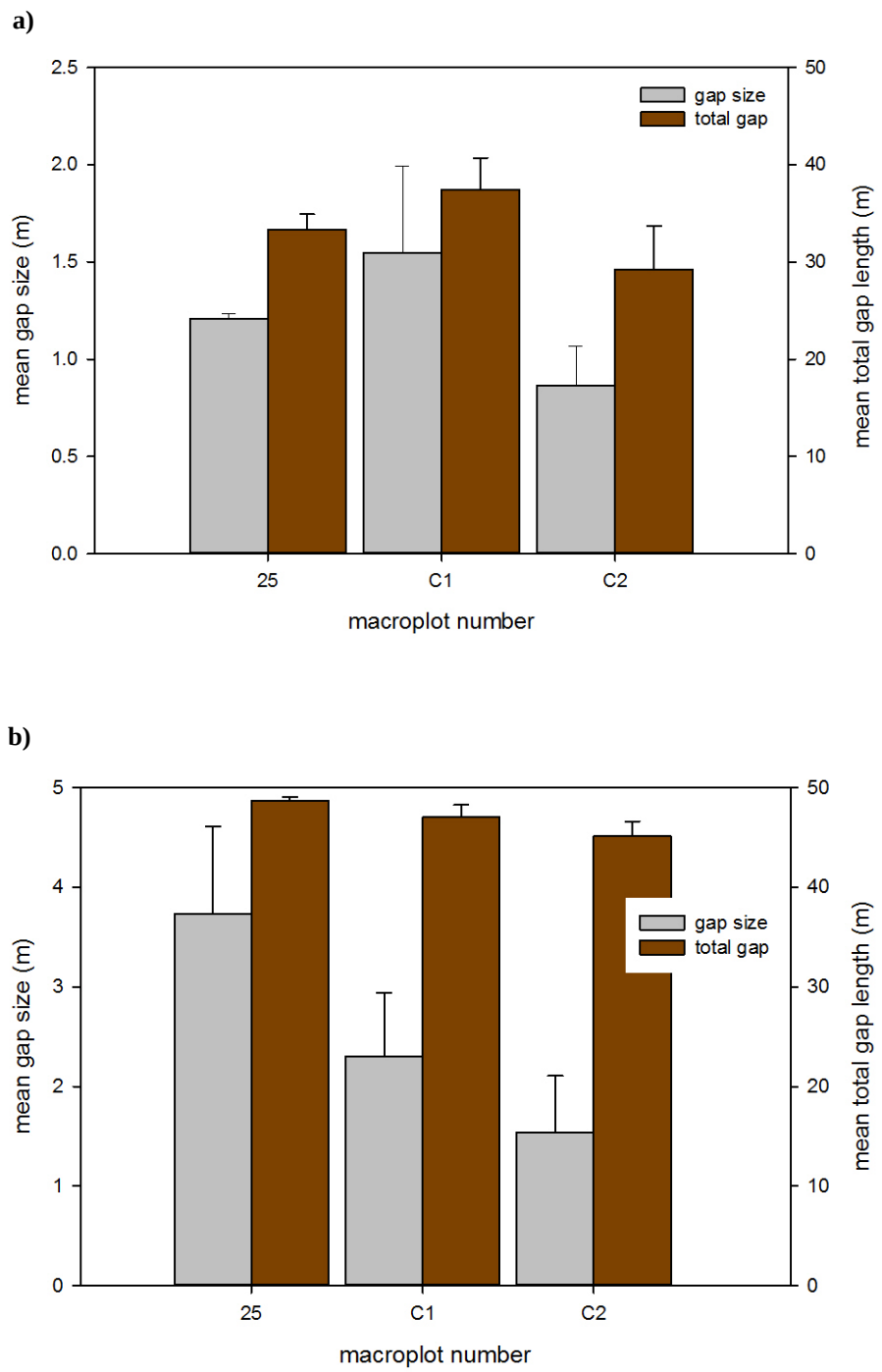


Figure C10. Mean (+SE) gap size and total gap length per transect by macroplot for a) canopy and b) basal gaps.

Basal gaps can be used to assess the potential for water erosion. The total number of basal gaps ≥0.2 m ranged from 14-36 gaps per macroplot. Unlike for canopy gaps, the basal gap distribution for macroplots 00C1 and 00C2 are more similar to each other than macroplot 25 (Figure C11). Nearly half of the basal gaps on macroplot 25 were in the largest gap category (>2 m) and mean gap size on this macroplot was >3.7 m (Figure C10b). Despite the differences in gap distribution and mean gap

size, mean total basal gap length was >45 m or >90% of the entire transect for all macroplots (Figure C10b).

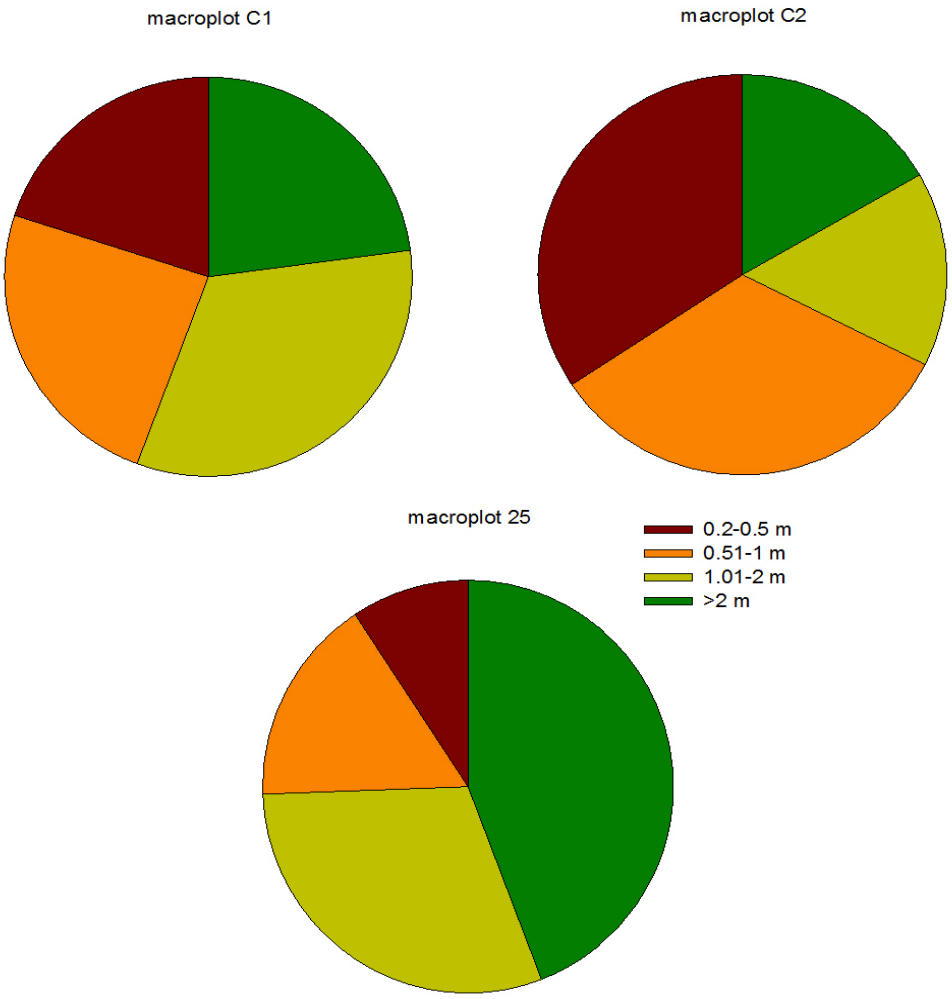


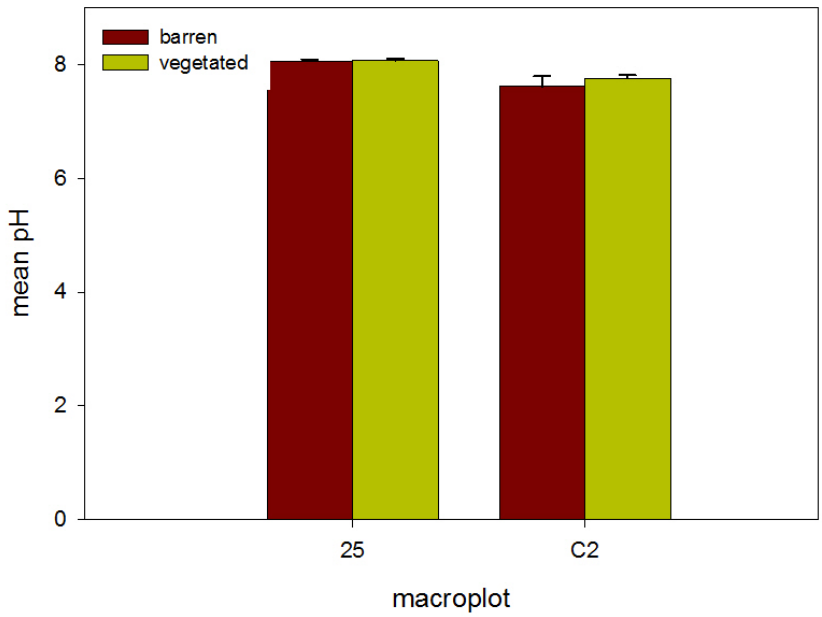
Figure C11. Mean number of basal gaps for a given size category per macroplot. Macroplot 00C1 had a total of 24 gaps, macroplot 00C2, 36 gaps, and macroplot 25, 14 gaps.

Soil compaction (penetration resistance) was extremely low for all points on all macroplots.

pH values were ~7.7 for both the vegetated and barren samples for macroplot 00C2. pH values were slightly higher on macroplot 025, with mean values for both vegetated and barren samples >8 (Figure C12a).

Soil salinity was fairly low on all macroplots, with mean values <0.45 mS/cm, and all macroplots were considered non-saline. Conductivity readings varied by macroplot, with macroplot 25 having lower mean readings at < 0.30 mS/cm (Figure C12b).

a)



b)

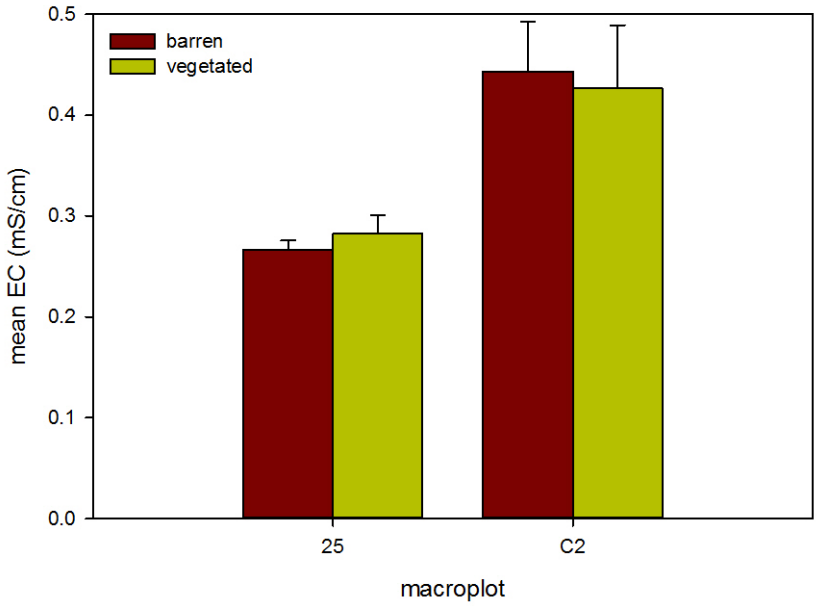


Figure C12. Mean (+SE) values for a) pH and b) electrical conductivity (EC) by macroplot.

Qualitative soil parameters are shown in Table C3 for barren and vegetated soil samples for each macroplot. For most of the soil parameters, the macroplots were fairly similar and the range of values detected overlapped across macroplots. For example, soils on both macroplots were generally moderately plastic, and samples ranged from non-plastic to moderately plastic. One parameter that varied greatly between the macroplots was the amount of carbonates; all samples on macroplot 25

were violently effervescent (high carbonates) compared to macroplot 00C2, where samples ranged from noneffervescent (no carbonates) to strongly effervescent (moderate amount of carbonates).

Table C3. Dominant qualitative soil characteristics for two monitored macroplots in 2012. Range of responses are in parentheses. Macroplot 00C2 data was based on four sampling points. No soil data was taken on macroplot 00C1.

Macroplot #	Soil From	Carbonates*	Soil Color	Rupture Resistance**	Stickiness***	Plasticity****	Texture
C2	Barren	NE (NE-ST)	Brown	S/VW (S/VW-HA)	SS (SO-MS)	SP/MP (SP-MP)	Silty clay (silty clay loam-gravelly silty clay)
	Vegetated	SL (NE-SL)	Brown	HA (S-HA)	SS	SP/MP (SP-MP)	Gravelly silty clay loam (gravelly silty clay loam-gravelly sandy clay)
25	Barren	VE	Brown	S (L-HA)	SS (SS-MS)	MP (PO-MP)	Gravelly loamy sand (gravelly loamy sand-very gravelly clay)
	Vegetated	VE	Brown	S (L-S)	SS (SS-MS)	MP (PO-MP)	Gravelly loamy sand (gravelly loamy sand-very gravelly clay)

*NE=noneffervescent (little/no carbonates), VS=very slightly effervescent, SL=slightly effervescent, ST=strongly effervescent, VE=violently effervescent (high amounts of carbonates).

**L/EW=loose/extremely weak, S/VW=soft/very weak, SH/W=slightly hard/weak, MH/M=moderately hard/moderate, HA/MS=hard/moderately strong.

***SO=non-sticky, SS=slightly sticky, MS=moderately sticky, VS=very sticky.

****PO=non-plastic, SP=slightly plastic, MP=moderately plastic, VP=very plastic.

Appendix D: Macroplot Overview Photographs from the 2012 Pilot Study

Photographs of the established macroplots taken through the repeat photos procedure (SOP 13) from the IU protocol.

Figure D1. Macroplot overview photo for macroplot 25.

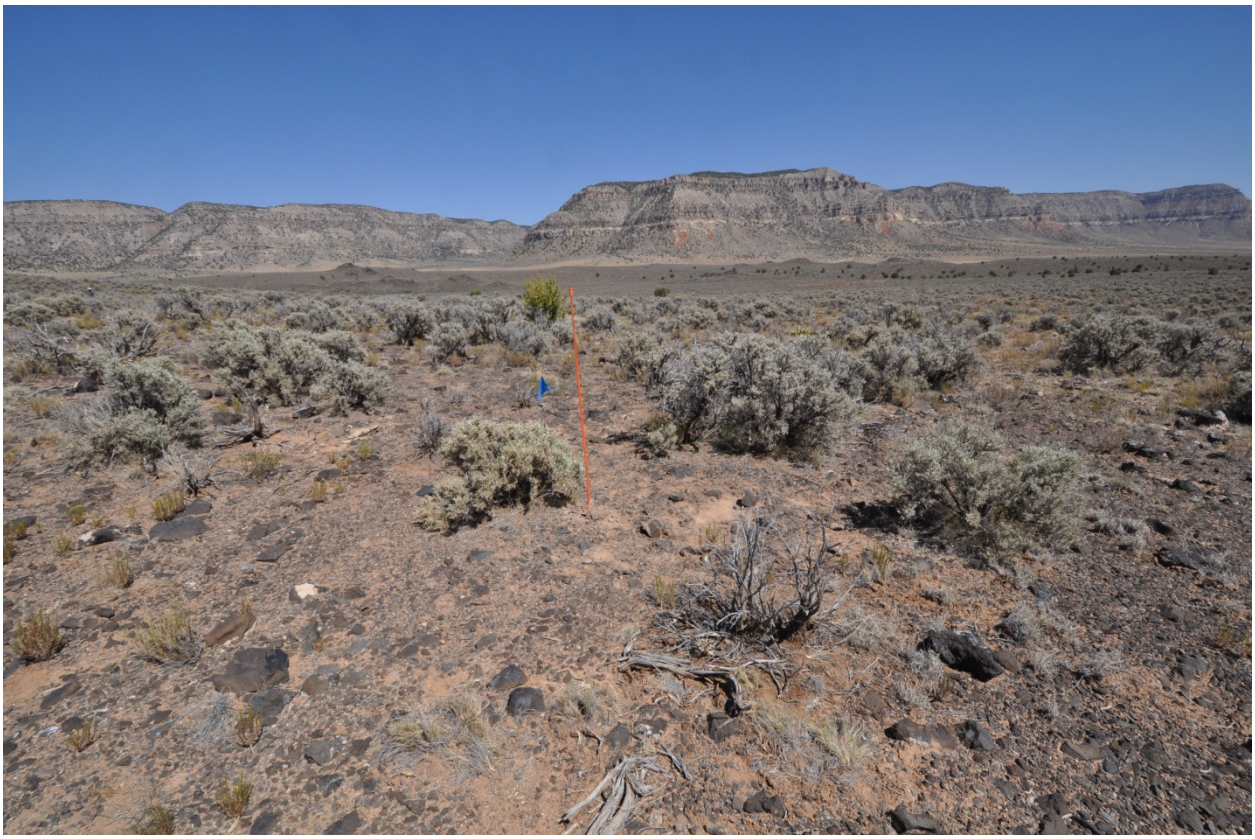


Figure D2. Macroplot overview photo for macroplot 00C1.

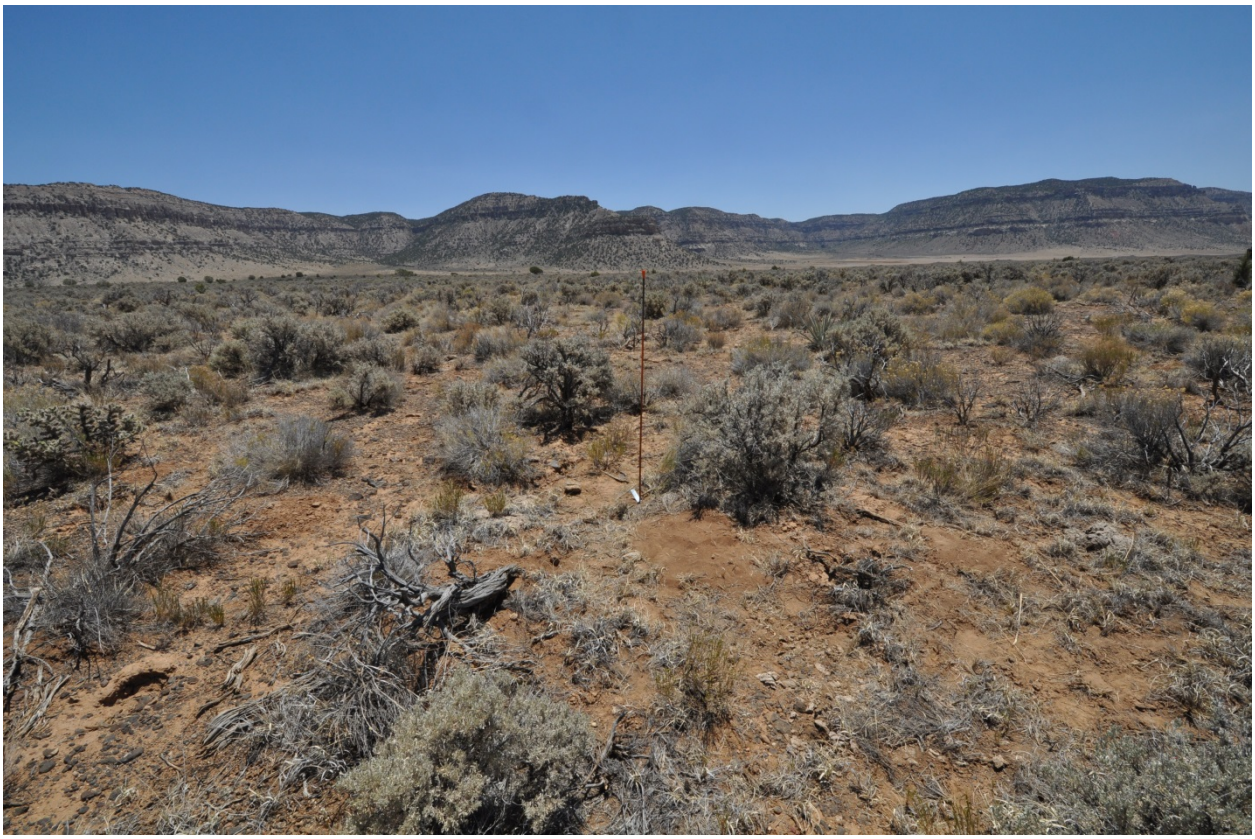


Figure D3. Macroplot overview photo for macroplot 00C2.

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