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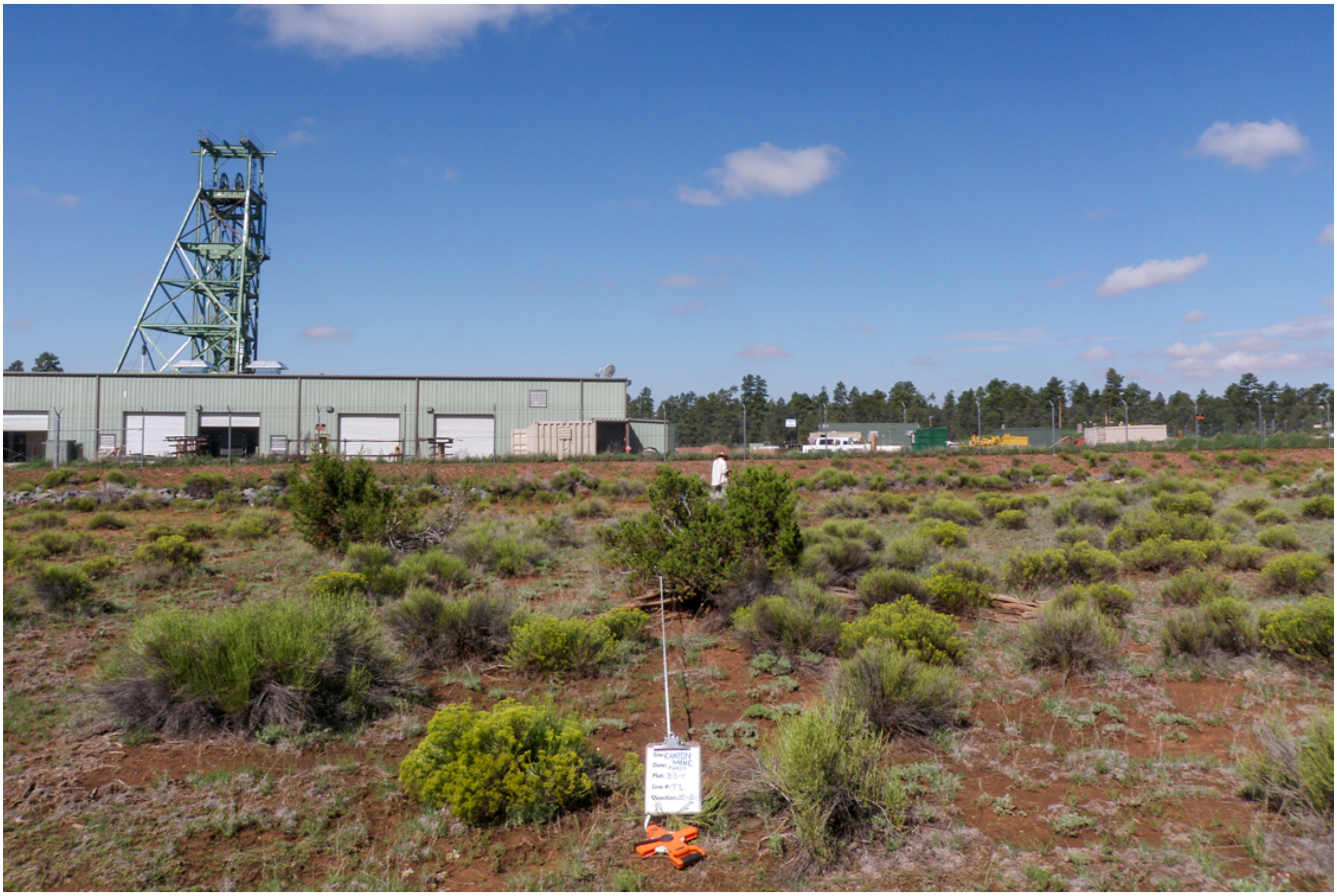
Vegetation Cover and Composition in Environments Surrounding Uranium Mines in the Grand Canyon Ecosystem, Northern Arizona



Open-File Report 2025–1024

U.S. Department of the Interior
U.S. Geological Survey

Cover: Photograph of vegetation sampling at the Pinyon Plain Mine in the Kaibab National Forest, Arizona.

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Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
square hectometer (hm^2)	2.471	acre

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Universal Transverse Mercator (UTM) projection in Zone 12 N.

Altitude, as used in this report, refers to distance above the vertical datum.

Supplemental Information

Note to U.S. Geological Survey users: Use of hectare (ha) as an alternative name for square hectometer (hm^2) is restricted to the measurement of small land or water areas.

Abbreviations

BLM	Bureau of Land Management
DIMA	Database for Inventory, Monitoring, and Assessment
LPI	line-point intercept
NMDS	nonmetric multidimensional scaling
NRCS	Natural Resources Conservation Service
PLANTS	Plant List of Attributes, Names, Taxonomy, and Symbols
p.z.	precipitation zone
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

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Abstract

Mining uranium from breccia-pipe deposits in the greater Grand Canyon region has occurred since the mid-1900s. However, possible ecosystem contamination with harmful levels of radionuclides may have occurred due to mining activities in the 21st century. In response, a 20-year Federal moratorium on new mining claims in the Grand Canyon watershed was initiated in 2012, to allow time to evaluate the potential effects of uranium exploration and mining on human health, wildlife, and water resources. This moratorium, nor the 2023 designation of the “Baaj Nwaavjo I’tah Kukveni–Ancestral Footprints of the Grand Canyon National Monument,” precludes operation or development of mining claims predating 2012.

Vegetation is a core ecosystem component that may be affected by uranium mining (for instance, through uptake and storage of radionuclides from the air or soil) or may act as a vector of exposure to wildlife, livestock, and humans (for instance, via their consumption of contaminated plant tissues). To provide baseline information about the plant communities associated with uranium mines in the Grand Canyon region, the U.S. Geological Survey surveyed an approximately 200-meter-wide buffer surrounding four breccia-pipe deposits, each in a unique stage of mine development, and at one reference area (a livestock water tank) that underwent ground disturbance but contains no mineral deposits. We sectioned the buffer zones into 0.65–4.52 hectare plots, within which we (1) inventoried all plant species, (2) measured percent cover of plant species, plant functional groups, and ground surface types (dark cyanobacteria, lichen, moss, bedrock, rock, embedded litter, duff, plant bases, and bare soil) using line-point intercept, and (3) measured length and frequency of gaps between perennial plant canopies using canopy gap intercept. We found that plant composition at the mines and the reference area differed from one another but were all characteristic of expected regional vegetation patterns. We provide this data summary as potential baseline information for future research and management efforts.

Introduction

High-grade uranium ore was discovered in breccia pipes in the Grand Canyon watershed within arid rangelands of northern Arizona during the late 1940s (Wenrich, 1985) and has since drawn attention as both a resource and public health concern. Breccia pipes are unique solution-collapse features, some of which contain high concentrations of uranium in the form of uranite (Wenrich, 1985). These geological features became the subject of intense exploration during the 1970s (Otton and Van Gosen, 2010), and a total of 13 breccia pipes have been mined in northern Arizona between the early 1950s and present day (Alpine, 2010; Van Gosen and others, 2016). Among the hundreds more breccia-pipe features scattered across this region, there may be additional uranium deposits that are economically viable for extraction (Alpine, 2010, Van Gosen and others, 2016). However, uranium exploration and mining may have contributed to possible ecosystem contamination of environmental and cultural resources in the area (Hinck and others, 2021). Ore and other byproducts from breccia-pipe mining can be a source of radiation and other co-occurring inorganic constituents such as arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc can have ecotoxicological effects (Wenrich, 1985; Hinck and others, 2021). In response, the then Secretary of the U.S. Department of the Interior, Ken Salazar, withdrew approximately 1 million acres of Federal lands surrounding Grand Canyon National Park from access to new mining claims for a 20-year period beginning in 2012 (U.S. Department of the Interior, 2012). This moratorium was put in place to allow time for the investigation of the hazards associated with uranium mining, although neither it nor the 2023 designation of the “Baaj Nwaavjo I’tah Kukveni–Ancestral Footprints of the Grand Canyon National Monument” (White House, 2023) precludes operation or further development of mines with valid existing claims in the region.

When the 2012 moratorium was initiated, scientific data were lacking about potential pathways of exposure for wildlife, livestock, and humans to radionuclides due to uranium mining in the Grand Canyon watershed (Hinck and others, 2014). The U.S. Geological Survey (USGS) was charged with carrying out studies to reduce these uncertainties (USGS, 2014, https://webapps.usgs.gov/uraniummine/) and since 2014, has published numerous scientific articles and reports to address data gaps (Walton-Day and others, 2024). Topics covered through this research effort have included (but are not limited to): geochemistry and flow patterns of groundwater (Beisner and others, 2017; Tillman and others, 2021; Bern and others, 2022; Knight and Huntoon, 2022); concentrations of chemical ore constituents and their potential transfer pathways within common biota (Hinck and others, 2014; 2017, 2021, Cleveland and others, 2019, 2021; Valdez and others, 2021); wildlife use of containment ponds and their chemistry (Klymus and others, 2017; Cleveland and Hinck, 2021); and soil concentrations of chemical elements found in mining ore (Naftz and Walton-Day, 2016; Van Gosen, 2016). However, there is still a lack of baseline data describing the types of plant communities surrounding mines in the Grand Canyon region; collection of this baseline data is identified among USGS research priorities in the Grand Canyon Science Plan as a "High Priority Task" (USGS, 2014). Plant community composition and rangeland quality are important because of their relationships to habitat and forage for wildlife and livestock, and effects on human health and resources, such air quality (Webb and others, 2017), food, and cultural use. Native Americans, for instance, have harvested desert plants for ceremonial, culinary, and medicinal purposes for centuries (Stoffle and others, 1997; Tilousi and Hinck, 2024). If contaminated, vegetation may be a core pathway of exposure for animals and humans to radionuclides and mining-related constituents in the Grand Canyon region (Hinck and others, 2010, 2014). Species presence and abundance data may help to parameterize these pathways at specific sites, given that species differ in relevant qualities such palatability, cultural utilities, and their ability to tolerate and (or) bioaccumulate.

The goal of this work was to characterize the vegetative communities surrounding four breccia pipes that are in various stages of mining development and at one reference site that contains no mineral uranium deposits but has surface disturbance comparable to that created by exploratory mining operations. We did this by carrying out plant species inventories and collecting data on vegetation cover, ground surface types, and gaps between perennial plant canopies. We identified whether the species observed at these sites were of special management concern or were indicators that have historically been used to locate ore deposits (Cannon, 1957). We summarize these baseline data using basic descriptive techniques, including both univariate and multivariate descriptive statistics, and compared the results of monitoring to conditions expected for the region, as depicted in the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) ecological site descriptions associated with the land units on which the sites occur (Caudle and others, 2013). While the purpose of this work was not to test for differences between sites or in relation to their mining status, these data may be useful in tracking changes in plant species abundance and composition through time at the selected locations in subsequent surveys. Additionally, these data may also be informative for future reclamation and other management efforts.

Methods

Study Sites

We identified five sites on which to conduct vegetation surveys (fig. 1), including four breccia-pipe mineral deposits that were leased to private operators for uranium mining and one reference site that has surface disturbance but no mineral ore deposits. Surveys were carried out between July 2013 and December 2015. These sites are on public lands managed by the Bureau of Land Management (BLM) or the U.S. Forest Service (USFS) and leased by those Federal agencies to private operators for the purpose of mining. Outside of fenced, active mining pads, the sites are open to wildlife and permitted livestock grazing. At the time of our surveys, the four breccia-pipe mines represent various phases of the uranium mining lifecycle (table 1) and are the same sites as those used for other USGS studies about landscape-scale effects of uranium mining in the Grand Canyon region (USGS, 2014). Due to a limited number of breccia pipes being leased to private operators for uranium mining in the Grand Canyon region, we were only able to sample a single mine from each of four identified mining phases: pre-development, pre-extraction, active extraction, and post-extraction. The EZ2 breccia-pipe uranium deposit (EZ2 deposit hereafter) is in the pre-development phase: it is permitted for mining, but no surface development had commenced at this site at the time of publication. The Pinyon Plain Mine (formerly known as the Canyon Mine) was in the pre-extraction phase at the time of vegetation surveys, with 6.59 hectares (ha) cleared for development. Its surface infrastructure was completely installed, but the mining shaft was not fully developed, and ore was not being extracted. The Pinenut Mine, on a 6.34-ha pad, was in an active extraction phase at the time of the vegetation surveys, where ore is brought to the surface for processing. The Arizona 1 Mine occupies an 8.02-ha pad and was in a post-extraction phase at the time of vegetation surveys; surface operations were ongoing, but no ore remained on the site. The reference site, Little Robinson Tank, contains a 1.01-ha reservoir used by livestock and wildlife as a water source. It does not contain uranium ore deposits and was selected because it has a degree of disturbance (including surface trampling and construction of an earthen dam) comparable to that created during initial mining development. Mining operations at the Pinyon Plain Mine, Pinenut Mine, and Arizona 1 Mine began in the 1980s; the Little Robinson Tank reservoir was developed in the 1970s–1980s (Rody Cox, Geologist, BLM Arizona Strip Field Office, oral commun., August 22, 2023). All sites allow for permitted cattle grazing.

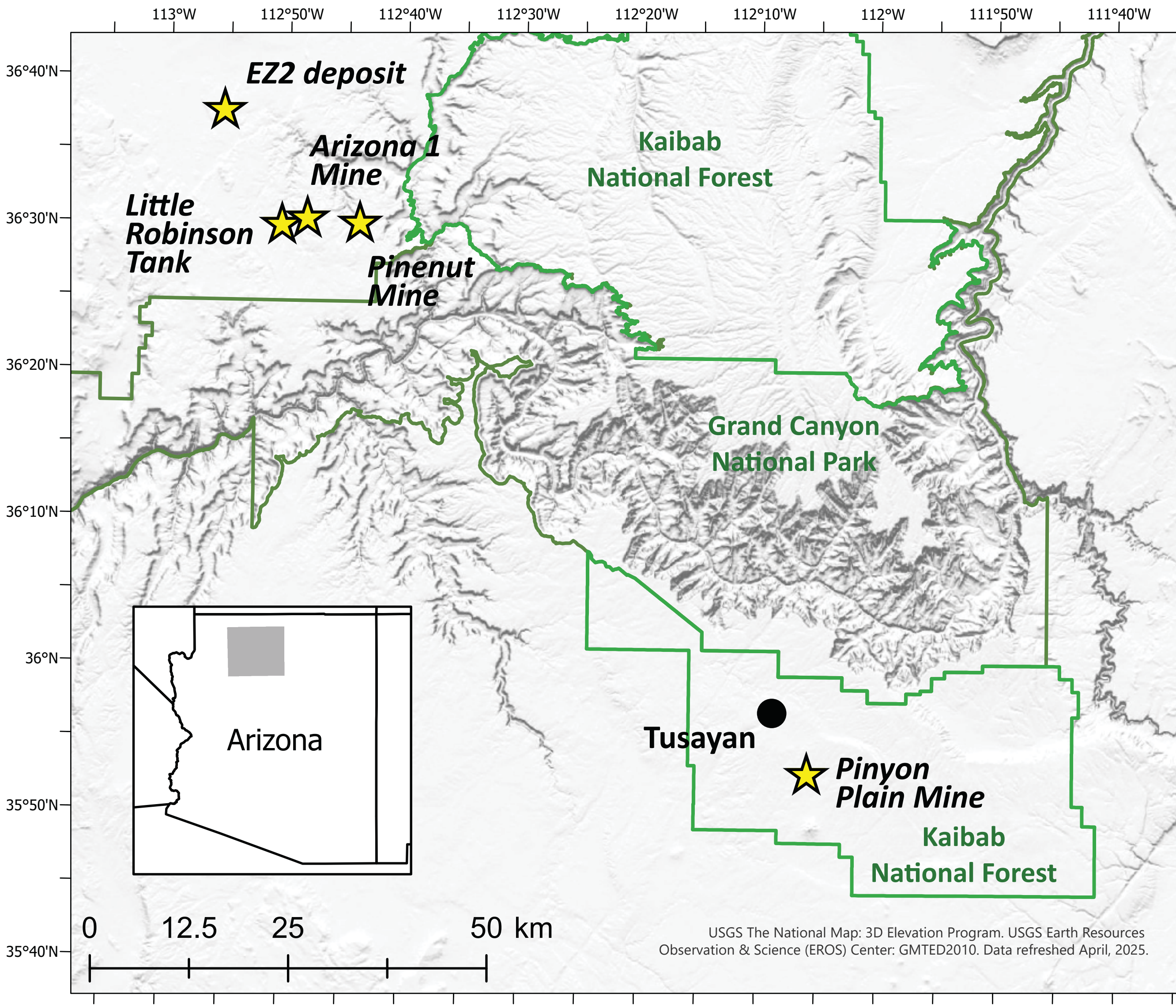

Figure 1. Map of vegetation study site locations in the Grand Canyon region within northern Arizona. Little Robinson Tank has no mineral deposits, and the remaining sites contain breccia-pipe mineral deposits in varying stages of uranium mining development. km, kilometer; USGS, U.S. Geological Survey.

Table 1. Parameters of study sites where vegetation community data were collected in environments surrounding uranium mines in the Grand Canyon ecosystem, northern Arizona.

[Sites included four breccia-pipe uranium deposits (EZ2 breccia-pipe uranium deposit, Pinyon Plain Mine, Pinenut Mine, and Arizona 1 Mine) and one reference site with no mineral deposits (Little Robinson Tank). Data collected in July 2013 at the Pinyon Plain Mine site and July or August 2015 for all other sites. Mine development phase is shown as it existed at the time of the vegetation surveys. Location coordinates (Easting, Northing) and elevation (elev.) are based on North American Datum of 1983, with Universal Transverse Mercator projection in Zone 12 N. Soil map units (SMU), map unit symbol (MUS), and ecological sites were determined using Web Soil Survey (https://websoilsurvey.nrcs.usda.gov/app/) and were not available (n/a) for the Pinyon Plain Mine. Ecological site names include precipitation zone (p.z) and ecological site code (NRCS, 2023a). Climate data, including mean annual precipitation (MAP) and mean annual temperature (MAT), were derived from 30-year (1981–2010) climatological averages modeled at an 800-meter resolution (PRISM Group, 2014). mm, millimeter; °C, degrees Celsius; %, percent; ″, inch]

Site code	Site name	Mine phase	Easting	Northing	Elev. (m)	SMU (MUS)	Ecological sites present	MAP (mm)	MAT (°C)
LRT	Little Robinson Tank	Reference site with no mineral deposits	335041	4040990	1,626	Mellenthin very gravelly loam, 1–25% slopes (33)	Limestone/Sandstone Upland 10–14″ p.z. (R035XC319AZ)	329	12.2
EZ2	EZ2 breccia-pipe uranium deposit	Undeveloped breccia pipe	327871	4055466	1,568	Pennell gravelly loam, 1–12% slopes (47); Kinan-Hatknoll-Grieta complex, 1–5% slopes (23)	Shallow Loamy 7–11″ p.z. (R035XD415AZ); Clay Loam Upland 7–11″ p.z. (R035XD421AZ)	307	12.4
PP	Pinyon Plain Mine	Pre-mining; no ore production	401070	3971530	1,989	n/a	n/a	393	9.1
PN	Pinenut Mine	Active production	344850	4041139	1,657	Mellenthin very gravelly loam, cool, 1–25% slopes (35)	Limestone/Sandstone Upland 10–14″ p.z. (R035XC319AZ)	344	12.8
AZ1	Arizona 1 Mine	Post-mining, pre-reclamation	338244	4041789	1,662	Mellenthin very gravelly loam, 1–25% slopes (33); Manikan silty clay loam, 1–4% slopes (29)	Limestone/Sandstone Upland 10–14″ p.z. (R035XC319AZ); Clay Loam Upland 10–14″ p.z. (R035XC307AZ)	332	12.2

We derived general information about the climate and expected vegetation communities associated with each study site using the Area of Interest Interactive Map available from the USDA NRCS Web Soil Survey application (Soil Survey Staff, 2018) and from 30-year (1981–2010) climatological averages modeled at an 800-meter (m) resolution (PRISM Group, 2014). The EZ2 deposit, Arizona 1 Mine, Pinenut Mine, and Little Robinson Tank study sites are approximately 12 kilometers north of western Grand Canyon National Park (Mohave County), on BLM-managed land. They are in a semi-desert shrub ecoregion with a mean elevation of 1,628 m (table 1). Precipitation is predominantly delivered during summer monsoonal rainstorms, which is typically associated with a pulse in herbaceous biomass production (McClaran and Brady, 1994). The final site, Pinyon Plain Mine, is south of Grand Canyon National Park and southeast of Tusayan, Arizona (Coconino County), on USFS-managed land (Kaibab National Forest). Compared to the other sites, Pinyon Plain Mine is at a higher elevation (1,989 m), and much of the precipitation in this region is delivered as snow, constraining most vegetation growth between late spring and late summer (McClaran and Brady, 1994).

Three of the northern sites—Little Robinson Tank, Arizona 1 Mine, and Pinenut Mine—primarily occur on a very gravelly loam in the Mellenthin soil series (Soil Survey Staff, 2018; Soil Survey Staff, 2023) and are associated with the Limestone/Sandstone Upland 10–14 inch (in.) precipitation zone (p.z.) ecological site R035XC319AZ (table 1; NRCS, 2023a). The landscape foundation is flat to gently dipping sedimentary rocks, which erode into plateaus, valleys, and deep canyons. The soils can be very shallow (less than [<] 25 centimeters [cm]) to moderately deep (<100 cm). This ecological site supports communities of drought-tolerant perennial grasses and shrubs, general functional groups that vary in their predominance depending on local topography and site history. Warm season grasses such as *Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths (blue grama), *Pleuraphis jamesii* (Torr.) Benth. (James' galleta), *Bouteloua eriopoda* (Torr.) Torr. (black grama), and *Sporobolus cryptandrus* (Torr.) A. Gray (sand dropseed) are more common than cool season grasses such as *Achnatherum hymenoides* (Roem. & Schult.) Barkworth (Indian ricegrass) or *Hesperostipa comata* (Trin. & Rupr.) Barkworth (needle and thread). *Artemisia tridentata* ssp. *wyomingensis* Beetle & Young (Wyoming big sagebrush) is dominant throughout the region, although *Artemisia nova* A. Nelson (black sagebrush) may replace Wyoming big sagebrush on rims and high plateaus. *Juniperus osteosperma* (Torr.) Little (Utah juniper) and *Pinus edulis* Engelm. (twoneedle pinyon) are more common in the north. Other potential woody species include *Atriplex canescens* (Pursh) Nutt. (fourwing saltbush), *Atriplex confertifolia* (Torr. & Frém.) S. Watson (shadscale), and *Ephedra viridis* Coville (mormon tea). *Bromus tectorum* L. (cheatgrass), *Salsola tragus* L. (prickly Russian thistle), and other non-native annual plants may increase in association with heavy grazing and other site disturbances (NRCS, 2023a). At the Arizona 1 Mine site, deeper silty clay loam associated with the Manikan series (Soil Survey Staff, 2018; Soil Survey Staff, 2023) runs through the northeastern corner (occupying approximately 11 percent of the surveyed area); it follows a shallow drainage and is associated with a Clay Loam Upland, 10–14 in. p.z. ecological site R035XC307AZ (NRCS, 2023a). Expected plant community composition for this ecological site is similar to that of the Limestone/Sandstone ecological site occupying the rest of the Arizona 1 Mine site, although biomass production is typically higher along drainage ways.

The EZ2 deposit, also north of Grand Canyon National Park, is in a lower precipitation zone in a landscape of plains and rolling hills with bedrock outcrops. The site occurs on the Pennell gravelly loam (Soil Survey Staff, 2018; Soil Survey Staff, 2023) and is associated with the Shallow Loamy 7–11 in. p.z. ecological site R035XD415AZ (table 1; NRCS, 2023a). This ecological site is dominated by short- and mid-stature grasses, including Indian ricegrass, grama grasses (*Bouteloua* Lag. species), needle and thread, galleta, and *Elymus elymoides* (Raf.) Swezey (squirreltail). Shrubs are also present but to a lesser abundance, and include fourwing saltbush, mormon tea, and *Krascheninnikovia lanata* (Pursh) A. Meeuse & A. Smit (winterfat). The far eastern edge of the EZ2 deposit (approximately 5 percent of the surveyed area) is mapped on deeper soil (the Kinan-Hatknoll-Grieta complex) and associated with the Clay Loam Upland 7–11 in. p.z. ecological site R035XD421AZ (Soil Survey Staff, 2018; NRCS, 2023a). *Chrysothamnus viscidiflorus* (Hook.) Nutt. (yellow rabbitbrush), fourwing saltbush, and winterfat are common woody plants associated with this ecological site; grasses include galleta, squirreltail, and *Scleropogon brevifolius* Phil. (burrograss) (NRCS, 2023a). Immediately southwest of, but not directly associated with, the surveyed area surrounding the EZ2 deposit is the Havasupai-Mellenthin soil complex (Soil Survey Staff, 2018; Soil Survey Staff, 2023), associated with the Limestone/Sandstone Upland 10-14 in. p.z. ecological site (R035XC319AZ; see NRCS, 2023a).

The Pinyon Plain Mine site is in a *Pinus ponderosa* Lawson & C. Lawson (ponderosa pine) community with a Wyoming big sagebrush understory. Detailed mapping of soils and ecological sites has not yet been completed for the forest region surrounding Pinyon Plain Mine, although moderately deep, well-drained soils such as Tovar fine sandy loam (Soil Survey Staff, 2023) are typical of shallow slopes on woodlands in central Arizona (Taylor, 1983). According to an early survey of vegetation zones in Arizona (Nichol, 1937), Pinyon Plain Mine occupies the western edge of a higher elevation ponderosa pine community, which transitions to a lower elevation pinyon juniper woodland and desert grasslands to the east. Ponderosa pine and *Quercus gambelii* Nutt. (Gambel oak) are common in these higher elevation woodlands, and Utah juniper, twoneedle pinyon, and *Mahonia fremontii* (Torr.) Fedde (Fremont's mahonia) are typical in the lower elevation forests. Frequent high elevation grasses include *Muhlenbergia montana* (Nutt.) Hitchc. (mountain muhly), bottlebrush squirreltail, galleta grass, and *Festuca arizonica* Vasey (Arizona fescue). In low elevations, grama grasses are more common (Nichol, 1937; McClaran and Brady, 1994). Where the canopy is open, a variety of forb species can be expected, including *Lupinus* L. sp. (lupine), *Phlox* L. sp. (phlox), *Delphinium* L. sp. (larkspur), and *Senecio* L. sp., (groundsels) (Nichol, 1937).

Field Sampling

We conducted vegetation surveys within polygonal plots at each study site (fig. 2). The plot arrangement had been designed for previous studies (Hinck and others, 2014, 2017; Naftz and Walton-Day, 2016; Cleveland and others, 2021) and used again for our vegetation surveys to maintain consistency of sampled areas between studies. Plots were arranged such that they surround either the central disturbed area of active sites (that is, around the developed mine area for the Pinyon Plain Mine, Pinenut Mine, and Arizona 1 Mine sites; and around the stock tank of the Little Robinson Tank site) or, in the case of the EZ2 deposit site, around a central 1.75-ha undisturbed core, which was also sampled as a plot. Service Pack 5 of ArcGIS v. 10.0 (Esri, 2011) was used to delineate the plot boundaries. Plots were arranged in two concentric rings that were between 70-m and 100-m-wide. Plots in the interior ring had inner boundaries that were constrained by the central disturbed area (fences surrounding the mines at the Pinyon Plain Mine, Pinenut Mine, and Arizona 1 Mine sites; or the berms surrounding the Little Robinson Tank stock tank). Plot shape, area, and total number varied by site (fig. 2, table 2). Across sites, there were between 4 and 10 plots in the inner ring ranging from 0.65 to 1.72 ha, and between 4 and 6 plots in the outer ring, ranging from 3.53 to 4.53 ha.

Transects were established for line-point intercept and gap intercept data collection within each polygon plot. Two 25-m transects were established in each of the inner-ring plots, and three 50-m transects were established in each of the outer-ring plots. To achieve a spatially balanced distribution of transects, plots were first split into two (for inner-ring plots) or three (for outer-ring plots) evenly sized sub-polygons using the Esri “Split” tool. One transect was then created within each sub-polygon, using the Geospatial Modelling Environment toolbox to randomly assign a start point and azimuth (constrained to keep transect within polygon).

The line-point intercept method (LPI, following Herrick and others, 2005) was used to measure foliar and ground-surface cover along all established transects. Data were collected at 50 evenly spaced sample points per transect, such that inner-ring plots had a total of 100 sampled points with 0.5 m spacing between sample points along the two 25-m transects, and outer-ring plots had a total of 150 sampled points with 1-m spacing between sample points along the three 50-m transects. At each sample point, a pin flag (with a shaft approximately 1 millimeter [mm] in diameter) was dropped vertically and any plant species (live or dead) or plant litter (unrooted plant debris) that were touching the pin anywhere along its length were recorded. Plants were identified in the field to the most detailed taxonomic classification achievable (subspecies, species, or genus), or if the field specimen was unidentifiable, it was assigned to a plant functional group (tree, shrub, sub-shrub, perennial grass, perennial forb, annual grass, annual forb). The ground surface type that the base of the pin touched was also recorded for each sampling point. Ground surface type definitions followed Herrick and others (2005) and included dark cyanobacteria (cyanobacteria with pigmentation visible to the naked eye), lichen, moss, bedrock, rock (rock fragments greater than [>] 5 mm in diameter), embedded litter (plant litter that would leave an indentation in the soil surface or would disturb the soil surface if removed), duff (partially decomposed plant litter with no recognizable plant parts), plant bases (described to most detailed taxonomic classification achievable), and soil (loose or cemented mineral soil that is visibly unprotected by any of the aforementioned surface types). The LPI data were collected during the peak summer season, in July 2013 at the Pinyon Plain Mine site; July 2015 at the Pinenut Mine site; and August 2015 at the Arizona 1 Mine, EZ2 deposit, and Little Robinson Tank sites (table 2). Although effort was made during field sampling to identify all plants present in the plots, whether they were actively growing, senesced, or dead, some spring ephemeral species may have been missed during the one-time sampling effort.

Immediately after collection of LPI data, an additional inventory of all plant species was made for each plot by a team of three to five people. The observers spread out approximately 10 m from one another along one of the long edges of the plot then walked at a constant pace until they reached its opposite edge. The walks were repeated for as many passes as required to cover the entire plot area, which took 30 minutes to 1 hour per plot. All observers recorded the live plant species they saw during the walk, including both current-year senesced and actively growing plants. To aid in keeping track of where plot boundaries were while making the passes, the observers searched inner-ring plots from their long outer edge towards their inner edge (towards the center of the site), and they searched outer-ring plots from their inner edge towards their outer edge (away from the center of the site). A composite plot-level species list was compiled from all observers’ individual lists, plus any species encountered during the LPI observations.

The same transect lines used for LPI were re-established to collect perennial canopy gap intercept data at the Little Robinson Tank, EZ2 deposit, Arizona 1 Mine, and Pinenut Mine sites between October and December 2015 (table 2). Canopy gap data were not collected at the Pinyon Plain Mine site due to high tree cover, infrequent occurrence of large gaps, and limited relevance of this data to wind-erosion susceptibility. Canopy gaps are the spaces between perennial

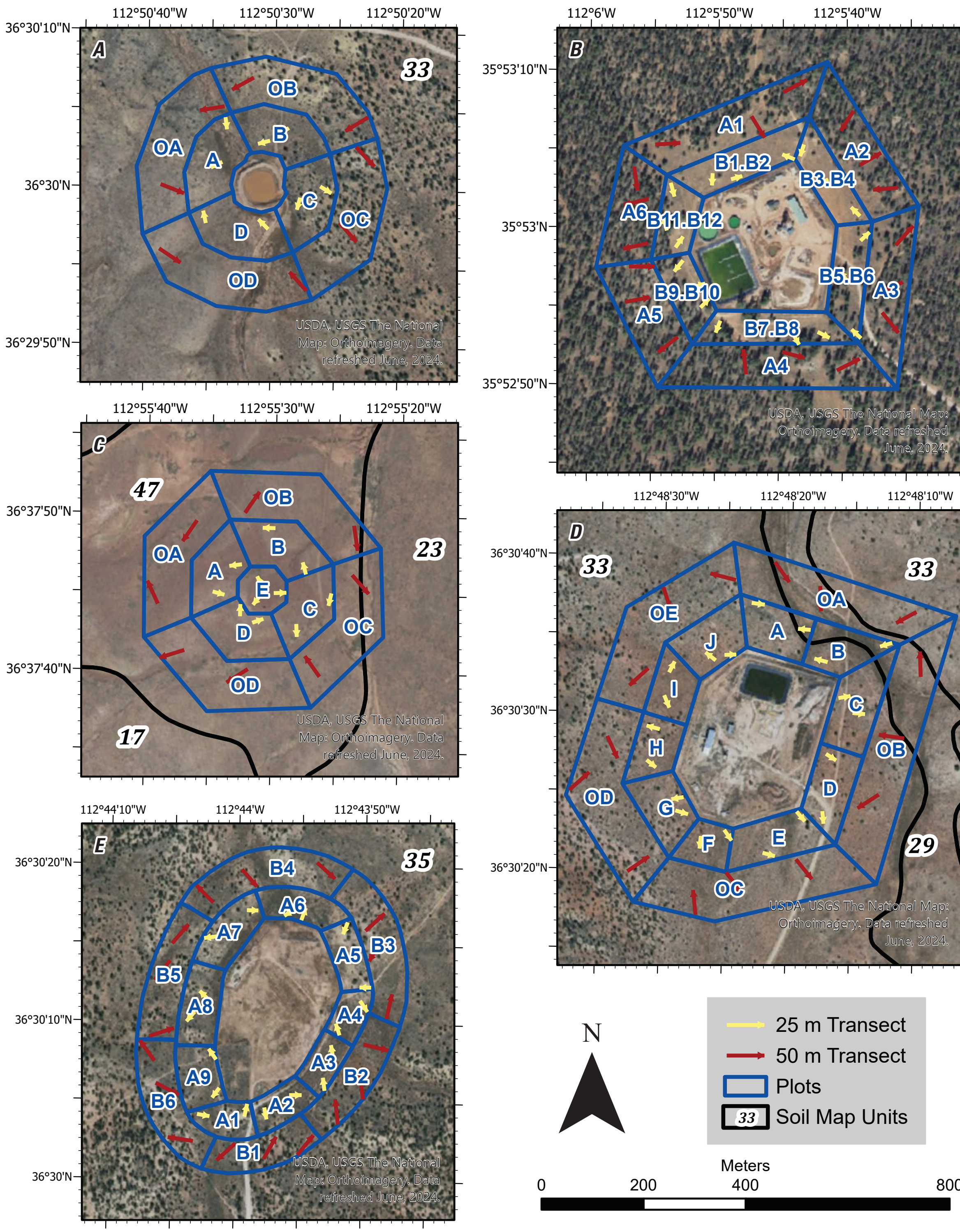

Figure 2. Detailed maps of the study sites in the Grand Canyon area, northern Arizona. *A*, Little Robinson Tank site; *B*, Pinyon Plain Mine site; *C*, EZ2 breccia-pipe uranium deposit site; *D*, Arizona 1 Mine site; *E*, Pinenut Mine site. All study sites contain breccia-pipe mineral deposits in varying stages of mining development except Little Robinson Tank, which has no mineral deposits. Map for each site includes sampling plot and transect locations, underlying soil map units (Soil Survey Staff, 2018; see table 1), and imagery showing vegetation distribution (USDA, USGS The National Map: Orthoimagery; data refreshed June 2024). Sampling plots were arranged in two concentric rings that were between 70-m and 100-m-wide. Plots in the interior ring had inner boundaries that were constrained by the central disturbed areas at developed mines. Transects were established for data collection within each polygonal plot. Two 25-m transects were established in each of the inner-ring plots, and three 50-m transects were established in each of the outer-ring plots. For plant species occurrence and cover refer to appendix 1 (tables 1.1–1.5). m, meter.

Table 2. Sampling parameters of uranium mine study sites in the Grand Canyon area, northern Arizona.

[Site codes correspond to sampled sites as follows: LRT, Little Robinson Tank; EZ2, EZ2 breccia-pipe uranium deposit; PP, Pinyon Plain Mine; PN, Pinenut Mine; and AZ1, Arizona 1 Mine. The LRT site has no mineral deposits; the four other sites contain breccia-pipe mineral deposits and are shown in order of increasing mine development phase. Each site contained two concentric rings of plots (fig. 2). Plots in the inner ring contained two 25-meter (m) transects, and plots in the outer ring contained three 50-m transects. The difference in total transect length sampled across sites was due to differing number of plots per site. Sampling dates for line-point intercept (LPI), plant species inventory, and canopy gap data collection are provided. Plant species inventories were conducted during the same timeframe as LPI data collection. Canopy gap, a measurement of the space between perennial plant canopies, was not sampled at the PP site due to high tree cover, infrequent occurrence of large gaps, and limited relevance of this data to wind-erosion susceptibility. n/a, not available.]

Site code	Cumulative plot area sampled (in hectares)	Number of plots	Number of transects	Total transect length (in m)	Sample dates	
					LPI and plant species inventory data	Canopy gap data
LRT	18.37	8	16	800	Aug. 26–27, 2015	Oct. 26–Dec. 4, 2015
EZ2	18.09	9	19	675	Aug. 25–27, 2015	Dec. 4, 2015
PP	24.32	12	36	1,350	July 23–26, 2013	n/a
PN	19.75	15	36	1,350	July 11–16, 2015	Oct. 23–26, 2015
AZ1	31.89	15	35	1,250	Aug. 4–7, 2015	Oct. 22–23, 2015

plant canopies, recorded by noting the stop and start point of segments of the transect line that are not covered by perennial plant canopies (followed protocols in Herrick and others, 2005). We only recorded gaps if they were 20 cm long or longer, and we recorded their length to the nearest 1 cm. Because of the early winter sampling dates, some foliage on the perennial plants may have been senesced, potentially resulting in increased length and frequency of gaps compared to measurements that could have been recorded during expected peak-greenness (May–September, as per Jameson, 1965; Walker and others, 2014). However, any effects to our gap data due to this timing were expected to be minimized by restricting measurements to perennial plants, which tend to have more seasonally persistent vegetative structures than annual species, and differences noted across sites were minimized by sampling all of them in generally the same season as one another.

Data Summarization and Analysis

The LPI and canopy gap data were entered into the Database for Inventory, Monitoring, and Assessment (DIMA) version 5.2a (Courtright and Van Zee, 2011), and species inventory data were entered into a spreadsheet. For all plants noted in either LPI data or species inventories, taxonomic details and botanical information were derived from the NRCS Plant List of Attributes, Names, Taxonomy, and Symbols (PLANTS) database (https://plants.usda.gov/home; NRCS, 2023b). This information included the formal USDA plant code, the full scientific name, the lifecycle category (annual, perennial, biennial), the growth form (tree, shrub, sub-shrub, succulent, graminoid, forb), and the nativity (native or non-native for the State of Arizona). For species observed in LPI data, if more than one duration or growth form was listed on the NRCS PLANTS database, a single classification was assigned to the species based on what was most commonly observed for the individuals noted at the study sites, so that the plant could be assigned to a functional group for summarizing cover data. For all species, we also checked whether they were listed as Federally threatened or endangered within the state of Arizona using the U.S. Fish and Wildlife Service (USFWS) Environmental Conservation Online System (https://ecos.fws.gov/ecp/), or whether they occurred in the *Astragalus* L. (milkvetch), *Allium* L. (onion), or *Eriogonum* Michx. (buckwheat) genera, which were historically noted as indicator species, associated with uranium ore deposits (Cannon, 1957).

We used the automated reporting tools in DIMA to calculate plot-level percent cover of canopy gaps. This was obtained for user-defined gap length classes and calculated as the portion of the total transect length (50 m for inner-ring plots and 150 m for outer-ring plots) occupied by the specified class. Our length classes were defined as follows: gaps greater than 25 cm, gaps greater than 50 cm, gaps greater than 100 cm, and gaps greater than 200 cm. These classes overlapped, such that any single gap was included in percent cover calculations for each length classes it fell within; for instance, a 152 cm gap would be included in the calculation for percent cover of gaps greater than 25 cm, gaps greater than 50 cm, and gaps greater than 100 cm.

We again used the automated reporting tools in DIMA to derive plot-level percent cover of LPI data (vegetation, litter, and ground surface types). Percent cover is calculated as the number of sampled points for which the variable was encountered, divided by the total number of sampled points. Sample points from all transects are merged for this calculation, so that there were 100 total points for inner-ring plots and 150 total points for outer-ring plots. Percent cover within each plot was calculated for multiple vegetative categories, which included: each plant species, functional groups defined by a combination of growth form and lifecycle (tree, shrub, subshrub, perennial graminoid, perennial forb, and annual species), total non-native species (which may include members from multiple functional groups), and a “total foliar” category, indicating that any plant, regardless of species or group, was present. Percent cover was also calculated for “total litter,” a category indicating that plant litter had been detected at any layer of a sampled point (within the canopy or at the soil surface). Finally, percent cover within each plot was calculated for ground surface types: biological soil crust components (cyanobacteria, lichen, and moss), rocks (any fragment >5 mm in diameter), duff, and two composite categories: “total ground cover” (indicating that the ground surface type was either cyanobacteria, lichen, moss, rock, duff, litter, a plant base, or was overlain by loose plant litter) and “bare soil” (the ground surface type was soil and it was not covered by any vegetation or plant litter). The “total ground cover” category represents points that are more resistant to erosional forces and the “bare soil” category represents points where soil is completely exposed and more susceptible to erosion. These categories are not mutually exclusive, however; points for which the ground surface type was soil covered by vegetation but not plant litter were not included in either calculation. We performed a non-parametric test of rank correlation using Kendall’s Tau (τ_b) to assess correlation between the cover values derived for vegetation functional groups, total litter, and all ground surface types, using the Hmisc package (Harrell, 2023) in R version 1.0.136 (R Core Team, 2016). Cover data was not transformed or weighted prior to correlation test.

Because of the lack of replication of mines within the four target phases of uranium mining (pre-development, pre-extraction, active extraction, post-extraction), no statistical analyses of the sampled data were conducted other than ordination to compare differences between sites in their vegetation communities. However, we did summarize the data collected by site, as described here. For all cover variables (vegetation categories, litter, and ground surface types), we calculated site-level mean from area-weighted plot values to account for large differences in area between inner- and outer-ring plots. The normalized weight for each plot was derived by dividing the plot area by the total measured area at a given site, such that the sum of all plot weights within a site was equal to 1. Plot-level cover values were multiplied by their weights prior to averaging them to obtain the site mean. Plot-level weighted variance was estimated by multiplying the unweighted variance by Kish's design effect (Gatz and Smith, 1995; Harrell, 2023). Weighted means were calculated using the Hmisc package in R. Finally, relative percent cover for each functional group (tree, shrub, subshrub, perennial graminoid, perennial forb, and annual species) was calculated by dividing the functional group’s cover value by the sum of all groups’ cover values (which could add up to greater than 100 percent due to overlapping plant canopies). The resulting set of relative cover values for these functional groups sums to 100 percent.

We also assessed the multivariate range of vegetation conditions across the focal mines and the reference area using nonmetric multidimensional scaling (NMDS) (Kruskal, 1964). NMDS is an ordination technique used to depict complex, multi-dimensional data, such as abundance data for numerous plant taxa observed across multiple sample units, in lower-dimensional space, such as a two-dimensional plot with x- and y-axes. This method iterates through configurations of the sample units in the low dimensional space in order to maximize the rank-order correlation between the high- and the low-dimension distance matrices, creating a low-dimension plot most representative of the high-dimensional data (Kruskal, 1964; also see explanation by Gu and others, 2015). The degree to which the two matrices diverge in their rank-order of data is represented by a stress value. An NMDS plot with a stress value of <0.2 is generally considered adequate for meaningful interpretation, and the risk of drawing false conclusions lowers as the value approaches 0 (Clarke, 1993). The axes of the low dimensional NMDS output plots do not represent numerical information, but rather the ordinal distance between sample units being transformed to lower-dimension space (Kruskal, 1964). For this study, we performed an NMDS ordination using the vegan package in R (Oksanen and others, 2022) with a Bray-Curtis distance dissimilarity matrix. Our input data was a species abundance matrix generated from the unweighted, plot-level percent cover of plant species derived from LPI data in the DIMA database. We used a two-dimensional ordination with a random starting configuration, and allowed the ordination to iterate 100 times, or until a stable solution was reached. To test whether sites differed from one another in ordination space, we used the Adonis function in the vegan package, which partitions distance matrices among sources of variation and fits linear models using permutation tests with pseudo-F ratios (Oksanen and others, 2022). This was carried out through post hoc, pairwise comparisons between all site pairs.

Results

Species Inventory

Plant surveys revealed variation between sites in species richness (appendix 1). Surveys at Pinyon Plain Mine site identified more than double the number of total species at that site compared to the others; including a particularly high number of forbs (75 species; see appendix 1, table 1.3). Fourteen of the species observed across all sites were non-native, of which *Salsola tragus* (prickly Russian thistle) and *Portulaca oleracea* L. (little hogweed) were the most recurrent. None of the species observed were Federally listed by the USFWS as threatened or endangered. We observed greater richness of uranium ore indicator species (any species in the *Astragalus*, *Allium*, and *Eriogonum* genera) at the mine sites than we did at the reference site. At Little Robinson Tank, the site without mineral deposits, a single indicator species was present (0.3 percent cover in LPI data), compared to four indicator species present at the EZ2 deposit site (0.2 percent cover), seven at the Pinyon Plain Mine site (0.3 percent cover), two at the Pinenut Mine site (but not observed in LPI cover method), and two at the Arizona 1 Mine site (0.1 percent cover). However, we were unable to run statistical tests on this data due to lack of replication, so the results are not conclusive evidence of a pattern.

Canopy Gap and Line-Point Intercept

Canopy gaps were measured at all sites except Pinyon Plain Mine site between late October and early December 2015 (table 2, fig. 3*A*). LPI data, which includes cover of vegetation and ground surface types, were collected at Pinyon Plain Mine site in July 2013 and at all other sites in July and August 2015 (table 2). Across the sites, canopy gaps 25 cm or greater average 55.9 percent cover, and canopy gaps 200 cm or greater average 16.1 percent cover. The Little Robinson Tank site has the lowest canopy gap cover of any size class, and the Pinenut Mine site has the greatest cover (except for gaps >25 cm), but differences are relatively minor. The lower cover of gaps at the Little Robinson Tank site is associated with a high abundance of blue grama (appendix 1), a rhizomatous perennial grass that forms patchy mats (Welsh and others, 2015).

Sites differed from one another in plant and soil cover (table 3, fig. 3*B* and *C*). Total foliar cover is greater than 40 percent at all sites (fig. 3*B*), highest at the Little Robinson Tank site (63 percent), and lowest at the Arizona 1 Mine site (42 percent). At the Arizona 1 Mine and Pinenut Mine sites, the plant communities are dominated by woody species, particularly shrubs, whereas perennial grasses are the most prevalent functional group at the Little Robinson Tank and EZ2 deposit sites, and the Pinyon Plain Mine site has a relatively even distribution of perennial grasses and woody plants (table 3). Relative cover of annual and non-native species is greatest at the EZ2 deposit and Little Robinson Tank sites, but less than 1 percent at the other sites (table 3). Relative cover of perennial forbs is also greatest at the EZ2 deposit site (table 3) due to the prevalence of *Sphaeralcea parvifolia* A. Nelson (small-leaf globemallow), which has 5.7 percent absolute cover at the site (table 1.2). For the ground surface, unprotected bare soil is lowest at Pinyon Plain Mine site (12.5 percent) and highest at Arizona 1 Mine site (52.0 percent). In contrast, protected total ground cover is highest at the forested Pinyon Plain Mine site (80 percent) and lowest at the Arizona 1 Mine (30 percent) and EZ2 deposit (29 percent) sites. The other sites had intermediate values for both metrics (fig. 3*C*). Rock cover averaged 17.0 percent at the EZ2 deposit site, 17.1 percent at the Little Robinson Tank site, and 17.5 percent at the Pinenut Mine site; these sites have gravelly soils. Rock cover was comparatively lower at the Arizona 1 Mine (2.7 percent) and Pinyon Plain Mine (6.6 percent) sites.

There were several statistically significant correlations between the LPI metrics (table 2.1). Among the vegetation metrics, total foliar cover is highly correlated with perennial graminoid cover (τ_b=0.83, *p*-value [*p*] of 8.9×10^{-16}) and weakly correlated with subshrubs (τ_b=−0.33, *p*=0.010), annual species (τ_b=0.31, *p*=0.015), and perennial forbs (τ_b=0.31, *p*=0.02) but not with tree or shrub cover. Other significant correlations in vegetation metrics include a negative correlation between trees and shrubs (τ_b=−0.44, *p*=4.9×10^{-4}), a negative correlation between subshrubs and perennial graminoids (τ_b=−0.46, *p*=2.3×10^{-4}), a negative correlation

Table 3. Summary of functional group diversity and species richness for each site in the Grand Canyon area, northern Arizona.

[Site codes correspond to sampled sites as follows: LRT, Little Robinson Tank; EZ2, EZ2 breccia-pipe uranium deposit; PP, Pinyon Plain Mine; PN, Pinenut Mine; and AZ1, Arizona 1 Mine. The LRT site has no mineral deposits; the four other sites contain breccia-pipe mineral deposits and are shown in order of increasing mine development phase. “Number of species (total)” includes all species observed during both site inventories and line-point intercept (LPI) data collection combined, and “number of species (LPI)” indicates number of species noted only during LPI sampling. Relative percent cover of functional groups and non-native species cover were calculated for each site from plot averages weighted by plot area using LPI data. Relative cover for each functional group is calculated by dividing the group’s cover by the sum of all group’s cover values; the resulting set of relative cover values sums to 100 percent (%) (any overage in the table is due to rounding inadequacies). Relative cover calculations do not include non-native species cover, which can fall into different functional groups categories.]

Site code	Number of species (total)	Number of species (LPI)	Relative percent cover of functional groups					Non-native species cover (%)
			Trees	Shrubs and sub-shrubs	Perennial grasses	Perennial forbs	Annuals	
LRT	42	18	2.1	32.4	61.7	1.0	2.9	2.7
EZ2	45	24	0.0	25.1	54.8	12.1	8.0	7.7
PP	117	39	32.5	13.9	49.4	4.0	0.2	0.3
PN	56	25	10.8	61.2	25.8	1.8	0.5	0.2
AZ1	49	22	4.7	58.8	35.2	1.0	0.3	0.3

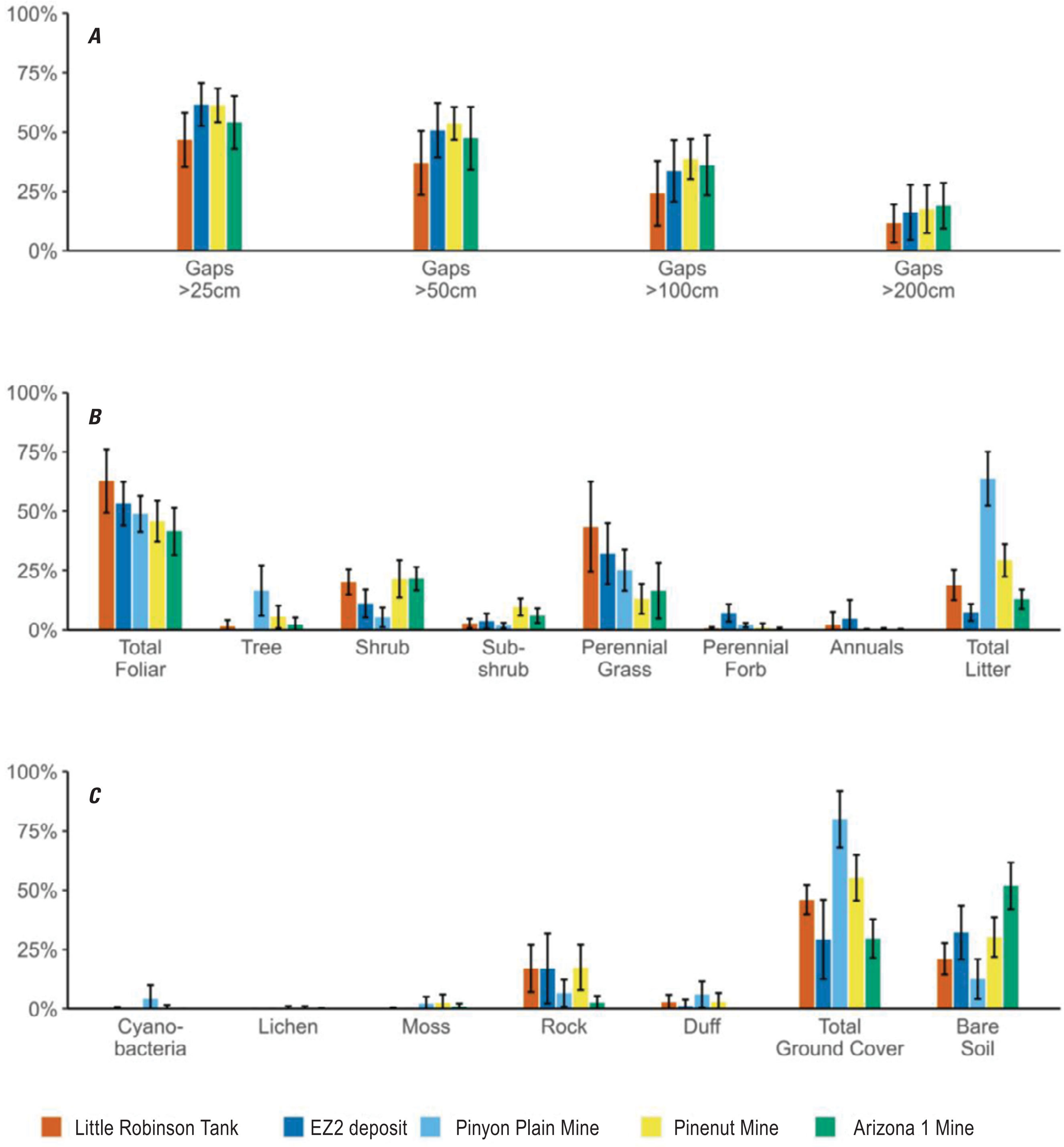

Figure 3. Results of line-point intercept and canopy-gap intercept sampling at five sites in the Grand Canyon region, northern Arizona, consisting of four mines at various stages of mine development and one reference area (Little Robinson Tank). Panels show: *A*, mean percent cover (%) of perennial gaps (space between perennial vegetation) within four size classes; *B*, mean percent cover of plant functional groups; and *C*, mean percent cover for ground surface types. Error bars represent standard deviation. Site-level means and standard deviations were weighted by plot area. Gap data were not collected at Pinyon Plain Mine. >, greater than; cm, centimeter.

between subshrubs and perennial forbs (τ_b=−0.26, p=0.048), and a positive correlation between perennial graminoids and perennial forbs (τ_b=0.26, p=0.05). At the ground surface, the two composite metrics, bare soil and total ground cover, are negatively correlated (τ_b=−0.77, $p=9.6\times10^{-13}$; table 2.1), as would be expected given their representation of protected versus unprotected ground surfaces. Bare soil is negatively correlated with rock cover (τ_b=−0.34, p=0.01), total litter (τ_b=−0.65, $p=2.4\times10^{-8}$), cyanobacteria (τ_b=−0.30, p=0.02), and duff (τ_b=−0.50, $p=5.6\times10^{-5}$). Other statistically significant correlations in ground surface types include a positive correlation between biological soil components (lichen, cyanobacteria, and moss), and a positive correlation between total litter and cyanobacteria, moss, and duff (refer to table 2.1). Some correlations are also present between the vegetation and ground surface type metrics (app. 2, table 2.1). In particular, tree cover is highly correlated with total litter (τ_b=0.73, $p=5.8\times10^{-11}$), duff (τ_b=0.72, $p=1.1\times10^{-10}$), and total ground cover (τ_b=0.70, $p=6.7\times10^{-10}$), moderately correlated with cyanobacteria, lichen, and negatively correlated with bare soil. Conversely, shrubs are moderately negatively correlated with total litter, cyanobacteria, duff, and total ground cover, and positively correlated with bare soil. Other statistically significant relationships include strong negative correlations between bare soil and total foliar cover (τ_b=−0.60, $p=4.8\times10^{-7}$) and bare soil and perennial graminoid cover (τ_b=−0.52, $p=2.9\times10^{-5}$), a moderate positive correlation between bare soil and subshrub cover, and a moderate negative correlation between total ground cover and annual species.

Site-Level Vegetation Summaries

Little Robinson Tank (Reference Site)

The plant community at the Little Robinson Tank site is primarily composed of perennial grasses and woody species, particularly shrubs and sub-shrubs (table 3, fig. 3*B*). This site also had the highest mean total foliar cover (fig. 3*B*). The dominant species (table 1.1) include blue grama (39.6 percent mean cover) and big sagebrush (17.8 percent mean cover), with a minor component of *Gutierrezia sarothrae* (Pursh) Britton & Rusby (broom snakeweed; 2.7 percent mean cover), *Sporobolus airoides* (Torr.) Torr. (alkali sacaton; 2.4 percent mean cover), *Mahonia fremontii* (Torr.) Fedde (Fremont's mahonia; 1.3 percent mean cover), and *Chrysothamnus greenei* (A. Gray) Greene (Greene's rabbitbrush; 1.2 percent mean cover). Non-native species have greater cover at Little Robinson Tank than three of the four other sites (table 3) due to prickly Russian thistle (1.8 percent mean cover; see table 1.1). The site is mapped within a single soil map unit and ecological site, the Limestone/Sandstone Upland (R035XC319AZ; table 1), and the species distribution observed at this site are representative of that in the historic climax plant community (NRCS, 2023a). There is some within-site variation in the plant community composition following local topography. To the east, the water tank abuts the slope of a Utah juniper-covered structural bench, to the west, a mixed grass-shrub community, and a shallow ephemeral drainage runs roughly north to south through the center of the site (fig. 2).

EZ2 Breccia-Pipe Uranium Deposit (Undeveloped Mine Site with Underlying Ore Deposit)

The vegetation community at the EZ2 deposit site is primarily composed of perennial grasses and woody species, particularly shrubs and sub-shrubs (table 3, fig. 3*B*), although 12.1 percent of relative vegetative cover is due to perennial forbs and 7.7 percent due to a non-native annual, prickly Russian thistle, which has higher cover here than at any other site (4.6 percent; table 1.2). Dominant grasses included galleta grass (21.3 percent mean cover), alkali sacaton (4.9 percent mean cover), black grama (2.9 percent mean cover), and *Aristida purpurea* Nutt. (purple threeawn; 2.2 percent mean cover). The most abundant woody species are Greene's rabbitbrush and winterfat, with 6.1 percent and 3.2 percent mean cover, respectively (table 1.2). This site has higher cover of perennial forbs than any other, of which small-leaved globemallow (5.7 percent mean cover) and *Chaetopappa ericoides* (Torr.) G.L. Nesom (rose heath; 1.0 percent mean cover) are the most common. The site spans two soil map units and ecological sites (table 1, fig. 2), and without further investigation into the soil substrate, it is difficult to determine which ecological site the vegetation community at the EZ2 deposit site most resembles. However, the prevalence of galleta grass, purple threeawn, and winterfat, plus a scarcity of Indian ricegrass, resembles the Historic Climax Plant Community of the Clay Loam Upland (R035XD421AZ) more so than the Shallow Loamy (R035XD415AZ) ecological site (table 1; NRCS, 2023a).

Pinyon Plain Mine (Pre-Mining Site)

The Pinyon Plain Mine site is in a higher elevation, forested plant community, with greater cover of trees compared to the other sites (table 3, fig. 3*B*). Although perennial forb cover at Pinyon Plain Mine is less than at the EZ2 deposit site, the Pinyon Plain Mine site has more than double the number of plant species noted at the other sites, as well as particularly high forb diversity—75 total forb species were identified (table 1.3). Blue grama has the highest cover among any individual species (19.0 percent mean cover), followed by woody species, including ponderosa pine, twoneedle pinyon, rubber rabbitbrush, and Utah juniper (at 8.7, 6.9, 3.0, and 2.0 percent mean cover respectively). Soil and ecological site mapping has not occurred in the area where the Pinyon Plain Mine was developed, but this site contains species (including twoneedle pinyon and Utah juniper) representative of a lower elevation ponderosa pine vegetation zone in Arizona (Nichol, 1937).

Pinenut Mine (Active Mine Site)

The vegetation community surrounding the Pinenut Mine is primarily composed of woody plants (72.0 percent relative cover; table 3, fig. 3*B*), especially big sagebrush (20.1 percent mean cover), snakeweed (9.6 percent mean cover), and Utah juniper (4.8 percent mean cover; see table 1.4). Cover of non-woody functional groups is relatively low, especially among perennial grasses; blue grama (5.8 percent mean cover) and *Sporobolus airoides* (Torr.) Torr. (alkali sacaton; 2.8 percent mean cover) are the most common (table 1.4). Among the northern sites, Pinenut Mine site has the highest amount of total litter and total ground cover (fig. 3*B*, and *C*). The Pinenut Mine site falls within the Limestone/Sandstone Upland (R035XC319AZ; table 1). The woody-species dominated distribution at the Pinenut Mine site is more characteristic of either the woody plant community phase of the Reference State, or the Dense Sagebrush State (NRCS, 2023a).

Arizona 1 Mine (Post-Production Mine Site)

Woody plants are the dominant functional group at the Arizona 1 Mine site (table 3, fig. 3*B*), with big sagebrush (19.4 percent mean cover) and snakeweed (6.0 percent mean cover) the most common; minor species include Utah juniper (2.2 percent mean cover) and Greene's rabbitbrush (2.2 percent mean cover; see table 1.5). Grasses include blue grama (12.6 percent mean cover) and alkali sacaton (1.5 percent mean cover). Two soils and associated ecological sites are mapped at the Arizona 1 Mine site (fig. 2). The majority of the site is associated with the Limestone/Sandstone Upland ecological site (R035XC319AZ; table 1), and the species distribution measured at this location is representative of the woody plant community phase of the Reference State (NRCS, 2023a). The eastern portion of the site is mapped as a Clay Loam Upland ecological site (R035XC307AZ; fig. 2, table 1). Plots on the east side exhibit higher cover of blue

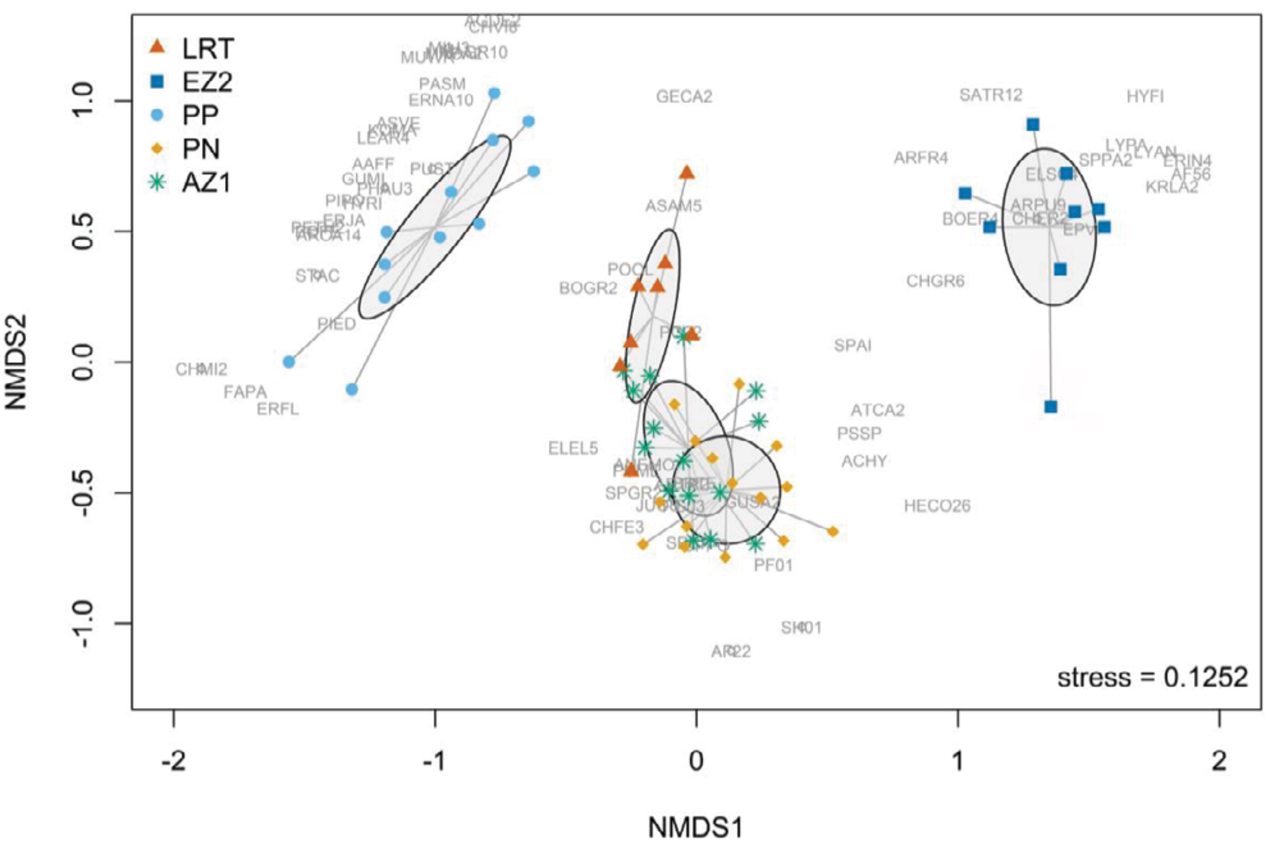

Figure 4. Results of ordination using non-metric multidimensional scaling (NMDS) of plant species composition for five study sites, Grand Canyon area, northern Arizona. The Little Robinson Tank (LRT) site has no mineral deposits; the four other sites contain breccia-pipe mineral deposits in varying stages of mining development. The deposits include the EZ2 breccia-pipe uranium deposit (EZ2), Pinyon Plain Mine (PP), Pinenut Mine (PN), and Arizona 1 Mine (AZ1). Point color and shape indicate the site at which plot observations were made. Gray symbol codes indicate species observed across the sites (codes from U.S. Department of Agriculture PLANTS database, accessed September 29, 2023, at https://plants.usda.gov); species' corresponding common and Latin names can be found in appendix 1 of this publication. The NMDS shows ordination distance plot-level mean vegetation cover as calculated from a dissimilarity matrix; axes depict that distance and do not represent data values.

grama than those in the west (data not shown here but are available in the data release that accompanies this report; Mann and Duniway, 2020).

Nonmetric Multidimensional Scaling Analysis of Plant Community Composition

Species composition is significantly different across sites (NMDS stress of 0.1252, fig. 4). The vegetation communities at the Pinyon Plain Mine and EZ2 deposit sites show the greatest divergence. Post hoc pairwise site comparisons show that all sites significantly differ from one another in plant community composition (p<0.005), even between the two most similar sites, the Arizona 1 Mine and the Pinenut Mine ($F_{1,29}$=3.3173, p=0.0004). The Arizona 1 Mine site has lower abundance of woody plants and higher perennial grass when compared to the Pinenut Mine site. Both the Arizona 1 Mine and Pinenut Mine sites differ from the Little Robinson Tank site (the next most similar site) in their predominance of shrubs over perennial grasses.

Discussion

Our primary goal through this work was to characterize the vegetation communities at four sites (EZ2 deposit, Arizona 1 Mine, Pinenut Mine, and Pinyon Plain Mine) that are in various stages of uranium mining development and at one site with no mineral deposits (Little Robinson Tank). At the mine sites, we characterized the vegetation surrounding the active mine area (all vegetation was removed from within the mine areas). We did this by collecting data using the line-point intercept and canopy-gap intercept methods and carrying out species inventories at all sites. All data are available in the USGS data release that accompanies this report (Mann and Duniway, 2020), and species-level data for each site are summarized in appendix 1. The five sites differed in their vegetation composition according to our ordination analysis. Although we did not observe relationships between species richness, cover of ground surface types, or gap distribution and mining history, there did appear to be a slight trend where perennial grass cover and total foliar cover decreased with the level of development the mine had undergone. However, given our lack of replication of mining sites within phases of development and important differences in topographic, soil, and climate setting among the sites, it is not possible to attribute any cover patterns to mining history based on the results of this study.

Second, we compared the results of our vegetation community surveys to the expected plant community conditions that are depicted in the NRCS ecological site descriptions (NRCS, 2023a). We found that species abundance at the five sites were indeed characteristic of the ecological sites in which they occur. Any variation in plant communities between and within sites may be associated with typical underlying gradations in soil, topography, and climate.

The Pinyon Plain Mine site is the only site in a forested ecosystem. The species present at that site represent a potential transition zone between two regionally common ecoregions, a high-elevation ponderosa pine plant community (dominated by pine, oak, and a rich forb component), and a lower-elevation pinyon-juniper community (dominated by Utah junipers, twoneedle pinyon, Fremont’s barberry, grama grasses) (Nichol, 1937; McClaran and Brady, 1994). It has high plant diversity with a particularly high number of forbs, and exhibits several indicators of a stable ecological site, including low abundance of exotic species, high plant litter cover, high total ground cover, and low cover of bare ground.

The three sites in close proximity to one another (Little Robinson Tank, Pinenut Mine, and Arizona 1 Mine) have several dominant species in common (blue grama, alkali sacaton, big sagebrush, snakeweed, Utah juniper), but these species differ in their relative abundance across sites. Most notably, the Pinenut Mine and Arizona 1 Mine sites are woody-plant dominated, and the Little Robinson Tank site is perennial grass-dominated. Both grass- and woody-dominated communities are recognized phases within the reference state of the Limestone/Sandstone Upland ecological site (NRCS, 2023a) and can occur naturally due to underlying edaphic or climatic drivers (Lauenroth and others, 1994), although if woody species are especially abundant, it may indicate a historical shift due to disturbance such as improper grazing or lack of fire (Milchunas and others, 1989; NRCS, 2023a). Although not tested for statistical significance, the vegetation community surrounding the Arizona 1 Mine exhibits lower total foliar cover, lower litter cover, and higher bare soil cover compared to all other sites, whereas the Little Robinson Tank site has higher total foliar cover, lower cover of bare soil, and fewer large perennial canopy gaps than the Pinenut Mine and Arizona 1 Mine sites. The Little Robinson Tank site also had higher cover of non-native species than the Pinenut Mine and Arizona 1 Mine sites, potentially a result of more frequent vehicular visits by ranchers, managers, or recreationists to the livestock tank, potential vectors for non-native ruderal species.

The final and most northern site, the EZ2 deposit, occurs in a drier precipitation zone (178–279 mm [7–11 in.]), where *Atriplex* species and galleta grass are more common than the sagebrush and blue grama, as seen at the other northern sites (NRCS, 2023a). Weedy annual species, particularly prickly Russian thistle, have higher cover at this site. Annual species have the potential to increase in abundance in response to human disturbances such as mine development (Gelbard and Belnap, 2003) and their annually senesced tissues have the potential to spread off site as part of their seed dispersal mechanisms (Stallings and others, 1995). We also observed relatively high total foliar and perennial grass cover at the EZ2 deposit site, and bare soil cover there is moderate compared to the other surveyed sites.

These data and observations may provide baseline information for tracking changes in plant species abundance and composition through time at the selected locations and may also be informative for current management of the rangeland surrounding the mines. For instance, the data collected (including total ground cover, bare soil cover, perennial grass cover, perennial forb cover, and cover of perennial gap size classes) can provide information about how resilient and resistant plant communities in arid climates may change (Pyke and others, 2002; Herrick and others 2006). These qualities are indicative of site stability and are important to consider in light of mining-related disturbances. For instance, sites with greater total ground cover are arguably more resistant to wind- and water-driven soil erosion, whereas sites with a high percentage of bare soil and longer or more frequent canopy gaps are more susceptible to erosion (Wolfe and Nickling, 1993; Rietkerk and van de Koppel, 1997; Zuazo and Pleguezuelo, 2009; Webb and others, 2014). Susceptibility or resistance to erosion can affect transfer of chemical constituents (if present), due to sediment movement via aeolian or hydrological processes (Hinck and others, 2014).

Another application of this vegetation survey may be for informing reclamation strategies. Plant species can have specific traditional and cultural uses to many tribes in the region that could also be considered during reclamation discussions (Tilousi and Hinck, 2024). Development of mineral resources on Federally-owned public lands includes a bonded lease agreement requiring the operator to reclaim disturbed areas upon closure of the mine (Surface Mining Control and Reclamation Act of 1977, Public Law 95–85, 91 Stat. 445). However, successful revegetation of mines and other highly disturbed lands remains difficult in arid environments and may be prone to failure (Nauman and others, 2017). Oldfield and Olwell (2015) suggest that one tactic to increase chances of successful plant establishment in harsh environments is to use seed mixes that are comparable to the historic native vegetation of the site. Ecological site descriptions (NRCS, 2023a) can guide species selection, but species surveys such as those conducted in this work can be beneficial for refining seed mixes to match the specific species occurrence and abundance that naturally occur at the site. We observed several native species during our surveys that are commonly available from commercial vendors, which can be useful in restoration contexts, including Indian ricegrass, *Atriplex* species, rabbitbrush, *Sporobolus* species, and bottlebrush squirreltail (Winkler and others, 2018). Furthermore, the biological soil crust cover that we observed surrounding these mines could be considered as a reclamation strategy given its ability to facilitate soil stabilization, nutrient retention, and water infiltration (Belnap and Büdel, 2016). Some annual non-native species are present at all sites, and they may increase in response to soil disturbance (Knapp, 1996; Bradford and Lauenroth, 2006). Weed control may therefore be another measure to consider for improving the establishment of native plants on regraded and reclaimed mines (Monsen, 1994; Rafferty and Young, 2002; Huddleston and Young, 2005).

Summary

This work presents the first comprehensive vegetation surveys conducted across several uranium mines in the Grand Canyon region in northern Arizona, plus a comparable reference area that had no mineral deposits. This baseline dataset may be useful for assessing future change in plant communities or may be used to evaluate the risk for off-site transfer of mining-related radionuclides by considering key traits (palatability, bioaccumulation potential, dispersal strategies) of the plant species observed in the survey, and indicators of site resistance to erosion (perennial canopy gaps, bare soil cover). Finally, the data describing the species and functional groups found on the surface of the mined areas in the Grand Canyon region in northern Arizona could help support eventual reclamation efforts, such as by informing reclamation benchmarks or by identifying site-appropriate species for revegetation.

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Appendix 1. Plant Species Occurrence and Cover Within Plots of All Study Sites, Grand Canyon Area, Northern Arizona

Tables 1.1–1.5 list all species observed at each of the five study sites, four of which (the EZ2 breccia-pipe uranium deposit, Pinyon Plain Mine, Pinenut Mine, and Arizona 1 Mine) are active mines in the Grand Canyon region and one (Little Robinson Tank) that is a reference area with surface disturbance but no mineral ore deposits. Species observed during both line-point intercept (LPI) monitoring and a per-plot species inventory are included, and plots in which the species were observed, regardless of method, are indicated with an “x.” The LPI data were collected during the peak summer season, in July 2013 at the Pinyon Plain Mine site, July 2015 at the Pinenut Mine site, and August 2015 at the Arizona 1 Mine, EZ2 breccia-pipe uranium deposit, and Little Robinson Tank sites.

The tables include for each species: a common name, scientific name, duration (annual [A], perennial [P], or annual or perennial [A/P]), nativity to the State of Arizona (native [N] or exotic [E]), and a growth form (tree, shrub, sub-shrub, succulent, graminoid, or forb). All plant attributes were derived from the U.S. Department of Agriculture’s Plant List of Attributes, Names, Taxonomy, and Symbols (PLANTS) database (https://plants.usda.gov, accessed October 16, 2023). When possible, species listed as either annual or perennial (A/P) in the PLANTS database that were observed in the LPI data were assigned a single duration based on how the species exhibited at the time of field monitoring. A value for weighted percent cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted plot level cover. Refer to the “Methods” section of this report for detailed descriptions of methodologies used to generate data.

Some species were observed that the field team were unable to identify. These are shown in the table with “Unknown” as the common name. They are assigned an alphanumeric plant code and functional group classifications (duration, nativity, growth form). All data are available in the USGS data release that accompanies this report (Mann and Duniway, 2020).

Table 1.1. Vegetation cover and composition at the Little Robinson Tank study site.

[The Little Robinson tank study site (site code LRT) is approximately 6 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. At the time of vegetation sampling, it contained a 1.01-hectare reservoir used by livestock and wildlife as a water source. It was selected as a reference site to compare to the uranium mines in the study because it has no ore deposits but did have a degree of disturbance (including surface trampling and construction of an earthen dam) comparable to that created during initial mining development. Data were collected at the LRT site from August 26–27, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the “Field Sampling” section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name “Unknown” and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the “Data Summarization and Analysis” section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot							
						A	B	C	D	OA	OB	OC	OD
			Forbs										
slim amaranth	*Amaranthus hybridus* L.	AMHY	A	N	n/a	x	–	x	–	–	–	–	–
skeletonleaf bur ragweed	*Ambrosia tomentosa* Nutt.	AMTO3	P	N	n/a	–	x	x	x	–	–	–	–
Crescent milkvetch	*Astragalus amphioxys* A. Gray	ASAM5	P	N	0.3	x	x	–	x	x	x	–	x
Pincushion	*Chaenactis* DC.	CHAEN	A/P	N	n/a	–	–	x	–	–	–	–	–
rose heath	*Chaetopappa ericoides* (Torr.) G.L. Nesom	CHER2	P	N	0.2	x	–	–	–	x	–	x	–
Fendler's sandmat	*Chamaesyce fendleri* (Torr. & A. Gray) Small	CHFE3	P	N	0.2	–	x	–	–	x	x	x	–
Lambsquarters	*Chenopodium album* L.	CHAL7	A	E	n/a	–	–	–	–	–	x	–	–
Fremont’s goosefoot	*Chenopodium fremontii* S. Watson	CHFR3	A	N	n/a	–	–	x	x	–	–	–	–
hairy desertsunflower	*Geraea canescens* Torr. & A. Gray	GECA2	A	N	0.1	–	x	x	x	x	–	–	–
Groundcherry	*Physalis* L.	PHYSA	A/P	N	n/a	x	x	x	x	x	x	x	x
little hogweed	*Portulaca oleracea* L.	POOL	A	E	0.1	x	–	x	x	–	–	x	–
Horehound	*Marrubium vulgare* L.	MAVU	P	E	n/a	–	x	x	x	–	–	–	–
greenstem paperflower	*Psilostrophe sparsiflora* (A. Gray) A. Nelson	PSSP	P	N	n/a	–	–	–	–	–	x	x	–
prickly Russian thistle	*Salsola tragus* L.	SATR12	A	E	1.8	x	x	x	x	x	–	x	x
smallflower globemallow	*Sphaeralcea parvifolia* A. Nelson	SPPA2	P	N	0.1	x	x	x	x	x	x	x	x
bigbract verbena	*Verbena bracteata* Cav. ex Lag. & Rodr.	VEBR	A/P	N	n/a	–	–	–	x	–	–	–	–
rough cocklebur	*Xanthium strumarium* L.	XAST	A	N	n/a	–	–	x	x	–	–	–	–

Table 1.1. Vegetation cover and composition at the Little Robinson Tank study site.—Continued

[The Little Robinson tank study site (site code LRT) is approximately 6 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. At the time of vegetation sampling, it contained a 1.01-hectare reservoir used by livestock and wildlife as a water source. It was selected as a reference site to compare to the uranium mines in the study because it has no ore deposits but did have a degree of disturbance (including surface trampling and construction of an earthen dam) comparable to that created during initial mining development. Data were collected at the LRT site from August 26–27, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the “Field Sampling” section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name “Unknown” and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the “Data Summarization and Analysis” section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot							
						A	B	C	D	0A	0B	0C	0D
Graminoids													
Indian ricegrass	*Achnatherum hymenoides* (Roem. & Schult.) Barkworth	ACHY	P	N	0.1	–	–	x	–	–	–	–	–
purple threeawn	*Aristida purpurea* Nutt.	ARPU9	P	N	n/a	x	–	–	x	–	x	x	x
sideoats grama	*Bouteloua curtipendula* (Michx.) Torr.	BOCU	P	N	n/a	–	x	–	–	–	–	x	–
black grama	*Bouteloua eriopoda* (Torr.) Torr.	BOER4	P	N	1.0	x	x	–	–	x	–	x	x
blue grama	*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths	BOGR2	P	N	39.6	x	x	x	x	x	x	x	x
false buffalograss	*Munroa squarrosa* (Nutt.) Torr.	MUSQ3	A	N	n/a	x	x	–	–	–	–	–	–
vine mesquite	*Panicum obtusum* Kunth	PAOB	P	N	n/a	–	–	x	–	–	–	–	–
James’ galleta	*Pleuraphis jamesii* Torr.	PLJA	P	N	0.9	x	x	–	x	x	x	x	x
alkali sacaton	*Sporobolus airoides* (Torr.) Torr.	SPAI	P	N	2.4	x	x	–	x	x	x	x	x
sand dropseed	*Sporobolus cryptandrus* (Torr.) A. Gray	SPCR	P	N	n/a	–	x	–	x	x	–	–	–
Shrubs													
big sagebrush	*Artemisia tridentata* Nutt.	ARTR2	P	N	17.8	x	x	x	x	x	x	x	x
fourwing saltbush	*Atriplex canescens* (Pursh) Nutt.	ATCA2	P	N	n/a	x	x	–	–	–	–	–	–
Greene’s rabbitbrush	*Chrysothamnus greenei* (A. Gray) Greene	CHGR6	P	N	1.2	x	–	x	–	x	–	x	x
Fremont's mahonia	*Mahonia fremontii* (Torr.) Fedde	MAFR3	P	N	1.3	x	x	x	x	x	x	x	x
Mexican cliffrose	*Purshia mexicana* (D. Don) Henrickson	PUME	P	N	0.2	–	–	–	–	–	x	–	–
Sub-shrubs													
pineneedle milkweed	*Asclepias linaria* Cav.	ASLI6	P	N	n/a	–	–	x	x	–	–	–	–
broom snakeweed	*Gutierrezia sarothrae* (Pursh) Britton & Rusby	GUSA2	P	N	2.7	x	x	x	x	x	x	x	x
Colorado four o’clock	*Mirabilis multiflora* (Torr.) A. Gray	MIMU	P	N	n/a	x	x	–	–	–	x	x	x

Table 1.1. Vegetation cover and composition at the Little Robinson Tank study site.—Continued

[The Little Robinson tank study site (site code LRT) is approximately 6 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. At the time of vegetation sampling, it contained a 1.01-hectare reservoir used by livestock and wildlife as a water source. It was selected as a reference site to compare to the uranium mines in the study because it has no ore deposits but did have a degree of disturbance (including surface trampling and construction of an earthen dam) comparable to that created during initial mining development. Data were collected at the LRT site from August 26–27, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the "Field Sampling" section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name "Unknown" and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the "Data Summarization and Analysis" section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot							
						A	B	C	D	OA	OB	OC	OD
			Succulents										
Cholla	*Cylindropuntia* (Engelm.) Kreuzinger	CYLIN2	P	N	n/a	–	–	–	–	x	x	–	–
plains pricklypear	*Opuntia polyacantha* Haw.	OPPO	P	N	n/a	x	–	–	x	x	x	–	–
white fishhook cactus	*Echinomastus intertextus* (Engelm.) Britton & Rose	ECIN2	P	N	n/a	–	–	–	–	–	–	–	x
longspine fishhook cactus	*Sclerocactus parviflorus* Clover & Jotter	SCPA9	P	N	n/a	–	x	–	–	–	–	–	–
			Trees										
Utah juniper	*Juniperus osteopsperma* (Torr.) Little	JUOS	P	N	1.5	x	x	x	–	x	x	x	–
twoneedle pinyon	*Pinus edulis* Engelm.	PIED	P	N	n/a	–	–	–	–	–	x	x	–

Table 1.2. Vegetation cover and composition at the EZ2 breccia-pipe uranium deposit study site.

[The EZ2 breccia-pipe uranium deposit study site (site code EZ2) is approximately 15 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. This site was permitted for uranium mining but remained an undeveloped breccia pipe with no surface disturbance at the time of vegetation sampling. Data were collected at the EZ2 site from August 25–27, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the "Field Sampling" section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name "Unknown" and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the "Data Summarization and Analysis" section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot								
						A	B	C	D	E	OA	OB	OC	OD
				Forbs										
skeletonleaf bur ragweed	*Ambrosia tomentosa* Nutt.	AMTO3	P	N	n/a	–	–	x	–	–	–	–	–	x
anemone	*Anemone* L.	ANEMO	P	N	n/a	–	–	–	–	–	–	–	–	x
Crescent milkvetch	*Astragalus amphioxys* A. Gray	ASAM5	P	N	n/a	x	x	x	x	–	–	x	x	x
Torrey's milkvetch	*Astragalus calycosus*	ASCA9	P	N	n/a	–	x	–	–	–	–	x	–	x
rose heath	*Chaetopappa ericoides* (Torr.) G.L. Nesom	CHER2	P	N	1.0	x	x	x	x	x	x	x	x	x
Fendler's sandmat	*Chamaesyce fendleri* (Torr. & A. Gray) Small	CHFE3	P	N	n/a	x	x	–	–	–	–	–	–	–
desert trumpet	*Eriogonum inflatum* Torr. & Frém.	ERIN4	P	N	0.2	–	x	–	–	x	x	x	–	–
buckwheat	*Eriogonum* Michx.	ERIOG	A/P	N	n/a	–	–	–	–	x	–	–	–	x
fineleaf hymenopappus	*Hymenopappus filifolius* Hook.	HYFI	P	N	0.2	x	x	x	x	x	x	x	–	x
foothill deervetch	*Lotus humistratus* Greene	LOHU2	A	N	n/a	–	–	–	–	–	–	–	–	x
tanseyleaf tansyaster	*Machaeranthera tanacetifolia* (Kunth) Nees	MATA2	A	N	n/a	–	–	–	–	–	–	–	x	–
pinkladies	*Oenothera speciosa* Nutt.	OESP2	P	N	n/a	–	–	–	–	–	–	–	x	–
greenstem paperflower	*Psilostrophe sparsiflora* (A. Gray) A. Nelson	PSSP	P	N	0.2	–	x	x	x	–	x	–	–	x
prickly Russian thistle	*Salsola tragus* L.	SATR12	A	E	4.6	x	x	x	x	x	x	x	x	x
threadleaf ragwort	*Senecio flaccidus* Less.	SEFL3	P	N	n/a	–	–	–	–	–	–	x	x	–
smallflower globemallow	*Sphaeralcea parvifolia* A. Nelson	SPPA2	P	N	5.7	x	x	x	x	x	x	x	x	x
Unknown	n/a	(AF56)	A	N	0.1	–	x	–	–	–	–	–	–	–

Table 1.2. Vegetation cover and composition at the EZ2 breccia-pipe uranium deposit study site.—Continued

[The EZ2 breccia-pipe uranium deposit study site (site code EZ2) is approximately 15 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. This site was permitted for uranium mining but remained an undeveloped breccia pipe with no surface disturbance at the time of vegetation sampling. Data were collected at the EZ2 site from August 25–27, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the "Field Sampling" section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name "Unknown" and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the "Data Summarization and Analysis" section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot								
						A	B	C	D	E	OA	OB	OC	OD
			Graminoids											
Indian ricegrass	*Achnatherum hymenoides* (Roem. & Schult.) Barkworth	ACHY	P	N	0.6	x	x	x	x	x	x	x	x	x
purple threeawn	*Aristida purpurea* Nutt.	ARPU9	P	N	2.2	x	x	x	x	x	x	x	x	x
black grama	*Bouteloua eriopoda* (Torr.) Torr.	BOER4	P	N	2.9	x	x	x	x	–	–	x	–	x
blue grama	*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths	BOGR2	P	N	0.8	x	–	–	–	–	x	–	x	x
squirreltail	*Elymus elymoides* (Raf.) Swezey	ELEL5	P	N	n/a	x	x	x	–	–	–	–	x	–
spreading wheatgrass	*Elymus scribneri*	ELSC4	P	N	0.3	–	–	–	–	–	–	–	x	–
needle and thread	*Hesperostipa comata* (Trin. & Rupr.) Barkworth	HECO26	P	N	0.1	x	–	–	x	x	x	x	–	x
ear muhly	*Muhlenbergia arenacea* (Buckley) Hitchc.	MUAR	P	N	n/a	–	–	–	–	–	–	–	x	–
false buffalograss	*Munroa squarrosa* (Nutt.) Torr.	MUSQ3	A	N	n/a	–	–	–	–	–	–	x	–	–
James' galleta	*Pleuraphis jamesii* Torr.	PLJA	P	N	21.3	x	x	x	x	x	x	x	x	x
alkali sacaton	*Sporobolus airoides* (Torr.) Torr.	SPAI	P	N	4.9	x	x	x	x	–	x	x	x	x
sand dropseed	*Sporobolus cryptandrus* (Torr.) A. Gray	SPCR	P	N	n/a	–	–	–	x	–	–	–	x	–
			Shrubs											
big sagebrush	*Artemisia tridentata* Nutt.	ARTR2	P	N	0.2	–	–	–	–	–	–	–	–	x
fourwing saltbush	*Atriplex canescens* (Pursh) Nutt.	ATCA2	P	N	0.6	x	x	x	x	x	x	x	x	x
Greene's rabbitbrush	*Chrysothamnus greenei* (A. Gray) Greene	CHGR6	P	N	6.1	x	x	x	x	x	x	x	x	x
mormon tea	*Ephedra viridis* Coville	EPVI	P	N	0.5	x	x	x	x	x	x	x	–	x
winterfat	*Krascheninnikovia lanata* (Pursh) A. Meeuse & Smit	KRLA2	P	N	3.2	x	x	x	x	x	x	x	x	x

Table 1.2. Vegetation cover and composition at the EZ2 breccia-pipe uranium deposit study site.—Continued

[The EZ2 breccia-pipe uranium deposit study site (site code EZ2) is approximately 15 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. This site was permitted for uranium mining but remained an undeveloped breccia pipe with no surface disturbance at the time of vegetation sampling. Data were collected at the EZ2 site from August 25–27, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the "Field Sampling" section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name "Unknown" and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the "Data Summarization and Analysis" section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot								
						A	B	C	D	E	OA	OB	OC	OD
Shrubs—Continued														
water jacket	*Lycium andersonii* A. Gray	LYAN	P	N	0.2	x	–	–	–	x	x	–	–	x
pale desert-thorn	*Lycium pallidum* Miers	LYPA	P	N	0.6	x	x	x	x	x	x	x	x	x
Fremont's mahonia	*Mahonia fremontii* (Torr.) Fedde	MAFR3	P	N	n/a	x	–	–	–	x	–	–	–	–
yucca	*Yucca* L.	YUCCA	P	N	n/a	x	–	–	–	–	–	–	–	–
Sub-shrubs														
prairie sagewort	*Artemisia frigida* Willd.	ARFR4	P	N	1.2	x	x	x	x	x	x	x	x	x
broom snakeweed	*Gutierrezia sarothrae* (Pursh) Britton & Rusby	GUSA2	P	N	2.5	–	–	x	x	x	x	x	x	x
Succulents														
cholla	*Cylindropuntia* (Engelm.) Kreuzinger	CYLIN2	P	N	n/a	–	x	x	x	–	–	x	–	x
plains pricklypear	*Opuntia polyacantha* Haw.	OPPO	P	N	n/a	x	x	x	x	x	x	x	x	x
white fishhook cactus	*Echinomastus intertextus* (Engelm.) Britton & Rose	ECIN2	P	N	n/a	–	–	–	–	–	–	–	–	x
longspine fishhook cactus	*Sclerocactus parviflorus* Clover & Jotter	SCPA9	P	N	n/a	x	–	–	x	–	–	x	–	–

Table 1.3. Vegetation cover and composition at the Pinyon Plain Mine study site.

[The Pinyon Plain Mine (formerly known as the Canyon Mine) study site (site code PP) is approximately 5.5 miles south of Tusayan (11 miles south of Grand Canyon National Park) in northwestern Arizona. This site was permitted for uranium mining and in the pre-mining phase (developed but with no uranium ore production) at the time of the vegetation surveys. Data were collected at the PP site from July 23–26, 2013 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the “Field Sampling” section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name “Unknown” and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the “Data Summarization and Analysis” section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot											
						A1	A2	A3	A4	A5	A6	B1.2	B3.4	B5.6	B7.8	B9.10	B11.12
				Forbs													
pussytoes	*Antennaria* Gaertn.	ANTEN	P	N	n/a	–	–	–	–	–	–	–	–	–	–	x	–
Eastwood’s sandwort	*Arenaria eastwoodiae* Rydb.	AREA	P	N	n/a	x	–	–	–	–	–	–	–	–	–	–	–
spreading sandwort	*Arenaria lanuginose* (Michx.) Rohrb.	ARLA4	P	N	n/a	–	–	–	–	x	–	–	–	–	–	–	–
Carruth’s sagewort	*Artemisia carruthii* Alph. Wood ex Carruth.	ARCA14	P	N	0.4	x	x	x	x	x	x	x	–	x	x	x	x
tarragon	*Artemisia dracunculus* L.	ARDR4	P	N	<0.1	x	x	–	x	–	–	–	–	x	x	x	x
spider milkweed	*Asclepias asperula* (Decne.) Woodson	ASAS	P	N	n/a	–	–	–	x	x	x	–	–	–	–	x	–
whorled milkweed	*Asclepias verticillata* L.	ASVE	P	N	0.1	x	–	–	–	–	–	–	x	x	–	x	x
Torrey’s milkvetch	*Astragalus calycosus* Torr. ex S. Watson	ASCA9	P	N	n/a	x	–	–	x	x	x	–	–	–	x	x	–
groundcover milkvetch	*Astragalus humistratus* A. Gray	ASHU2	P	P	<0.1	–	–	x	x	x	x	–	x	–	x	x	–
freckled milkvetch	*Astragalus lentiginosus* Douglas ex Hook.	ASLE8	A/P	N	n/a	–	–	–	–	–	–	–	–	–	–	x	–
woolly locoweed	*Astragalus mollissimus*	ASMO	P	N	n/a	–	–	–	–	–	–	–	–	x	x	x	–
Indian paintbrush	*Castilleja* Cerv.	CASTI	P	N	0.1	x	–	x	x	x	x	–	–	x	x	x	x
rose heath	*Chaetopappa ericoides* (Torr.) G.L. Nesom	CHER2	P	N	0.1	x	x	x	x	x	x	x	x	x	x	x	x
Fendler’s sandmat	*Chamaesyce fendleri* (Torr. & A. Gray) Small	CHFE3	P	N	n/a	–	x	x	x	x	x	–	–	–	x	x	x
Wheeler’s thistle	*Cirsium wheeleri* (A. Gray) Petr.	CIWH	P	N	n/a	–	–	–	x	x	–	–	–	–	x	x	–
bastard toadflax	*Comandra umbellata* (L.) Nutt.	COUM	P	N	n/a	–	–	–	–	–	–	x	–	–	–	–	–

Table 1.3. Vegetation cover and composition at the Pinyon Plain Mine study site.—Continued

[The Pinyon Plain Mine (formerly known as the Canyon Mine) study site (site code PP) is approximately 5.5 miles south of Tusayan (11 miles south of Grand Canyon National Park) in northwestern Arizona. This site was permitted for uranium mining and in the pre-mining phase (developed but with no uranium ore production) at the time of the vegetation surveys. Data were collected at the PP site from July 23–26, 2013 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the “Field Sampling” section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name “Unknown” and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the “Data Summarization and Analysis” section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot											
						A1	A2	A3	A4	A5	A6	B1.2	B3.4	B5.6	B7.8	B9.10	B11.12
Forbs—Continued																	
fetid goosefoot	*Dysphania graveolens* (Willd.) Mosyakin & Clemants	DYGR	A	E	0.1	x	x	x	–	–	–	–	–	–	x	–	–
Torrey’s craglily	*Echeandia flavescens* (Schult. & Schult. f.) Cruden	ECFL	P	N	n/a	–	–	–	x	x	x	–	–	–	–	x	–
tall annual willowherb	*Epilobium brachycarpum* C. Presl	EPBR3	A	N	n/a	–	–	–	–	–	–	x	–	–	–	–	–
willowherb	*Epilobium* L.	EPILO	A/P	N	n/a	x	–	–	–	–	–	–	–	–	–	–	–
Navajo fleabane	*Erigeron concinnus* (Hook. & Arn.) Torr. & A. Gray	ERCO27	P	N	n/a	–	x	–	–	–	–	–	–	–	–	–	–
spreading fleabane	*Erigeron divergens* Torr. & A. Gray	ERDI4	B	N	n/a	–	–	–	x	x	x	x	–	–	x	x	x
trailing fleabane	*Erigeron flagellaris* A. Gray	ERFL	P	N	0.1	–	–	x	x	x	x	–	–	–	x	x	x
winged buckwheat	*Eriogonum alatum* Torr.	ERAL4	P	N	n/a	–	x	x	x	–	x	–	–	–	–	–	x
James' buckwheat	*Eriogonum jamesii* Benth.	ERJA	P	N	0.1	x	x	x	x	x	x	–	x	x	x	x	x
redroot buckwheat	*Eriogonum racemosum* Nutt.	ERRA3	P	N	0.1	x	x	x	x	–	–	–	x	x	x	x	–
redstem stork’s bill	*Erodium cicutarium* (L.) L'Hér. ex Aiton	ERCI6	A	E	n/a	–	–	–	–	–	–	x	–	–	–	–	–
dwarf false pennyroyal	*Hedeoma nana* (Torr.) Briq.	HENA	A/P	N	n/a	–	–	–	x	x	x	–	–	–	–	x	x
fineleaf hymenopappus	*Hymenopappus filifolius* Hook.	HYFI	P	N	n/a	x	x	x	x	x	x	–	–	–	x	x	x
pingue rubberweed	*Hymenoxys richardsonii* (Hook.) Cockerell	HYRI	P	N	0.3	x	x	x	x	x	x	x	x	x	x	x	x
manyflowered ipomopsis	*Ipomopsis multiflora* (Nutt.) V.E. Grant	IPMU3	P	N	n/a	–	–	–	x	x	–	–	–	–	–	x	–

Table 1.3. Vegetation cover and composition at the Pinyon Plain Mine study site.—Continued

[The Pinyon Plain Mine (formerly known as the Canyon Mine) study site (site code PP) is approximately 5.5 miles south of Tusayan (11 miles south of Grand Canyon National Park) in northwestern Arizona. This site was permitted for uranium mining and in the pre-mining phase (developed but with no uranium ore production) at the time of the vegetation surveys. Data were collected at the PP site from July 23–26, 2013 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the "Field Sampling" section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name "Unknown" and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the "Data Summarization and Analysis" section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot											
						A1	A2	A3	A4	A5	A6	B1.2	B3.4	B5.6	B7.8	B9.10	B11.12
				Forbs—Continued													
prickly lettuce	*Lactuca serriola* L.	LASE	A	E	n/a	x	–	–	x	x	–	x	–	x	x	x	x
flatspine stickseed	*Lappula occidentalis* (S. Watson) Greene	LAOC3	A	N	n/a	–	–	–	–	–	–	x	–	–	–	–	–
common pepperweed	*Lepidium densiflorum* Schrad.	LEDE	A	N	n/a	x	–	–	–	–	–	x	–	–	–	–	–
Arizona bladderpod	*Lesquerella arizonica* S. Watson	LEAR4	P	N	0.2	x	x	x	x	–	–	–	–	–	–	–	x
bristle flax	*Linum aristatum* Engelm.	LIAR3	A	N	n/a	–	–	x	–	–	x	–	–	–	–	x	–
Lewis flax	*Linum lewisii* Pursh	LILE3	P	N	n/a	x	–	–	–	x	–	–	x	–	–	–	x
Wright's deervetch	*Lotus wrightii* (A. Gray) Greene	LOWR	P	N	n/a	x	x	x	x	x	x	x	–	x	x	x	x
King's lupine	*Lupinus kingii* S. Watson	LUKI	A	N	n/a	x	x	–	x	–	x	–	–	–	x	x	x
hoary tansyaster	*Machaeranthera canescens* (Pursh) A. Gray	MACA2	P	N	0.2	x	x	x	x	–	x	x	–	x	x	x	x
slender goldenweed	*Machaeranthera gracilis* (Nutt.) Shinners	MAGR10	A	N	0.2	x	x	–	–	–	–	–	–	–	–	x	x
sweetclover	*Melilotus officinalis* (L.) Lam.	MEOF	A/P	E	n/a	–	–	–	–	–	–	–	x	x	–	–	–
rough menodora	*Menodora scabra* A. Gray	MESC	P	N	n/a	x	–	–	x	x	x	x	x	–	x	–	–
smooth spreading four o'clock	*Mirabilis oxybaphoides* (A. Gray) A. Gray	MIOX	P	N	n/a	–	x	–	–	–	–	–	–	–	–	–	–
evening primrose	*Oenothera* L.	OENOT	A/P	N	n/a	–	–	–	–	x	–	–	–	–	–	–	–
harlequinbush	*Oenothera hexandra* (Ortega) W.L. Wagner & Hoch	OEHE5	A	N	n/a	–	–	–	–	–	–	–	–	–	x	x	x
purplewhite owl's-clover	*Orthocarpus purpureoalbus* A. Gray ex S. Watson	ORPU2	A	N	n/a	–	–	–	–	–	x	–	–	–	x	–	–
purple locoweed	*Oxytropis lambertii* Pursh	OXLA3	P	N	n/a	x	–	–	–	–	–	–	–	–	–	–	–

Table 1.3. Vegetation cover and composition at the Pinyon Plain Mine study site.—Continued

[The Pinyon Plain Mine (formerly known as the Canyon Mine) study site (site code PP) is approximately 5.5 miles south of Tusayan (11 miles south of Grand Canyon National Park) in northwestern Arizona. This site was permitted for uranium mining and in the pre-mining phase (developed but with no uranium ore production) at the time of the vegetation surveys. Data were collected at the PP site from July 23–26, 2013 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the "Field Sampling" section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name "Unknown" and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the "Data Summarization and Analysis" section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

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Forbs—Continued																	
hoary groundsel	*Packera werneriifolia* (A. Gray) W.A. Weber & Á. Löve	PAWE4	P	N	n/a	–	–	–	–	–	x	–	–	–	–	–	–
longleaf mock thelypody	*Pennellia longifolia* (Benth.) Rollins	PELO3	P	N	n/a	x	x	x	x	–	x	–	–	–	–	–	–
beardlip penstemon	*Penstemon barbatus* (Cav.) Roth	PEBA2	P	N	n/a	–	x	–	x	–	–	–	–	x	–	–	–
coiled anther penstemon	*Penstemon ophianthus* Pennell	PEOP	P	N	n/a	–	–	–	–	–	–	–	–	–	x	–	–
thickleaf beardtongue	*Penstemon pachyphyllus* A. Gray ex Rydb.	PEPA6	P	N	n/a	–	x	x	x	–	–	x	–	x	x		–
Thompson's beardtongue	*Penstemon thompsoniae* (A. Gray) Rydb.	PETH2	P	N	0.1	–	–	x	–	–	–	–	–	–	x	x	x
Tusayan fameflower	*Phemeranthus validulus* (Greene) Kiger	PHVA8	P	N	n/a	x	–	–	–	x	–	–	–	–	–	x	–
mountain phlox	*Phlox austromontana* Coville	PHAU3	P	N	0.1	–	–	–	–	–	–	–	–	–	x	–	–
groundcherry	*Physalis* L.	PHYSA	A/P	N	n/a	–	x	–	–	–	–	–	–	–	x	x	x
woolly plantain	*Plantago patagonica* Jacq.	PLPA2	A	N	n/a	–	–	–	–	–	–	–	–	–	x	–	–
white milkwort	*Polygala alba* Nutt.	POAL4	P	N	n/a	–	–	–	x	x	–	–	–	–	–	–	–
little hogweed	*Portulaca oleracea* L.	POOL	A	E	<0.1	x	x	–	–	–	–	x	x	–	x	–	x
Pennsylvania cinquefoil	*Potentilla pensylvanica* L.	POPE8	P	N	n/a	–	–	–	x	–	–	–	–	–	–	–	–
greenstem paperflower	*Psilostrophe sparsiflora* (A. Gray) A. Nelson	PSSP	P	N	n/a	x	–	x	x	x	–	–	–	–	–	–	x
prickly Russian thistle	*Salsola tragus* L.	SATR12	A	E	n/a	–	–	–	–	–	–	–	x	–	–	–	–
desert globemallow	*Sphaeralcea ambigua* A. Gray	SPAM2	P	N	n/a	x	–	–	–	–	–	–	–	–	–	–	–

Table 1.3. Vegetation cover and composition at the Pinyon Plain Mine study site.—Continued

[The Pinyon Plain Mine (formerly known as the Canyon Mine) study site (site code PP) is approximately 5.5 miles south of Tusayan (11 miles south of Grand Canyon National Park) in northwestern Arizona. This site was permitted for uranium mining and in the pre-mining phase (developed but with no uranium ore production) at the time of the vegetation surveys. Data were collected at the PP site from July 23–26, 2013 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the “Field Sampling” section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name “Unknown” and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the “Data Summarization and Analysis” section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

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						A1	A2	A3	A4	A5	A6	B1.2	B3.4	B5.6	B7.8	B9.10	B11.12
Forbs—Continued																	
Fendler’s globe-mallow	*Sphaeralcea fendleri* A. Gray	SPFE	P	N	n/a	–	–	–	–	–	–	–	–	–	–	–	x
smallflower globemallow	*Sphaeralcea parvifolia* A. Nelson	SPPA2	P	N	n/a	–	–	–	x	x	x	x	x	x	x	x	x
stemless mock goldenweed	*Stenotus acaulis* (Nutt.) Nutt.	STAC	P	N	<0.1	–	x	–	–	–	–	–	–	–	–	–	–
small wirelettuce	*Stephanomeria exigua* Nutt.	STEX	A/P	N	n/a	x	–	–	–	–	–	–	–	–	x	–	–
common dande-lion	*Taraxacum officinale* F.H. Wigg.	TAOF	P	E	n/a	–	–	–	x	–	–	–	–	–	–	–	–
stemless four-nerve daisy	*Tetraneuris acaulis* (Pursh) Greene	TEAC	P	N	n/a	x	x	x	x	x	x	–	–	–	x	–	–
hoary Townsend daisy	*Townsendia incana* Nutt.	TOIN	A/P	N	n/a	–	–	x	–	–	–	–	–	–	–	–	–
branched nose-burn	*Tragia ramosa* Torr.	TRRA5	P	N	n/a	–	–	–	x	x	–	–	–	–	–	–	–
yellow salsify	*Tragopogon dubius* Scop.	TRDU	A	E	n/a	–	–	–	x	–	–	–	–	–	x	–	x
common mullein	*Verbascum Thapsus* L.	VETH	B	E	n/a	–	–	–	x	x	–	–	–	–	–	x	–
MacDougal verbena	*Verbena macdougalii* A. Heller	VEMA	P	N	n/a	–	–	–	–	x	–	–	x	–	x	x	x
Unknown	n/a	(AAFF)	A	N	2.28	x	–	–	x	x	x	x	x	x	x	x	x
Graminoids																	
Indian ricegrass	*Achnatherum hymenoides* (Roem. & Schult.) Barkworth	ACHY	P	N	n/a	x	–	x	–	x	x	–	–	–	x	–	–
desert wheatgrass	*Agropyron desertorum* (Fisch. ex Link) Schult.	AGDE2	P	E	<0.1	–	–	–	–	–	–	–	x	–	–	–	–
purple threeawn	*Aristida purpurea* Nutt.	ARPU9	P	N	n/a	–	–	–	–	–	–	–	–	–	x	–	–

Table 1.3. Vegetation cover and composition at the Pinyon Plain Mine study site.—Continued

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				Graminoids—Continued													
blue grama	*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths	BOGR2	P	N	19.0	x	x	x	x	x	x	x	x	x	x	x	x
smooth brome	*Bromus inermis* Leyss.	BRIN2	P	E	n/a	–	–	–	–	–	–	–	–	x	–	–	–
cheatgrass	*Bromus tectorum* L.	BRTE	A	E	n/a	–	–	–	x	x	–	–	–	x	x	x	x
Ross' sedge	*Carex rossii* Boott	CARO5	P	N	n/a	–	–	–	–	x	–	–	–	–	–	–	–
squirreltail	*Elymus elymoides* (Raf.) Swezey	ELEL5	P	N	1.3	x	x	x	x	x	x	–	x	x	x	x	x
needle and thread	*Hesperostipa comata* (Trin. & Rupr.) Barkworth	HECO26	P	N	n/a	–	–	x	x	–	x	–	–	–	x	–	x
prairie Junegrass	*Koeleria macrantha* (Ledeb.) Schult.	KOMA	P	N	0.6	x	x	x	x	x	x	–	–	–	x	x	x
spike muhly	*Muhlenbergia wrightii* Vasey ex J.M. Coult.	MUWR	P	N	1.5	x	x	–	x	–	–	x	–	–	x	x	x
western wheatgrass	*Pascopyrum smithii* (Rydb.) Á. Löve	PASM	P	N	1.8	x	–	–	x	–	x	x	–	x	x	x	x
littleseed ricegrass	*Piptatherum micranthum* (Trin. & Rupr.) Romasch., P.M. Peterson & R.J. Soreng	PIMI	P	N	n/a	–	–	–	–	–	–	–	–	–	x	–	–
muttongrass	*Poa fendleriana*		P	N	1.4	x	x	x	x	x	x	–	–	–	x	x	x
alkali sacaton	*Sporobolus airoides* (Torr.) Torr.	SPAI	P	N	<0.1	x	–	–	x	x	–	–	–	x	x	x	x
sand dropseed	*Sporobolus cryptandrus* (Torr.) A. Gray	SPCR	P	N	n/a	x	–	–	–	–	–	x	x	–	–	x	–
intermediate wheatgrass	*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey	THIN6	P	E	n/a	x	–	–	–	–	–	x	–	x	x	–	–

Table 1.3. Vegetation cover and composition at the Pinyon Plain Mine study site.—Continued

[The Pinyon Plain Mine (formerly known as the Canyon Mine) study site (site code PP) is approximately 5.5 miles south of Tusayan (11 miles south of Grand Canyon National Park) in northwestern Arizona. This site was permitted for uranium mining and in the pre-mining phase (developed but with no uranium ore production) at the time of the vegetation surveys. Data were collected at the PP site from July 23–26, 2013 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the "Field Sampling" section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name "Unknown" and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the "Data Summarization and Analysis" section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot											
						A1	A2	A3	A4	A5	A6	B1.2	B3.4	B5.6	B7.8	B9.10	B11.12
					Shrubs												
big sagebrush	*Artemisia tridentata* Nutt.	ARTR2	P	N	1.3	x	x	x	x	x	x	x	–	–	x	x	x
fourwing saltbush	*Atriplex canescens* (Pursh) Nutt.	ATCA2	P	N	n/a	–	–	–	–	–	–	–	–	–	x	–	–
desert sweet	*Chamaebatiaria millefolium* (Torr.) Maxim.	CHMI2	P	N	0.1	x	–	–	x	x	x	–	–	–	–	x	x
yellow rabbit-brush	*Chrysothamnus viscidiflorus* (Hook.) Nutt.	CHVI8	P	N	0.4	x	–	–	–	–	–	x	x	x	–	–	x
rubber rabbit-brush	*Ericameria nauseosa* (Pall. ex Pursh) G.L. Nesom & Baird	ERNA10	P	N	3.0	x	x	x	x	x	x	x	x	x	x	x	x
Apache plume	*Fallugia paradoxa* (D. Don) Endl. ex Torr.	FAPA	P	N	0.4	x	–	–	x	x	x	–	–	–	x	x	x
winterfat	*Krascheninnikovia lanata* (Pursh) A. Meeuse & Smit	KRLA2	P	N	n/a	–	–	–	–	–	–	x	–	–	–	–	–
Fremont's ma-honia	*Mahonia fremontii* (Torr.) Fedde	MAFR3	P	N	n/a	x	–	–	x	x	x	–	–	x	x	–	–
Stansbury clif-frose	*Purshia stansburiana* (Torr.) Henrickson	PUST	P	N	<0.1	x	x	x	x	x	x	–	–	–	–	–	x
Gambel oak	*Quercus gambelii* Nutt.	QUGA	P	N	n/a	–	–	x	–	–	x	–	–	–	–	–	–
skunkbush sumac	*Rhus trilobata* Nutt.	RHTR	P	N	n/a	x	x	x	x	x	x	–	x	–	x	x	x
wax currant	*Ribes cereum* Douglas	RICE	P	N	n/a	x	x	–	x	x	x	–	–	x	x	x	x
spineless horse-brush	*Tetradymia canescens* DC.	TECA2	P	N	n/a	–	x	x	x	x	–	x	–	–	–	x	–
narrowleaf yucca	*Yucca angustissima* Engelm. ex Trel.	YUAN2	P	N	n/a	x	–	–	x	–	–	–	–	–	–	–	–

Table 1.3. Vegetation cover and composition at the Pinyon Plain Mine study site.—Continued

[The Pinyon Plain Mine (formerly known as the Canyon Mine) study site (site code PP) is approximately 5.5 miles south of Tusayan (11 miles south of Grand Canyon National Park) in northwestern Arizona. This site was permitted for uranium mining and in the pre-mining phase (developed but with no uranium ore production) at the time of the vegetation surveys. Data were collected at the PP site from July 23–26, 2013 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the “Field Sampling” section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name “Unknown” and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the “Data Summarization and Analysis” section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot											
						A1	A2	A3	A4	A5	A6	B1.2	B3.4	B5.6	B7.8	B9.10	B11.12
					Sub-shrubs												
prairie sagewort	*Artemisia frigida* Willd.	ARFR4	P	N	0.3	x	x	x	–	x	x	x	x	x	x	x	x
longflower rabbitbrush	*Chrysothamnus depressus* Nutt.	CHDE2	P	N	n/a	–	–	–	x	x	–	–	–	–	–	–	–
threadleaf snakeweed	*Gutierrezia microcephala* (DC.) A. Gray	GUMI	P	N	1.5	x	x	x	x	x	x	–	–	x	x	x	x
narrowleaf four o’clock	*Mirabilis linearis* (Standl.) Standl.	MIDE5	P	N	0.1	x	–	–	x	–	–	x	x	–	x	–	x
					Succulents												
Whipple cholla	*Cylindropuntia whipplei* (Engelm. & J.M. Bigelow) F.M. Knuth	CYWH	P	N	n/a	–	–	–	x	x	x	–	x	–	x	x	–
pinkflower hedgehog cactus	*Echinocereus fendleri* (Engelm.) Sencke ex J.N. Haage	ECFE	P	N	n/a	–	–	–	–	–	x	–	–	–	–	–	–
spinystar	*Escobaria vivipara* (Nutt.) Buxbaum	ESVI2	P	N	n/a	x	x	x	–	–	x	–	–	–	–	–	x
plains pricklypear	*Opuntia polyacantha* Haw.	OPPO	P	N	n/a	x	x	x	–	x	x	x	x	x	x	x	x
					Trees												
Utah juniper	*Juniperus osteopsperma* (Torr.) Little	JUOS	P	N	2.0	x	x	x	x	x	x	x	–	x	x	x	x
twoneedle pinyon	*Pinus edulis* Engelm.	PIED	P	N	6.9	x	x	x	x	x	x	–	–	x	x	x	x
ponderosa pine	*Pinus ponderosa* Lawson & C. Lawson	PIPO	P	N	8.7	x	x	x	x	x	x	x	–	x	–	x	x

Table 1.4. Vegetation cover and composition at the Pinenut Mine study site.

[The Pinenut Mine study site (site code PN) is approximately 6.3 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. It was in an active production site at the time of the vegetation surveys, where uranium ore was being brought to the surface for processing. Data were collected at the PN site from July 11–16, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the "Field Sampling" section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name "Unknown" and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the "Data Summarization and Analysis" section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot														
						A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6
					Forbs															
sand verbena	*Abronia* Juss.	ABRON	A/P	N	n/a	–	–	–	–	–	–	–	–	–	–	–	–	–	–	x
anemone	*Anemone* L.	ANEMO	P	N	n/a	–	x	–	–	–	–	x	–	–	–	–	–	–	x	x
Crescent milkvetch	*Astragalus amphioxys* A. Gray	ASAM5	P	N	n/a	x	x	–	x	–	x	x	x	x	x	–	x	x	x	x
pincushion	*Chaenactis* DC.	CHAEN	A/P	N	n/a	–	–	–	x	–	–	–	–	–	–	x	–	–	–	–
rose heath	*Chaetopappa ericoides* (Torr.) G.L. Nesom	CHER2	P	N	0.1	x	–	–	x	x	x	–	–	x	x	x	x	x	x	x
Fendler's sandmat	*Chamaesyce fendleri* (Torr. & A. Gray) Small	CHFE3	P	N	n/a	–	x	–	–	x	–	–	–	–	x	x	–	–	x	–
lambsquarters	*Chenopodium album* L.	CHAL7	A	E	n/a	x	x	–	x	x	–	–	–	–	x	–	–	–	x	–
redstem stork's bill	*Erodium cicutarium* (L.) L'Hér. ex Aiton	ERCI6	A	E	n/a	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–
false pennyroyal	*Hedeoma* Pers.	HEDEO	A/P	N	n/a	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
fineleaf hymeno-pappus	*Hymenopappus filifolius* Hook.	HYFI	P	N	n/a	–	x	–	–	–	–	–	–	–	–	–	–	–	–	–
foothill deervetch	*Lotus humistratus* Greene	LOHU2	A	N	n/a	–	–	x	x	x	–	–	–	–	–	x	–	–	x	–
horehound	*Marrubium vulgare* L.	MAVU	P	E	n/a	–	–	–	–	–	x	x	–	x	–	–	–	x	x	–
thickleaf beard-tongue	*Penstemon pachyphyllus* A. Gray ex Rydb.	PEPA6	P	N	n/a	–	x	–	x	–	–	–	–	–	x	–	–	–	x	x
groundcherry	*Physalis* L.	PHYSA	A/P	N	n/a	–	–	–	–	–	–	x	x	–	–	–	–	–	–	–
little hogweed	*Portulaca oleracea* L.	POOL	A	E	<0.1	–	x	–	x	–	–	–	x	–	x	–	–	–	–	x
greenstem paper-flower	*Psilostrophe sparsiflora* (A. Gray) A. Nelson	PSSP	P	N	0.4	x	x	x	–	x	–	x	–	x	x	–	x	x	x	x
prickly Russian thistle	*Salsola tragus* L.	SATR12	A	E	n/a	x	x	x	–	x	–	x	–	–	–	–	–	x	–	–

Table 1.4. Vegetation cover and composition at the Pinenut Mine study site.—Continued

[The Pinenut Mine study site (site code PN) is approximately 6.3 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. It was in an active production site at the time of the vegetation surveys, where uranium ore was being brought to the surface for processing. Data were collected at the PN site from July 11–16, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the “Field Sampling” section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name “Unknown” and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the “Data Summarization and Analysis” section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot														
						A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6
Forbs—Continued																				
gooseberryleaf globemallow	*Sphaeralcea grossulariifolia* (Hook. & Arn.) Rydb.	SPGR2	P	N	n/a	x	x	–	x	x	x	x	–	x	x	x	x	x	x	–
smallflower globemallow	*Sphaeralcea parvifolia* A. Nelson	SPPA2	P	N	n/a	x	–	x	x	–	–	x	x	x	x	–	x	x	x	x
Unknown	n/a	(AF01)	A	N	0.1	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
Unknown	n/a	(AF21)	A	N	<0.1	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Unknown	n/a	(AF22)	A	N	<0.1	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
Unknown	n/a	(PF01)	P	N	0.4	–	–	–	–	–	x	–	–	–	–	–	–	–	–	–
Graminoids																				
Indian ricegrass	*Achnatherum hymenoides* (Roem. & Schult.) Barkworth	ACHY	P	N	0.9	x	x	x	x	x	x	x	–	x	–	x	x	–	x	x
purple threeawn	*Aristida purpurea* Nutt.	ARPU9	P	N	n/a	–	–	–	x	x	–	x	–	–	x	–	x	–	x	–
blue grama	*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths	BOGR2	P	N	5.8	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
cheatgrass	*Bromus tectorum* L.	BRTE	A	E	0.1	–	–	–	–	x	–	–	–	–	–	–	–	x	–	–
squirreltail	*Elymus elymoides* (Raf.) Swezey	ELEL5	P	N	1.1	x	x	x	x	x	–	x	x	x	x	x	x	x	x	x
needle and thread	*Hesperostipa comata* (Trin. & Rupr.) Barkworth	HECO26	P	N	0.1	x	–	x	x	x	–	x	–	x	x	–	x	x	–	–
false buffalograss	*Munroa squarrosa* (Nutt.) Torr.	MUSQ3	A	N	n/a	x	x	–	–	–	–	–	x	–	–	–	–	–	x	–
James’ galleta	*Pleuraphis jamesii* Torr.	PLJA	P	N	1.6	x	–	x	–	x	x	x	–	x	x	x	x	x	x	–
alkali sacaton	*Sporobolus airoides* (Torr.) Torr.	SPAI	P	N	2.8	x	x	x	x	x	x	x	x	–	x	x	x	x	x	x
sand dropseed	*Sporobolus cryptandrus* (Torr.) A. Gray	SPCR	P	N	0.4	–	–	x	x	–	–	x	x	–	x	–	–	–	x	x
Unknown	n/a	(PG03)	P	N	0.3	–	–	–	–	–	–	–	–	–	–	x	–	x	–	–

Table 1.4. Vegetation cover and composition at the Pinenut Mine study site.—Continued

[The Pinenut Mine study site (site code PN) is approximately 6.3 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. It was in an active production site at the time of the vegetation surveys, where uranium ore was being brought to the surface for processing. Data were collected at the PN site from July 11–16, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the “Field Sampling” section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name “Unknown” and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the “Data Summarization and Analysis” section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot														
						A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6
Shrubs																				
big sagebrush	*Artemisia tridentata* Nutt.	ARTR2	P	N	20.1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
fourwing saltbush	*Atriplex canescens* (Pursh) Nutt.	ATCA2	P	N	0.4	x	x	x	x	–	x	x	–	x	x	–	x	x	x	x
Greene’s rabbitbrush	*Chrysothamnus greenei* (A. Gray) Greene	CHGR6	P	N	n/a	–	–	–	–	–	–	–	–	–	–	–	–	–	x	–
mormon tea	*Ephedra viridis* Coville	EPVI	P	N	n/a	x	x	x	x	x	–	–	x	–	x	–	x	–	x	x
stretchberry	*Forestiera pubescens* Nutt. var. *pubescens*	FOPUP	P	N	n/a	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–
winterfat	*Krascheninnikovia lanata* (Pursh) A. Meeuse & Smit	KRLA2	P	N	n/a	–	–	–	–	x	–	–	–	–	–	–	x	–	–	–
Fremont’s mahonia	*Mahonia fremontii* (Torr.) Fedde	MAFR3	P	N	0.9	x	x	x	–	x	–	x	x	x	x	x	–	–	x	x
Mexican cliffrose	*Purshia mexicana* (D. Don) Henrickson	PUME	P	N	0.1	x	–	–	–	–	–	–	x	–	x	–	x	–	x	x
yucca	*Yucca* L.	YUCCA	P	N	n/a	–	–	–	–	–	–	–	x	–	x	–	–	–	x	x
Unknown	n/a	(SH01)	P	N	0.1	–	–	–	–	–	–	x	–	–	–	–	–	–	–	–
Sub-shrubs																				
prairie sagewort	*Artemisia frigida* Willd.	ARFR4	P	N	n/a	–	–	x	–	–	x	–	–	–	–	–	–	x	–	–
bastardsage	*Eriogonum wrightii* Torr. ex Benth.	ERWR	P	N	n/a	–	–	x	x	–	–	–	–	–	–	–	x	–	–	–
broom snakeweed	*Gutierrezia sarothrae* (Pursh) Britton & Rusby	GUSA2	P	N	9.6	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Colorado four o’clock	*Mirabilis multiflora* (Torr.) A. Gray	MIMU	P	N	n/a	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–

Table 1.4. Vegetation cover and composition at the Pinenut Mine study site.—Continued

[The Pinenut Mine study site (site code PN) is approximately 6.3 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. It was in an active production site at the time of the vegetation surveys, where uranium ore was being brought to the surface for processing. Data were collected at the PN site from July 11–16, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the “Field Sampling” section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name “Unknown” and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the “Data Summarization and Analysis” section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot														
						A1	A2	A3	A4	A5	A6	A7	A8	A9	B1	B2	B3	B4	B5	B6
Succulents																				
cholla	*Cylindropuntia* (Engelm.) Kreuzinger	CYLIN2	P	N	n/a	x	x	x	x	–	x	x	x	x	x	x	x	–	x	x
brittle pricklypear	*Opuntia fragilis* (Nutt.) Haw.	OPFR	P	N	n/a	–	–	–	x	x	–	–	–	–	–	–	–	–	–	–
plains pricklypear	*Opuntia polyacantha* Haw.	OPPO	P	N	1.2	x	x	x	x	x	–	x	x	x	x	x	x	x	x	x
white fishhook cactus	*Echinomastus intertextus* (Engelm.) Britton & Rose	ECIN2	P	N	n/a	–	–	–	–	–	–	x	x	–	x	x	–	–	–	x
longspine fishhook cactus	*Sclerocactus parviflorus* Clover & Jotter	SCPA9	P	N	n/a	–	–	–	–	–	–	x	–	–	x	–	–	–	–	x
Trees																				
Utah juniper	*Juniperus osteosperma* (Torr.) Little	JUOS	P	N	4.8	x	x	x	x	x	x	x	–	x	x	x	x	x	x	x
twoneedle pinyon	*Pinus edulis* Engelm.	PIED	P	N	0.7	x	x	–	–	–	–	x	–	x	x	–	–	–	x	x

Table 1.5. Vegetation cover and composition at the Arizona 1 Mine study site.

[The Arizona 1 Mine study site (site code AZ1) is approximately 6.5 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. It was in a post-mining, pre-reclamation phase at the time of the vegetation surveys, with relict surface disturbance but no active uranium ore production. Data were collected at the AZ1 site from August 4–7, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the "Field Sampling" section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name "Unknown" and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the "Data Summarization and Analysis" section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot														
						A	B	C	D	E	F	G	H	I	J	OA	OB	OC	OD	OE
Forbs																				
sand verbena	*Abronia* Juss.	ABRON	A/P	N	n/a	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–
slim amaranth	*Amaranthus hybridus* L.	AMHY	A	N	n/a	–	x	–	–	–	–	–	–	–	–	x	–	–	–	–
anemone	*Anemone* L.	ANEMO	P	N	0.1	x	–	x	–	–	–	–	–	–	–	–	x	x	–	x
crescent milkvetch	*Astragalus amphioxys* A. Gray	ASAM5	P	N	0.1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
rose heath	*Chaetopappa ericoides* (Torr.) G.L. Nesom	CHER2	P	N	n/a	x	–	x	x	x	x	x	–	x	x	x	x	x	x	x
Fendler's sandmat	*Chamaesyce fendleri* (Torr. & A. Gray) Small	CHFE3	P	N	n/a	–	–	x	–	–	–	x	–	–	x	–	x	x	x	–
lambsquarters	*Chenopodium album* L.	CHAL7	A	E	n/a	–	x	–	–	–	–	–	–	–	–	–	x	–	–	–
Fremont's goosefoot	*Chenopodium fremontii* S. Watson	CHFR3	A	N	n/a	–	–	–	–	x	–	–	–	–	x	–	–	–	–	–
Wheeler's thistle	*Cirsium wheeleri* (A. Gray) Petr.	CIWH	P	N	n/a	–	–	–	–	–	–	x	x	–	–	–	–	–	–	–
hairy desertsunflower	*Geraea canescens* Torr. & A. Gray	GECA2	A	N	n/a	–	x	x	–	x	–	x	x	x	–	x	–	–	–	–
fineleaf hymenopappus	*Hymenopappus filifolius* Hook.	HYFI	P	N	n/a	–	–	–	–	–	–	–	–	–	–	–	x	–	x	–
foothill deervetch	*Lotus humistratus* Greene	LOHU2	A	N	n/a	x	–	–	x	–	–	x	x	–	–	–	x	x	x	–
thickleaf beardtongue	*Penstemon pachyphyllus* A. Gray ex Rydb.	PEPA6	P	N	n/a	–	–	–	–	x	–	x	x	x	–	x	–	x	x	x
groundcherry	*Physalis* L.	PHYSA	A/P	N	n/a	x	x	–	–	x	–	x	x	–	–	x	x	–	x	–
little hogweed	*Portulaca oleracea* L.	POOL	A	E	n/a	–	x	x	–	x	–	x	–	–	–	x	–	–	x	–
greenstem paperflower	*Psilostrophe sparsiflora* (A. Gray) A. Nelson	PSSP	P	N	0.2	x	x	x	x	x	–	x	x	–	–	x	x	x	x	–
prickly Russian thistle	*Salsola tragus* L.	SATR12	A	E	0.1	x	x	x	x	x	–	x	x	x	x	x	x	x	x	–

Table 1.5. Vegetation cover and composition at the Arizona 1 Mine study site.—Continued

[The Arizona 1 Mine study site (site code AZ1) is approximately 6.5 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. It was in a post-mining, pre-reclamation phase at the time of the vegetation surveys, with relict surface disturbance but no active uranium ore production. Data were collected at the AZ1 site from August 4–7, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the "Field Sampling" section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name "Unknown" and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the "Data Summarization and Analysis" section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot														
						A	B	C	D	E	F	G	H	I	J	OA	OB	OC	OD	OE
					Forbs—Continued															
threadleaf ragwort	*Senecio flaccidus* Less.	SEFL3	P	N	n/a	–	–	–	–	–	–	–	x	–	x	x	–	–	–	–
gooseberryleaf globemallow	*Sphaeralcea grossulariifolia* (Hook. & Arn.) Rydb.	SPGR2	P	N	0.1	x	x	x	x	x	–	x	–	x	x	x	x	–	–	x
smallflower globe-mallow	*Sphaeralcea parvifolia* A. Nelson	SPPA2	P	N	0.1	x	–	–	–	–	–	–	x	–	x	–	–	x	x	–
					Graminoids															
Indian ricegrass	*Achnatherum hymenoides* (Roem. & Schult.) Barkworth	ACHY	P	N	0.4	x	–	x	x	–	–	x	x	x	–	x	x	x	x	x
purple threeawn	*Aristida purpurea* Nutt.	ARPU9	P	N	0.1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
black grama	*Bouteloua eriopoda* (Torr.) Torr.	BOER4	P	N	0.5	x	–	–	–	–	–	–	–	–	–	x	–	–	–	–
blue grama	*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths	BOGR2	P	N	12.6	x	x	x	x	x	x	–	x	x	x	x	x	x	x	x
squirreltail	*Elymus elymoides* (Raf.) Swezey	ELEL5	P	N	0.2	–	x	–	–	–	–	–	–	–	x	–	x	–	–	x
false buffalograss	*Munroa squarrosa* (Nutt.) Torr.	MUSQ3	A	N	n/a	–	–	x	–	–	–	–	–	–	–	–	–	–	–	–
James' galleta	*Pleuraphis jamesii* Torr.	PLJA	P	N	0.9	x	–	x	x	x	x	x	x	x	x	x	–	x	x	x
alkali sacaton	*Sporobolus airoides* (Torr.) Torr.	SPAI	P	N	1.5	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
sand dropseed	*Sporobolus cryptandrus* (Torr.) A. Gray	SPCR	P	N	0.1	–	–	–	–	–	–	–	–	–	–	x	x	–	–	–
Unknown	n/a	(PG32)	P	N	0.1	–	–	–	–	–	–	–	–	–	–	x	–	–	–	–

Table 1.5. Vegetation cover and composition at the Arizona 1 Mine study site.—Continued

[The Arizona 1 Mine study site (site code AZ1) is approximately 6.5 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. It was in a post-mining, pre-reclamation phase at the time of the vegetation surveys, with relict surface disturbance but no active uranium ore production. Data were collected at the AZ1 site from August 4–7, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the “Field Sampling” section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name “Unknown” and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the “Data Summarization and Analysis” section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot														
						A	B	C	D	E	F	G	H	I	J	OA	OB	OC	OD	OE
Shrubs																				
acacia	*Acacia* Mill.	ACACI	P	N	n/a	–	–	–	–	–	–	–	–	–	x	–	–	–	–	–
big sagebrush	*Artemisia tridentata* Nutt.	ARTR2	P	N	19.4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
fourwing saltbush	*Atriplex canescens* (Pursh) Nutt.	ATCA2	P	N	0.2	x	x	x	x	–	x	x	x	x	x	x	x	x	x	x
Greene's rabbit-brush	*Chrysothamnus greenei* (A. Gray) Greene	CHGR6	P	N	2.2	–	–	x	x	x	–	x	–	–	x	x	x	x	x	x
mormon tea	*Ephedra viridis* Coville	EPVI	P	N	0.1	x	–	–	x	–	–	x	–	–	x	–	–	x	x	x
Fremont's mahonia	*Mahonia fremontii* (Torr.) Fedde	MAFR3	P	N	n/a	x	x	–	x	–	–	–	–	–	x	–	x	–	–	x
Mexican cliffrose	*Purshia mexicana* (D. Don) Henrickson	PUME	P	N	n/a	x	–	–	–	–	–	–	–	–	x	–	–	–	–	x
yucca	*Yucca* L.	YUCCA	P	N	n/a	–	–	x	x	–	–	–	–	–	–	–	–	x	x	x
Sub-shrubs																				
bastardsage	*Eriogonum wrightii* Torr. ex Benth.	ERWR	P	N	n/a	x	–	–	–	–	–	–	–	–	–	–	–	–	–	–
broom snakeweed	*Gutierrezia sarothrae* (Pursh) Britton & Rusby	GUSA2	P	N	6.0	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
narrowleaf four o’clock	*Mirabilis linearis* (Pursh) Heimerl	MILI3	P	N	n/a	–	–	–	–	x	–	–	–	–	–	–	–	–	–	–
Colorado four o'clock	*Mirabilis multiflora* (Torr.) A. Gray	MIMU	P	N	n/a	–	–	x	x	x	–	x	–	–	–	x	x	–	x	–
Succulents																				
cholla	*Cylindropuntia* (Engelm.) Kreuzinger	CYLIN2	P	N	n/a	x	–	x	–	–	–	–	x	x	x	–	x	x	–	x
plains pricklypear	*Opuntia polyacantha* Haw.	OPPO	P	N	0.4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Table 1.5. Vegetation cover and composition at the Arizona 1 Mine study site.—Continued

[The Arizona 1 Mine study site (site code AZ1) is approximately 6.5 miles north of the northwestern boundary of Grand Canyon National Park in northwestern Arizona. It was in a post-mining, pre-reclamation phase at the time of the vegetation surveys, with relict surface disturbance but no active uranium ore production. Data were collected at the AZ1 site from August 4–7, 2015 (table 2), within plots shown in figure 2. Species observed within each plot during either line-point intercept (LPI) data collection or plant species inventories are shown in the table below. Details of how LPI and plant inventory data were collected in the field can be found in the "Field Sampling" section of the report. All plant attributes shown in the table were derived from the U.S. Department of Agriculture (USDA) PLANTS database (https://plants.usda.gov, accessed October 16, 2023). The USDA plant code is the symbol used in the PLANTS database. Duration categories are annual (A), annual or perennial (A/P), and perennial (P); nativity categories are native (N) or exotic (E, not native) in the State of Arizona. Any species that could not be identified by the field observation team are shown in the table with the common name "Unknown" and the identifying code used by the field team is shown in parentheses in the USDA plant code column. A value for weighted percent (wtd %) cover is provided for those species observed in the LPI data and was calculated at the site level by averaging area-weighted, plot-level cover; more details can be found in the "Data Summarization and Analysis" section of the report. Species observed during plant species inventory but not in LPI data show a value of n/a (not available) for weighted percent cover.]

Common name	Scientific name	USDA plant code	Duration	Nativity	Wtd % cover	Plot														
						A	B	C	D	E	F	G	H	I	J	OA	OB	OC	OD	OE
					Succulents—Continued															
white fishhook cactus	*Echinomastus intertextus* (Engelm.) Britton & Rose	ECIN2	P	N	n/a	x	–	–	–	–	–	–	–	–	x	x	x	–	–	x
longspine fishhook cactus	*Sclerocactus parviflorus* Clover & Jotter	SCPA9	P	N	n/a	–	–	–	–	–	–	x	–	x	x	–	–	–	x	x
					Trees															
Utah juniper	*Juniperus osteopsperma* (Torr.) Little	JUOS	P	N	2.2	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
twoneedle pinyon	*Pinus edulis* Engelm.	PIED	P	N	n/a	–	–	–	–	–	–	–	–	–	x	–	–	x	x	x

Appendix 2. Correlations Between Vegetation and Surface Metrics in Environments Surrounding Uranium Mines in the Grand Canyon Ecosystem, Northern Arizona

We calculated a non-parametric measure of rank, Kendall's Tau (τ_b) and associated *p*-values, to assess correlation among the cover values derived for vegetation functional groups, total litter, and ground surface types, using the Hmisc package (Harrell, 2023) in R version 1.0.136 (R Core Team, 2016).

Table 2.1. Results from a non-parametric correlation test (Kendall's Tau, τ_b) among metrics derived from line-point intercept sampling at five study sites in the Grand Canyon ecosystem, northern Arizona.

[Four of the sites were environments surrounding uranium mines in various phases of development, and one site was a reference area with no uranium ore deposits but with surface disturbance similar to that created during initial mining development. Cover data was not transformed or weighted prior to correlation test. Metrics are grouped into vegetation functional groups and ground surface types. Kendall's Tau (τ_b) correlation coefficients are listed first in cells, followed by associated *p*-values (*p*); for example, "−0.02, 0.87" indicates a Kendall's τ_b correlation coefficient of −0.02 and a *p*-value of 0.87. *p*-values less than 0.01 are written in exponential notation, such that 4.9e−4 means 4.9×10^{-4}. Correlations that are statistically significant ($p\leq0.05$) are shown in **bold**.]

Correlate	Vegetation Cover							Ground Surface Type Cover						
	Total Foliar	Tree	Shrub	Sub-Shrub	Perennial Graminoid	Perennial Forb	Total Annual	Total Litter	Cyanobacteria	Lichen	Moss	Rock	Duff	Total Ground Cover
Vegetation Group Cover														
Tree	−0.02, 0.87													
Shrub	0.03, 0.83	**−0.44, 4.9e−4**												
Sub-Shrub	−0.33, **0.01**	−0.10, 0.47	0.24, 0.07											
Perennial Graminoid	0.83, **8.9e−16**	−0.21, 0.11	−0.24, 0.07	**−0.46, 2.3e−4**										
Perennial Forb	0.31, **0.02**	−0.12, 0.37	−0.21, 0.11	**−0.26, 0.05**	**0.26, 0.05**									
Total Annual	0.31, **0.02**	−0.19, 0.16	−0.21, 0.11	−0.21, 0.11	0.21, 0.10	0.25, 0.06								
Ground Surface Type Cover														
Total Litter	0.07, 0.57	**0.73, 5.8e−11**	**−0.38, 3.4e−3**	−0.18, 0.18	−0.02, 0.88	−0.12, 0.39	−0.20, 0.14							
Cyanobacteria	−0.01, 0.97	**0.32, 0.02**	**−0.29, 0.03**	−0.16, 0.22	0.04, 0.74	−0.02, 0.9	−0.07, 0.58	0.39, **2.1e−3**						
Lichen	0.03, 0.79	**0.29, 0.03**	−0.10, 0.46	0.03, 0.83	−0.04, 0.75	−0.06, 0.64	−0.06, 0.64	0.15, 0.25	**0.57, 2.8e−6**					
Moss	−0.12, 0.35	0.23, 0.08	−0.08, 0.53	0.08, 0.56	−0.14, 0.28	−0.18, 0.18	−0.12, 0.35	**0.30, 0.02**	**0.40, 1.9e−3**	**0.63, 7.9e−8**				
Rock	−0.01, 0.96	−0.02, 0.85	−0.08, 0.54	0.22, 0.09	0.03, 0.84	0.12, 0.35	−0.14, 0.30	−0.17, 0.2	−0.14, 0.30	0, 0.98	0.09, 0.49			
Duff	0.14, 0.28	**0.72, 1.1e−10**	**−0.28, 0.03**	−0.13, 0.33	−0.05, 0.69	0.04, 0.74	−0.10, 0.45	**0.47, 1.9e−4**	0.23, 0.08	0.25, 0.06	0.09, 0.48	0.20, 0.13		
Total Ground Cover	0.10, 0.47	**0.70, 6.7e−10**	**−0.33, 0.01**	−0.08, 0.54	0.02, 0.89	−0.15, 0.25	**−0.33, 0.01**	0.86, **0**	**0.42, 9.8e−4**	0.24, 0.07	**0.38, 3.1e−3**	0.23, 0.08	**0.55, 6.9e−6**	
Bare Soil	−0.6, **4.8e−7**	**−0.45, 3.6e−4**	**0.37, 4.3e−3**	**0.28, 0.03**	**−0.52, 2.9e−5**	−0.20, 0.13	−0.01, 0.97	**−0.65, 2.4e−8**	**−0.30, 0.02**	−0.18, 0.18	−0.25, 0.06	**−0.34, 0.01**	**−0.50, 5.6e−5**	**−0.77, 9.6e−13**

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